Chapter 17
Digital Heritage

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Abstract Natural and cultural heritage, the common wealth of human beings, are keys to human understanding of the evolution of our planet and social development. The protection and conservation of natural and cultural heritage is the common responsibility of all mankind. Spatial information technology provides a new applied theory and tool for the protection and utilization of natural and cultural heritage. This chapter is divided into four parts. The first part elaborates the connotation of digital heritage, the differences and connections between digital heritage and physical heritage, the technology of digital heritage formation and the research objectives and content of digital heritage. Parts 2 and 3 discuss the contents and methods of digital natural heritage and cultural heritage, respectively, and some practical case studies. In the fourth part, the future development trends of digital heritage research in protection and utilization are described, as well as six research directions that deserve attention.

Keywords Digital heritage · Spatial information technology · Remote sensing · Archaeology · Heritage conservation · Case study

17.1 A Brief Introduction to Digital Heritage

Natural and cultural heritage, with unique value in the realms of science, culture, history and art, are like jewels emerging from a wide variety of ground object types that shine on the surface of the Earth. Heritage is defined as our legacy from the past, what

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we live with today, and what we pass on to future generations. As common wealth of all mankind, its enduring value should be kept for future generations. Accordingly, the recognition and preservation of its outstanding universal value (OUV) has been a great concern for UNESCO, highlighting the emerging role of digital heritage, which is defined by UNESCO as the use of digital media in the service of preserving, protecting, studying and presenting these heritages.

The great value and significance of digital heritage was affirmed by two UNESCO documents released in 2003: the Guidelines for the Preservation of Digital Heritage (National Library of Australia 2003) and the Charter on the Preservation of the Digital Heritage (UNESCO 2009). The Charter describes digital heritage as "resources of human knowledge or expression, whether cultural, educational, scientific and administrative, or embracing technical, legal, medical and other kinds of information, are increasingly created digitally, or converted into digital form from existing analogue resources." When resources are "born digital", there is no other format but the digital original, including text, databases, still and animated images, audio tapes, photos, software, and web pages.

Many of these digital heritage materials will be passed down from generation to generation. Digital heritage may be classified by genres: information resources stored in specific carriers (such as optical disks, disks, and tapes), computer databases, or disseminated via the internet or digital media, and preprint materials or archives held in e-prints.

"Digital heritage", a concept that is distinguished from its physical counterpart, constitutes an integral part of the Digital Earth program. Digitalizing heritage enables the enduring value of physical heritage to be long-term preserved, easily accessible to, widely shared and disseminated to the public. Heritage in the digital form also facilitates in-depth research from various perspectives (Hu et al. 2003). Digital heritage plays an important role in permanently preserving the information derived from physical heritage. The implication of "digital heritage" used in this handbook is compatible with that described in the two UNESCO documents mentioned above. However, unless otherwise specified, the term of "digital heritage" here refers to "digital natural and cultural heritage", which means digital resources or products converted from existing natural and cultural heritage or analogue resources. It includes dynamic or static digital information created during the process of digitalization, which includes creation and documentation, preservation and protection, processing, dissemination and presentation. In this handbook, digital heritage refers to the categories of cultural relics and natural landscapes. Similar to general digital heritage, digital culture and natural heritage exist as information resources that are stored in specific carriers (such as optical disks, magnetic disks and tapes) or computer databases, or presented on display and disseminated via the internet.

The technologies involved in digital heritage cover a variety of aspects including creation, storage, monitoring, dissemination, presentation and protection.

The creation and documentation of digital heritage consist of technological processes such as digital perception, data collection and processing, information extraction and interpretation, and digitally documenting.

Joint efforts should be undertaken to preserve and protect digital heritage and to keep it accessible to the public and maintain its long-term availability to future generations. Efforts include developing technology and tools, designing management frameworks, initiating protection programs, taking management measures, and related law-making issues.

The dissemination and presentation of digital heritage involves several aspects including the technology and tools for digital creation, channels and measures for dissemination, management measures, and the support from regulations and laws. Digital heritage should be presented vividly to ensure that the public can understand, share and make good use of it.

Digital heritage focuses on the digital products derived from its cultural and natural heritage ontologies and related environment. The research covers the process of how digital heritage is created and presented, how to protect it and develop related products, and how to transform these products into new digital products in the form of knowledge. It is also necessary to have a profound understanding of the ontology-environment interaction, and therefore take effective protective measures in advance. Digital heritage research features noncontact and nondestructive ontologies.

Digital heritage shares some common characteristics of cultural heritage. The research is centered on the techniques and knowledge for (1) digitalization of the heritage ontology; (2) preservation of digital heritage; (3) the use of digital heritage (4) demonstration, sharing, and publicity of digital heritage; and (5) laws and regulations on digital heritage protection.

The creation of digital heritage, namely, the digitization of heritage ontologies, involves the use of satellite-based or airborne data as well as data obtained from ground and underground exploration or manual observation. It involves a set of techniques and methods for nondestructive detection, monitoring, and evaluation. In addition, heritage preservation and digitalization also need the support of legislation at the national level, which constitutes the cornerstone for implementing digital heritage programs. The use of digital heritage involves a wide range of technologies and knowledge in terms of digital generation, heritage protection, monitoring, and law-making issues on heritage protection.

The purpose of digital heritage preservation is to ensure that it remains accessible to the public and to prevent it from disappearing. Accordingly, digital representation of heritage ensures that the essential value of its ontology is widespread and enduring. To achieve this, specified approaches are suggested for the use, research and protection of two kinds of heritage, corresponding to its natural or cultural characteristics.

17.2 Digital Natural Heritage

17.2.1 Technology and Research Methods of Digital Natural Heritage

The Convention for the Protection of the World Cultural and Natural Heritage describes "natural heritage" as "natural features consisting of material and biological structures or groups of such structures of outstanding universal value from an aesthetic or scientific point of view; geological and natural geographical structures of outstanding universal value from a scientific or protective point of view, and clearly designated as threatened animal and plant habitats; natural attractions or clearly defined natural areas with outstanding universal value from a scientific, conservation or natural beauty point of view." Comprehensive use of digital technologies and methods for outstanding universal value (OUV) characterization of elements of natural heritage include the observation and its originality, integrity (AI) monitoring and evaluation as effective measures to achieve heritage protection and management.

To ensure the feasibility, effectiveness and long-term nature of digital technology for natural heritage monitoring, practical and simple monitoring and evaluation methods should be adopted, and the collection and management of monitoring data should be standardized. With the rapid development of 3S technology, multisource high-resolution (temporal, spatial, spectral) images form a large amount of remote sensing data. We have carried out different remote sensing spatial scale data fusion techniques. The spatial analysis function of GIS, high-precision satellite navigation and positioning functions, and different evaluation models of natural heritage site protection are used for Sustainable Heritage Protection and development monitoring, taking into account the monitoring objectives and conditions of different types of natural heritage sites. By combining qualitative and quantitative methods, field investigation and remote sensing investigation, the OUV and its original integrity can be effectively monitored and assessed, and natural heritage can be effectively protected and managed.

17.2.2 Case Study of Digital Natural Heritage

17.2.2.1 Information Extraction from Mountain Vertical Belt Based on an NDVI-DEM Method Model

Xinjiang Tianshan Mountain is an outstanding representative of the mountain ecosystem in temperate arid regions. It has a typical vertical natural belt spectrum in temperate arid regions. Within a horizontal distance of less than 30 km, Bogda's elevation rises from 1,380 to 5,445 m, and the vertical elevation difference is nearly 4,100 m. Six vertical natural belts from desert steppe to ice and snow belts have developed: temperate desert steppe belt, mountain steppe belt, alpine coniferous forest belt, alpine meadow belt, Alpine cushion vegetation belt and ice and Snow Belt. At the Bogda World Heritage Site, snow-capped mountains, glaciers, rivers, lakes, forests and meadows coexist with each other to present the superlative natural beauty of mountains in a desert area. The vertical natural belt distribution reflects the water and heat variations at different elevations, gradients and slopes. It is an outstanding example for the study of biological community succession in mountain ecosystems in an arid belt undergoing global climate change.

The impacts of climate change are the main driving factor of vertical belt change. According to the seasonal and periodic characteristics of the monitoring objects for the protection of the Bogda Heritage Site, Wang Xinyuan's research group (Ji et al. 2018) selected TM data from June 19, 1989, and OLI data from July 28, 2016 (Fig. 17.1), combined with auxiliary data such as ground object spectrometer information, field GPS acquisition and UAV data, and made use of scatter plot of DEM-NDVI-Land Cover Classification (Fig. 17.2) based on probability and statistics. Based on the study, the demarcation elevation of the vertical natural belts was

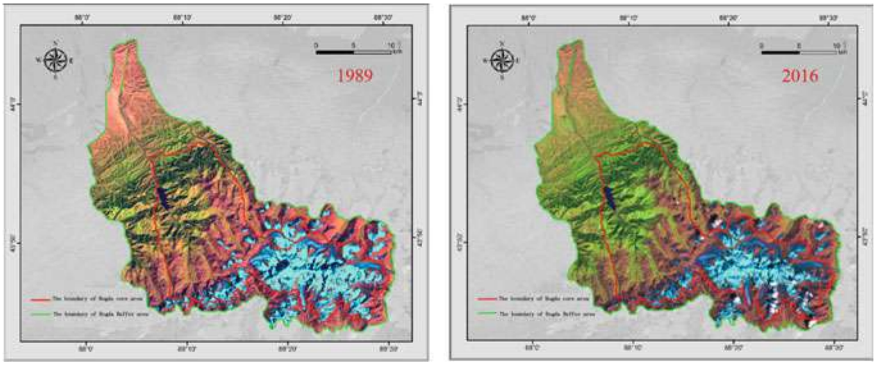

Fig. 17.1 Bogda images for (left) 1989 and 2016 (right)

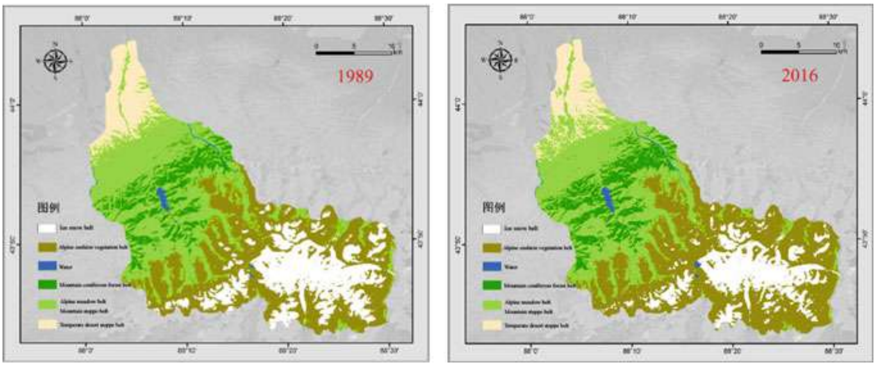

Fig. 17.2 Bogda classification results for 1989 (left) and 2016 (right)

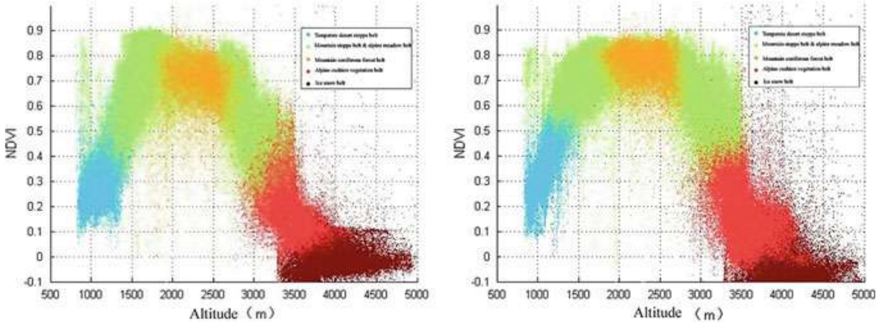

Fig. 17.3 Bogda scatter plot for 1989 (left) and for 2016 (right)

extracted to monitor the changes in the vertical belts in the Bogda Heritage Site in the past 30 years.

Remote sensing images are classified according to the zoning content of vertical zones. The images are classified by comprehensive supervised classification, decision tree hierarchical classification and visual interpretation.

Using the superpositioned DEM data, NDVI (Chang et al. 2015) and classification results of the Bogda Heritage Site, the "DEM-NDVI-classification information scatter plots" for 1989 and 2016 were created, as shown in Fig. 17.3. The two-year trend in the distribution of scatters shows an inverted U-shape of "uniform rise-remain stable-uniform decline".

With the elevation increase in the Bogda area, the heat and water and the environment of vegetation growth change, and the coverage types change regularly, corresponding to the six colors in the scatter plot. There was a clear demarcation between scatters in different vertical belts. The proportions of pixel classification attributes at different elevation ranges in the scatter map of the DEM-NDVI-Land Cover Classification was calculated by sliding statistics, and the vertical zoning results for the Bogda Heritage Site in 1989 and 2016 were obtained by setting thresholds. The extraction results are shown in Table 17.1.

Table 17.1 1989 and 2016 data with elevation results (spline data)

	Temperate desert steppe belt-mountain steppe belt (m)	Mountain steppe belt-alpine coniferous forest belt (m)	Alpine coniferous forest belt-alpine meadow belt (m)	Alpine meadow belt-alpine cushion vegetation belt (m)	Alpine cushion vegetation belt-ice and snow belt (m)
1989	1278	1784	2714	3277	3636
2016	1185	1759	2730	3288	3690
Difference	−93	−25	+16	+11	+54

Note + indicates boundary line elevation, −indicates boundary line elevation drop

The vertical belts of the Bogda Natural Heritage Site in the Tianshan Mountains in 1989 and 2016 were extracted, as shown in Table 17.1. The boundary between the temperate desert steppe belt and mountain steppe belt decreased 93 m, the boundary between the alpine meadow belt and alpine cushion vegetation belt moved up 11 m, and the lower limit of the ice and Snow Belt increased 54 m. This shows that the area of mountain grassland has greatly expanded, and the protection of natural heritage is critical; due to the impacts of global climate change, the glaciers have retreated. Therefore, considering the problem of OUV performance in heritage sites, it is necessary to carry out Sustainable Heritage monitoring using qualitative and quantitative methods, field investigation, social investigation and remote sensing investigation to protect and manage natural heritage.

Using field research and Google Earth high-resolution image data, six points were selected in each area where the land type obviously changed. Thirty-six verification points were selected to verify the mountain vertical band extraction results. As shown in Table 17.2, the elevation of the verification points fluctuated above and below the demarcation elevations, but the overall trend was consistent with the research results.

17.2.2.2 Recognition of Coral Reef Health Status Based on RS and GIS

Corals require harsh growth conditions, and subtle changes in sea temperature, salinity, sediment content and other environmental factors can lead to widespread bleaching or death of corals. Coral reefs are the most responsive ecosystem to climate change on a global scale. Therefore, it is very important to grasp the health status of coral reefs in time to study the effects of climate change and the utilization and protection of marine ecological resources (Holden and Ledrew 1998). Australia's Great Barrier Reef (GBR) is 2011 km long and 161 km at its widest point. The scenery is charming and the flow of water is complex. It is a sensitive area of global change, with more than 400 different types of coral reefs. The GBR, extending 2000 km along Queensland's coast, is a globally outstanding example of an ecosystem that has evolved over millennia. The area has been exposed and flooded by at least four glacial and interglacial cycles, and reefs have grown on the continental shelf over the past 15,000 years.

Kutser et al. (2003) used hyperspectral sensors to measure the reflectivity spectra of six different colors of coral communities in the Great Barrier Reef (approximately 5–6 m deep), and analyzed live corals, dead corals, and algae. The reflectivity of ground objects obviously differs between 550 and 680 nm; the spectral reflectivity of sand is the highest, the reflectivity curve is gentle, and the reflectivity curve is the easiest to distinguish from those of other materials. Coral and seaweed have low reflectivity. The waveform is determined by the light absorption characteristics of pigments in the body, which comprises wavelengths from 500 to 625 nm for the big difference in reflectivity waveforms between coral and seaweed.

Table 17.2 Vertical natural belt extraction verification results

	Temperate desert steppe belt-mountain steppe belt		Mountain steppe belt-alpine coniferous forest belt		Alpine coniferous forest belt-alpine meadow belt		Alpine meadow belt-alpine cushion vegetation belt		Alpine cushion vegetation belt-ice and snow belt	
	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)	E(m)	D(m)
1	1174	+11	1774	−15	2713	+17	3309	−12	3681	+9
2	1186	−1	1761	−2	2745*	−15	3272	+21	3672	+18
3	1192	−7	1742*	+17	2726	+4	3232	+39	3697	−7
4	1105	+80	1740*	+19	2736	−6	3297	−4	3666	+24
5	1147	+38	1741	+18	2743	−13	3307	−19	3705	−15
6	1194	−9	1779	−20	2737	−7	3317	−29	3687	+3
R	1185 m		1759 m		2730 m		3293 m		3690 m	

Note E-elevation, D-difference value, R-extraction results, *represents in situ data
+ indicates the verification point elevation was greater than the extraction result
– indicates the verification point elevation was lower than the extraction result

In addition, Clark et al. (2000) found that recently dead corals can be distinguished from corals whose death time is longer than 6 months by derivative spectrum. In addition to spectral measurement and analysis of coral reefs, Landsat and SPOT series satellite data can be used to identify coral reefs with coarse accuracy (Benfield et al. 2007). Collin and Hench (2012) identified the healthy and unhealthy status of coral reefs from Worldview-2 high-resolution imagery using a support vector machine (SVM).

17.2.2.3 Habitat Suitability Assessment of Animal Habitat Based on Spatial Information Technology

A great deal of observed evidence shows that the combination of climate change and other pressure sources has led to the migration of species distribution, wildlife phenology, reproductive behavior, population composition and ecosystem function changes.

The giant panda is a rare wild animal unique to China. It is also the flagship species of biodiversity conservation in the world. The giant pandas are now confined to six mountain systems, from north to south: Qinling Mountain, Minshan Mountain, Qionglai Mountain, Big Facies Mountain, Small Facies Mountain and Liangshan Mountain. Based on spatial information technology, the Wang Xinyuan Research Group (Song et al. 2014; Zhen et al. 2018) carried out a habitat suitability assessment of giant panda habitat.

Based on remote sensing, geographic information system (GIS) and other spatial techniques, using the latest data from the fourth Giant Panda Survey and the maximum entropy model (MaxEnt), the assessment of the impacts of climate change on the habitat of giant panda (Ya'an) was carried out at this stage and is planned in 2050. In the course of carrying out the detailed assessment, the latest data on panda occurrences and human disturbance factors were based on the fourth Giant Panda Survey (2011–2014), with elevation, slope and aspect as physical environmental variables. The distribution map of the staple food bamboo and distance from water source were biological factors. Human disturbance factors included the interference factors, with a high encounter rate in five study areas of roads, mines, hydropower stations transmission lines and scenic spots. The bioclimatic data were derived from climate variables on the WorldClim website, 12 land cover thematic data from 2001 to 2015 that were uniformly processed by NDVI, and high-resolution remote sensing data such as GF-1, as shown in Fig. 17.4.

The research analyzed the suitable conditions of giant panda habitat and its changing trends and related rules under the background of the current stage of and future climate change in Ya'an, Sichuan Province in China. Through on-site visits to nature reserve management agencies and local residents' research, the evaluation results were verified through field studies. The evaluation results, such as those shown in Fig. 17.5, provide a deep understanding of the trends and extent of habitat change in

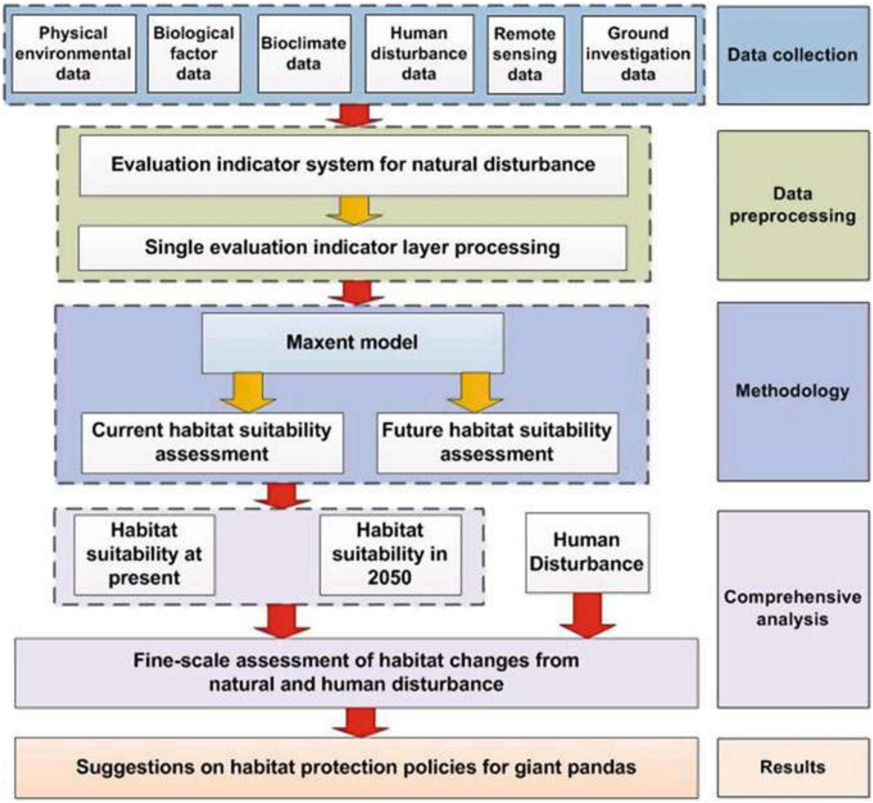

Fig. 17.4 Flow chart of fine-scale climate change evaluation and countermeasures

the context of climate change. They are of great significance for the effective protection of current and future giant panda habitat, ecological protection and coordinated development of the local economy.

17.3 Digital Cultural Heritage

Digital cultural heritage is the application of the theory, methodology and technology related to Digital Earth in the field of cultural heritage. Applying digital technology focused on spatial information technology to tangible cultural heritage is of great significance for the protection, inheritance and exploitation of cultural heritage.

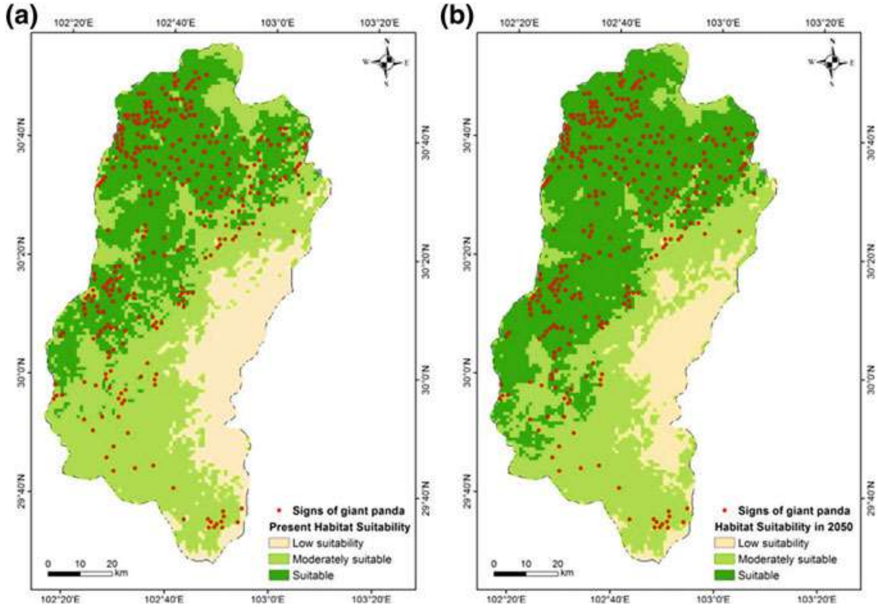

Fig. 17.5 Giant panda habitat suitability (**a**) at present; and (**b**) in A.D. 2050

17.3.1 Digital Cultural Heritage Research and Technical Methods

As the core technology supporting the deep development and wide application of Digital Earth, spatial technology provides new means as well as new tasks and connotations for digital cultural heritage research. Through digital technologies such as photogrammetry and remote sensing, digital cultural heritage can realize nondestructive archaeological detection, digital archiving, dynamic monitoring and evaluation of heritage, and support the preservation and sustainability of the heritage ontology and the environment on which it relies. The main technical methods for digital cultural heritage research include:

17.3.1.1 Space Archaeological Technology

Space archaeological technology integrates worldwide earth observation technology from space, air to ground and underground exploration technology to detect and discover archaeological objects (Luo et al. 2019). In the positioning and discovery of heritage, technical features of spatial earth observation technology including the high-resolution, multi-spectral and multi-resolution nature, objectivity and non-intrusiveness can be fully utilized to provide technical support for archaeological heritage investigation, exploration and research. The remains of ancient human activities (surface or subsurface) can lead to variances in the spatial structure between the remains and their surroundings. These are represented in the digital records of remotely sensed imagery as interpretation marks such as micro geomorphology, soil moisture, and vegetation growth distribution, which have become the theoretical basis of remote sensing archaeology. Space archaeology is the inheritance and development of remote sensing archaeology. It extends the working spectrum of remote sensing archaeology and has the advantages of multi-scale observation of a satellite with aerial and ground integration. The introduction of geophysical exploration and other technologies has enabled the development of spatial archaeological observations of the subsurface or even lower, providing a new approach for nondestructive detection of buried remains.

17.3.1.2 Digital Recording and Preservation of Cultural Heritage

Accurate digital recording is the premise of heritage protection and monitoring. Based on principles of photogrammetry and remote sensing, it collects and digitizes ground control points by acquiring satellite and aerial high-resolution remote sensing images, and uses photogrammetry software to produce high-precision maps of the heritage ontology. Through the three-dimensional (3D) data acquisition equipment of aerial, low-altitude aerial, car-based or ground platforms, 3D modeling software is used to construct 3D models and record the shapes and spatial attributes of the heritage ontology and the environment. A large heritage database system that can be queried and updated is then formed using geographic information system (GIS) and database technology to digitally manage various types of heritage information.

17.3.1.3 Heritage Ontological and Environmental Dynamic Monitoring

By obtaining data on the same heritage object at different times, through comparative analysis, changing information identification and model calculation, the status and potential risks of the heritage object can be evaluated. Earth observation technology based on Digital Earth has great potential for monitoring large cultural heritage remotely and dynamically and even in 3D form. The analysis and evaluation of the situation and risk of the heritage object are conducted by applying artificial or intelligent remote sensing recognition technology and monitoring and identification algorithms on remote sensing data at a certain interval (appropriate spatial resolution, spectral resolution and temporal resolution, etc.) or 3D digital models.

17.3.1.4 Heritage Demonstration on Virtual Reality Technology

Virtual reality (VR) is a new and integral technology in the sphere of computer science, which developed from the integration of disciplines involving computer graphics technology, multimedia technology, sensor technology, human-computer interaction technology, network technology, stereo display technology and simulation technology. With advantage of lifelike, immersive reconstructions, it can be applied in cultural heritage research, restoration and digital virtual tourism. The seamless integration of digitalization and virtual reality technology can be an effective means for digital protection.

17.3.2 Digital Cultural Heritage Application Cases

17.3.2.1 Space Archaeology

As a successor of remote sensing archaeology, Space archaeology is a new paradigm of space information technology employed in archaeology (Wang and Guo 2015). Through multiple technology integration and comprehensive analysis, it provides the essential information linked to the acquisition, interpretation and reconstruction of archaeological remains. Space archaeology research is in the emerging stages. At present, the work is mainly concentrated in deserts, Mayan jungles and the Nile Delta using remote sensing-based methods of archaeological faint information extraction, and has achieved a series of important scientific achievements and archaeological discoveries. American archaeologists discovered the notable ancient Egyptian city of Alexandria, which had slept in the sea for thousands of years; Greek archaeologists employed infrared photographs to discover the ancient city of Hekike, which was destroyed by an earthquake in 373 B.C. in Corinth. Guo (1997) used space shuttle imaging radar data to discover the great walls of the Sui and Ming Dynasties buried in the dry sand at the junction of Shanxi and Ningxia. Ninfo et al. (2009) visually interpreted and digitally reconstructed the urban structure and paleoenvironmental background of the ancient port of Altinum using high-resolution visible and near-infrared aerial photographs and digital elevation models. Evans et al. (2007) used GIS tools to map the most detailed archaeological information of the Angkor Wat site based on multisource remote sensing data such as optical and SAR information. Parcak et al. (2016) conducted a spatial archaeological study of the Nile Delta. They investigated thousands of ancient sites in the area and identified ancient city street ruins and unfinished pyramids based on high-resolution remote sensing data to reconstruct the ancient Egyptian empire.

The Silk Road is precious cultural heritage owned and shared by all mankind. To enhance the ability to rescue archaeological discoveries, space archaeology provides new technical methods for the detection, discovery and reconstruction of sites along the Silk Road at different scales. With the benefit of spatial information technology, a spatial forecast model of heritages based on GIS spatial analysis was built by Wang and Guo (2015) by considering the similarity of environmental and geomorphological landscapes of the ancient Silk Road between NW China (Luo et al. 2014a, b) and southern Tunisia using satellite imagery, historical documents, archaeological survey data and other multivariate data. Three ancient city sites related to old stages in Dunhuang, northwest China, were discovered on the high-resolution satellite remote sensing imagery. The field archaeological survey supported by GPS technologies and historical research material confirmed the specific locations of the ancient stages. Based on the Digital Earth platform and existing spatial archaeological results, the postal system between Guazhou and Shazhou (two prefectures) in the period of the post-Wuhou Tianshou second year (A.D. 691) was digitally reconstructed (Fig. 17.6). It laid a scientific database foundation to study the route of the ancient Silk Road and the changes in the ancient oasis in medieval China. The new

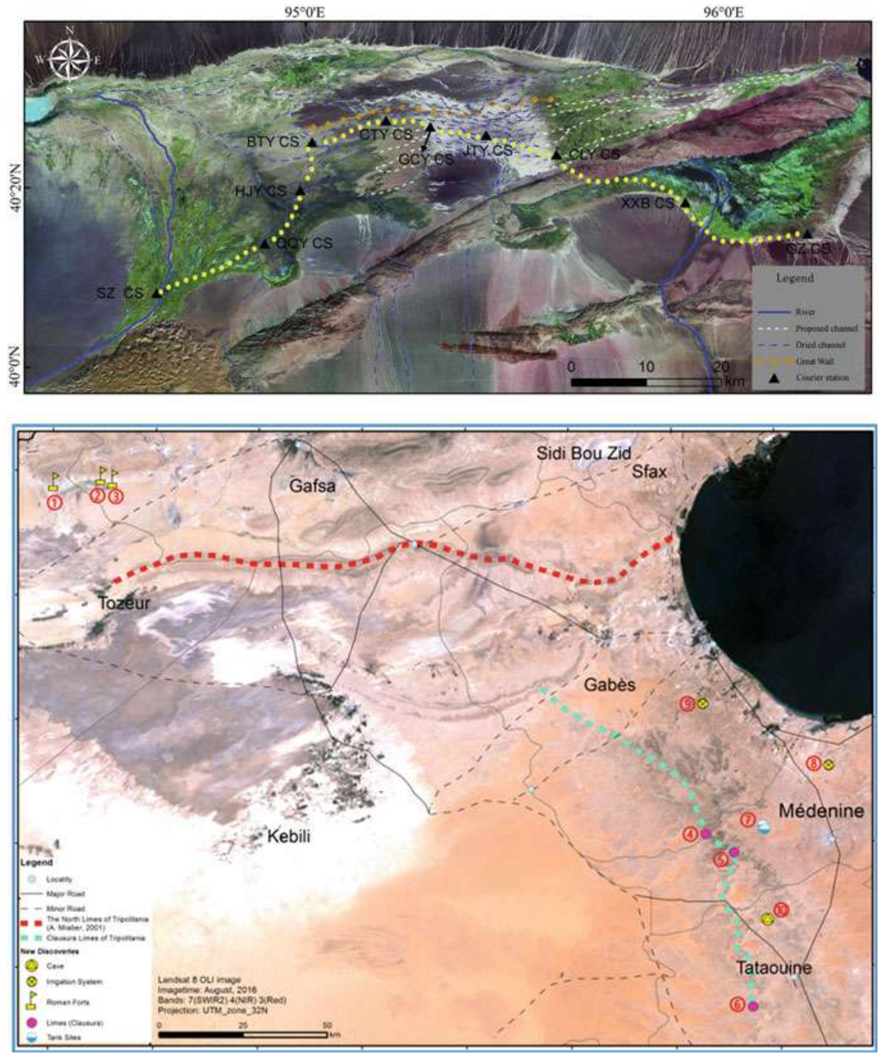

Fig. 17.6 Space archaeology of the silk road in China (upper) and Southern Tunisia (lower)

paradigm of spatial archaeology has been promoted and applied to Tunisia, where 10 ancient Roman remains have been discovered; the legacy evidence chain reflected the military defense system of the southern frontiers of the Roman Empire (Fig. 17.6).

The comparative space archaeological study of the defense system along the Silk Road between the Han Great Wall and the Roman Lima system provides detailed knowledge of the defense system, border defense strategy, human-land relationship and environmental changes in areas along the Silk Road as scientific references.

17.3.2.2 Cultural Heritage Monitoring and Protection

In the face of frequent natural disasters, global changes and increased human activities (such as urbanization, tourism development and local wars), the sustainable protection of cultural heritage has encountered challenges. As a common nonrenewable wealth of all mankind, safeguarding and protecting the world's heritage is the focus of the UN 2030 Sustainable Development Goal 'Sustainable Cities and Communities'. Considering the wide coverage, diverse types and different landscapes of cultural heritage, it is urgent to take advantage of near real-time, wide coverage and high precision of remote sensing big data under the digital earth framework for dynamic monitoring and intelligent protection of cultural heritage.

First, due to the rapid development of sensor technology and the Internet of Things in recent years, heritage protectors can now automatically monitor elements of micro environmental change information in near real-time, from the monument to the landscape (e.g., humidity, temperature, air pollution, power, precipitation, structure vibration and deformation), providing quantitative data for the identification of trigger mechanisms for heritage sites affected by diseases and for the consequent conservation measures.

Second, high-resolution remote sensing platforms with multiple bands and high revisit frequency and satellite-airborne (low-altitude) information processing technology make it possible to monitor the whole-day and all-weather dynamics of a heritage scene; the extraction and storage of topographic factors such as slope and water catchment can aid in detailed mapping for heritage protection; natural disasters such as landslides and human activities such as urbanization can be identified by remote sensing images, and the GIS platform space-time analysis function can be used to support early warning and assessment of heritage risks.

Third, the key advantage of Digital Earth platforms such as Google Earth, WorldWind and ArcGIS Explorer is the wide use of Keyhole Markup Language (KML) to ease the integration of multisource datasets from different providers and to simultaneously visualize and identify relationships for use in subsequent quantitative investigations. Cultural heritage applications require the integration of heterogeneous georeferenced 1D/2D/3D/4D data from local computers or data obtained 'on the fly' from distributed sources due to the demands of comprehensive archaeological understanding and knowledge discovery. In Google Earth, these data are usually in KML format. A case study was conducted on part of the Great Wall (Fig. 17.7a) in NW China (Luo et al. 2018) in the early 20th century by famous archaeologists and

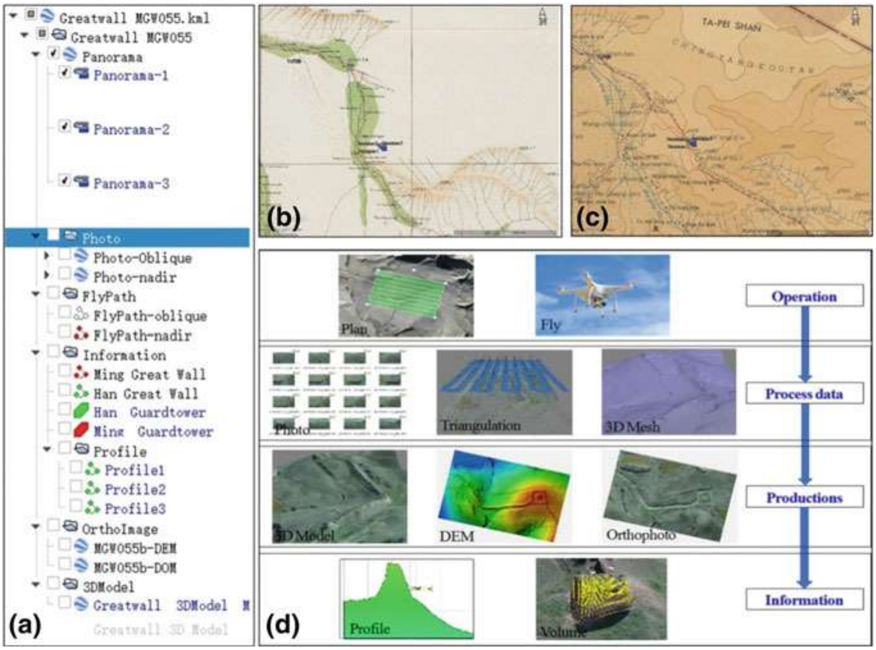

Fig. 17.7 The integration of geospatial data of the Great Wall in northwestern China. **a** The overall tree structure of the KML layers in GE; **b** the archaeological maps made by Stein; **c** the archaeological maps made by Hedin; **d** the operation flowchart for our UAV investigation. We deleted the photo layer in the supplementary file because the volume was too large

geographers, who made many great discoveries and uncovered its mysteries. The work of these expeditions served different roles and provided clues to researchers seeking to find unknown sites. The most famous explorers were Stein and Hedin, and their precious investigation reports and archaeological maps (Fig. 17.7b, c) play important roles in understanding the changes that have occurred in the Middle East and Central Asia in the past century, especially in terms of land use and land cover (LULC).

An unmanned aerial vehicle (UAV) investigation of the Great Wall was carried out (Fig. 17.7d). All of the original and processed data (courses, photos, triangulation and mesh), final products (orthophotos, DEM and 3D model) and derivative information (profiles and volumes) were saved in KML format. Members of the public and scientific peers can download and reproduce the data for integration with archaeological maps and their own data. For example, based on these high-resolution UAV-generated DEM and 3D model analyses, a Great Wall Integrity Index was defined and applied in quantitative evaluation of Ming earthen Great Wall erosion status. Stein and Hedin's archaeological maps were also used in this case; these can be downloaded from the Japanese National Institute of Informatics (http://dsr.nii.ac.jp). By browsing in GoogleEarth, it was evident that Hedin's archaeological map of our proposed pilot area was more detailed than Stein's (Fig. 17.7b). We were unable to find any marks showing the linear traces of the Great Wall in Stein's map but they are present in Hedin's map (Fig. 17.7c). In future research based on data visualization and integration in GE and the LULC specific situations established by GE VHR imagery, it will be possible to use UAV data and archaeological maps to deduce historical LULC changes in the past century along the Great Wall.

However, compared with spatial archaeological detection (which can be traced back to remote sensing archaeology), there is still a lack of research in the methodology and applied strategy of spatial technology employed for heritage monitoring and protection. The existing work on the monitoring of the heritage ontology and environment is often isolated and the monitoring elements and means are relatively simple, which affects the comprehensive understanding and systematic response to the sustainable protection of cultural heritage. Recently, Xiao et al. (2018), from the perspective of UN Sustainable Development Goals 11 and 8, proposed that geospatial information technology such as photogrammetry, remote sensing and spatial information would play an important role in defending and protecting cultural heritage and sustainable tourism. Chen et al. (2017) developed a two-scale radar interferometry method and model for deformation monitoring and health diagnosis of heritage sites affected by disease (Fig. 17.8) that considered the dynamic changes in heritage

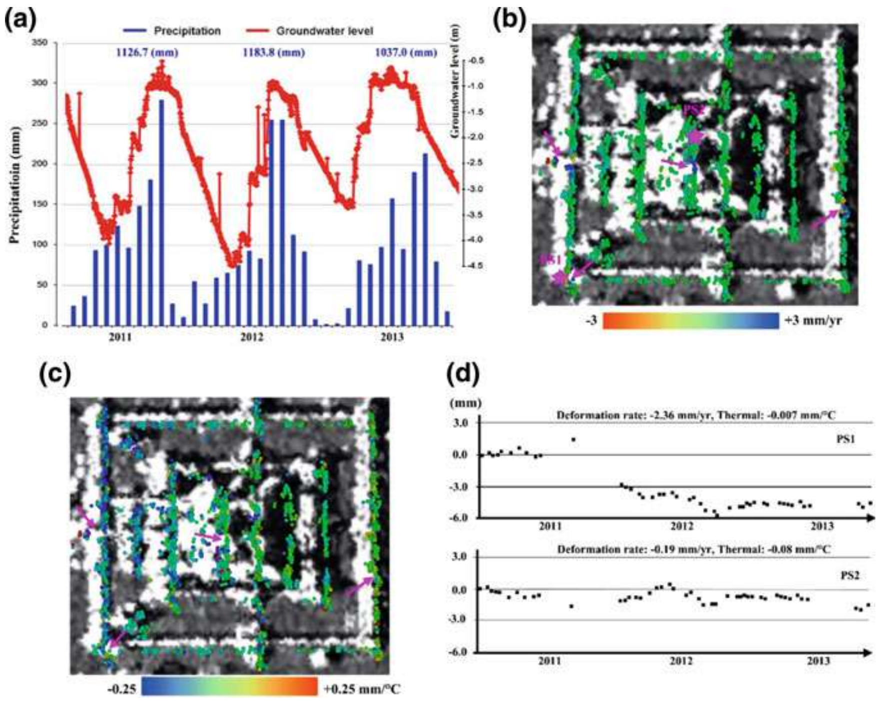

Fig. 17.8 Angkor's environmental remote sensing revealed the collapse of ancient temples and contributed to the sustainable protection of heritage sites. (following Chen et al. (2017))

ecosystems, monitored environmental factors (including urbanization, forest degradation, land use, groundwater level) to resolve the current controversy surrounding the potential structural collapse of monuments in Angkor. They constructed the dynamic model of the disease evolution of the Angkor temple complex and unveiled the mystery of the decline of the heritage site, bringing a new insight for the site sustainable conservation.

17.3.2.3 Virtual Reconstruction of Cultural Heritage

The protection and sustainable development of cultural heritage can be understood from a narrow point of view as the documentation, restoration and maintenance of the heritage site. From a broad perspective, it should be extended to the cognition, understanding and inheritance of the human civilization based on the protection of the heritage entity. Due to the rapid development of information technology in the internet and big data era, the visual demonstration of heritage information from multiple sources can be realized through virtual reconstruction scientifically, intuitively and vividly, which greatly promotes the dissemination and inheritance of ancient civilization.

The virtual reconstruction of digital heritage includes three main aspects. The first is to combine multisource data to model historical sites and the paleoenvironment and establish virtual ancient scenes; the second is to design lively and representative key historical and cultural events and scene elements (such as costumes or hairstyles that reflect the cultural elements of the time, street arrangements, etc.) considering the cultural background and geographical environment of specific historical periods; the last is to realize the digital display of virtual ancient scenes integrating virtual reality, holographic projection, augmented reality, digital animation and other technologies. By providing visual, auditory, tactile and other sensory simulations, it allows for users to immerse themselves in the cultural relic environment and its historical context (Mortara et al. 2014).

Some relevant experts and scholars have achieved fruitful results in this field, such as the virtual reconstruction of the cultural site of Pompeii by the University of Geneva and the digital restoration of Yuanmingyuanby Tsinghua University, but there are still some major challenges in the virtual reconstruction process for cultural heritage.

First, cultural heritage often contains various elements and complicated space characteristics. It is difficult for a single platform or sensor to meet the requirements of all types of data acquisition due to multi-platform, multisource, heterogeneous sensors. The need for collaborative stereoscopic observations is increasingly evident (Lin et al. 2014). The cultural heritage HuaixiuShanzhuang (HXSZ) in Suzhou, China, has a complex structure, which is a challenge for modeling. To acquire high-accuracy 3D models, Liang et al. (2018) collected point clouds via terrestrial laser scanning(TLS) and modeled texture via terrestrial digital photogrammetry(TDP) (Luo et al. 2014a, b). They fused the TLS and unmanned aerial vehicle digital photogrammetry (UAVDP) point clouds and integrated the TDP point clouds with the already-merged point clouds for 3D modeling and digital documentation. The multiple surveying methods, multisource and multi-scale data collection, procession and presentation and documentation overcome the limitations of a single technology and data source, providing a solution for high-accuracy preservation of cultural heritage sites that contain complex space characteristics.

Second, multi-sensor observations are prone to many structural problems such as data structure differences, uneven acquisition granularity, and weak spatial and temporal coupling. The development of collaborative observation, joint registration, and multisource data fusion modeling techniques can provide digital protection for cultural heritage. In addition, the integration of multi-source/multi-scale data and models requires efficient management platform. Hua et al. (2018) developed an internet-based 3D geographic information service system for Hakka culture preservation with data storage on the cloud and service functions such as scene loading and browsing, thematic cultural map display, online virtual experiences for tours, and tourist route navigation for users. The data sources were based on surveyed and collected materials and knowledge of Hakka culture through field work and the 3D model of Tulou reconstructed with TLS, UAV and digital camera data. It provides a virtual experience for a cultural tour in a 3D interactive way and a novel platform for Hakka culture presentation, cognition and heritage.

Third, to enhance the vivid experience and the comprehension of the public, Barsanti et al. built a virtual museum with 3D interactive scenarios of Egyptian funeral objects that was exhibited at the Archaeological Museum in Milan (Barsanti et al. 2015) (Fig. 17.9). In this scenario, users could grab, wave and rotate 3D models to observe them from different points of view with the movement of their virtual hands, which was implemented by wearable virtual reality devices named HMD. In addition, Eva et al. realized gesture-based natural interaction in a virtual reproduction of the Regolini-Galassi tomb, one of the richest and most famous tombs of the Orientalizing period (Pietroni et al. 2013). By exploiting the recognition of the skeleton and the grammar of common gestures, this application leaves users completely free to walk through the 3D scenes of the ancient cultural heritage site and dynamically choose 3D objects they are interested in with a gesture of their arms.

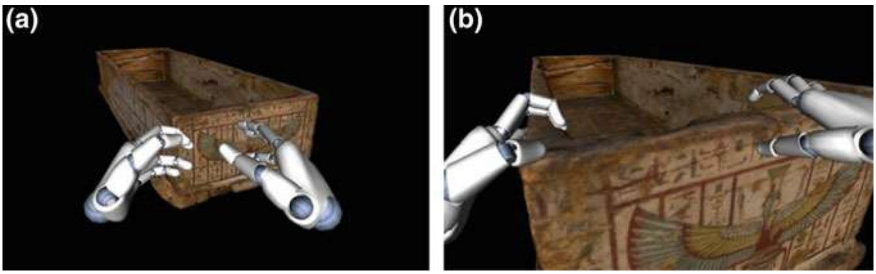

Fig. 17.9 Pictures of the implemented VR scenario: **a**, **b** grabbing and rotating of an object with the option to enlargeit (following Barsanti et al. (2015))

Furthermore, in most outdoor cases, users are inclined to compare the current site with the immemorial one that shared the same location with it, so that they can infer the changes that occurred over time. To address this issue and allow for the capability of combining the natural world and artificial world, augmented reality technology appears to be a suitable choice. Quattrini et al. (2016) reconstructed a Roman theatre in Italy using TLS point cloud data and validated the 3D models using a geometrical survey of evidence. Moreover, they showed how it is possible to realize on-site visualization of cultural heritage that no longer exists based on a mobile augmented reality (MAR) platform (Quattrini et al. 2016) (Fig. 17.10).

Notably, the whole life cycle of cultural heritage is a complex historical process that includes site selection, construction, completion, maintenance, and the current physical restoration, which comprises both natural processes and human activities. For example, the EU's Seventh R&D Framework Program officially launched research on the impacts of natural processes (climate change) on historical and cultural heritage (http://www.climateforculture.eu/index.php?inhalt=project.overview). To effectively recognize the temporal and spatial characteristics of cultural heritage, it is particularly important to develop and construct a dynamic knowledge environment. The dynamic knowledge environment requires integrated sensors for real-time observation, geographic process simulation and prediction, and agent behavior analysis methods and techniques to provide comprehensive analysis capabilities that can trace the past and more effectively predict the socialization process of cultural heritage.

Fig. 17.10 The development of MAR visualization for the reconstructed Roman Theatre in Fano, Italy, using Layar. (following Quattrini et al. (2016))

The effective solution of the above challenges rely on the development of related technologies such as the acquisition and digitization of cultural heritage related information, seamless integration of multisource/multi-scale data and models, non-rigid physical modeling and its free interaction and real-time response, space-time evolution modeling of ancient sites and ancient civilization activities, and behavioral model building. Narrowing the gap between high-tech virtual reality and cultural heritage remains a challenge. Academician Huadong Guo of the Chinese Academy of Sciences advocated constructing and developing spatial archaeology, an interdisciplinary field combining the strengths of spatial technology, cultural heritage, big data science, and computer technology, which practically applies new and sophisticated technology to heritage protection and sustainable development. At present, the pilot project “the Earth Big Data Science Project” of the Chinese Academy of Sciences, which oversees Academician Guo Huadong, has been set up to support related research on heritage protection along the Belt and Road. It will reproduce the past glory of the ancient civilization of the Belt and Road through the virtual reproduction of digital heritage.

17.4 The Development Trend of Digital Heritage

Cultural and natural heritage are the precious wealth of mankind, and the primary condition of heritage protection is to ensure the authenticity and integrity of heritage. Although digital technology applied to cultural and natural heritage, their preservation, protection, research and utilization provides an important support, digital heritage itself also faces issues such as data security, distribution, interoperability, cost, simplification and speed problems for application. It is also a challenge to open access and increase the ease of understanding. The preservation and protection of digital heritage involve technology and methods for preservation and protection, management systems, protection schemes, and management measures and laws regarding the protection of digital heritage. The future development of digital heritage preservation, protection, research and utilization has the following trends.

17.4.1 The Depiction of Heritage Objects via Remote Sensing Technology Is Becoming Increasingly Precise

Multi-platforms of satellite, airborne and ground remote sensing have increasingly higher spatial resolution. The development of multi-spectrum and hyper-spectrum technology has made object characterization more and more precise. Coupled with the progress of data processing technology and cognitive methods, the recognition of the geometry and attributes of natural and cultural heritage is closer to the actual items.

Especially in recent years, rapid development of laser radar technology as a new means of three-dimensional space data acquisition that can perform complex surface measurement quickly and accurately and obtain a record of the sites of cultural relics that is high-density, high-precision and three-dimensional, representing the information of cultural heritage sites truly, accurately and completely. In addition, hyper-spectrum data will become increasingly important in the fine classification of natural and cultural heritage. There will be great potential in the future for natural and cultural heritage information acquisition based on the fusion of hyperspectral information and LiDAR elevation information.

17.4.2 The Demand for Durable Digital Heritage Preservation Media Will Continue to Drive Innovation

How can advanced technology be used to monitor and protect valuable cultural and natural heritage, and what is the best medium for preserving such data? As early as the 1970s, people began to use photography, video and other technologies to record information about natural processes and cultural relics. However, these data are difficult to preserve for a long time due to the aging of videotapes, disk demagnetization, and image reproduction that produces distortion. In the late 20th century, with the emergence of virtual reality technology and the rapid development of networks, the heritage protection industry has a new opportunity—high-precision and high-fidelity digital heritage preservation technology. Modern high-quality digital image technology and advanced graphic image processing methods have brought the protection of natural and cultural heritage into a new era. Image-based rendering (IBR) and image-based modeling (IBM), three-dimensional scanning-based reconstruction and roaming, retrieval/restoration/color technology, multiple projection immersive virtual environment and other technologies have made digital natural and cultural heritage become a reality and have great potential in future applications of digital natural and cultural heritage.

17.4.3 Data Integration, Development, Publication and Dissemination for Heritage Protection Platform Software Urgently Need to Be Developed

To make full use of different sensors (obtained from aviation, space, and the ground), 3D models, airborne data, and ground laser scanning data, using a GIS environment and software to manage and integrate the available information (digital and the digital format) and synthesize, refine, comprehensively develop, and release multisource data (excavation reports, geophysical surveys, mapping, aviation and satellite photography) can provide effective solutions.

GIS environments or web-based GIS environment tools provide new and more efficient ways to conduct archaeological research, store and process data, and share multisource geospatial data collaboratively. To develop infrastructure, new methods and concepts are needed to handle the increasing big data and data integration requirements, the requirement of efficient archive processing and the simplification of GIS-based technology applications. These problems can be solved via building open source components based on the WebGIS platform. With the rapid development of archaeological WebGIS today, the combination and usage increase of related archaeological applications is occurring. Many platforms with various interfaces and functions have been created for professional and nonprofessional users.

WebGIS architecture provides flexible tools for multiple requirements, applications, and usage phases. The open source tools of WebGIS have played an important role for different application purposes in recent years, for example, a the release of mining results; b the design of archaeological clues to the land; and c the incorporation of archaeological data into the broader national geological portal for landscape conservation purposes.

A system platform and database for monitoring, evaluation, decision-making and exhibition of natural and cultural heritage are an expectation of researchers, users and the public around the world. The Digital Belt and Road (DBAR) Working Group (DBAR-Heritage) is developing such a platform.

17.4.4 Increasingly Convenient Digital Technologies Are Adapted to Non-professional and Wide Public Participation in Heritage Conservation

The growing availability of free data and open access software tools has strengthened the link between field surveys and computer analysis, providing new opportunities for the conservation, development and utilization of natural and cultural heritage sites. The key point is to create accessible tools for different people, including the domain expert groups (archaeologists, remote sensing experts, regulators, museums) and non-professional users, for tourism and education purposes concerning regional natural and cultural heritage of the people. In addition, the effective interoperability between different computer platforms, executing a program or data transmission between various functional units should allow for the user to have little or no need to understand the characteristics of these units. Related operations can also be hosted in the cloud by sending images to a remote powerful server and, after a short period of post-processing, the design model can be previewed. This makes digital archaeology work less exclusive than in the past, which makes it easier for government decision makers, schoolteachers and the public to use data and offers the possibility of wider participation.

17.4.5 Quantitative Research Based on the Value Assessment of Natural and Cultural Heritage via Digital Technology

Although the important role and significance of natural heritage in the ecological balance, scientific research, scientific popularization, natural aesthetics and tourism and leisure are difficult to estimate, some fields can be evaluated. In terms of ecological value, especially large natural heritage plays an extremely important role in the conservation of species and the ecological value of regional and global significance. The earth is an organic whole, and local destruction can affect the local or wider ecological environments. Although we may not see any examples of such local destruction causing an obvious overall imbalance, the changes in Antarctic glaciers and even mountain glaciers caused by current climate changes has been a “wake-up call” (e.g. Kaser et al. (2004)).

For both tangible cultural heritage and intangible cultural heritage, the value is diversified. The intangible cultural heritage of language, handicrafts, performance art and other forms of cultural expression make successive human knowledge to be realized from generation to generation. The result of the accumulation of knowledge greatly promoted human progress. Tangible and cultural heritage is the tangible evidence for humans to know themselves. The archaeological analysis and reconstruction of the physical remains (including artifacts, buildings, etc.) and their related living environments and cultural landscapes have led to the rediscovery of some lost ancient civilizations. The great value of cultural heritage must also be explored further.

Examples of the multiple values of nature and cultural heritage are numerous. Due to the large spaces, time spans and complex situations, quantitative research has not been well conducted. For quantitative research on the value of cultural heritage and natural heritage based on digital technology, the formation of a system and a standard are a possible and urgent innovation issue.

17.4.6 The Study of Effective Protection of Digital Heritage and Legal Protection Is Becoming Increasingly Urgent

At present, the main problems in the protection of digital heritage come from two aspects. One is the problem that researchers’ understanding of the value of digital heritage is insufficient. The value of the digital information of heritage may not be recognized before it disappears or changes and it is too late to provide effective protection. Digital data may be well preserved, but the identification and description may be so poor that potential users cannot find them. As the independence of data and data processing applications cannot be confirmed, the use of data is reduced. The second aspect is the problem of incomplete preservation of digital heritage due to insufficient funds and responsibilities. No one is responsible for the information, or the person responsible may lack the knowledge, systems or policy frameworks needed to perform their duties. Information is vulnerable to disasters such as fires, equipment failures, floods, viruses or direct attacks that disable storage equipment or operating systems; measures such as password protection, encryption, and security devices will cause data to be unavailable when they are not applied.

Cyber space generated by the internet is a kind of living form that has not been experienced by humans. It will have an inestimable impact on contemporary and future human beings. Due to the openness and sharing of resource information in the network environment, anyone can obtain the desired information in any place by some means. Digital heritage is faced with the problem of destructiveness caused by openness and sharing. In addition, the problem of infringement occurs relatively easily. As a kind of digital heritage with the characteristics of cultural heritage, the owner of its property rights should be protected by the corresponding laws. Infringement in the network is different from general infringement. Due to the disguised characteristics of network information transmission channels, the copyright and communication rights of digital heritage easily lead to infringement caused by the transmission of digital heritage without the permission of property owners. Therefore, it is necessary to systematically form international legal documents and universal legal protection of digital heritage.

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Chapter 18
Citizen Science in Support of Digital Earth

Maria Antonia Brovelli, Marisa Ponti, Sven Schade and Patricia Solís

Abstract Citizen science can be thought of as a tremendous catalyst for making Digital Earth a participation model of our world. This chapter presents a wide overview of the concept and practice of citizen science in terms of the technologies and social impact. Definitions of citizen science and various existing approaches to citizen involvement are described, from simple contributions to projects proposed by someone else to the design and planning of science as a bottom-up process. To illustrate these concepts, the relevant example of OpenStreetMap is described in detail, and other examples are mentioned and briefly discussed. Social innovation connected with citizen science is focused on to highlight different levels of direct citizen contributions to scientific research and indirect effects on academia, and studies driven by new questions that may support responsible research and innovation (RRI), governments and public administration in making better informed decisions. Despite its growth and success in relatively few years, citizen science has not fully overcome a number of persistent challenges related to quality, equity, inclusion, and governance. These themes and related complex facets are discussed in detail in the last section of the chapter.

Keywords Citizen science · Digital earth · OpenStreetMap · Social innovation · Public engagement

18.1 Introduction

The Digital Earth vision has evolved from a digital replica of the earth that enables knowledge sharing and simulation (Gore 1999) to a blending of our physical world with digital representations of past, present and possible future realities (Goodchild

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et al. 2012; Craglia et al. 2012; Ehlers et al. 2014). Digital Earth thereby provides innovative ways of interacting with our real and virtual environments. These interactions support different forms of decision-making and enable new approaches of data and knowledge cocreation and facilitate dialogue between conflicting communities (Ehlers et al. 2014). This chapter is dedicated to the possibilities for active contribution that Digital Earth offers citizens, with a special focus on the relationships between Digital Earth and public participation in scientific research (also known as citizen science).

First, central definitions for citizen science, crowdsourcing and volunteered geographic information (VGI) are elaborated. A detailed analysis of a crowdsourcing and VGI application (OpenStreetMap—OSM) provides concrete practical insights on the roles of communities and institutions, technical considerations, and data quality. Following this example, the view is widened to other approaches and categories of citizen science and their relationship to Digital Earth. Additional considerations are taken into account and briefly expanded to wider concepts such as social innovation and public engagement. The chapter concludes with a summary and lists central challenges for future research.

This chapter addresses citizen science broadly, but additional information about citizen science in the European context is presented in Chap. 20. Citizen science addresses the direct and self-conscious participation of people (citizens) in scientific research—which makes it considerably different from passive contributions to research that are carried out by third parties, for example, in the case of social media analysis (see Chap. 12).

18.2 Definitions

To fully understand the value and potential impact of citizen science, it is necessary to consider at least three relevant phenomena of the last twenty years. The first is Wikipedia, the free wiki encyclopedia, which was created in 2001 (Kock et al. 2016). Just over a decade later, in 2013, it had become such a successful enterprise that an asteroid was named after it (Workman 2013). Wikipedia currently boasts approximately 79 Million registered users and is probably the most widely known and used encyclopedia. By definition, an encyclopedia is a narrative model of the world that includes all human knowledge, and had always been written by scholars. As a result of new technology and the collaboration of volunteers (who are not necessarily scholars), Wikipedia has become the largest encyclopedia, written in a few short years.

A second example is the Global Biodiversity Information Facility (GBIF), an operational system that is very relevant for the environmental challenges addressed by Digital Earth. The GBIF was founded in 2001 upon the recommendation of the Biodiversity Informatics Subgroup of the Megascience Forum and subsequent endorsement by the Organisation for Economic Co-operation and Development (OECD) science ministers (GBIF 2011). Today, the GBIF has evolved into a renowned data infrastructure and single access point for biodiversity data (Robertson et al. 2014), much of which originates from volunteer citizen scientists (Chandler et al. 2017). According to its website, the GBIF provides access to almost 45 thousand data sets, including more than 1.3 billion species observation records. This tremendous source of knowledge has led to the publication of more than three-and-a-half thousand peer-reviewed scientific publications.

A third notable example is OpenStreetMap project, which is a free map of the world. Before considering the history and success of this initiative, it must be noted that mapping was a prerogative of governments (mainly for military purposes and land taxation) and that, in some countries both then and now, military forces hold the legislated national monopoly on mapping services. The knowledge of the territory and the science of "where" are a way to monitor and control territory. In this context, OSM represents a complete change of paradigm: everybody contributes to mapping the world; the map is free to everybody for every purpose. Created in 2004, OSM has seen success equivalent to that of Wikipedia and approximately 5 million volunteers have contributed to this project. OSM is the largest existing geospatial database. These examples illustrate the social and technological environment in which the concept and substance of citizen science are situated.

Although public participation in scientific achievements has a long history, recent decades have seen greater attention and an impressive increase in the number of people involved. The term citizen science was used in scientific papers in the mid-1990s (Kerson 1989; Irwin 1995; Bonney 1996). The term was first reported in Wikipedia in 2005 and entered the Oxford English Dictionary in (2014). It describes the scientific work done by laypeople often with the collaboration or under the supervision of scientists. (OED 2014).

However, citizen science is a very diverse practice that encompasses various forms, depths and aims of collaboration between scientists and public researchers in a broad range of scientific disciplines. There are different classifications of citizen science projects based on the degrees of influence and contributions of the public.

Shirk et al. (2012) classified projects into different models based on the degree of participation:

(1) *contributory projects,* which are mostly data collection;
(2) *collaborative projects,* involving data collection and project design refinement, data analysis, and disseminating results;
(3) *cocreated projects,* designed together by scientists and the public, and the public participates in most or all of the steps in a scientific project or process; and
(4) *collegial projects,* developed by noncredentialed individuals conducting research independently with varying degrees of expected recognition by scientists.

Haklay et al. (2018a, b) distinguish projects in three different classes:

(5) *long-running citizen science*, which are traditional projects similar to those run in the past (Kobori et al. 2016; Bonney et al. 2009);
(6) *citizen cyberscience,* strictly connected with the usage of technologies (Grey 2009), which can be subclassified as follows:

(6.1) *volunteer computing,* where citizens offer the unused computing resources of their computers;
(6.2) *volunteer thinking,* where citizens offer their cognitive abilities for performing tasks that are difficult for machines; and
(6.3) *passive sensing,* where citizens use sensors integrated into mobile computing devices to carry out automatic sensing tasks.

(7) community science, involving a greater commitment of citizens in designing and planning project activities in a more egalitarian (if not bottom-up) approach between scientists and citizen scientists (Jepson and Ladle 2015; Figueiredo Nascimento et al. 2014; Breen et al. 2015). This can be divided into the following:

(7.1) participatory sensing, where citizens use the sensors integrated into mobile computing devices to carry out sensing tasks;
(7.2) Do-it-yourself (DIY) science, in which participants create their own scientific tools and methodology to carry out studies; and
(7.3) civic science, the science built on the needs and expectations of the community (Haklay et al. 2018a, b).

In addition to citizen science, the term crowdsourcing (or geo crowdsourcing or crowdsourcing geographic information) is used. The general term (with no geographic declination) was coined in 2005 to describe the outsourcing and spreading, generally through an open call, of a job previously made by a worker to the crowd, i.e. a large group of people (Safire 2009). When related to the location, it refers to a new source of geographic information that has become available in the form of user-generated content accessible over the Internet.

Citizen science considers the process as a whole, and attention is paid to the community of contributors. Geo-crowdsourcing also considers the contributed data and their condition of usage. In some cases, the contributors (e.g., when they are using Twitter, Instagram, Facebook or Google traffic) are unaware that they are contributing to a project: they simply want to communicate with friends and relatives (in the former cases) or to find directions and traffic conditions (in the latter case). Thus, they are treated more like moving sensors than human beings. The person is an appendix of the sensor and not vice versa. The user-generated data can be provided as open to everybody or (more often) used by the service provider for analytics for diverse purposes. For instance, in the case of Google, one advantage could be to build a powerful database for self-driving cars.

Considering the (re)use potential of citizen science contributions, issues related to fitness for the purpose and data quality should be discussed. Those who are new to the field of citizen science often doubt the quality of the results produced. However, it has been shown on numerous occasions that citizen science can deliver high-quality information (Kelling et al. 2015; Bell et al. 2015; Senaratne et al. 2017), and provide new knowledge that could not be gathered with any other approach (see, for example, Walther and Kampen 2017). Literature on data management, quality assurance, and

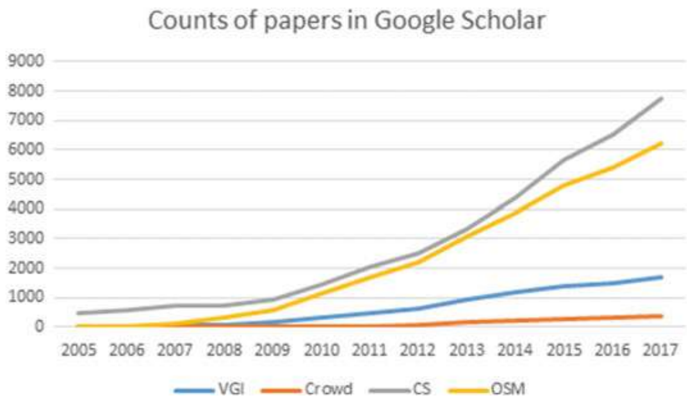

Fig. 18.1 Google Scholar results for papers matching the terms 'volunteered geographic information', 'geo crowdsourced' and 'crowdsourced geographic information' (Crowd); 'citizen science' (CS); and 'openstreetmap'

the provision of accompanying metadata is available for a wide variety of application fields (see, for example, Bastin et al. 2017, 2018; and Williams et al. 2018).

Notably, the term "citizen science" is not uncontested in the sense that the term "citizen" evokes a normative role of what it means to belong to and act as a member of a particular social group, including implications of what it means to participate in public science projects for "noncitizen" residents (e.g., Woolley et al. 2016). These perspectives are not just rhetorical, as labels matter in practical terms if actors such as refugees or resident immigrants participate in contributing. In contrast to the previous terms, volunteered geographic information highlights the active attitude of people when contributing data. VGI was proposed in 2007 and includes examples such as WikiMapia and OSM.

To evaluate the rapid evolution of terms related to user-generated content, Fig. 18.1 shows Google Scholar results for references that match the terms 'volunteered geographic information'; 'geo crowdsourced' and 'crowdsourced geographic information'; 'citizen science'; and 'openstreetmap' are reported. The growth over time is impressive. Moreover, the success of a single project, OSM, is also relevant and deserves more thorough exploration within this chapter.

18.3 Digital Earth Technologies for Citizen Science

The previous definitions allow for specification of the possible roles of Digital Earth as an enabler of citizen engagement—especially for citizen science. Digital Earth technologies provide citizens with advanced sensing devices (see the Chap. 11 on the Internet of Things) and mobile applications that allow for data collection by anyone who possesses a smart device or acquires a sampling tool. In addition, the use of existing social media platforms helps people collect data about a wide range of phenomena, including natural hazards, crop production and the spread of diseases. Following the Digital Earth vision, these data streams can be interconnected and real-time deliveries can be assimilated with data from complementary sources such as authoritative measurement stations or remote sensing imagery. Accordingly, data contributed by citizen scientists might help improve models about our environment (e.g., for air quality, water quality or extreme events) by ground truthing or validation—or by providing additional data points that are used for improved geographic predictions or forecasting. These possible contributions of citizen science could be considered the Digital Earth Nervous System—DENS (De Longueville et al. 2010).

The concept of VGI fits well into this kind of Digital Earth support for citizen science. VGI platforms can be viewed as a part of the Digital Earth infrastructure, but the uptake and use of VGI in combination with data from other sources are essential. In addition, crowdsourced data directly connects to this view, as data is passively collected before it is used as part of a dynamic and intertwined flow of stimuli and contextual information that is integrated into a gigantic knowledge base that keeps the pulse of our planet. User location information is a direct and obvious example. While protecting privacy, valuable information can be derived that, in combination with other data sources, can provide valuable decision support. For example, real-time locations can help optimize green transport or save lives in a crisis situation by individually guiding evacuees along safe routes or sending rescue teams to locations where they are most needed.

Transitioning from pure data collection, Digital Earth technology can also help other dimensions of citizen science. Once data is collected, Digital Earth could provide access to artificial intelligence that could be used for quality control, which is frequently demanded in citizen science. In this area of citizen science activities, automated algorithms can help assess the probability of a certain measurement or observation. For example, automated image recognition (based on machine learning) could analyze pictures of plants recorded by a participant and suggest the most likely species. This could also take into account when and where a record was made. Similarly, an algorithm might calculate risks based on findings from citizen science. For example, it might calculate the risks associated with a possible new sighting of an invasive alien species in an area where it has not been reported yet. Thus, automated support can help overcome the current difficulties in finding enough expertise to validate species information.

With respect to the next possible area of citizen science activities, Digital Earth technologies—especially visualizations—can help people analyze available data sets and display them in context. Offering multiple visualization techniques and map-based integrations with related information can help explore the latest information available and identify possible correlations or other dependencies. Visual approaches (with maps and graphs) might also help communicate the scientific findings to a particular audience, even audiences with low literacy rates. Interactive story maps can created to convey core messages in combination with the supporting data.

Through this highly dynamic situation in which data is contributed and can be used for modeling and storytelling in real time, the most advanced possibility of

Digital Earth as an enabler for citizen engagement can be reached. With this fully integrated view, any individual or group could access a Digital Earth representation on their preferred device to experience a certain situation, simulate possible decisions, and immediately assess the possible impacts. Such an advanced functionality can facilitate debates between any physically connected or remote group of people. In such settings, knowledge can be cocreated and experimented with and situations can be reassessed. In such a way, Digital Earth can create a safe space of interaction and cocreation to arrive at group decision-making before taking concrete actions in the real world.

Concerning the use of citizen-contributed knowledge, Digital Earth provides another essential enabler, namely, the possibility to track and trace data through processing chains and its use for decision-making. This traceability is fundamental to provide feedback to citizen scientists about the use of their data.

18.4 OpenStreetMap

18.4.1 Social Ecosystem

OpenStreetMap is one of the most well-known and researched examples of a volunteered geographic project in which data is crowdsourced at a global scale. Many people consider OSM to be an object or to be the free map of the world, which is contributed by volunteers and is available for everyone, being based on an open-content license (OpenStreetMap Wiki Contributors 2017). However, it is also commonly thought of as a data platform where as many as 5 million users contribute, edit, download and assess the data that are shared. As opposed to a map or platform, many others consider it an "online project," a perspective that refocuses attention on the efforts to create the map instead of the map or database itself. Others, who are often part of the project, speak of "OpenStreetMap" as a community, emphasizing the set of actors responsible for its existence. OSM should be thought of as a community of communities, (Solís 2017) in the sense that this community is increasingly diverse and incorporates the motivations of many different groups with varied approaches to OSM. Together with the technology products and systems, they form a complex sociotechno ecosystem that operates as a multiscalar network (Vespignani 2009). There are fluidities in the kinds of actors that participate in OpenStreetMap, which can be generally categorized and thought of (see Table 18.1) using typical descriptors such as sector-based characteristics: private enterprise, for-profit entities, nonprofit or civil society, and government or public institutions at various scales. It can also be categorized by community through their modality of engagement with OSM: those who directly create map data, locally and/or remotely, entities that add value through map-based services and third-party open source software, algorithms, scripts, or materials, consumers of the data, including individual users exporting for a discrete use, companies that run their navigation or social media platforms live

Table 18.1 Dimensions of characterizing OpenStreetMap as a community of communities

Sector-based categories	Modality of engagement	Social-based categories
Nonprofit/civil society • Humanitarian Sector (e.g., International Federation of Red Cross/Red Crescent) • Local nonprofit entities Education/Academic Sector • K-12 teachers • University students/faculty Government/Public Sector • Local municipalities (e.g., World Bank's Open Cities) • State /Regional governance (e.g., Transport planning entities) • National agencies • Multinational (e.g., World Bank's Open Cities) Private Industry/For-Profit or Commercial Sector[a] • Information Technology and Services • Computer/GIS Software (e.g., MapBox, • Internet Companies (including Social Media) • Use-Driven (e.g., Restaurants, Construction, Retail, Health Care)	Data contributors • Local mapping (e.g., Craftmappers) • Local and remote (e.g., YouthMappers) • Remote mapping • Dataset uploading (e.g., road networks) Providers of Map-based Services or Value Added to OSM[b] • General (e.g., Geofabrik, OpenTopoMap) • Functional Providers – *Edit/Compare* (e.g., *OSMCompare)* – *Live/real-time edits* (e.g., *Show me the way)* – *Quality Assurance* (e.g., *Keep Right, Osmose)* – *Export* (e.g., *Walking Papers, Field Papers)* – *3D Rendering* (e.g., *OSM Buildings)* – *Routing* (e.g., *OpenTripPlanner)* – *Interaction* (e.g., *Wikipedia overlay)* – *Services* (e.g., *OSMNames, OSM Landuse, OpenFireMap)* • Thematic Providers – *Biking, geocaching, hiking, sport* – *Art, history, archaeology, monuments* – *Public Transport* – *Other* • Educational (e.g., TeachOSM, LearnOSM) Consumers[c] • As Base Maps (e.g., Facebook, Wikipedia, Weather.com, Snapchat) • As Data (e.g., Pokémon Go) • As Media (e.g., films and TV) [d] • Internal systems (e.g., Uber)	**Purpose-driven** (e.g., Humanitarian OpenStreetMap Team) **Identity-focused** (e.g., GeoChicas) **Place-based** (e.g., Tanzania Development Trust)

[a]The OSM Wiki lists 80 entities in this category (https://wiki.openstreetmap.org/wiki/Commercial_OSM_Software_and_Services); iDataLabs identified 281 https://idatalabs.com/tech/products/openstreetmap
[b]Summarized with counts from OSM Wiki (https://wiki.openstreetmap.org/wiki/List_of_OSMbased_services)
[c]Adapted from https://wiki.openstreetmap.org/wiki/Major_OpenStreetMap_Consumers; see also https://wiki.openstreetmap.org/wiki/They_are_using_OpenStreetMap
[d]More detail at https://wiki.openstreetmap.org/wiki/Films and https://wiki.openstreetmap.org/wiki/TV_series

with underlying OSM data, and governments that download data for comparison in official geodataset validations. These categories are not mutually exclusive, as a single individual or organization often operates in more than one sector and engages in multiple modalities over the course of interaction with OSM, and thus, understanding this social ecosystem is highly complex. Furthermore, in the construction of communities in the OSM community, the way that social bonds formed around purposes (e.g., the Humanitarian OpenStreetMap Team's humanitarian mission), identity (e.g., YouthMappers academic actors and GeoChicas), or place must also be considered as another dimension of connectedness.

For example, one set of these communities that has experienced tremendous growth recently are the communities that engage with the OSM community with an express humanitarian or development purpose. Beginning with the incorporation of the Humanitarian OpenStreetMap Team (HOT) in the international civil society sector, which formed in the immediate aftermath of the 2010 Haiti earthquake, various groups have begun to distinguish and highlight the purposeful creation of volunteered spatial data rather than the creation of open data for its own sake. HOT has since registered as a nonprofit organization and has a structured governance comprising a core group of voting members that support a larger set of global volunteers with specific local and remote mapping campaigns. The Missing Maps project was later founded by HOT, Medecins Sans Frontieres/Doctors Without Borders, and the American and British Red Cross agencies. Similar to other purpose-driven efforts, this project aims to map the world's most vulnerable people. It has since grown to include participation from other organizations, and has developed a presence as a related OSM community in its own right, with close ties to HOT.

The participation of university actors intersecting with this purposefully humanitarian community was present, even if not consolidated, from the outset; in 2014, the academic community developed YouthMappers to explicitly bring together and nurture the community of students and their faculty that operate within and together with the broader set of OSM communities around youth-based identities. Founded by faculty from Texas Tech University, The George Washington University, and West Virginia University, with support from the US Agency for International Development's GeoCenter, and now administered by Arizona State University, YouthMappers organize as chapters on university campuses, run by student leadership under the guidance of university professor mentors. Chapters apply for recognition by the YouthMappers steering committee as existing student organizations that affiliate or as newly formed student-led groups. The network encourages students to participate in global remote campaigns of USAID, HOT and other humanitarian groups, develop and implement local mapping campaigns that create and use geospatial data for needs at the local or national levels, and seek and provide resources for students to expand their volunteerism through internships, leadership development, and research fellowships. Activities center on the concept of not just building maps, but building mappers and promoting exchange and solidarity among student peers across continents. Campaigns create data directly for development programming and seek to promote greater inclusion and participation of students from countries in development as well as female mappers via the #LetGirlsMap campaigns. By late 2018, the network had grown to 143 campus chapters in 41 countries, linking more than 5,000 OSM volunteers. Although the YouthMappers purpose falls along the humanitarian or development realm, where activities are defined as contributions to global targets such as the UN Sustainable Development Goals (Solís et al. 2018), the community has a strong identity-based composition, as participants are students in universities and learning through the mapping experience carries significant import (Hite et al. 2018; Coetzee et al. 2018). Similarly, consolidating community space for particular actors within the social ecosystem of OSM, GeoChicas formed at the State of the Map Latin America conference in 2016. GeoChicas is a group of women who volunteer map in OSM and work to close the significant gender gap within the OSM community. Their activities promote mapping campaigns that address women's issues such as mapping gender violence and promote female participation by creating more training spaces for women and ensuring harassment-free mapping. They also raise awareness of OSM technical matters such as tagging in support of women and girls in the OSM map and data platform.

An impressive example of a place-based community is Crowd2Map Tanzania, which was established in 2015 to improve the rural maps of Tanzania to fight female genital mutilation and improve development of the region. The community of volunteers creating OSM data in the context of Crowd2Map intersects with all of the above communities (HOT, Missing Maps, YouthMappers chapters in Tanzania, GeoChicas), especially local residents. This demonstrates how the communities of OSM engage and create a multiplicity of volunteer impacts within the social ecosystem of OSM.

End-user communities are important in shaping OSM institutionally and should not be underestimated because they are not actively involved in the construction and constitution of OSM. This community is much more difficult to track and assess, since OSM is free and open for anyone to use. In addition to the user-contributor communities noted above, governmental entities, including at the very small scale such as local civil protection agencies, local disaster response units, and local businesses, are using OSM data in their functions. At the country scale, actors such as national mapping agencies incorporate OSM data with official data sources, especially in times of urgency such as disaster response, e.g., the earthquake in Ecuador in 2016 where OSM data supplemented with official data was used to validate or gap-fill missing data. Multinational organizations such as the World Bank span local to global categories, considering the city-level action that work such as the Open Cities Project supports. The participation of governments and the public sector is significant due to the unique challenges for such actors and communities of actors for adopting crowdsourced geographic data, despite its potential value. The landscape of participation among governments has been highly dynamic in recent years, as the reliability and accuracy of volunteered data has been increasingly seen as appropriate for (to inform or accompany) official use. Obstacles remain; most recently, Haklay et al. (2018a, b) conducted qualitative comparative analysis of multiple use case studies to identify success factors for users with governance missions. The use cases included activities such as base mapping or focus on a particular area of interest, generating updates to authoritative datasets, upgrading public services, policy development or reporting, and disaster management or response. The authors find that individual champions and change agents are critical, organizational business models are necessary, technical capacity is essential, and conceptual buy-into acceptance of issues such as uncertainty, collaboration, and new ways of serving the public good must accompany this community's involvement in open Digital Earth landscapes.

On a broader scale, the user policies and open license of OSM provide a public good that commercial and for-profit enterprises are keen to leverage or even support in some cases. This is unsurprising in a rapidly growing context where geospatial information is valued as a multibillion dollar industry (Eddy 2014). With an Open Database License, adopted in 2010, OSM is enabled and simultaneously constrained for use in the private sector, and thus, calls for more "business-friendly" approaches are not uncommon (Gale 2015). The range of themes, applications, and industries in this sector are broad and growing and are difficult to comprehensively capture. The inclusion of the OSM layer as a base map in widely used proprietary geospatial software (such as ArcGIS Online) and examples of OSM powering services such as Craigslist and The Weather Channel show that the public may be consuming this volunteer-contributed content base without much awareness. Passive users are less affected by licensing frameworks than actors that seek to build services or add value and comingle data sources and types, who must contend with share-alike clauses. Explicit commercial contributors to the OSM ecosystem include companies that offer commercial OSM software and services that expressly add value to OSM in terms of architecture, analysis, visualization, and/or consulting on a multinational, regional or, very frequently, worldwide scope. Although Google Maps still dominates web mapping, OSM has captured approximately 0.1% of the market share of web mapping, which is impressive for a community that is completely powered by volunteer contributors (iDataLabs 2017). Top industries include IT software and services and Internet companies, with revenues reaching the $200 M range. Nearly one third of companies have fewer than 10 employees, and Germany, the US, France, and the UK currently account for 40% of estimated formal business activity. However, as OSM grows, its presence in lower-to-middle-income countries (LMICs) is increasing, as the ability to access scarce geospatial data and location-based information is gaining traction as an international economic development strategy in the context of digital development (USAID 2018). Open geospatial data such as OSM powers businesses in real estate, transportation, agriculture, and technology in 177 countries (Bliss 2015), and the corporate sector sees OSM as a priority in the open source community (Moody 2018). The increasing presence and influence of large-scale commercial or for-profit entities within the OSM community of communities is changing the countenance of the social ecosystem in ways that are sometimes contradictory and contested. The OSM Foundation, as the nonprofit entity that exists to protect, promote and support the project (though it does not own the data), continues to navigate this complex array of actors, visions, uses, and contributors in a dynamic landscape of volunteered geographic information.

18.4.2 Technological Ecosystem

One of the main reasons for the success of OSM is that the technology behind the project allows for everybody to contribute regardless of their level of expertise. More than a simple geospatial crowdsourced database, OSM is an ecosystem of data, software and web-based information stores. The tools and systems developed by different actors in the social ecosystem of OSM are generally characterized as being free and open source, i.e., available for further development by other people in the community. Access to the different applications is often possible using the same personal account as that for the OSM platform.

The geometric OSM data model is easy and simple, based on simple data types such as nodes, ways (polygons and polylines) and relations (logical collections of ways and nodes). The semantic model, i.e., the nonspatial attributes associated with the geometric objects, is more complex but services such as the taginfo (OpenStreetMap Contributors 2018a) help contributors to choose the most appropriate tags (key/value pairs). As an example, the most basic and common representation for a building is by means of a way and the pair: "building = yes".

After signing up for free access to OSM (OpenStreetMap Contributors 2018b), users can begin contributing by mapping new data in OSM or editing existing data stored in the OSM geospatial database. In December 2018, there were more than 5 million users (OpenStreetMap Stats 2018). There are three ways to contribute:

(1) by physically surveying an area and inserting the information collected by GPS receivers and paper-based tools into the OSM database;
(2) by digitizing objects into the OSM platform using available aerial and satellite imagery; and
(3) by bulk-importing suitably licensed geospatial data.

The first two modalities are more generally used whereas the third must be coordinated with the OSM community.

Many guides and tutorials on how to map with OSM are available; excellent examples include those made available by the company Mapbox (Mapbox 2018) and the Humanitarian OpenStreetMap Team (HOT 2018).

Editing and visualization are the two basic functionalities for interacting with the OSM geospatial database. The choices are very broad for both and depend on the exigencies and skill of the user. As the OSM platform has an editing API, many editors have been developed, some with a simplified subset of functionality and others that operate on specific platforms such as mobile technology (OpenStreetMap Wiki Contributors 2018a). The three main editors are iD, which is the default editor for the user when accessing the OSM platform and is meant for beginners; MAPS.ME, which is an app for iOS, Android and BlackBerry designed mainly for travelers, with more than 50,000,000 installations, that provides offline maps and a straightforward editor (Maps.me 2018); and JOSM (Java OpenStreetMap Editor), which is a desktop application popular among expert editors because of its more advanced performance (JOSM 2018).

In addition to enabling individual contributions, the OSM technical ecosystem is designed to elicit and simplify collaboration among contributors. One fundamental tool for this purpose is the Tasking Manager developed by HOT (HOTOSM Community 2018).

The main purpose of this tool is the subdivision of a large area into smaller areas, which require less time and effort to map. Individual contributors work on smaller areas to avoid problems of overlap and confusion. Moreover, the Tasking Manager allows for a second level of contribution: validation of the mapping of other users. Validation is generally done by expert OSM users and consists of verifying the geometric and semantic accuracy of the mapped objects and reviewing the mapping for completeness.

The Tasking Manager has a graphical interface that shows the main characteristics for every project (status, project creator, last updates, difficulty, priority, types of mapping, organization, campaign, and contribution level required) and the map with activity and stats. Figure 18.2 shows the example of Typhoon Ompong: Cagayan and Batanes Structures (task: #5236) as published on 6 October 2018. The map helps contributors know where to edit or validate, depending on their role.

TeachOSM is another site eliciting collaboration that is useful, but not limited, to educators (TeachOSM 2018). It is another instance of the HOT Tasking Manager and is used mostly by the academic and educational community. It provides training documentation and resources that help instructors identify, assign, manage and grade mapping assignments.

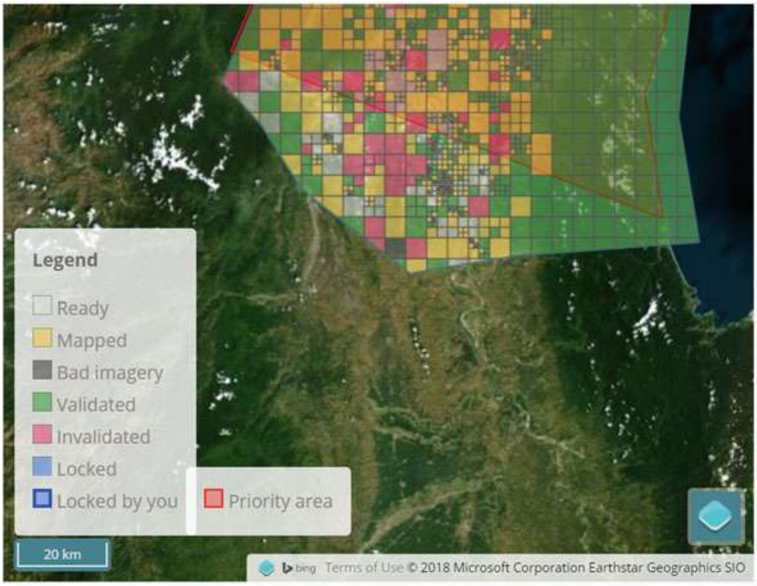

Fig. 18.2 Example of activity and status on the HOT tasking manager

The OSM ecosystem provides many opportunities for collaborating, and the possibilities of using these data are many and various. The license of the project, Open Database License (ODbL), permits free copying, distribution, transmission and adaption of part or the whole dataset as long as credit is provided to OSM and its contributors. If someone alters or builds upon OSM data, the results must be distributed under the same license.

As noted above, this free and viral license has been pivotal in the development of communities, research, and business around the project. Moreover, it has led to the creation of a very wide range of applications.

Many visualization tools have been created with different sensitivities and needs: rendering for cyclists, transportation maps, rendering for humanitarian purposes, maps of specific collections (hydrants, fire stations, etc.), 3D maps and artistic maps such as those provided by the US company Stamen (see Fig. 18.3).

Data can be downloaded in several ways. The first option is to download in .osm format directly from the OSM geoportal by selecting the area of interest and using the "export" button. As an alternative, the Planet.osm (OpenStreetMap Wiki Contributors 2018b) file is released weekly and contains the entire global dataset. It is a big file, almost 40 GB compressed. For the complete time-varying dataset, a full history planet dump is made available at irregular intervals.

For selected downloads, Geofabrik (Geofabrik GmbH Karlsruhe 2018) provides access to continental, national and regional data extracts as OSM raw data or in shapefile format and most of these files are updated daily. The same service is offered by OSMaax (HSR Hochschule für Technik Rapperswil 2018), through which OSM data are downloadable in the most common GIS formats. The HOT Export Tool (HOT

Fig. 18.3 Stamen watercolor rendering of OSM data (Tiber River in Rome)

2018) creates customized extracts of up-to-date OSM data in various file formats, with the limitation of at most 10 Million nodes.

Additionally, there are API calls to directly create, read, update and delete map data for OSM (OpenStreetMap Wiki Contributors 2018c), and this provides software developers and applications with the most up-to-date data available. The Overpass API service (OpenStreetMap Wiki Contributors 2018d) allows clients to send queries using a special API query language or a graphical interface and obtain the requested data (which can be huge). The ecosystem also includes free and open source GIS packages, for instance, QGIS. In this case, a plugin, QuickOSM, allows users to extract customized OSM data.

The availability of the data and this rich technological ecosystem has created opportunities to invent services and applications suited for different aims. In addition to "traditional" routing services (for cars, bikes and pedestrians), there are customizable ones. Among the many examples, Via Regina is a project related to "slow" tourism (Brovelli et al. 2015), i.e., tourism based on environmentally friendly forms of transportation, the appreciation of nature and the rediscovery of local history and cultural identity. Using OSM as a database, customized routes according to the user's preferred points of interest (religious, civil, museums, rural, archaeological, military, factory, panoramic, or geological) can be shown on the interactive map, as shown in Fig. 18.4 (I Cammini della Regina 2018). Before departure, the user can create a personalized itinerary according to her/his own choices, supported by other information such as the slope of the route and the presence of suitable tourist services (restaurants, hotels) in the area.

Furthermore, many other services unrelated to routing have been created. A detailed list of services is available on the wiki section of OSM (OpenStreetMap Wiki Contributors 2018e).

In conclusion, OSM is a very vital collaborative project with a flourishing and vibrant social ecosystem and a strong technologic support.

One of the main criticisms of this dataset is that, as a collaborative product created mainly by citizens without formal qualifications, its quality has not been assessed

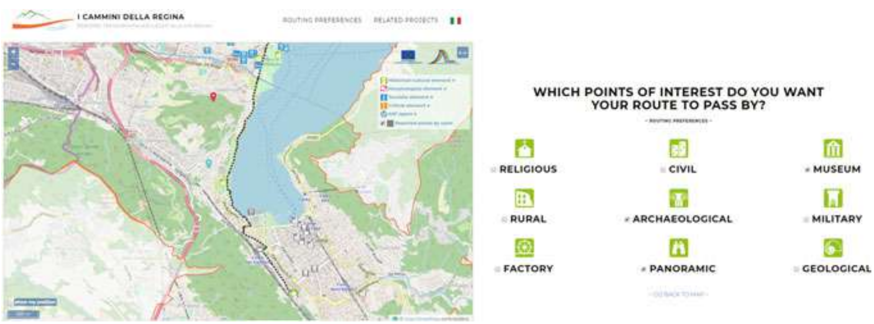

Fig. 18.4 Routing according to preferred points of interest (via Regina geoportal http://viaregina3.como.polimi.it/ViaRegina/index-en.html)

and therefore its usage can be detrimental for some applications. The assessment of OSM is a hot research topic and the majority of scholars have compared the database against authoritative ones. Whereas significant attention has been paid to OSM positional accuracy assessment and completeness, fewer authors have investigated its semantic, temporal and thematic accuracy and consistency (Antoniou and Skopeliti 2015) and none, to the best of our knowledge, have assessed all the elements of data quality. Some scholars have sought alternative quality metrics through "fitness of purpose" tests (Wentz and Shimizu 2018; Solís et al. 2018) in ways that prioritize how the data are used over abstract technical attributes of fidelity. The purpose for mapping has been suggested to influence productivity and quality in surprising ways: humanitarian mappers knowledgeable of the end use of the data may be on par with respect to productivity and error rates relative to mappers who operate without regard to purpose; however, they tend to make more and different *kinds of* errors, although they are more confident in the quality of their work. The implications of this so-called "do good effect", where new volunteers may think they are doing well just because they are doing good, holds significant implications for tailoring the training and quality control of new mappers motivated by humanitarian mapping purposes (Solís and DeLucia 2019).

It is impossible to draw a unique conclusion about the spatial accuracy and completeness, although recent case studies of OSM have indicated that they are comparable to those of regional-scale official datasets (Brovelli and Zamboni 2018). In other cases, for instance, in some developing countries, OSM is the only available dataset and therefore comparisons are not possible. The activism of the communities and attention paid to validation of the collected data (for brevity, many available tools are not mentioned) gives hope for continuous improvement of this product, as has occurred for other collaborative projects such as Wikipedia. As a practical reinforcement of our idea of "communities of communities" contributing in the scale-up of this resource, the OpenStreetMap community recently issued guidelines (OpenStreetMap Contributors 2019) for groups who are contributing collectively to the resource, making the ethic that quality matters to OSM creators and users more explicit and transparent.

18.4.3 Other Citizen Science Projects: Social Innovation and Public Engagement

OSM is a flagship example of citizen science. As noted above, although the primary purpose is to collect up-to-date topographic and other spatial data, it has additional benefits such as community building and active citizenship. Turrini et al. (2018) recently described the multiple benefits of citizen science more formally (Fig. 18.5). Their research examined how citizen science contributes to knowledge generation, learning and civic participation. The contributions can be clearly identified for the knowledge dimension, e.g., by the contributed data and quality control of OSM.

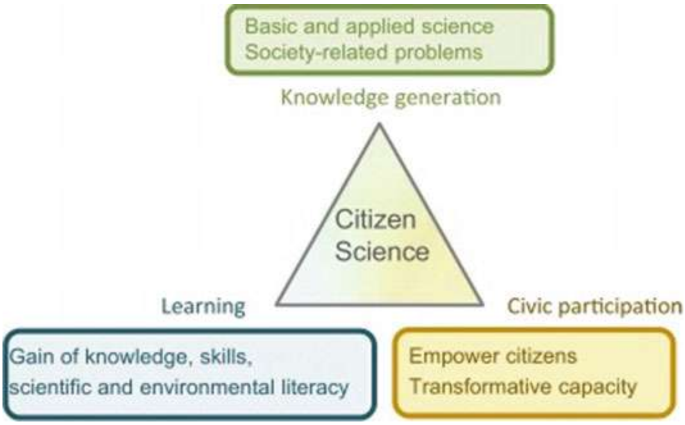

Fig. 18.5 The threefold potential of citizen science (*Source* Turrini et al. 2018)

With respect to learning, citizen science contributes to scientific literacy and to the improvement of topically related skills, e.g., those related to mapping. In addition, self-organized learning and education networks such as Geo4All (OSGeo 2015) for open geospatial software comprise this dimension. Lastly, civic participation is stimulated and facilitated. The YouthMappers community is an excellent example of this aspect of citizen science, as well as GeoChicas. The latter group adds different perspectives and experiences about conceptions of gender and ways of participation within the OSM community and analyze the roles, representation and participation of women in OSM to find a path of dialogue and close the gender gap. Improved gender inclusion also promises to impact the map and data and, ultimately, the knowledge products and decisions made with it (e.g., Holder 2018).

In addition to these multifold dimensions that materialize with different intensities in all citizen science initiatives, the concept of citizen science covers a much wider set of possibilities for (i) the public to understand and contribute to scientific research; (ii) academia to research new questions and carry out Responsible Research and Innovation (RRI); and (iii) governments and public administration to make better-informed decisions.

The different forms of contributions of citizens to science is likely the most debated and researched topic of citizen science. There are many different categorizations (see, for example, Shirk and Bonney (2015) for an overview), within specific contexts and justifications for existence. The framing introduced by Pocock and others (2017) is the most self-explanatory to describe the relationship to the research process, see also Fig. 18.6.

In addition, the relationship between academia and citizen science has been widely discussed; see, for example, the report of the League of European Universities (LERU 2016) or Mitchell et al. (2017). The form and shape of these discussions clearly depend on the way that citizen science is seen and embraced in different countries around the globe. There is great diversity across cultural regions and between more-

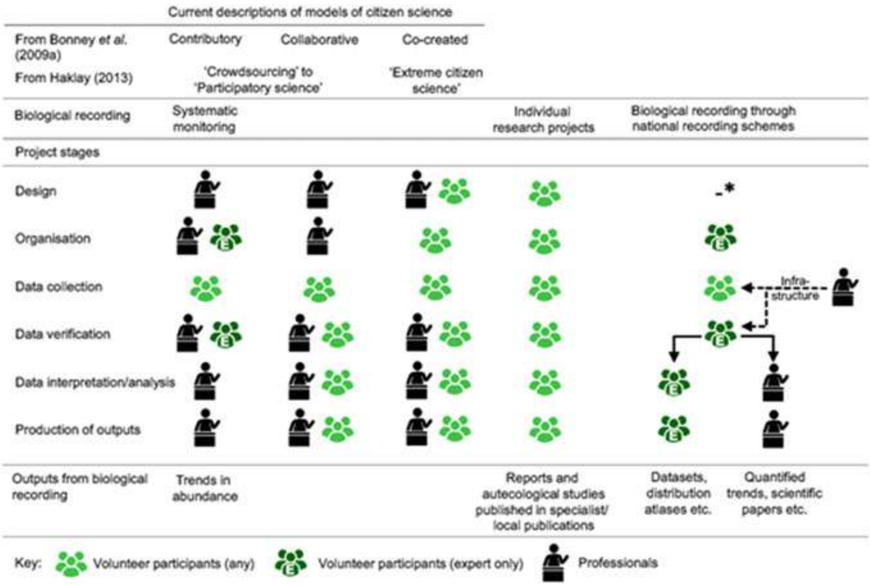

Fig. 18.6 Roy's categories of citizen science (*Source* Pocock et al. 2017)

and less-developed countries. It is also closely related to where the funding for citizen science comes from. For example, in Europe, the overarching topics of responsible research and innovation (RRI) and the open science agenda are strong promoters of citizen science—as is the funding of citizens' observatories in the context of innovative Earth Observation. In the US, citizen science is more often linked to open innovation (Congress.gov 2016).

In regard to the uptake of citizen science by governmental organizations, there are many different approaches (Schade et al. 2017). A possible overall model is summarized in Fig. 18.7. In this framing, the typical elements of citizen science (data gathering, quality control and analysis) are connected to the policy-making process. This imposes a need to provide feedback about the influence on political decisions, and creates an opportunity to consider citizen science to monitor the impacts of those decisions. Such an "accountability cycle" could be imagined at any administrative level, municipalities, regions, nations, macroregions or the entire earth. It can be distinguished by whether the contributing citizen science initiatives are initiated from the top down (i.e., on request by governmental institutions) or bottom-up (i.e., by an active citizenry that wants to raise an issue or challenge a governmental decision). Both approaches have success stories, and they face different challenges. Top-down approaches often have issues about acceptance or community uptake or buy-in. Bottom-up approaches often face difficulty in reaching the relevant decision makers or being taken seriously.

Given the multifaceted nature of citizen science, its relationships to the notion of Digital Earth are manifold. As set forth in the visionary work on the European

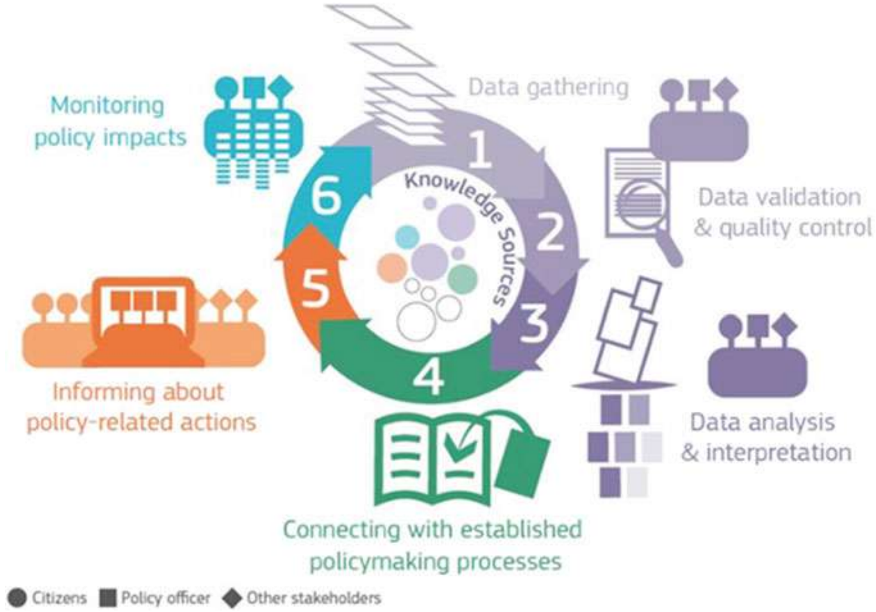

Fig. 18.7 Cyclic value chain of citizen science for policy (*Source* Schade et al. 2017)

Perspective to Digital Earth (Annoni et al. 2011), the Digital Earth Nervous System (De Longueville et al. 2010), the Digital Earth Living Lab—DELI (Schade and Granell 2014) and views beyond the next-generation Digital Earth (Ehlers et al. 2014), a clear direction of Digital Earth and related research concentrates on the possible contributions of and interrelationships with citizens—and citizen science is a very promising way to progress in this direction on local and global levels.

Digital Earth can be seen as an enabler of citizen science. With its enabling geospatial information infrastructures (see also Chap. 5) and Digital Earth platforms (see also Chap. 2), it offers citizen scientists a rich set of content and functionalities that can help develop and prepare citizen science initiatives. For example, technical solutions, recommendations and training material for geospatial data management could be offered by parts of the Digital Earth community (Chap. 5). Digital Earth technology can provide mapping tools and others forms of visualization, and can help any group of people explore, analyze, and model data collected by citizen scientists in combination with data from other sources. It can also provide access to machine learning algorithms and other forms of artificial intelligence (see also Chap. 10) that can help in quality control and quality assurance of citizen science data. With this capacity, Digital Earth technology can help address the continuing challenge of data processing scalability. With the potentially very high volume of citizen science data, it is impossible to rely on skilled community members and scientists alone to meet the need for quality-assured results. In addition, Digital Earth capabilities can help communicate core messages underpinned by research results. The story map of the European Year of Cultural Heritage is one example of many (Cultural Heritage 2018).

Digital Earth and Digital Earth research are also a beneficiary of citizen science. Citizen scientists can provide valuable input on priority items for research agendas and in terms of data provisioning, for example, from mobile apps or lower-cost sensors systems. Citizen scientists can also provide valuable contributions to field validation (e.g., to validate land use types that have been extracted from satellite imagery) or training of artificial intelligence algorithms (e.g., by crowdsourced applications that combine human reasoning with machine learning to extract damaged buildings in remotely sensed images). Concrete cases can be found on the GEO-Wiki platform (Geo-Wiki 2018).

The above examples only scratch the surface of the possibilities to advance Digital Earth research. Projecting these capabilities into the not too distant future, it can be imagined that new technologies will enable citizens to contribute to individual data and to our reasoning capabilities and interpretations via a global Digital Earth infrastructure for dedicated use. Possible uses might include new scientific discoveries in the earth and environmental sciences or in areas such as astronomy, social science and economics. Whereas most cases of citizen science apply to the former fields, possible applications might address more holistic approaches to overcoming challenges including energy, food and water. It has been illustrated that citizen science can contribute to all of the United Nations Sustainable Development Goals (European Commission, Directorate-General for Environment et al. 2018).

In exploring these new possibilities of citizen science within the context of Digital Earth, it cannot be forgotten that the indicated approaches must adhere to ethical and legal considerations. When operating on a global scale, the values and standards of the communities involved vary largely, as well as the cultures and habits of participants. Any realistic future scenario should adhere to local circumstances and define the possible contributions to (geographically) larger scale initiatives. The example of Let's do it World (Let's do it 2018) underlines some of the difficulties and Global Mosquito Alert (European Citizen Science Association 2018) confirms and, to some extent, complements these issues. Both initiatives aim at data collection and actions around our planet. However, they also allow for diversities, for example, in the data collection approach and additional community activities. By doing so, they provide a global framework and initiate movements while remaining open to the emerging (unpredictable) dynamics of those that react to the call for action. This openness and readiness to adapt to and accommodate specific needs is a key success criterion when dealing with local communities and stakeholder groups, and becomes even more important when the activity is spread across the globe.

18.5 Forms of Citizen Engagement and Distribution of Participation

Citizen science can be considered one form of citizen engagement, which is a broader concept encompassing other practices such as civic engagement, public participation and do-it-yourself (DIY) science (Figueiredo Nascimento et al. 2016). These practices involve different forms of contributions from citizens and collaboration with actors other than the academic community. A common feature of citizen science is the collaboration between the public and professional scientists in civic engagement rather than collaboration with academics, and the primary aim is to develop the knowledge, skills and values that can make a difference in the civic life of communities (Ehrlich 2000). DIY Science (Figueiredo Nascimento et al. 2014) includes nonspecialists, hobbyists and amateurs who do research outside institutional research centers in settings such as Makerspaces, FabLabs, and Hackerspaces, where people meet and work together to develop new projects and devices (Figueiredo Nascimento et al. 2016). Technically savvy people can carry out their own DIY science efforts using low-cost sensors and other devices including easy-to-program control boards, miniaturized computers (such as Arduino or Raspberry Pi) and 3D printers, and share information over collaborative websites (Haklay et al. 2018a, b).

Regardless of the differences in contributions, actors, and settings, these forms of citizen engagement provide opportunities for citizens to engage in science and innovation and, more generally, in the challenges that affect our society (Figueiredo Nascimento et al. 2016). As argued by previous authors, better use and integration of the inputs from citizens can expand the evidence used for policy-making and science, turning citizens into generators of innovation (Figueiredo Nascimento et al. 2016).

18.5.1 The "Power Law" Distribution of Participation

Digital technologies such as smartphones and tablets enable many people to engage but participation in online communities plots along a solid core/periphery model—provided that social software supports both low threshold participation and high engagement. Although the number of citizen science initiatives has grown, many projects fail to attract and retain enough participants. Participants tend to engage with projects for short periods of time, and successful projects rely on a small number of contributors who do most of the work (Dickinson and Bonney 2012; Curtis 2014; Sauermann and Franzoni 2015). For example, in GalaxyZoo, a very successful crowdsourced astronomy project, Lintott et al. (2008) show that a small number of participants complete a high number of classifications and that there is a tendency of participant withdrawal over time (Fig. 18.8). In their study of individual-level activity in seven different citizen science projects, Franzoni and Sauermann (2014) found that most participants contributed only once and with little effort, and the top 10% of contributors were responsible for almost 80% of classifications. This pattern

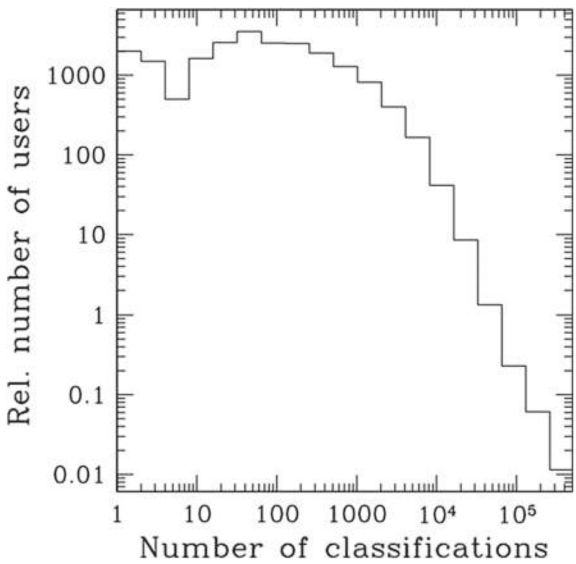

Fig. 18.8 The distribution of classifications among users. A small number completed more than 100,000 classifications each and the peak of the distribution is at approximately 30 classifications per user (*Source* Lintott et al. 2008)

of participation is known as a 'power law' distribution, or the 'Pareto Principle', and has been observed in several online communities such as Wikipedia, where most content is generated by a minority of users. Therefore, this phenomenon is not specific to citizen science projects. Franzoni and Sauermann note that the reasons for this uneven distribution of contributions are unclear. In their opinion, one reason could be that, as soon as the volunteers start contributing to the project, they realize that the match does not fit their expectation or is not suitable for their skills. One can argue that the specific demographics in citizen science may influence this distribution of participation.

18.5.2 Citizen Scientists Are a Minority and Have Specific Demographics

Digital technologies enable mass participation and increase the potential for considerable diversity among citizens in terms of age, gender, experience, race, and education, but participation in most citizen science projects is biased towards white men aged 20–65 from well-to-do socioeconomic backgrounds (Haklay 2015). For example, a study found that 87% of participants in a volunteer computing project were men, and a similar bias was identified in ecological observations of birds (Krebs 2010). A report by the Stockholm Environment Institute for the UK Government (DEFRA 2015) showed that the percentage of the UK population that had participated in environmental volunteering was biased towards white, male, middle-aged, higher income people. Low-income people, those with disabilities, and those of black and minority ethnic origin are traditionally underrepresented in citizen science, for example, in environmental volunteering (Ockenden 2007). Identity-based communities such as YouthMappers and GeoChicas can achieve higher inclusion rates among specific demographics but may not achieve other goals such as racial and ethnic or economic diversity.

At the international level, citizen science is concentrated in advanced economies, especially the US and northern Europe. Access to connectivity represents a barrier to wider participation, with a level of access of 87% in the UK, 81% in the US, and 65% in European countries such as Poland and Portugal (Haklay 2015). Haklay noted that many software applications developed for citizen science projects require continuous connectivity, but 3G and 4G coverage is partial even in highly urbanized environments such as London or New York City and less in remote nature reserves. Another barrier to broad participation is language. English is the main language in science, and many tools and technologies that support citizen science projects presuppose knowledge of English and are not available in local languages (Haklay 2015).

18.5.3 Not Only Science: Citizen Science for Digital Social Innovation and the Role of Local Authorities and Governments

It can be argued that citizen science should extend beyond the framing of citizen engagement in scientific research. The European Commission stated this need in relation to responsible research and innovation (RRI), which is an element of the EU Horizon 2020 program. RRI calls for researchers, companies, NGOs, and members of the public to collaborate during the research and innovation process to align both the process and its outcomes with the values, needs, and expectations of the European society (European Commission 2018). This view reflects the aspiration to cocreate the future with citizens and include diverse stakeholders to address social challenges.

Digital technologies such as social media and online platforms, open data, and open and standardized APIs have led to opportunities for different modes of citizen engagement and new forms of interaction among different stakeholders. Therefore, digital technologies and the Internet have the potential to enable forms of digital social innovation, that is, social and collaborative innovations in which different actors use these technologies to cocreate knowledge and solutions for issues of social concern (Bria 2015). In a study commissioned by the European Commission, Bria illustrated examples of digital social innovation involving citizen science, including the Globe at Night project in which citizens used a camera and geo-tagging functions on their smartphones to help the research project measure global levels of light pollution, effectively coupling open data and citizen science.

The growth of data generated by citizens can benefit scientists as well as other social actors. For example, the public sector could use data volunteered by citizens to address critical socioeconomic and environmental issues and inform policies. Two projects are worth mentioning: CuriousNoses (Curieuze Neuzen 2018), a citizen science project in which 20,000 citizens measured the air quality near their homes in Antwerp, Belgium in May 2018, and the Decentralised Network for Odour Sensing, Empowerment and Sustainability (D-Noses 2018), a large project in which citizens in 7 European and 3 non-European countries use innovative mapping tools to detect odor issues and cocreate specific solutions with several stakeholders including local authorities. Local authorities and governments can play a leading role in championing citizen science and social innovation projects. As noted by the Earthwatch Institute (n.d.), local authorities can champion citizen science to raise awareness of the surrounding environment and support environmental protection and education programs. Furthermore, local authorities and governments can enlist citizen scientists to participate in efforts to study social problems and cocreate actionable solutions. To this end, open data platforms can provide powerful tools for sharing information and developing collaborations to apply knowledge in the real world.

18.6 Conclusions

The rapid and profound nature of the technological innovations related to Digital Earth resources are matched, and even outpaced, by the social innovations unfolding in relation to creating and using them for citizen science. These dynamic configurations bring together new arrays of actors and diverse communities of interest to contribute to and apply the data and knowledge in ways that are only made possible by the massive participation of individuals and institutions.

In this chapter, we deliberately took a positive stance towards citizen science but some important operational challenges should not be overlooked. In the previous section, we addressed one of challenge, which is the difficulty of attracting and retaining a diverse base of contributors. Another main issue faced by citizen science is ensuring quality, especially the intrinsic quality of data, that is, the accuracy and believability of data provided by citizens (Prestopnik et al. 2014). Quality concerns are a large barrier to wider use of citizen science approaches by professional scientists and policy makers and the diffusion of citizen science project findings (Burgess et al. 2017; West and Pateman 2017). The reasons for this concern include participants' lack of formal scientific training and limited scientific knowledge, uneven levels of expertise and anonymity, as well as nonstandardized and poorly designed methods of data collection (Hunter et al. 2012). Research findings and data are sometimes not published because the ownership and property rights were not clarified during project initiation, leading to disagreements or misunderstandings among diverse participants with different norms and interests (Guerrini et al. 2018; Resnik et al. 2015). Therefore, it is important to understand how citizen scientists produce data, how accurate these data can be, and the factors that influence data quality. The literature suggests a number of approaches that can help projects ensure high-quality processes and results (Wiggins et al. 2011). Among others, reviews by experts can help establish scientific standards, and training of new participants can improve the consistency of research processes and results.

Despite these challenges, the current state of progress is encouraging given the results of humanitarian, environmental, and economic efforts but it has not fully overcome complex challenges related to quality, equity, inclusion, and governance. Outcomes unfolding in present contexts will determine the future extent to which Digital Earth created with and for citizen science is accountable to the needs of the planet and its inhabitants.

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Chapter 19
The Economic Value of Digital Earth

Max Craglia and Katarzyna Pogorzelska

Abstract In this chapter, we approach the economic value of Digital Earth with a broad definition of economic value, i.e., the measure of benefits from goods or services to an economic agent and the trade-offs the agent makes in view of scarce resources. The concept of Digital Earth has several components: data, models, technology and infrastructure. We focus on Earth Observation (EO) data because this component has been undergoing the most dramatic change since the beginning of this century. We review the available recent studies to assess the value of EO/geospatial/open data and related infrastructures and identify three main sets of approaches focusing on the value of information, the economic approach to the value of EO to the economy from both macro- and microeconomic perspectives, and a third set that aims to maximize value through infrastructure and policy. We conclude that the economic value of Digital Earth critically depends on the perspective: the value for whom, what purpose, and when. This multiplicity is not a bad thing: it acknowledges that Digital Earth is a global concept in which everyone can recognize their viewpoint and collaborate with others to increase the common good.

Keywords Economic value · Social value · Earth observation · Private sector · Public sector

19.1 Introduction: Framing the Issue

Previous chapters of this manual introduced the concept and definitions of Digital Earth (Chap. 1) and the data and technologies that contribute to it (Chaps. 2–12) and focused on the role of Digital Earth in supporting the achievement of sustainable development, particularly the UN Sustainable Development Goals (Chap. 13) linked to climate change (Chap. 14) and disaster risk reduction (Chap. 15). Each of these areas has both social value to present and future generations (Brundtland Commission

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1987) and economic value, i.e., the measure of benefits from goods or services to an economic agent (person, company or organization involved in an economic transaction) and the trade-offs the agent makes in view of scarce resources.[1] Given that each area of application of Digital Earth has both economic and social value and, by definition, this value varies according to different economic agents (the key question: value for whom?), how can we approach the economic value of Digital Earth?

Previous studies have dealt with the economics of issues linked to sustainable development. For example, Pezzey and Tonan (2017) addressed the economics of sustainability, Anand and Sen (2000) addressed human development and economic sustainability, the review by Stern analyzed the economics of climate change (Stern 2007), and Shreve and Kelman (2014) among others, reviewed the cost-benefit analyses of disaster risk reduction. As far as the value of Digital Earth is concerned, a review of the literature is not much help. A query on "the economic value of digital earth" on Google Scholar returns no entries, and a search on the web returns only the table of contents of this manual. A more fruitful approach may be to deconstruct Digital Earth into its constituent components. As indicated in Chap. 1, Digital Earth can be viewed from multiple perspectives; some emphasize the conceptual/representation aspects of Digital Earth (Gore 1999; Goodchild et al. 2012) and the data/information component (Goodchild 2013), others emphasize the information system component (Guo et al. 2009; Guo 2012; Grossner et al. 2008), and others emphasize the multidisciplinary body of knowledge and theoretical component (Goodchild et al. 2012; Guo et al. 2009). Each of these perspectives could be the subject of an economic analysis, but the one that has received greatest attention of late is data, described as the "new oil or the most valuable resource" of the digital economy (Economist 2017).

The rise of big data has recently been outpacing the growth in computer processing power and is set to speed up even further with the advent of the Internet of Things and billions of devices connected to the internet via 5G networks. For example, between 2002 and 2009, data traffic grew 56-fold, compared with a corresponding 16-fold increase in computing power (largely tracking Moore's law), as shown in Fig. 19.1 (Short et al. 2011; Kambatla et al. 2014).

The evolution of Digital Earth as a result of big (Earth) data, the Internet of Things, social media and new participatory approaches in which people contribute to sensing the environment were partially foreseen by Goodchild et al. (2012) and Craglia et al. (2012). What we did not expect was that the convergence of data and computing availability would lead to a major change in the development and use of artificial intelligence (largely since 2012) (Craglia et al. 2018) and that Earth observation would become such a big business for private sector companies and investors. Data seem to be the more significant change factor of the last decade, and therefore, this chapter focuses on reviewing the recently adopted approaches to assess the value of EO data, building on a study carried out at the Joint Research Centre by Pogorzelska (2018), as a lens through which to see the value of Digital Earth.

[1] https://www.investopedia.com/terms/e/economic-value.asp.

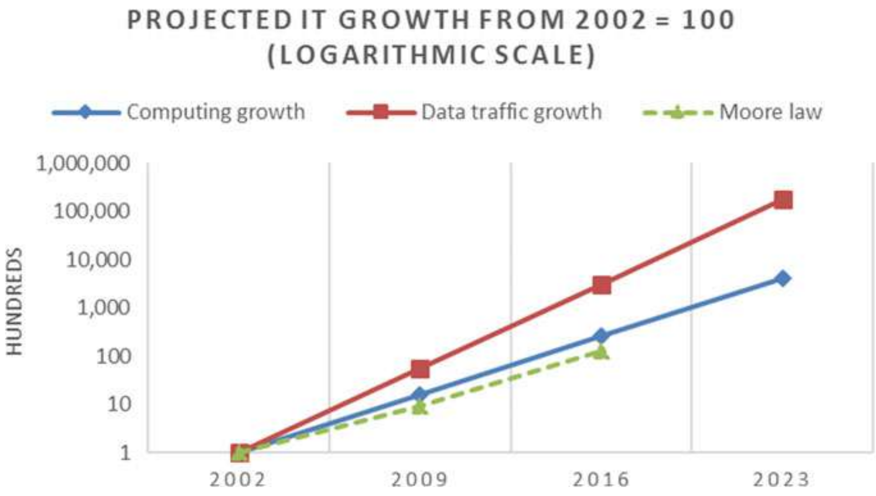

Fig. 19.1 Projection of data and computing growths (**logarithmic scale**). *Source* JRC based on Kambatla et al. (2014)

This chapter is organized as follows. After the Introduction, Sect. 19.2 outlines different viewpoints on the value of EO, Sect. 19.3 reviews approaches and methodologies to assess the value of EO, and Sect. 19.4 draws conclusions that are relevant to Digital Earth.

19.2 Different Viewpoints on the Value of Earth Observation

19.2.1 Definition of EO

In this chapter, we adopt the definition of Earth observation as developed by the Group on Earth Observations (GEO). EO is understood as "the gathering of information about planet Earth's physical, chemical and biological systems"[2] through a range of technological means such as satellites, aircrafts and drones, in situ measurements or ground-based monitoring stations. Remote sensing (RS) is a technique used in EO to observe objects from a distance without being in direct contact with them.

Various studies deal with EO as part of broader "geospatial data" or "spatial data". The adjectives "geospatial" and "spatial" are usually used interchangeably. The term "spatial data" is legally recognized in Europe as defined in the INSPIRE directive (European Commission 2007) and means "any data with a direct or indirect reference to a specific location or geographical area" (ibid, Art 3). Spatial data,

[2]GEO: https://www.earthobservations.org/g_faq.html. Accessed 7 Apr 2019.

apart from EO, encompasses data from other technology segments such as the global navigation satellite system (GNSS) and positioning, geographic information systems (GIS)/spatial analytics, and 3D scanning.[3] Since all of the above are relevant for Digital Earth, we use the GEO definition and therefore use EO as a broad label that also covers (geo)spatial data.

19.2.2 Value for Whom?

The value of data and information varies according to who values it and for what purpose, and often also carries a time dimension, i.e., some data may very valuable now (e.g., stock market prices or agricultural yield data) but almost worthless in a few hours (Blakemore and Craglia 2006).

The socioeconomic value of EO data is often greater when combined with other data. The value for a user of a digital map is greater when one can also navigate to a chosen destination as a result of combining EO data with location data. The value can be greater still if EO is combined with the social data of other participants in traffic because predictions of the traffic flow can be made and alternative routes can be proposed (to measure the value of a digital map, see, for example, Alpha Beta 2017). The value of EO data is easier to appreciate from the perspective of an individual in the mass market because of the daily use of EO–based solutions; assessment of the value of EO from the perspectives of the public and private sectors is more complex.

19.2.2.1 Public Sector Perspective

Governments have traditionally been the main users of various forms of geographic information, such as maps, for taxation, way-finding, navigation, and defense. With the expansion of commercial aviation and the launch of civilian space programs in the twentieth century, the public sector, often in partnership with the private sector or through private sector contractors, continued to remain the main producer and user of EO, largely for scientific purposes, weather monitoring and forecasting, and to support policy in the environmental, societal and economic domains. The public sector greatly relies on EO data—often combined with social and economic data—to help inform policies directed towards a range of environmental and socioeconomic objectives. The environmental policy objectives that rely on EO information revolve around the management of natural resources and battling environmental threats such as land, air and water pollution, deforestation, biodiversity loss, and climate change.[4] The EO-supported social policies touch on citizens' wellbeing and include areas such as security and defense, science, education, agriculture, safety and rescue, disaster

[3]Geospatial Media and Communications (2018), p 14.

[4]Science for Environment Policy: Earth Observation's Potential for the EU Environment, Copernicus: http://www.copernicus.eu/sites/default/files/library/FutureBrief6_Feb2013.pdf.

and disease response, health, transport and urban planning. Economic objectives include the development of innovations, knowledge and solutions that can increase competitiveness and create new products, services, and prosperity. In Europe, there has been a noticeable shift in EO policy to add objectives aimed at developing the digital single market and harnessing opportunities for economic growth and jobs in the private sector.

From the standpoint of the public sector, the value of EO mostly lies in informing policy making and decision making. EO can inform the full policy cycle: it helps identify needs and areas for policy intervention, formulate policies, and tailor regulatory responses that can use legal tools that rely on EO to support policy implementation and decision making. EO also supports policy monitoring and policy change.

There are numerous examples of how EO supports policy making. To identify policy intervention areas, satellite imagery allows for realizing the scale and rate of deforestation, for example, in the Amazon rainforest, which eventually led to passage of a regulation that resulted in a significant decrease in the pace of deforestation (see, for example, Finer et al. 2018).

As far as lawmaking is considered, the most visible use of EO is as a regulatory compliance tool (Purdy 2010), especially in enforcement of environmental legislation. There are at least three forms of the use of EO as a regulatory compliance tool: (a) as part of a targeted enforcement strategy to monitor specific laws, (b) in monitoring of individual sites or areas where environmental offenses have occurred, such as marine pollution (Wahl et al. 1996), and (c) as a form of historical evidence. There is a form of targeted regulatory monitoring, for example, in the agriculture sector in the EU, where legislation gives Member States the option of using data from "unmanned aircraft systems, geo-tagged photographs, GNSS-receivers combined with EGNOS and Galileo, data captured by the Copernicus Sentinels satellites and others" to monitor farm subsidy payments under agricultural cross-compliance schemes (European Commission 2018). The introduction of EO to replace or supplement on-field checks is aimed at reducing both the administrative burden on the EU member states and the cost of monitoring farm subsidies for potential fraud. For example, Australia incorporated satellite surveillance of tree clearing in the policy strategies of relevant legislation (Purdy 2010). EO data have also been increasingly used as evidence. Systematic archiving of satellite images provides regulators or a court with a relatively impartial snapshot of any location at any given time, providing accurate evidence that would often be otherwise unavailable. Such satellite imagery has been used as evidence in lawsuits. In the 2012 UK pollution case, satellite images were used as primary evidence to prove the breach of UK maritime pollution legislation by Maersk Tankers Singapore; in another case in the US, imagery was used to show false insurance claims (Rocchio 2006).

Regarding policy implementation, public institutions use EO for their decision making. Large financial institutions such as the World Bank or the Asian Development Bank often tailor their official development assistance (ODA) in accordance with EO-based environmental information.[5] Another example of the use of EO data

[5]ESA: http://eo4sd.esa.int/files/2017/10/1_esa_eo4sd_and_sdgs_oct_2017.pdf.

is the US federal decision making for drought disaster assistance, which heavily depends on drought indicators fed by EO data (Steinemann et al. 2015). Finally, EO supports the statistics necessary to monitor progress towards policy objectives (see UN 2017) and helps evaluate the outcomes and necessary changes to policies (see BRYCE 2017).

The last decade saw a huge increase in the number of EO satellites, including privately funded ones; combined with advancements in ICT, EO satellites changed the way that public institutions can use EO data and information. Due to the satellite-based infrastructure, EO data now provide insights into nearly real time geographical distributions of various phenomena that are commensurable across countries, regions and cities, allowing for timely and targeted responses to various needs or threats. Open and free access to data and analytical tools, advances in algorithms and data processing have started to enable the widespread use of this information. Harmonized and interoperable EO data infrastructures are often combined with other geo-referenced sociodemographic, economic and public administration data to make the indicators and analysis more robust and international reports more harmonized (OECD 2017). This eventually equips public institutions with tools that allow for better cooperation, particularly in face of challenges of a global scale. In this respect, the global cooperation achieved through the Group on Earth Observations (GEO)[6] is also important.

19.2.2.2 Private Sector Perspective

Whereas the EO upstream and end-user segments used to be significantly dominated by the governmental institutions, the private sector has been traditionally more pronounced in the EO downstream segment concerned with the creation of added-value products and services. Because the existing EO market was mostly driven by the demand from the public sector, particularly from the defense and security segments (ca. 60%, see Keith 2016), in 2014 there was still no functioning EO market (Smart 2014). The last few years witnessed the staggering growth of the EO market (European Commission 2017) in both the amount of money flowing to the EO sector economy and the number of new players at all levels of the EO value chain. These are good indicators of the advancement of the EO market towards maturity.

To large extent, the fast maturing of the EO market has been enabled and driven by technology developments in both the upstream and downstream EO segments. The miniaturization of satellites and the reusability of rockets were upstream-related technology developments, and increased analytical capabilities coupled with the enhanced ICT infrastructure reshaped the EO sector from the bottom. The former developments allowed for democratization of the access to space and vertical integration across different sectors; and the latter created a significant thirst for data outside the public sector and demand from the individual mass markets (e.g., digital imagery). These developments heavily impacted the dynamic in the whole EO sector.

[6] http://earthobservations.org.

They facilitated different forms of collaboration between the public and private sectors. Currently, innovative companies and businesses more actively contribute to the socioeconomic policymaking by proposing solutions based on the innovative technological developments (for the issue of building partnership between the sectors, see EARSC 2014).

Technology developments also enabled different business models and contributed to the growth of the individual mass market. The space industry has developed into a multibillion-dollar industry with global revenues increasing from $175 billion in 2005 to almost $385 billion in 2017—a growth rate of approximately 7% per year (US Chamber of Commerce 2019). According to Morgan Stanley (2018), the global space industry could generate a revenue of $1.1 trillion or more in 2040, with almost 50% of projected growth coming from satellite broadband internet access. While the demand for data has been growing at an exponential rate, particularly with the increasing demand for bandwidth from autonomous cars, the Internet of Things, artificial intelligence, virtual reality, and video, the cost of access to space (and, by extension, data) is falling rapidly. With the development of reusable rockets, the cost to launch a satellite has decreased from approximately $200 million to approximately $60 million, with a potential drop to as low as $5 million, according to Morgan Stanley (2018). The mass production of pico satellites such as CubeSat has brought costs down from hundreds of millions to several thousand dollars,[7] so that companies such as Planet can afford to send dozens of satellites in space every launch and operate a constellation of over 150 satellites orbiting the Earth. This is creating entirely new markets as an increasing number of companies offer daily high-resolution images of the Earth to monitor change. It also creates opportunities for companies providing launch and ground-segment facilities. In November 2018, Amazon Web Services announced the deployment of their first ground stations, with an aim of having 12 operational by mid-2019 and expanding their business to pay-as-you-go EO (Barr 2018). This announcement is potentially a big step in the expanding market for EO given the market size and reach of AWS.

The amount of private sector capital in the space sector is staggering, considering that this industry was dominated by large government-backed national space agencies until recently. According to Seraphim Capital, a venture capital fund, the amount of VC in the space sector was $3.25 billion in 2018, up 30% from 2017, with over 180 companies receiving backing, an increase of over 40% compared with the previous year. The launching sector received the highest investment flow of just over $1 billion in 2018 and data collection platforms (satellite constellations and drones) followed closely behind at $868 million.[8] Notably, China is also becoming a big player in the commercial space market since the government opened the country to private investment in 2014. In 2018, China became the world's top launch provider, with 39

[7] https://space.stackexchange.com.

[8] http://seraphimcapital.passle.net/post/102f50i/seraphim-q3-global-space-index-investment-remains-concentrated-in-launch-and-co.

launches versus 34 from the US, and its BeiDou GPS navigation constellation aims to rival the American (GPS) and European (Galileo) satellite navigation systems.[9]

While the development of the space industry is making the headlines, there are many other areas in which private sector companies are investing in geospatial data capture, processing, and value-adding, which are relevant to the further development of Digital Earth. Examples include well-established companies such as Trimble, which traditionally serviced the surveying and construction industry, and has now expanded into mining and precision agriculture; DigitalGlobe, which has moved from being a data supplier to a solution provider for specific sectors such as the automotive industry[10]; and new companies such as NextNav, which specializes in indoor positioning systems with a dedicated infrastructure of indoor antennae for applications including geo-advertising, public safety, and emergency services.

The increasing availability of EO with integrated multiple sensors from both space and the ground together with processing power and storage at diminishing costs, business models based on pay-as-you-go for everything-as-a-service and the development of AI algorithms to process the data and extract meaningful information are opening EO to a much wider audience of companies that are not experts in EO or geo-processing. A good example is Orbital Insight, a start-up established in 2013 that combines detailed imagery provided by companies such as Planet with public sector data and develops AI algorithms to provide solutions for specific sectors such as energy and advanced consumer intelligence.[11]

The above mentioned technology developments can also be linked to the creation of the distinguished ramification of the EO market, namely, the EO data market, which does not quite fit the traditional upstream or downstream EO segments but rather conveniently nests in between, being pulled by the gravity of the big data market. The commercial EO data market was estimated at EUR 1.5 billion in 2015 with the opportunity to grow to EUR 2.6 billion in 2025 (European Commission 2017). While upstream companies naturally expanded into this market segment and benefit from selling VHR EO or data products, the new influx from outside the EO sector is a relatively new phenomenon. The big IT techs such as Google or Facebook introduced new business models to the EO domain. They do not seek profits from selling EO data or EO-based services or products but profit from business intelligence based on combining EO big data with different streams of other data, especially location and social data. In such cases, IT platforms play the role of a content aggregator that can satisfy different customer needs while making profits from targeted advertising based on big data-based business intelligence. The recent developments by Amazon and Google are in this direction.

While the market is changing so rapidly, assessing the value of EO from both economic and social perspectives is not easy. In the next section, we review some

[9]http://seraphimcapital.passle.net/post/102fd5w/seraphim-space-predictions-2019.

[10]https://www.digitalglobe.com/markets/automotive.

[11]See Orbital Insight: https://orbitalinsight.com/products/go-energy/ or https://orbitalinsight.com/products/go-consumer/.

recent studies that estimated such value and then assess the extent to which they can inform the analysis of the economic value of Digital Earth.

19.3 Review of Approaches and Methodologies to Assess the Value of EO

Assessing the value of EO has been the subject of research for several years worldwide (Borzacchiello and Craglia 2011). The interdisciplinary and cross-cutting nature of the use of EO data resulted in a wide range of approaches to identify and measure the value of EO. A review of recent studies on the subject by Pogorzelska (2018) identified three main clusters of approaches. The first focuses on capturing economic value of EO and gathers micro- and macroeconomic methodologies. The second enters the discussion on EO value through the more interdisciplinary conceptual framework of the value of information (VOI). Since EO exhibits characteristics of an all-purpose infrastructure good, many have noted that measuring the value of EO in a comprehensive and exhaustive way is impossible; therefore, some approaches primarily focus on ways to maximize its value. The third cluster gathers methodologies concerned with maximization of the value of EO through enhancement of the data infrastructure and open access to EO data. These clusters are by no means exhaustive or exclusive. They represent different perspectives or entry points to the discussion and are often combined within one study. The methodologies used within one cluster may be used along with others or adapted to serve a specific purpose (e.g., VOI studies adapt micro- and macroeconomic methodologies to reflect value of EO-based information).

19.3.1 Value of Information (VOI) Approach

The studies framed by the value of information generally examine how EO-based information can be tied to decision making, how those decisions can be linked to societal outcomes, and how those societal outcomes produce value.

VOI studies underline that the value of information is tightly linked to its use. Barr and Masser (1997) claim that "information has no inherent value, it is only of value once used and that value is related to the nature of the use rather than the nature of the information [thus] information has very different values for different users." EO-derived information is valuable when it informs decisions aimed at achieving various environmental, social and economic benefits.

Since the value of EO-derived information changes depending on the specific use and the user, VOI studies also deal with different value propositions. Macauley (2005) proposed a framework to provide a common basis to evaluate information depending on the type of user. Macauley (2006) also provided a theoretical foundation for establishing the value of space-derived information and a framework that uses economic principles.

As far as the subsequent quantification of this value is considered, the VOI approach gathers a very diverse set of methodologies. There have been ongoing efforts in the fields of GIS and related systems as well as remote sensing to accelerate the development of methodologies to quantify the benefits arising from EO-based decisions. Meta reviews of the literature in this field have been carried out, for example, by Lance et al. (2006), Genovese et al. (2009), Richter et al. (2010). GEO-related work and research focused on remote sensing have been carried out, for example, by Fritz et al. (2008) and Rydzak et al. (2010).

While there is a widely recognized need for EO value to denote a quantitative measure, many agree that it does not need to be expressed in monetary terms (Borzacchiello and Craglia 2011). The VOI economists usually seek to monetize the difference between decisions made with and without the EO-derived information (Gallo et al. 2018). However, the benefits are often expressed in nonmonetary terms such as in reductions in mortality and morbidity, reduced damage to capital assets, improved community well-being, time saved, fuel saved, reduced carbon emissions and many other social and economic measurements (Kruse et al. 2018). Studies have identified a set of methodologies used to quantify the value of EO-derived information, e.g., McCallum et al. (2010), Borzacchiello and Craglia (2011), Slotin (2018). The range of the methodologies identified includes the following:

- Value-measuring methodology (VMM) was developed to calculate the return on investment (ROI) relating to decisions based on intangible values.[12] It was adapted by the International Institute for Applied System Analysis (IASA) to assess the benefits of the EuroGEOSS;
- Impact-based methodology—this methodology determines value by qualitatively assessing the causal effect of information availability on economic and social outcomes, or the costs in terms of inefficiencies or poor policy decisions due to limited or poor-quality information;
- Systems dynamics modeling—like the methodology above, it measures the impact of EO-derived information. The value of EO is described through system dynamics models, where a change in one variable (e.g., EO-based information affects other variables over time, for example, the FeliX model[13]);
- Bayesian belief network—this conventional statistical approach assumes that people's expectations are updated when new information is available (for use of the methodology, see, for example, Bouma et al. 2009);
- Regulatory cost-effectiveness—this methodology assesses the direct cost savings achieved when a regulatory framework is in place;
- Willingness-to-pay methodology—this methodology concentrates on monetization of benefits through surveys of individuals and private and public institutions

[12]The VMM was initially developed by the Federal Chief Information Officers Council (2002) and applied in a case study by Hamilton (2005).
[13]www.felixmodel.com.

that estimate their willingness to pay or the amount they are willing to accept for not having the data/information; and

- Case-based monetization of benefits—this method focuses on measuring (often monetizing) the benefits resulting from a specific EO-supported decision, solution, product or service. The approach usually relies on qualitative analysis to identify and measure the benefits that arise.

19.3.2 Economic Approaches

This cluster of approaches gathers macro- and microeconomic methodologies to capture the economic value arising in the context of EO. This set of methodologies has clearly become more relevant as the EO market has matured.

Macroeconomic

This group of approaches enters the discussion on the value of EO from the perspective of the economic impact of the EO sector on the economy and links the value of EO to the macroeconomic statistics characterizing the sector. The macroeconomic methodologies include the following:

- GDP impact assessment—this approach focuses on calculating the return on public investment in the EO sector. The following indicators are usually taken into account: investment of the upstream sector, spending by suppliers, wages/salaries of employees, employment impact, government tax revenues (income direct tax, VAT, employer social security contributions, employee social security contributions; see, for example, Strategy 2015);
- Economic impact assessment—focuses on the use of specific economic tools to assess impact, such as input-output tables and computable general equilibrium models (CGEM); and
- EO value chain approaches—these approaches focus on assessment of the value of EO across a whole value chain. A specific value chain is identified and qualitatively analyzed. The methodology usually relies on quantification of the value of EO as the increase in revenues and reductions in costs related to the EO-supported activities, compared with a situation where no EO-derived solutions are available (see, for example, PwC 2016).

Microeconomic

Microeconomic approaches focus on EO market characteristics and market approaches to value EO data and customer behavior. This cluster includes the following:

- Characterization of the EO market—this approach focuses on EO expressed through the statistics characterizing the EO market, the EO data market and specific markets for EO-based solutions, products and services;

- Stated/revealed preferences—these methods assess the value of EO-derived data/information though the amount that users are willing to pay or the amount they are willing to accept for not having the data/information;
- Market equivalent pricing—this is the market price that should have been received if the statistical or EO data outputs were sold in a market environment. This approach approximates market prices by looking at the market prices of similar data products, such as those from companies that offer data for prices, or business trends drawn from a range of sources including open government data;
- Cost-based derivation—this method determines value based on the full cost of producing the data, statistics or information; and
- Discounted cash flows (DCF) methodology—this method ascribes a value/price to a specific dataset (intrinsic value) based on a projection of its future cash flows that is discounted to today's value.

19.3.3 Approaches Concerned with Maximization of EO Value

This group of approaches recognizes that, although measuring EO value is difficult and relative, if not impossible, the improvements in the EO data infrastructure and open access to data are key prerequisites for maximizing the value of EO. This cluster often uses impact-based methodology to demonstrate how data infrastructure investments and removal of specific barriers to access data affect or may affect people's lives or the economy. With respect to this approach, Slotin (2018) argues that "[b]y linking to real-life outcomes, impact-based case studies show how investments in data systems can translate into meaningful outcomes for people." Many case studies show these impacts, including deliberate experiments such as randomized control trials and retrospective assessments of impact[14] (Slotin 2018).

19.3.3.1 Spatial data infrastructure

Spatial data infrastructures (SDIs) have been (largely) public sector-led investments by governments across the world to increase the availability and accessibility of geospatial data for public policy, an informed society, and market development. The development of SDIs has been documented by many studies, including by Masser (1999, 2005), Williamson et al. (2003), Crompvoets et al. (2008). For many years, the global community of researchers and practitioners of SDIs gathered through the Global SDI association,[15] which was formed in 2004 and dissolved in 2018. Now, global discussions on SDIs are held in many groups, including the International

[14]See, for example, www.dataimpacts.org.
[15]www.gsdiassociation.org.

Society for Digital Earth,[16] the UN Committee on Global Geospatial Information Management[17] and the Group on Earth Observations, to coordinate efforts to develop a global Earth observation system of systems (GEOSS).[18]

In Europe, the adoption of the INSPIRE directive in 2007 (European Commission 2007) provided a major impetus towards the assessment of spatial data infrastructures and their socioeconomic impacts. A study on the expected economic impact of INSPIRE was carried out in 2003–2004 prior to adoption of the law (Inspire and Craglia 2003; Dufourmont et al. 2004). Progress in over 30 European countries on the implementation of SDIs was reported in a set of studies by Vandenbroucke and Janssen (2008). Crompvoets et al. (2008) collected a range of theoretical perspectives informing the work on SDIs and focused on the improvement of SDIs. Vandenbroucke et al. (2009) proposed the application of a network perspective to SDIs. The increased availability and quality of data and data sources are believed to help inform the actions taken by decision makers and the resulting socioeconomic benefits (Kruse et al. 2018).

19.3.3.2 Open access to data

Maximization of the value of EO through open access to data is similar to the previous approach. It primarily differs in the entry point to the discussion. Instead of focusing on the infrastructure, this approach focuses on the benefits of open access to EO data as a part of bigger data ecosystem. It considers access to data a key factor in determining EO-enabled creation of added value and promotes the openness of data.

Approaches that address the value of EO from the perspective of open data often focus on "unlocking the value of open data" via removal of specific barriers to data, not on measuring the actual value of EO. A study by McKinsey (2013) found that open data can help unlock 3.2 trillion to 5.4 trillion USD in economic value per year across seven chosen domains: education, transportation, consumer products, electricity, oil and gas, healthcare, and consumer finance.

From the economic perspective, the term "open data" falls back on the economic notion of a "public good". As a good, EO data are not homogenous. A public good is a type of good that, once produced for some consumers, can be consumed by additional consumers at no additional cost.[19] The definition includes the two main characteristics of a public good, nonrivalry and nonexcludability. "Nonrivalry" means that the consumption or use of the good does not diminish or remove the availability of the good to others. "Nonexcludability" means that everyone has access to a good since no exclusion mechanisms are in place. In contrast to public goods, private goods are often rivalrous, i.e., the consumption or use of the good diminishes or removes

[16] http://www.digitalearth-isde.org.

[17] http://ggim.un.org.

[18] https://www.earthobservations.org.

[19] For public good theory, see Holcombe (1997). For the theory of public expenditure, see Samuelson (1954).

the availability of the good to others, and excludable, i.e., prices, licenses and other exclusion mechanisms effectively control the number of beneficiaries, and property rights are applied to establish legitimate ownership. If nonpaying users cannot be excluded from benefits, then the market for the good fails as a result of free-riding (Harris and Miller 2011; Pearce 1995).

In general, EO data are largely nonrivalrous although some technical measures may be put in place to limit the number of users and applications. Although non-rivalrous, EO data tend to vary on the scale of excludability, which resulted in the heterogeneous landscape of the economic nature of EO data (for a proposition of mapping economic goods on the two axes of rivalry and excludability, see Harris and Miller 2011). This variation in excludability is reflected in the international legal provisions relating to access to RS EO data. The Remote Sensing Principles,[20] while promoting widespread access to satellite remote sensing data, contain a provision on the possibility of "provision of data on reasonable cost terms".[21]

The resulting regional and national regulatory frameworks allow for varying access to EO data. For example, the 2016 US Common Framework for Earth Observation Data states that "[a] core principle of the U.S. Government is that Federal Earth-observation data are public goods paid for by the American people and that free, full and open access to these data significantly enhances their value".[22] In the EU, the Copernicus Regulation provides that Copernicus data shall be made available on a full, open and free-of-charge basis. This general provision suggests that Copernicus data are a public good. Nevertheless, *lex specialis* provides for a series of possible access limitations that include (a) licensing conditions for third-party data and information; (b) formats, characteristics and dissemination means; (c) security interests and external relations of the Union or its Member States; (d) risk of disruption, for safety or technical reasons, of the system producing Copernicus data and Copernicus information; and (e) ensuring reliable access to Copernicus data and Copernicus information for European users.[23]

Similarly, other EU key regulations on data such as the Public Sector Information (PSI) directive (European Commission 2013) or INSPIRE directive (European Commission 2007) do not guarantee free access to governmental data. They all promote the idea of open data and encourage public institutions to open the vaults of their data, resulting in large amounts of data, including EO information, that exhibits characteristics of a public good (Uhlir and Schroeder 2007; Smith and Doldirina 2016). The opening of the vaults of PSI is often considered a boost for democratic accountability and for business to create value-added products, foster innovation and

[20] RS Principles, Principle XII.

[21] Since the term "reasonable cost" is not defined, Harris and Baumann (2015) suggest that compared with many other EO data policies, the term should be interpreted as the marginal cost or the cost of fulfilling a user request.

[22] US National Science and Technology Council: Committee on Environment, Natural Resources, and Sustainability (2016) Common Framework for Earth Observation Data. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/common_framework_for_earth_observation_data.pdf.

[23] Copernicus Regulation, Article 23(2).

Table 19.1 Summary of studies, approaches and methodologies

Study	Approach	Main methodology
PwC 2016	Economic approach/GDP impact assessment (upstream and downstream space sector)	Revenue and reduction in costs attributable to the use of Copernicus-based solutions across 8 specific industries (value chains)
Geospatial Media and Communication (2018)	Economic approach/combination of micro- and macroeconomic approaches	– Characteristics of the global geospatial/EO market (size and trends) based on surveys and secondary sources; – Value impact of the EO solutions on the global economy; – The country readiness index for the absorption of the geospatial/EO solutions
Alpha Beta (2017)	VOI	Quantification of indicators relevant for estimation of the environmental, social and economic benefits arising from the use of digital maps for individual users and the private sector
OECD (2016a)	VOI	Quantification of indicators relevant for capturing knowledge and innovation spillover effects relating to EO
Miller et al. (2013)	VOI	The willingness-to-pay methodology—monetization of the benefits for the users of Landsat imagery. Survey-based
OECD (2016b)	Maximization of EO value/data access	Qualitative and conceptual analysis of the possible forms of data access
OECD (2014)	Economic approach	Indicator-based statistics on the digital economy (focusing on closing gaps in the measurement of the digital economy)
Cattaneo et al. (2016)—EDM Report	Economic approach: value of EO/the EU data market	Characterizes the European Data Market (EDM) through identification and measurement of a set of indicators within the private sector
EARSC and The Green Land case studies (2016a, b, and c)	VOI	Case-based monetization of benefits. Monetization of indicators relevant for estimation of the benefits/impacts arising from the use of a specific EO-based solution

create jobs (Fornefeld et al. 2009; Uhlir 2009). In addition, by alluding to the notion of public good and accountability, advocates of open data emphasize the need and legitimacy of science in the policy sphere (Arzberger et al. 2004).

Since increasingly large amounts of EO data exhibit characteristics of a public good (Smith and Doldirina 2016), the EO market has primarily developed around the value added to EO data in form of processed EO data or/and information as well as EO-derived services and products that also integrate other data (for adding value with the use of open data, see, for example Berends et al. 2017). To add value to EO data, the high uptake of EO data is critically important. Delponte et al. (2016) identified a set of barriers to space market uptake originating in the areas of policy, governance, technology, skills, and the market itself. To overcome these barriers, various public initiatives have been put in place. For example, the European Commission, in cooperation with the ESA, is providing financial support to develop the Copernicus Data and Information Access Services (DIAS).[24] The DIAS are expected to be an access point to Copernicus data and to provide processing resources, tools and other relevant data to boost user uptake and stimulate innovation and the creation of new business models based on EO data.

The Table 19.1 summarizes the studies reviewed and the approaches summarized above.

19.4 Conclusions

In this chapter, we approached the economic value of Digital Earth with a broad definition of economic value, i.e., the measure of benefits from goods or services to an economic agent and the trade-offs the agent makes in view of scarce resources. This definition implies that the benefits that can accrue to the economic agent (person, firm, or organization) can be more than economic in nature and can encompass environmental or social benefits.

The complexity of determining the value of Digital Earth is multilayered. A first level of complexity stems from the multiple definitions of Digital Earth introduced in Chap. 1: as a concept, an information system, a data organization principle, a multidisciplinary endeavor, and a science. With such multiple and heterogeneous perspectives, there is no single value of Digital Earth to measure and there is a whole range of values depending on the point of view. A second level of complexity is exposed when deconstructing Digital Earth into its key components: data, models, technology, and infrastructure. In this chapter, we focused on EO data because it is undergoing the most dramatic change at the beginning of this century. However, the value of EO critically depends on the value for whom, for what purpose, and when.

As indicated in Sect. 19.2.2.2, the commercial EO data market is reaching a level of maturity fueled by the availability of big EO data, cloud-based processing facilities, increased connectivity, and new business models based on everything-as-a-service.

[24] http://copernicus.eu/news/upcoming-copernicus-data-and-information-access-services-dias.

This maturity is indicated by the level of private investments in the EO market for all segments, including the launching of satellites, data processing, integration, and value adding. However, there are no published studies with repeatable methodologies on the economic return of these large investments.

With this in mind, we reviewed the available recent studies to assess the value of EO/geospatial/open data and related infrastructures and illustrated that the variety of purpose and applications requires multiple approaches. We identified three main sets of approaches that focus on the value of information, the economic approach to the value of EO to the economy from both macro- and microeconomic perspectives, and a third set aiming at maximizing value through infrastructure and policy. Each of these sets of approaches has something to offer to the understanding and valuation of Digital Earth. The conclusion that there is no single answer to the question posed at the beginning of the chapter is not a bad thing: it acknowledges that Digital Earth is a global concept in which everyone can recognize their viewpoint and collaborate with others to increase the common good. Ultimately, the true value of Digital Earth may rest in its values as a metaphor to increase global understanding and communication across disciplines and between science, policy, and civil society.

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Part III
Digital Earth Regional & National Development

Chapter 20
Digital Earth in Europe

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Abstract In recent years, with the advancements in technology and research as well as changes in society, Digital Earth transformed. It evolved from its original concept of a 3D multilayer representation of our planet into a more practical system design to fulfil the demand for information sharing, which now embraces fields such as global climate change, food security and natural disaster prevention. In this novel scenario, Europe has become one of the major players at the global level; accordingly, the goal of this chapter is to provide a general overview of the major European contributions to the overall objectives of Digital Earth. These include the establishment of a European spatial data infrastructure through the Infrastructure for Spatial Information in Europe (INSPIRE) directive, the initiation of the Galileo and Copernicus programs that provide a wealth of big data from space, the launch of novel cloud-based platforms for data processing and integration and the emergence of citizen science. An outlook on major upcoming initiatives is also provided.

Keywords Information infrastructure · INSPIRE · Big data · Copernicus · Data access and information services - DIAS · Thematic exploitation platforms - TEPs · Citizen science · Digital europe · Horizon europe

20.1 Introduction

The original idea of Digital Earth (DE) first introduced by US Vice President Al Gore in 1998 envisioned a 3D multiresolution representation of our planet embedded with a variety of geo-referenced data to be transformed into understandable information (Gore 1999). Two decades ago, the major challenges in achieving such a vision were related to developing effective solutions for properly displaying, organizing and harmonizing data in space and time, as well as efficiently linking them to each other. Progress was necessary in the frameworks of Earth observation (EO), computational science, mass storage capacity and network speed, along with the definition of adequate metadata standards. At that time, the DE goal seemed difficult to achieve, if

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not impossible, but remarkable developments in data collection, hardware and software have led to several online web-mapping services (e.g., Google Maps, Microsoft Bing Maps) and desktop virtual globes (e.g., Google Earth, NASA's World Wind) that implement many of the features described by Gore in his speech just 10 years later, making DE real and accessible to millions of users (Annoni et al. 2011; Craglia et al. 2012). In this framework, the leading part was played by the United States, with key contributions from both the public and private sectors. However, with the advent of big data from space, the emergence of volunteered geographic information—VGI (e.g., citizen science, crowd-sourcing), the advancements in technology and research, as well as changes in society, the concept of DE also transformed (Goodchild et al. 2012). DE evolved into a more practical system design to fulfil the demand for information sharing and overcome the socioeconomic inequality in accessing and using the data (i.e., the digital divide) (Guo et al. 2016). Moreover, DE expanded its role in other fields related to global climate change, urban planning and management, agriculture and food security, and natural disaster prevention and response. This new vision will only become reality with effective integration of technologies from EO, global positioning and geo-information systems, sensor webs, virtual reality, and grid computing, as well as with proper gathering, harmonizing and sharing of data (also directly collected by nonexperts) through suitable information infrastructures. In this new paradigm, the role of Europe has gradually become more prominent, placing it at the forefront of DE implementation.

Notably, both research and commercial activities falling within the DE concept have been undertaken in the past 20 years at the single-country level in Europe; nevertheless, it is beyond the scope of this chapter to describe all these specific initiatives. Rather, our purpose is to provide a general overview of the major contributions to the overall objectives of DE from Europe as a whole. In this context, the first political initiatives embedding the DE concept date back to 2010 as part of the Europe 2020 strategy proposed by the European Commission (EC) (EC 2010), i.e., the executive branch of the European Union (EU), which, to date, is composed of 28 Member States. Europe 2020 aims to advance the economy in the EU, with a major focus on research and innovation. Among its 7 flagship initiatives, one has been specifically dedicated to the "Digital Agenda" (Annoni et al. 2011). In particular, this aims to improve the exploitation of information and communication technologies (ICTs) to foster innovation and develop a digital single market for generating smart, sustainable and inclusive growth in Europe.

In parallel, key European developments have provided major contributions to DE in the framework of information infrastructure, big data from space, geo-positioning and citizen science.

Effective data sharing is at the heart of DE and requires suitable and efficient dedicated information infrastructure, i.e., a framework of policies, standards and technologies that allow for finding, accessing, sharing and publishing information. The EC launched the spatial data infrastructure (SDI) initiative in 2001, which marked the beginning of SDI development in Europe. A few years later, this was followed by the "Infrastructure for Spatial Information in Europe" (INSPIRE) directive in 2007, a legal framework that requires EU Member States to share and properly document harmonized spatial and environmental data as well as establish a dedicated technical infrastructure. In particular, INSPIRE has become a model in the world; indeed, with respect to other SDIs solely supporting information discovery and access, it also addresses data harmonization, which allows them to be used seamlessly across national borders (EC 2018a).

Big data from space bring new opportunities in Earth Science and, in turn, to DE. These refer to the massive spatiotemporal Earth and space observation data collected by a variety of sensors ranging from ground-based to space-borne (EO satellites, navigation systems) and the synergetic use of data from other sources and communities (ESA 2019a). The first major European activity was the Envisat satellite mission started in 2002 and operated until 2012 by the European Space Agency (ESA) (ESA 2001). Envisat was the biggest and most complex satellite ever built and carried 9 EO instruments onboard, including imaging, atmospheric and temperature sensors (ESA 2019b). The mission (with an overall cost of ~2.3 billion euros) was the basis for the establishment of GMES, the Global Monitoring for Environment and Security initiative headed by the EC in partnership with ESA and the European Environment Agency (EEA). In particular, it first aimed to develop operational information services on a global scale using both space- and ground-based monitoring systems to support environment and security policy needs. GMES, officially endorsed in 2001, evolved over the next decade and, after the EU became directly involved in its financing and development, transformed into Copernicus in 2012. Specifically, Copernicus is the current EU's EO and monitoring program, which builds on existing national and European capacities; it includes both space and ground-based components and provides users with advanced data services (Copernicus 2019).

Concurrently, Europe has also been massively investing in the development and implementation of Galileo, its own civilian global navigation satellite system (GNSS). Galileo, whose conceptualization goes back to 1994, received major economic support from 2002 onwards. Two test satellites were successfully launched in 2005 and 2008, and the first satellite of the final constellation went into orbit in 2016. As of July 2018, 26 of the 30 planned active satellites have been launched and the system is expected to be completed by 2021. With respect to other existing GNSS, Galileo will provide higher precision positioning as well as a series of unique features aimed at improving people's security and safety in many fields.

Citizen science describes the nonprofessional involvement of citizens in a scientific process (Irwin (1995) and Bonney (1996)). Citizens can participate as observers or funders, by analyzing data or by providing data; moreover, they freely choose their degree of involvement based on personal interests, time or resources. After publishing a dedicated report in 2013 (Science Communication Unit; University of the West of England 2013), the EC officially began promoting and supporting citizen science due to its potential benefits for European researchers and society at large (EC 2017a). Since then, many projects have been funded that complement hundreds of dedicated citizen science activities in the different Member States.

In the following, major European contributions to DE are presented in detail. Section 20.2 is dedicated to an analysis of the information infrastructure in Europe, and Sect. 20.3 presents the many developments in the context of big data from space (including Copernicus and Galileo) and its exploitation. Section 20.4 provides an overview of the most relevant European citizen science projects; Sect. 20.5 introduces the two upcoming major programs supporting future digital innovation, Digital Europe and Horizon Europe. Finally, a brief conclusion is given in Sect. 20.6.

20.2 Information Infrastructure

A major element of the Europe 2020 Strategy—which set the objectives for smart, sustainable and inclusive growth of the EU by 2020—is the Digital Agenda. One of the seven pillars sustaining it is dedicated to the enhancement of interoperability and standards related to devices, applications, data repositories, services and networks (EC 2010). Therefore, efficient exploitation of spatial data infrastructures (SDIs) in combination with open data initiatives and portals have become a key component of Europe's efforts to assure more informed decision making as a basis for successful policy implementation.

The initial concepts related to the systematic realization—and later harmonization and linking—of SDIs emerged approximately two decades ago at the national level when governments began to initiate dedicated frameworks for enhanced utilization and sharing of data and information for applications in the public sector. These national spatial data infrastructures (NSDIs) primarily included technologies, standards, organizational and institutional structures, and Directives. The targeted applications were mostly aimed at sectors such as good governance, smart growth, or sustainable development (Nebert 2004). The NSDIs usually provide an institutionally sanctioned, automated means for remote search, access, use, and sharing of geospatial information by various providers and users (Pashova and Bandrova 2017). However, although the NDSIs in Europe often use similar technologies and standards, each country has many distinctive characteristics that result from specific national traditions, cultures and socioeconomic models.

To foster harmonization of the various national SDI developments at the European level, the EC started the first transnational SDI initiative in 2001 (EC 1995), which was succeeded in 2007 by the "Infrastructure for Spatial Information in Europe" (INSPIRE) directive (EC 2007, 2008). INSPIRE represents a legal framework implemented in a phased manner that defines a set of organizational rules and agreements for the establishment of an infrastructure for spatial information in the EU by the end of 2021. At the political level, the Directorate General Environment (DG Environment) is in charge of the overall coordination efforts, the Joint Research Centre (JRC) is responsible for the technical review, and EEA and Eurostat (the European Statistical Office) facilitate application and use case support.

According to the INSPIRE regulations, each Member State has to apply a minimum standard for open access to interoperable harmonized spatial and environmental data, along with related infrastructures, metadata and network services, which shall be completed with detailed documentation and reporting, as well as the establishment of a dedicated national coordination institution (EC 2018a). It is important to note that INSPIRE represents a transversal innovation that capitalizes on the manifold national and subnational SDIs that were already established and operated in the Member States across Europe. Hence, instead of creating any new centralized entity and data, INSPIRE focuses on making geoinformation seamlessly and easily searchable, accessible and interoperable across national borders through the harmonization and unification of standards, metadata and tools (EC 2015). A comprehensive overview of the INSPIRE initiative and contents is provided on the corresponding geoportal (http://inspire.ec.europa.eu/).

From the thematic point of view, INSPIRE covers 34 themes organized in three different annexes. These cover data and information related to the cadaster, land use and land cover, geology and soils, hydrology, agriculture, meteorology, transport and infrastructure, population, and environmental risks. In this context, one challenging factor is the requirement that all the data defined in the 34 themes of the three annexes can be utilized coherently and independently from the intended application. The key functionalities to fulfill this requirement and share the INSPIRE data and metadata are realized in the form of web-based services (Network Services) employing a service-oriented architecture (SOA) approach based on well-established standards such the Open Geospatial Consortium (OGC) (Döllner et al. 2019). Among others, the services include the catalogue service for web (CSW), web map service (WMS), web map tile service (WMTS), web feature service (WFS), web coverage service (WCS) and sensor observation service (SOS).

To control and evaluate the progress and extent of the INSPIRE implementation in the individual Member States, the directive provides two indicator-based mechanisms (Pashova and Bandrova 2017). Every three years, written reports must be submitted that address aspects such as coordination and organization structures, infrastructure management, monitoring of infrastructure and data use, data-sharing models and agreements, allocated budgets and arising costs, and gains and benefits at national and subnational levels. In addition, a dedicated set of performance indicators must be collected by the Member States on a yearly basis, describing the newly developed geo-information layers with all relevant metadata and related services. This reporting is administered by the INSPIRE committee, which is composed of representatives of all Member States, and the respective national contact points. According to the implementation plan, the Member States were obliged to transpose the directive into their national legislation by May 2009. Next, they had to provide their relevant national data collections “as-is” with the corresponding metadata through network services by December 2013, and all data listed in Annex I had to be accessible and interoperable by the end of 2017 (Döllner et al. 2019). Finally, the data covered by annexes II and III must be in place by end of 2021. In parallel to the Member State activities, stakeholder communities have been involved from the start of INSPIRE to actively help shape its implementation and critically review all technical developments.

The mid-term evaluation report published by the EEA in 2014 (EEA 2014) assessed an adequate progress of the implementation efforts and recommended some optimizations and improvements to close pending implementation gaps (often due to ineffective coordination at multiple levels) and foster exploitation of the profits through intensified integration of the private sector. Several alternative approaches were also applied to assess the progress in the development of SDI/NSDIs based on various political, institutional, organizational, conceptual, technical, and legal criteria (Pashova and Bandrova 2017). As a result, one of the outcomes was that Austria, Germany, Finland, France, Italy, the Netherlands, Poland, Portugal, and the UK are among the leading countries in SDI implementation.

Concerning the current challenges related to INSPIRE, the EU countries encountered many obstacles and shortcomings since the directive was put into effect almost 20 years ago. First, INSPIRE had to be initiated and established under complex conditions. Hundreds of national experts had to develop the technical specifications and standards for each specific thematic sector (including common and legally binding implementation rules), which had to be translated into more than 24 languages. Moreover, the various Member States showed a rather heterogeneous level of awareness and readiness in complying with the INSPIRE timelines, technical specifications and related recommendations. This effect was further amplified by the possibility given to each Member State to decide the most suitable strategy for implementing the INSPIRE framework based on specific individual needs. Consequently, the success of European-wide SDI realization strongly depends on the initiative, strategy and coherence of NSDI implementation at the national level.

However, the INSPIRE directive generally ensures that national and local governments provide high-quality and ready-to-use data and geoinformation to citizens, science and business across boundaries to support European environmental policies as well as initiatives such as e-Government and the EU interoperability framework. The INSPIRE datasets serve the European Water Framework Directive, the Habitats Directive, and the Clean Air Policy Package (EC 2015). INSPIRE makes quite valuable and direct contributions to the implementation of effective policies across Europe. The individual Member States also benefit from INSPIRE (Pashova and Bandrova 2017) due to the significantly enhanced access to geospatial information and the accelerated harmonization of their federal and municipal data inventories, improving the functionality and efficiency of public administration at all levels. This increased the effectiveness of several services that rely on geospatial data (e.g., disaster prevention and response, environmental impact analysis, risk assessment). In addition, the entry into force of INSPIRE could mitigate the drawbacks due to widespread national practices (and related business models) of selling geospatial data and incomplete and inconsistent policy frameworks.

As a means for offering easier access to spatial data in the EU, the Commission launched the new INSPIRE Geoportal on 18 September 2018 (http://inspire-geoportal.ec.europa.eu/). The redesigned portal is meant to become a "one-stop shop" for public authorities, businesses and citizens for discovering, accessing and using geospatial datasets relevant for specific application areas, particularly European environmental policy (EC 2018b). Moreover, the new Geoportal provides overviews of the availability of INSPIRE datasets by country and thematic area based on the metadata regularly harvested from the national data catalogs of different Member States. The Geoportal also allows for direct access to the so-called "priority datasets" (that were jointly selected by the Commission and the EEA) related to environmental reporting obligations in 6 different domains, "air and noise", "industry", "waste", "nature and biodiversity", "water" and "marine". The priority dataset list is a living inventory of environmental information needs and provides an instrument for i) monitoring progress on INSPIRE implementation; ii) incrementally building comparable INSPIRE maturity across Member States based on common settings; iii) planning tangible and usable INSPIRE deliverables for eReporting; and iv) promoting the reuse of the INSPIRE infrastructure for reporting purposes.

Of particular interest to the INSPIRE community are the novel funding opportunities offered to Member States by the Connecting European Facilities (CEF) instrument (EC 2018c); as an example, the recent 2018 CEF Telecom Public Open Data call (with an overall budget of approximately €18.5 million) key objectives include the generation of cross-border services providing access to harmonized thematic open datasets and the corresponding metadata.

For a comprehensive review of past and recent INSPIRE activities, the reader is referred to Cetl et al. (2019).

20.3 Big Data from Space

Given the key role of big data (including big data from space), in June 2015 the EC established the new "Space data for Societal Challenges and Growth" unit within the Directorate-General "Internal Market, Industry, Entrepreneurship and SMEs" (DG GROW). The unit is dedicated to implementing activities supporting the uptake of big data as a key economic asset to stimulate competitiveness and foster the growth of the European economy and employment (BDVA 2017). During the same period, its private counterpart was also established, namely, the Big Data Value Association (BDVA). The BDVA is an industry-driven international not-for-profit organization (counting 200 members all over Europe from large, small, and medium-sized industries and research and user organizations) that aims to develop the innovation ecosystem that will enable data and artificial-intelligence-driven digital transformation in Europe to deliver maximum economic and societal benefit. The importance of big data from space for the EC is further emphasized by the many dedicated calls for proposals included in the different Framework Programs for Research and Technological Development. Within Horizon 2020 (H2020—the current Framework Program), EO activities are recognized as a key element to accompany the remarkable EU investments in Copernicus (i.e., the European EO and monitoring program) and Galileo (i.e., the EU's civilian global navigation satellite system—GNSS) (BDVA 2017). Since 2014, H2020 has funded two work programs (i.e., 2014–2015 and 2016–2017) and is now running the third for 2018–2020. The "Leadership in Enabling and Industrial Technologies" actions for Space (LEIT-Space) comprise specific calls dedicated to EO that target the evolution of Copernicus as well as the exploitation of existing European space infrastructure for the development of novel products and services based on remote sensing, geo-positioning and other types of satellite-enabled data. Other H2020 focus areas also support the uptake of big data from space and related technologies. These are of particular interest in the Societal Challenge framework in support of the "Climate action, environment, resource efficiency and raw materials" challenge, where one of the key actions is dedicated to strengthening the benefits for Europe of the Global Earth Observation System of Systems (GEOSS) (BDVA 2017). In addition to these calls, other European intergovernmental organizations strongly foster the exploitation of big data from space, among which ESA has a leading position.

In the following, the most relevant initiatives with a prominent role of big data from space in Europe are introduced. An overview of Copernicus is provided, including details on its three main components and the newly established data access and information services (DIAS). Next, the EuroGEOSS initiative is presented, followed by a description of ESA's Thematic Exploitation Platforms (TEPs) and a brief review of Galileo and its major benefits.

20.3.1 Copernicus

The Copernicus program is a cornerstone of the EU's efforts to monitor the Earth and its diverse ecosystems, and ensure that European citizens are prepared and protected in the face of natural or man-made disasters (EC 2016a). Copernicus is Europe's eyes on Earth and a symbol of European strategic cooperation in space research and industrial development. It was established in 2012, building on the previous Global Monitoring for Environment and Security (GMES) program, and is coordinated and managed by the EC in partnership with ESA, the EU Member States and EU Agencies (Copernicus 2019). Copernicus aims to achieve a global, continuous, autonomous, high-quality, wide-range EO capacity by bringing together data collected in space, on the ground, in the sea and in the air to produce timely, reliable and easily accessible information. Moreover, it grants easy, autonomous and independent access to such information to support service providers, public authorities and other international organizations in improving the quality of life for European citizens. The program also drives economic growth, as it acts as a data source for several applications and services; recent estimates of the EC predict that its cumulative economic value will be on the order of 13.5 billion euros in 2008–2020 (EC 2016a). One of the major benefits of Copernicus relies on the policy for its data and products, which are released to all users and the public in general on a full, open and free-of-charge basis (EC 2014) (subject to appropriate conditions and limitations in specific cases), allowing for the development of several downstream services.

Copernicus comprises three different components: *Space*, In Situ and *Core Services*.

- The *Space* component includes the 5 families of dedicated Sentinel satellites as well as existing national and international missions (both commercial and public), known as the Copernicus Contributing Missions. The development of the *Space* component, including the launch and operation of the Sentinels and management of the ground segment, was delegated to ESA. The European Organization for the

Exploitation of Meteorological Satellites (EUMETSAT) coordinates the provision of space data and operational support for the climate change, marine environment and atmosphere monitoring services;

- The Copernicus In Situ component is responsible for gathering environmental measurements collected by data providers external to Copernicus, including ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data, collectively referred to as "in situ" data. It also identifies data access gaps or bottlenecks, supports the provision of cross-cutting data and manages partnerships with data providers to improve access and use conditions;
- The Copernicus *Core Services* produce value-added products available to the public that are generated based on the space and in situ data from the other two components. Products include six specific services: land monitoring, marine environment monitoring, atmosphere monitoring, emergency management, security, and climate change.

In the following, each component is presented in detail.

20.3.1.1 Space Component

The success of Copernicus is possible due to a well-engineered *Space* component for the provision of EO data to feed into a range of services to monitor the environment and support civil security activities. With more than 30 years of experience implementing missions to monitor Earth from space, ESA is responsible for developing and managing this core component of the program. The *Space* component includes ESA's families of dedicated Sentinel satellites and missions from other space agencies, referred to as contributing missions. A unified ground segment through which the data are streamed and made freely available for the *Copernicus Services* completes the *Space* component. ESA is establishing a mechanism to integrate, harmonize and coordinate access to all the relevant data from the multitude of different satellite missions (ESA 2019c). This is being carried out in close cooperation with national space agencies, EUMETSAT and, where relevant, owners of non-European missions contributing to the Copernicus objectives.

The Sentinels carry a range of technologies such as radar and multispectral imaging instruments for land, ocean and atmospheric monitoring (ESA 2019c).

- Sentinel-1 provides all-weather, day and night radar imagery for land and ocean services. The twin satellites Sentinel-1A and Sentinel-1B were launched on 3rd April 2014 and 25th April 2016, respectively, and the mission currently delivers high-resolution data globally every 6 to 12 days at a rate of 2.5 TB per day. In January 2019, more than 3.5 million products were available for download, with a total volume of more than 5.5 PB of data;
- Sentinel-2 provides high-resolution optical imagery for land services. The twin satellites Sentinel-2A and Sentinel-2B were launched on 22nd June 2015 and 7th March 2017, respectively. After March 2018, the mission has a revisit frequency

of 5 days worldwide. In January 2019, approximately 8 million products were available for download, with a total volume of more than 4.2 PB of data;

- Sentinel-3 provides high-accuracy optical, radar and altimetry data for marine and land services. The twin satellites Sentinel-3A and Sentinel-3B were launched on 16th February 2016 and 25th April 2018, respectively. The mission will reach a revisit time shorter than 2 days globally with an expected rate of 0.3 TB of data per day;
- Sentinel-4 and Sentinel-5 (whose launches are planned for 2021 and 2020, respectively) will provide data for atmospheric composition monitoring from geostationary and polar orbits, respectively;
- Sentinel-5 Precursor was launched on 13th October 2017 and bridges the gap between Envisat (which delivered data from 2002 to 2012) and Sentinel-5; and
- Sentinel-6 (whose launch is planned for 2020) will provide radar altimetry data to measure global sea-surface height, primarily for operational oceanography and climate studies.

The contributing missions include 30 past, existing and planned missions from ESA, the Member States, EUMETSAT and other European and international third-party mission operators that share part of their data with Copernicus (ESA 2019c). They are grouped in 5 different categories:

- Synthetic aperture radar (SAR) sensors, for all weather day/night observations of land, ocean and ice surfaces (e.g., TerraSAR-X, TanDEM-X, RADARSAT-2, ALOS/PALSAR, Kompsat-5);
- Very high resolution (VHR) optical sensors for targeting specific sites, mostly in urban areas and for security applications (e.g., WorldView-1/2/3/4, Kompsat-2/3, DEIMOS-2, SPOT-5/6/7);
- High-resolution and medium-resolution optical sensors for supporting regional/national land monitoring activities (e.g., Landsat-5/7/8, Proba, DEIMOS-1);
- Medium-low-resolution optical sensors for gathering information on land cover as well as for monitoring oceans, coastal dynamics and ecosystems (e.g., Proba-V, Oceansat-2);
- High-accuracy radar altimeter systems for sea level measurements and climate applications (e.g., Envisat RA-2);
- Radiometers to monitor land and ocean temperature (e.g., ODIN); and
- Spectrometer measurements for air quality and atmospheric composition monitoring (e.g., GOSAT).

Notably, the free and open access policy of Copernicus has triggered unprecedented opportunities for both academia and industry. The main challenges are the growing volume of data from the *Space* component and its heterogeneity (in terms of formats, semantics, measurements, resolutions, and modalities) due to the diversity of sensors employed. Accordingly, volume, variety, velocity and veracity apply to this type of datasets, which cannot be handled by traditional databases and processing methodologies; rather, they require advanced preprocessing, data harmonization, analytics, and uncertainty propagation analyses and the deployment of suitable knowledge models (BDVA 2017).

20.3.1.2 In Situ Component

The Copernicus In Situ component comprises a number of environmental local measurements collected from ground-based, sea-borne or air-borne monitoring systems. These are used to calibrate, assess and supplement the information provided by satellites, which is essential to deliver consistent and reliable data over time (EC 2015). The In Situ component includes data collected from sensors mounted onboard airplanes or weather balloons, positioned on riverbanks or high towers, drifting in the ocean on buoys or pulled through the sea by ships. Background topographic information (e.g., digital elevation models, administrative boundaries, transportation network maps) also falls under the In Situ umbrella, along with information collected by citizen scientists or volunteer contributors (e.g., OpenStreetMap) as well as data gathered by unmanned aerial vehicles—UAVs (i.e., drones) (EC 2015).

The In Situ component mostly includes contributions from the Copernicus Member States, since a consistent part of the data and monitoring infrastructure is owned and operated by single national governments. However, it also benefits from international efforts to collect and share information, in many cases from international research infrastructures. To guarantee reliable and sustainable provision of data for its services, Copernicus has to effectively coordinate with a variety of providers, from local conservation groups to global meteorological bodies. The goal of the In Situ component is to comprehensively explore the complex and manifold landscape of local data, identify gaps by comparing requirements against available information, support the provision of cross-cutting data, and establish and manage partnerships with data providers to improve the conditions of access and use (EC 2015). Timely implementation of the INSPIRE directive is expected to improve access to local datasets and considerably facilitate data discovery and access operations. INSPIRE will also improve the timeliness and quality of the Copernicus services.

All Copernicus service operators are granted direct access to data from the In Situ component as an integrated part of their workflows and according to their day-to-day operational needs (provided that they set up and manage the technical interfaces themselves). Since December 2014, under a delegation agreement with the EC, EEA has been appointed coordinator of this component (EC 2015).

20.3.1.3 Core Services

The Copernicus *Core Services* provide standardized multipurpose information common to a broad range of application areas relevant to EU policies in six different domains, namely, ocean (CMEMS 2019), land (CLMS 2019) and atmosphere (CAMS 2019) monitoring, emergency response (CEMS 2019), security (Copernicus Security Service 2019), and climate change (C3S 2019). The effective use of big data (from the *Space* and In Situ components) and advanced data mining techniques are two key elements to their success. The development of the preoperational version of the services was undertaken a few years ago through a series of projects launched by the EC and partly funded through the EU's 7th Framework Program (FP7). These projects were: MyOcean (ocean), Geoland2 (land), MACC and its successor MACC II (atmosphere), SAFER (emergency response) and G-MOSAIC (security). Most of them also contributed to the monitoring of climate change. In each of the target thematic areas, the range of products developed in response to users' needs is growing, along with the number of users. In addition, projects designed to explore the scope for downstream services supporting specialized topics have been launched, widening the range of available products. These will directly support national, regional or local activities as well as niche European and global markets. Below, additional details are provided for each of the existing *Core Services*.

Copernicus Atmosphere Monitoring Service (CAMS): CAMS is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the EC. It has been fully operational since 2014 and provides businesses, policy makers and scientists with consistent and quality-controlled information on the atmosphere anywhere in the world; it also allows for assessing the past (based on the analysis of historical data records) and generating predictions for the next few days. The service monitors and forecasts parameters related to air pollution and health, solar energy, greenhouse gases and climate forcing. CAMS also compiles emissions inventories to support modeling and estimation of the CO_2 and CH_4 fluxes at the Earth's surface. The main application domains benefiting from use of this service include renewable energies, meteorology, climatology, environmental monitoring and health.

Copernicus Marine Environment Monitoring Service (CMEMS): CMEMS has been operational since 2015 and provides regular and systematic core reference information on the state of the physical oceans and regional seas. It delivers data and products that support major applications in the marine area such as maritime operations (e.g., search and rescue, transport and ship routing, marine safety), marine resources (e.g., fishery, aquaculture), coastal and marine environment (e.g., coastal erosion, sea temperature monitoring, water quality monitoring, pollution control). It also provides key information for weather, climate and seasonal forecasting (e.g., temperature, salinity, currents, wind, sea ice). By jointly exploiting satellite data and in situ observations, the service provides state-of-the-art analyses and forecasts on a daily basis, which offer an unprecedented capability to observe, understand and anticipate marine environment events.

Copernicus Land Monitoring Service (CLMS): CLMS has been operational since 2012 and comprises 4 main components: i) a *global* component providing a series of qualified biogeophysical global products on the status and evolution of the land surface (e.g., albedo, land surface temperature, top-of-canopy reflectance) at mid to low spatial resolution, which are used to monitor the vegetation, water cycle, energy budget and terrestrial cryosphere; ii) a *Pan-European* component aimed at generating land-use/land-cover maps (i.e., CORINE) and high-resolution layers (HRSLs) describing the 5 major land cover types, i.e., artificial surfaces, forest areas, agricultural areas (permanent grasslands), wetlands, and water bodies; iii) a *local* component providing specific and more detailed information that is complementary to the *Pan-European* component and is focused on identified hotspots (i.e., major EU city areas, riparian zones, grassland rich sites) prone to different environmental challenges; and

iv) an *imagery and reference data* component gathering satellite images and in situ data, forming the input for the creation of many information products and services (e.g., the Land Use and Coverage Area frame Survey—LUCAS database).

Copernicus Climate Change Service (C3S): C3S has been operational since 2018 and addresses the environmental and societal challenges related to the climate changes associated with human activities. C3S supports the adaptation and mitigation policies of the EU by providing consistent and authoritative information about the past, present and future climate, as well as tools to enable climate change mitigation and adaptation strategies by policy makers and businesses. The service complements the established range of meteorological and environmental services that each European country has in place and provides access to several climate indicators (e.g., temperature increase, sea level rise, ice sheet melting, ocean warming) and climate indices (e.g., based on records of temperature, precipitation, and drought events). C3S is implemented by ECMWF and relies on climate research carried out within the World Climate Research Program (WCRP) responding to user requirements defined by the Global Climate Observing System (GCOS).

Copernicus Emergency Management Service (EMS): EMS produces timely and reliable geo-spatial information derived from satellite and in situ data supporting the management of geophysical, meteorological and man-made hazards, as well as emergency situations and humanitarian crises. The service comprises 2 different components: i) an *on-demand mapping* component that provides maps for rapid emergency response as well as risk and recovery maps, bolstering the decision-making process in all the phases of the emergency cycle (i.e., preparedness, prevention, disaster risk reduction, emergency response and recovery); and ii) an *early warning* component including the European Forest Fire Information System—EFFIS (aimed at monitoring forest fires and forest fire regimes in the European, Middle Eastern and North African regions) and the European Flood Awareness System—EFAS (aimed at providing flood forecasts to support flood risk management).

Copernicus Security Service: This service tackles Europe's security challenges by providing key information to support crisis prevention, preparedness and response improvement in three application areas: (i) *border surveillance*—to increase the internal security of the European Union using near real-time data over land and sea, as well as fight cross-border crime and reduce the death toll of illegal immigrants at sea; (ii) *maritime surveillance*—to increase maritime security in the framework of navigation, fisheries control, marine pollution, and law enforcement by jointly exploiting Sentinel-1 and other sources of maritime information; and (iii) *support to EU External Action*—to assist third-world countries in crisis situations and prevent global and trans-regional threats with potential destabilizing effects using available geo-information for remote areas experiencing critical security issues.

20.3.2 Data Access and Information Services

To improve access to big data from space and maximize the benefit to different user communities (on an equal basis to all Member States and countries participating in the program), the EC recently funded the development of 5 competitive cloud-based platforms known as data and information access services (DIAS) (CREODIAS 2019; MUNDI 2019; ONDA 2019; SOBLOO 2019; WEKEO 2019). The DIAS allow for centralized access to Copernicus data and products and offer advanced computing resources and tools (open source and/or on a pay-per-use basis) for online processing and analysis (Copernicus 2019). This will create the possibility to easily build new applications and offer added-value services. Each platform also provides access to additional commercial satellite or nonspace datasets, and premium offers in terms of priority or support. By providing a single access point for all Copernicus data and information, the DIAS allow for users to develop and host their own applications in the cloud (ensuring protection of intellectual property rights), without the need to download bulky files from multiple access points and process them locally. This will enable simpler and more user friendly exploitation and data combination, and thus promote innovation. Furthermore, competition between the DIAS will ensure that the best service is delivered to the users and avoid customer lock-in on a specific platform among the 5 (Copernicus 2019). A DIAS functionally consists of 3 types of services:

- **Back office services** that provide access to Copernicus data and information (unlimited, free and complete), as well as to any other data offered by the DIAS provider, in a scalable computing environment where users can build and operate their own services;
- **Interface services** encompassing tools that facilitate users in the development of applications. This environment is developed and managed by the DIAS service providers (according to their specific business models) and offers scalable computing and storage resources to the users at competitive commercial conditions;
- **Front office services** that are provided by third parties (e.g., EU Projects, ESA, EUMETSAT, developers and companies) and are based on exploitation of the Copernicus data and products available through the back office services.

The success of DIAS strongly depends on the strong relationship between the different Copernicus actors as well as on the involvement of Member States and participating countries, information and communication technology (ICT), the EO industry and third parties interested in using Copernicus data and information. The support to and integration of the DIAS into the workflows of ESA and EUMETSAT is expected to further enrich the environment offered by the platforms. Moreover, the integration of DIAS and DIAS-based services into the European Open Science Cloud (EOSC) will make it possible to connect the EO domain to other fields of science at a European level, facilitating the transition from research to commercialization (BDVA 2017).

20.3.3 Thematic Exploitation Platforms

ESA is Europe's gateway to space and its main mission is to shape the development of Europe's space capability and ensure that investments in space continue to deliver benefits to the citizens of Europe and the world. For more than 20 years, EO satellites developed or operated by ESA have provided a wealth of data, which is increasing like never before, especially due to the Sentinel missions. This expanding operational capability of global monitoring from space and data from long-term EO archives, models and in situ networks allow for unprecedented insight into the interconnections of the Earth system between oceans, ice, land and atmosphere. However, while the amount of big data from space represents a key opportunity for academia and industry, it also poses major challenges to achieving comprehensive exploitation of the data. Several initiatives are currently supported by ESA through different programs, among which the development and implementation of the Thematic Exploitation Platforms (TEPs) started in 2014 has a prominent role (ESA 2019d). The TEPs supply a collaborative virtual work environment that provides—through one coherent interface—access to the following:

- relevant big data from space;
- computing resources and hosted processing;
- a platform environment that allows for users to integrate, test, run, and manage applications without the need to build and maintain their own infrastructure;
- standard platform services and functions including collaborative tools, data mining and visualization applications, development tools (e.g., Python, IDL), communication tools (e.g., social networks), as well as documentation, accounting and reporting tools; and
- repositories of advanced processing applications (including those developed by other users).

Moreover, the user community is present (and visible), directly involved in the governance of the platforms and enabled to share and collaborate (ESA 2019d).

Seven different TEPs have been developed, each addressing a specific area of environmental research, namely, geohazards (GEP 2019), forestry (F-TEP 2019), hydrology (H-TEP 2019), food security (Food Security TEP 2019), as well as costal (C-TEP 2019), polar (Polar TEP 2019) and urban areas (U-TEP 2019). In the following, additional details are provided for each TEP.

Geohazards TEP (GEP): The GEP aims to support the exploitation of satellite EO information for geohazards and is based on the Supersites Exploitation Platform (SSEP), originally initiated in the context of the Geohazard Supersites & Natural Laboratories (GSNL) initiative (SSEP 2016). The core user communities for the GEP are the groups of practitioners working on the Seismic Hazards Pilot (CEOS 2019a) and the Volcano Pilot (CEOS 2019b) of the Committee on Earth Observation Satellites (CEOS). The former is a three-year demonstration project intended to showcase the benefits of EO satellite data in the context of seismic hazard research, whose major goals are to (i) support the generation of globally self-consistent strain rate estimates and mapping of active faults at the global scale; (ii) support and continuation of the GSNL for seismic hazards and volcanoes; and (iii) develop and demonstrate advanced science products for rapid earthquake response. The main objectives of the Volcano Pilot through the GEP are to (i) demonstrate the feasibility of integrated, systematic and sustained monitoring of Holocene (i.e., the current geological epoch) volcanoes using space-based EO; (ii) demonstrate the applicability and improved timeliness of space-based EO products for reducing the impact and risk of eruptions; and (iii) build the capacity for exploiting EO data in volcanic observatories in Latin America to showcase global capacity development opportunities.

Coastal TEP (C-TEP): Sustainable coastal development requires accurate and easily accessible knowledge about the dynamic processes shaping coastal zones as well as suitable long-term analysis and automatic trend detection tools. The C-TEP provides a dedicated service for observation and monitoring of the coastal environment. The integration of satellite and near real time (NRT) EO data, in situ data and model predictions in the virtual platform provide an effective means to characterize and understand the many linked coastal processes across a wide range of space and time scales. Key applications include coastal bathymetry, coastal change monitoring, and early warning for pollution discharges, harmful algal blooms and storm surges.

Forestry TEP (F-TEP): The F-TEP vision is to be a one-stop shop for forestry remote sensing applications. The platform offers online processing services and tools (e.g., versatile satellite image analysis, GIS software) for generating value-added forest information products by means of simple and easy-to-use push-button functionalities. It also supports the generation of forest and land cover maps, change maps, and the estimation of continuous forest variables (e.g., growing stock volume). The F-TEP serves users with expertise in forestry rather than EO as well as remote sensing professionals and service providers. These include UN REDD (i.e., the United Nations program on Reducing Emissions from Deforestation and Forest Degradation) and other international programs, national forest inventories, universities and research centers, forest managers, land use planning and nature conservation agencies, as well as value-adding industry and sustainable development NGOs. The platform is closely coordinated with the Food and Agriculture Organization of the United Nations (FAO), the JRC and the Global Forest Observation Initiative (GFOI).

Hydrology TEP (Hydro-TEP): As water affects all societal and environmental domains, there is a major need for integrated, open water information services offering efficient access to cross-regional and multidisciplinary water information. This is even more critical in the developing world, where data are generally sparse. The Hydro-TEP aims to facilitate exploitation, processing and visualization of different types of data (EO, in situ, socioeconomic or meteorological) to better comprehend water-related challenges by combining a holistic understanding of the water cycle with evidence-based governance and increased public awareness. The main services supported by the platform are water quality monitoring, floods and drought risk, climate change forecasts and hydropower and aquaculture assessment. Current users of the Hydro-TEP comprise water authorities, regional mandated authorities, river basin organizations, and universities and research centers.

Polar TEP: The polar regions are remote and hostile environments where collecting data is strongly hindered by the extreme weather conditions, lack of infrastructure and long periods of darkness during the winters. As a consequence, satellites are the only source of consistent, repeatable, year-round and wide-area coverage information. Polar TEP enables users to access and exploit this information to support their operations and science as efficiently as possible. The main current applications include iceberg risk assessment, derivation of ice sheet and ice stream surface velocities, and ice concentration and thickness estimation. An initial pilot project was carried out to demonstrate the potential of the platform to investigate the current and future iceberg risk in Baffin Bay. Different datasets, processors and models have been deployed and integrated to allow for investigating linkages between iceberg populations, observed and modeled changes in ice sheet movement and calving rates, ocean circulation and iceberg trajectories. Current user communities of the Polar TEP include scientific researchers, industry, local indigenous populations, and regional and national governments.

Urban TEP (U-TEP): From the beginning of the 2000s, more than half of the global human population is living in urban environments, and the dynamic trend of urbanization is growing at an unprecedented speed. The U-TEP aims to open up new opportunities to facilitate effective and efficient urban management and safeguard livable cities by systematically exploring the unique EO capabilities in Europe in combination with the big data perspective arising from the constantly growing sources of geo-data. The platform is envisaged to initiate a step change in the use of EO data and geospatial analytics by enabling any interested user to easily exploit and generate thematic information on the status and development of the built environment based on multisource data collections (e.g., EO imagery, statistics, surveying, and volunteered geographic information). The capabilities of participation and sharing of knowledge by using new media and ways of communication will help boost interdisciplinary applications with an urban background. The U-TEP provides a unique portfolio of thematic products and services and, by the end of 2018, was successfully used to process more than 3 PB of EO data and activate a community of more than 300 institutions from all around the world (including the UN, the World Bank, the Organization for Economic Co-operation and Development—OECD, the World Food Program and the Bill and Melinda Gates Foundation).

Food Security TEP: The challenge of increasing the food supply to feed a growing global population makes the sustainability of agriculture and aquaculture as critical as ensuring food security. Food production systems need to optimize the use of water, energy and fertilizers, reduce pollution and soil degradation, and maximizing high-quality agricultural yields and fish harvest under increasingly unstable environmental conditions. To support future sustainable and efficient farming and aquaculture, the Food Security TEP (i) offers direct access to key satellite products and derived data; (ii) allows for on-the-fly computation, visualization and manipulation of basic key indices; and (iii) provides high-accuracy, quality-checked biophysical parameters that are suitable for use in operational scenarios. The Food Security TEP builds on a large and heterogeneous user community that includes small-scale farmers and agricultural industry, public science and the finance and insurance sectors, local and national administrations and international agencies. A forum of experts from this community (i.e., the Partnership for Growth and Sustainability) supported ESA in defining the project requirements, and enables the team to continually develop the platform in accordance with their needs.

20.3.4 EuroGEOSS

The Group on Earth Observations (GEO) is a partnership of more than 100 national governments, 100 participating organizations and the EC. It envisions a future where decisions and measures for the benefit of humankind are informed by coordinated, comprehensive and sustained EO. A central part of the GEO's Mission is to build GEOSS, i.e., a set of coordinated, independent EO information and processing systems that interact and provide access to diverse information for a broad range of users in the private and public sectors (GEO 2019). EuroGEOSS is the European component of GEOSS and complements the other three ongoing GEO initiatives, namely, AfriGEOSS in Africa (initiated in 2013), AmeriGEOSS in the Americas (initiated in 2014), and AOGEOSS in Asia and Oceania (initiated in 2015). EuroGEOSS will be a gateway for European EO programs and projects to GEOSS, with Copernicus as a major element (GEO 2019). Its added value will comprise the following (EC 2017b):

- the user-driven systematic coordination, integration and scaling up of existing services (based on a wide range of data sources) to address sustainable development goals—SDGs, GEO societal benefit areas—SBA (e.g., biodiversity and ecosystem sustainability, food security and sustainable agriculture, sustainable urban development, energy and mineral resources management) and other GEO priorities in the European context;
- the leveraging of global datasets through the GEOSS common infrastructure (GCI) and their exploitation within a European context; and
- additional support to Copernicus to address new communities within GEO and act as an incubator for possible new Copernicus services and applications supporting European priorities.

It is not the objective of EuroGEOSS to establish new data platforms in Europe. Rather, it builds on the GCI and DIAS to take advantage of multiple, existing or upcoming capacities in Europe, including the INSPIRE database, the Copernicus *Space* component, Copernicus *Core Services* products, output products from services offered by the TEPs, citizen observations, and additional data/products from agencies and organizations (e.g., ESA, EUMETSAT, ECMWF) (EC 2017b).

The exploitation of EO data and products, including Copernicus, and the subsequent market creation will be boosted by global cooperation approaches regarding data collection, processing and codesign of information products within the GEOSS context. A more coherent European action towards GEO would complement existing national and supra-national strategies, leverage EO European investments including those from the commercial sector and reduce fragmentation within Europe.

The initial phase of EuroGEOSS was supported through H2020. The EuroGEOSS roadmap 2017–2019 foresaw an initial phase to establish EuroGEOSS during the fourth quarter of 2017, a consolidation phase to start addressing EuroGEOSS pilot applications in 2018 and a third phase in 2019 to showcase the EuroGEOSS added value (EC 2017b).

At the heart of the EuroGEOSS is the ambition to foster the European user dimension in the process of scaling up existing multidisciplinary pilot applications. Emphasis is placed on the "last mile" of the innovation process, enabling preoperational services that could extend/reinforce other GEO initiatives and flagships. For this purpose, reviews of European user needs will be conducted on a regular basis to consider all possible European user communities involved in ongoing GEO tasks as well as other communities in Europe identified by EuroGEOSS members (EC 2017b). The initiative will take full advantage of the many user platforms and consultation processes that are conducted at continental, national and local levels by the members of the European GEO Caucus. EuroGEOSS will aggregate user demand at regional levels from both GEO-aware and GEO-unaware European users. This process will ensure pilot applications driven by structured, consolidated user needs of regional significance.

20.3.5 Galileo

The original idea for Galileo—Europe's own global navigation satellite system (GNSS)—dates back several decades. Galileo was agreed upon in 1994 and, after many delays and setbacks, became available in December 2016 and is foreseen to reach full operational capability by 2021 (Reillon 2017). The system is operated by the European GNSS Agency (GSA) and ESA, with the program oversight by the EC and the political oversight by the European Council and the European Parliament.

Galileo allows for users to determine their location and the location of other people or objects at any given moment, and the ability to determine their velocity and the current system time. It is interoperable with GPS and GLONASS, (i.e., the US and Russian GNSS, respectively), and by relying on a large constellation of satellites and exploiting multiple frequencies, it will provide better service to the users, with real-time positioning accuracy in the meter range (Hecker et al. 2018c). At full deployment, Galileo will comprise 30 satellites (24 operational, plus 6 in-orbit spares) 26 of which have been launched as of July 2018. This large number, together with the optimized constellation design and the availability of three active spare satellites per orbital plane, ensure that the loss of one should not have a discernible effect on the users. Moreover, contrary to all other GNSS, Galileo will provide good coverage even at latitudes higher than 75°N (i.e., corresponding to the most northerly tip of Europe) (Hecker et al. 2018c).

Galileo has several other unique technical features. The two most relevant are the Search and Rescue (SAR) return data link for user notification and the signal authentication for civil users. Both represent important technologies that are expected to provide high added value to EU citizens and worldwide users.

To support the SAR function, satellites are equipped with a transponder, which is able to transfer the distress signals from a user's transmitter to regional rescue coordination centers, which then initiate rescue operations. The system sends a response signal to the users, informing them that the situation has been detected and help is on the way. This latter feature is new and is considered a major upgrade to the existing systems, which do not provide user feedback (Hecker et al. 2018c). The Galileo SAR service represents Europe's contribution to the worldwide satellite-based distress signal detection and localization system COSPAS-SARSAT (where COSPAS is an acronym for the Russian "Cosmicheskaya Sistema Poiska Avariynyh Sudov", which translates to "Space System for the Search of Vessels in Distress" and SARSAT is an acronym for search and rescue satellite-aided tracking). Currently supported by 44 countries, COSPAS-SARSAT was established by Canada, France, the former Soviet Union and the United States in 1979 and provides help to people in danger in the context of aviation, vessels, worldwide expeditions, and people equipped with personal locator beacons (COSPAS-SARSAT 2019). Galileo complements COSPAS-SARSAT with additional satellites and sensibly improves the coverage and accuracy of the located emergency position. Moreover, several research projects supported by the GSA under Horizon 2020 are creating end-to-end solutions based on the Galileo SAR service and leveraging its return link.

Galileo is the only GNSS envisaged to provide open and free signal authentication (Galileo GNSS 2017), i.e., a technical mechanism that allows for verifying if the received navigation signals truly originate from the stated source. Galileo is expected to start transmitting the "Open Service Navigation Message Authentication" in mid-2019 (EGSA 2019a). This feature will help effectively mitigate deliberate signal manipulation and strongly increase the security for Galileo-based timing and positioning applications (especially in critical and safety-relevant fields).

Since all other GNSS constellations are operated by organizations with a military background, there has been concern that navigation signals might be degraded or rejected for civil use (even in specific regions only). Dedicated techniques have been developed similar to the GPS' "Selective Availability", which intentionally reduced the quality of its open signal until the year 2000 (Hecker et al. 2018c). Although these tactics were rarely used in the past, their employment cannot be completely precluded, with potentially dangerous consequences as GNSS are increasingly used in safety critical applications and highly relevant infrastructure. Operated under civil control, Galileo ensures Europe's strategic autonomy with respect to satellite positioning under all circumstances, thus avoiding the abovementioned dependencies and risks. This will also strengthen the EU's position, which can actively influence the GNSS strategy and pave the way for long-term investments and technologies.

The range of applications that Galileo is expected to support is vast and spans different market segments in both the private and public sectors (EGSA 2019b). The most relevant comprise the following:

Emergency, security and humanitarian services: Galileo's SAR service will help save lives, e.g., in the event of an airplane or boat crash. The system will also be an invaluable asset for border control authorities and coastguards (e.g., ensuring faster rescue operations) and to support security-related applications (e.g., helping locate missing persons, stolen property or lost pets).

Environment and weather: Galileo will support geology, geodesy and meteorology research in mapping and measuring of oceans, tides and sea levels, and tracking icebergs, pollutants and dangerous goods. Moreover, it will allow for improving the quality of atmospheric measurements (especially the level of water vapor, which is particularly important in the context of weather forecasting), to advance the study of the ionosphere and space weather, and to better monitor (and hence comprehend) the movements of animal populations.

Agriculture: Galileo will become an asset for the agriculture community. Through the joint exploitation of in situ information, it will allow for improved parcel yield due to customized treatments, improved monitoring of the distribution and dilution of chemicals, and more efficient property management.

Fisheries: Galileo will provide fishermen with improved navigational aids and allow for more accurate and effective exchange of information between vessels and stations. The SAR service will be particularly important to the fishery industry.

Energy: Galileo's high-quality time synchronization will result in better services for the transportation and distribution of energy; modern energy networks strongly rely on accurate location systems (e.g., in case of failure, power grids monitoring instruments will be synchronized with maximum accuracy). Furthermore, by exploiting Galileo's services, marine drilling activities will become safer in the gas and oil fields (where precise time measurements are fundamental when employing seismic streamer or gun arrays).

Once fully operational, Galileo will offer 4 different high-performance services worldwide (EGSA 2019c):

- *Open Service (OS)*: open and free of charge positioning and timing services;
- *Commercial Service (CS)*: complements the OS by providing an additional navigation signal and added-value services in a different frequency band (the CS signal can be encrypted to control access to the service);
- *Public Regulated Service (PRS)*: restricted to government-authorized users to support sensitive applications requiring high-level service continuity; and
- *Search and Rescue Service (SAR)*: in support of COSPAS-SARSAT.

Although Galileo is running behind its original schedule, many application domains are already profiting from its entry into operation and many more will do so in the near future. This is also due to the system interoperability with other GNSS, which results in more satellites in view and thus more measurements and improved accuracies (Hecker et al. 2018c).

Furthermore, it is foreseen that Galileo and the European Geostationary Navigation Overlay Service—EGNOS (a system based on a network of ground stations and 3 geostationary satellites that combines GPS and Galileo signals to improve the accuracy and robustness of navigation in Europe), will provide consistent economic benefits to the European space industry, as well as for a variety of downstream GNSS-based services and applications. These are estimated to be on the order of ~ 130 billion euros for 2014–2034 (against the total Galileo costs of ~ 16 billion euros from the early 1990s until 2020) (Hecker et al. 2018c).

20.4 Citizen Science

The term citizen science (CS)—coined by Irwin (1995) and Bonney (1996) in the mid-1990s—describes the nonprofessional involvement of citizens in a scientific process. The concept of CS has been rapidly adopted in the international and European policy landscape as well as by the scientific research community and has received considerable attention in recent years. However, CS is not a new phenomenon. Depending on the definition, the concept of the participation of citizens in scientific processes can be traced back to the eighteenth century (Mahr et al. 2018). The field of CS is diverse, and there is no universally accepted definition. According to SiS.net (2017), CS can be described as a method to practice scientific research at larger scales, as a movement that democratizes scientific research processes or as a social capacity to produce knowledge. Various approaches of determining a definition for the term CS are discussed by Eitzel et al. (2017). The EC has used various definitions for CS in its policy documents. In EC (2016b), the definition of the Oxford English Dictionary (OED 2014) is applied: CS is *"scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions"*. Instead, in the H2020 work program 2018–2020 (EC 2018d) the definition *"Citizen Science* [...] *covers a range of different levels of participation: from raising public knowledge about science, encouraging citizens to participate in the scientific process by observing, gathering and processing data, right up to setting scientific agenda and co-designing and implementing science-related policies"* is used. In this context, the European Citizen Science Association (ECSA) developed ten principles of CS, which complement the above-mentioned definitions (ECSA 2015; Robinson et al. 2018). For a general overview of the most relevant CS activities in addition to those discussed in this chapter related to the European framework, refer to Chap. 18.

20.4.1 Citizen Science in the European Policy Landscape

The EC emphasizes the opportunities of CS in its Open Science Policy by stating "Citizen Science can contribute to the Commission's goal of Responsible Research and Innovation, as it reinforces public engagement and can redirect research agendas towards issues of concerns to citizens" (EC 2016b). CS is recognized by the EC as an important pillar of the Open Science (OS) concept and, together with Open Access, is at the forefront of new frameworks for research and innovation. The assignment of CS to OS, which is implied by this statement, is controversial. Science Europe (2018), an association of European research funding organizations (RFOs) and research performing organizations (RPOs), argues that CS is increasingly considered an independent discipline whereas DITOs (2018) and Hecker et al. (2018a) see them as equal disciplines that enrich and partly depend on each other.

In 2013, the EC dedicated an entire report to environmental CS, which highlighted the role of new and emerging mobile technologies for CS and the perception of the quality of research by CS and discussed the influence of CS on European environmental policymaking (UWE 2013). Together with the outcomes of a green paper on CS by socientize (EC 2013) and the resulting white paper on CS for Europe in 2015 (Sanz et al. 2015), the results of the report prepared the ground for the aforementioned statements on CS in the EU Open Science Policy "*Open Innovation, Open Science, Open to the World—a Vision for Europe*" (EC 2016b) and were streamlined into the *EC Action Plan for Environmental Reporting (Action 8)* (EC 2017c) and the *Horizon 2020—Work Program 2018–2020* (EC 2018d). The level of consideration of CS in the upcoming Horizon Europe Program is still under discussion.

For the practical implementation of CS, JRC is the EU organization with the highest activity level (Science Europe 2018). The JRC is collaborating with several other EU institutions (including EEA) in the Environmental Knowledge Community (EKC), which investigates the creation and exchange of knowledge in environmental policy making processes and the role of CS in environmental policy making (Schade et al. 2017). The EKC operates a Knowledge and Innovation Project (KIP) on CS, with a focus on how CS data could be used qualitatively to complement European environmental monitoring and reporting processes. Another activity of the JRC that directly addresses European policy making is the development of a CS platform (EC 2019a). The platform will support CS projects and foster the consideration of their needs in the European policy making process.

The EC observes the development of CS projects with the Open Science Monitor (EC 2019b), which currently utilizes the repositories of SciStarter (https://scistarter.com/) and Zooniverse (https://www.zooniverse.org/). In 2016, a detailed EU-wide survey on CS was conducted (see Fig. 20.1). It showed that the majority of CS projects were initiated in Central and Western Europe and that the primary subject of most projects was in life sciences. In 2018, JRC published an inventory of environmental CS projects based on a study of a consortium of the EC (DG Environment, DG JRC), Bio Innovation Service (FR), Fundacion Ibercivis (ES) and The Natural History Museum (UK) (Bio Innovation Service 2018). It identified 503 projects (444 with participating actors from European countries, 12 European initiatives, 29 global initiatives and 18 from other regions; see Fig. 20.2). Even though both studies have a different focus and might not cover all activities, they show that the CS engagement of Eastern European countries has increased.

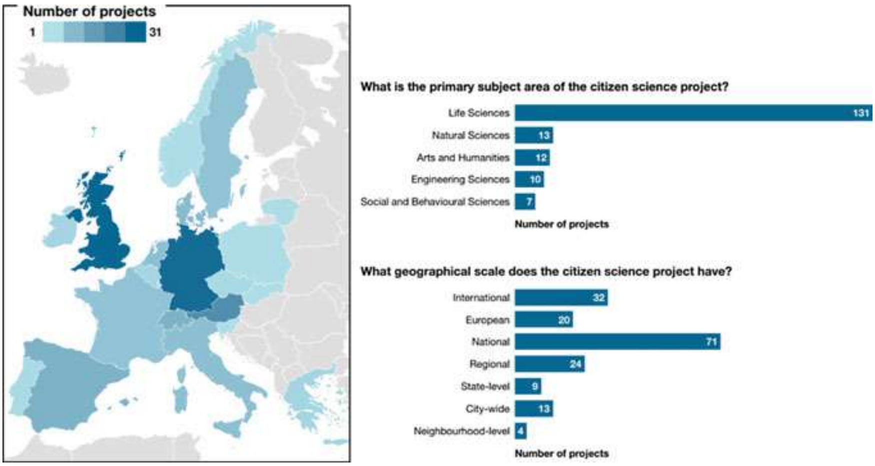

Fig. 20.1 Map of CS activities taking place across Europe; field of study of the project; and geographical scale of the project based on an EU-wide survey of CS conducted in 2016. *Source* European Commission (2016b) as cited in Science Europe (2018)

20.4.2 FP7 and H2020 Citizen Science Projects

With its Research and Innovation programs, the EU is an active funder of CS initiatives. The Seventh Framework program (FP7) was the EU funding program from 2007 to 2013, its successor H2020 is the framework program for 2014 to 2020, which will be followed by Horizon Europe. Some of the projects aim to enable CS participation and raise the general awareness of environmental and societal challenges; other projects focus on the involvement of citizens to engage in specific research questions. The following summary provides an incomplete overview of funding sections with instances of CS-related projects:

CAPS (Collective Awareness Platforms for Sustainability and Social Innovation): The CAPS seek new models to create awareness of emerging sustainability challenges. They aim to offer collaborative solutions based on modern information and communication technologies. A range of CAPS have been funded and are listed at https://capssi.eu. Among them, two of the most interesting are:

- *MakingSense*, which offers a toolkit of open source software and hardware, digital maker practices and open design that enables citizens and local communities to engage in pressing environmental questions (www.making-sense.eu); and
- *SOCRATIC*: whose main objective is to provide citizens and organizations with collaborative space and allow for them identify innovative solutions to achieve the United Nations Sustainable Development Goals (SDGs) (www.socratic.eu).

SwafS (Science with and for Society): The SwafS program objective is to build effective cooperation between science and society. The “Responsible Research and Innovation” program supports the design and implementation of innovative ways to

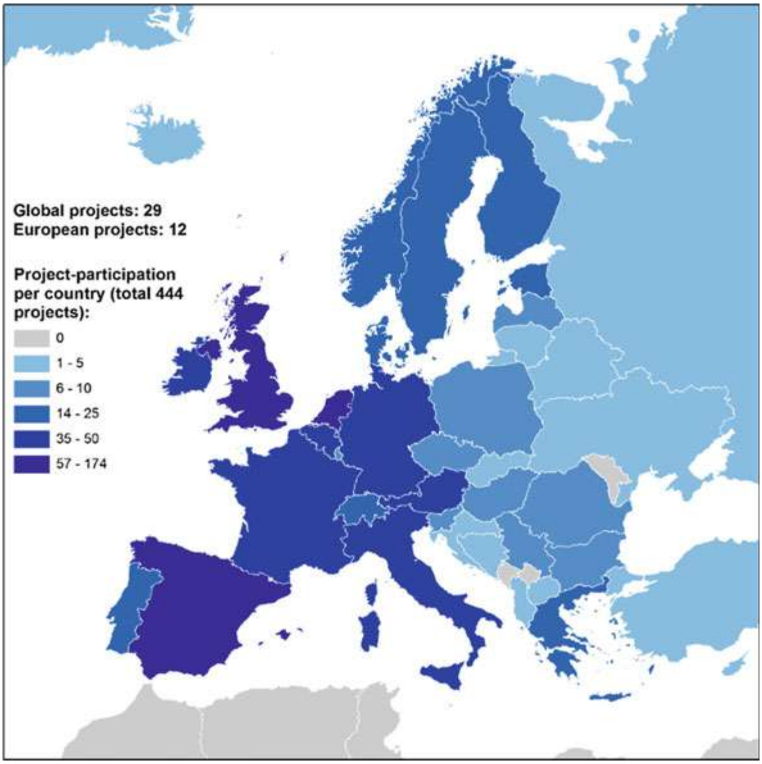

Fig. 20.2 Map of the environmental CS activities taking place across Europe based on the "Study on an inventory of CS activities for environmental policies". Twelve projects were listed as being on the European scale, and 26 were on a global scale. In addition, 444 projects had participants from European countries (multiple countries can be assigned to one project). *Source* own illustration based on EC (2018e)

connect science and society more broadly (http://ec.europa.eu/research/swafs/). In this framework, two representative activities are:

- *DITOs (Doing It Together Science)*, which connects research institutions, museums, science galleries and art institutions to engage people with CS in Europe (http://togetherscience.eu/); and
- *SPARKS*, which is an awareness-raising project dedicated to familiarizing and engaging European citizens with the concept and practice of Responsible Research and Innovation (RRI) (http://www.sparksproject.eu/).

Citizen Observatories: Citizen observatories commonly exploit the capabilities offered by the citizens' own devices (EC 2018e). Under the FP7 Environment Theme, 5 CS observatories were funded: COBWEB (biosphere monitoring), CITI-SENSE (air pollution monitoring), WeSenseIt (flood and drought monitoring) OMNISCIENTISTS (odor monitoring) and Citclops (coastal and water quality monitoring). Four others have been established through the H2020 Societal Challenge 5 (climate action, environment, resource efficiency and raw materials), namely, SCENT, Ground Truth 2.0, the GROW Observatory and Landsense (which contributes to EO analyses in the framework of land use and land cover monitoring (https://landsense.eu/)). Projects have also been undertaken to improve the coordination between CS observatories in Europe and support the integration of their outcomes in European policy (Gold 2018) (e.g., WeObserve www.weobserve.eu).

COST (European cooperation in science and technology): COST aims to connect research initiatives across Europe with initiatives outside Europe to enable researchers and innovators to develop ideas in any field of science and technology in cooperation with their peers. This includes the fostering of citizen participation in research activities (www.cost.eu). Interesting activities include:

- *Citizen Science COST Action CA15212*, which aims to investigate and extend the impact of the educational, policy, scientific and civic results and achievements of CS to use it for social innovation and socioecological transition (http://cs-eu.net/); and
- *Networking Lake Observatories in Europe (NETLAKE) COST Action ES1201*, which was funded from 2012 to 2016 and aimed to monitor 25 European lakes with the support of CS methods (NETLAKE 2017).

Notably, the FP7 *socientize* project aimed to promote the usage of science infrastructures and considered society itself as infrastructure for e-science by utilizing technology, innovation and creativity. *Socientize* compiled the aforementioned green and white papers on CS for Europe (Sanz et al. 2015) (www.socientize.eu).

20.4.3 Initiatives and Platforms in EU Member States and Public Organizations

In addition to CS projects and actions that are mainly based on funding by EU programs, many initiatives developed in Europe with national funding or through private and institutional engagement. A prominent role is played by the ECSA, a nonprofit association aimed at encouraging the growth of CS in Europe. It was launched in 2013 and consists of European and international individual and organizational members (Science Europe 2018). To foster policy advances and initiate and strengthen CS in Europe, the ECSA published 'Citizen Science as part of EU Policy Delivery-EU Directives' (ECSA 2016) and developed ten principles of CS (ECSA 2015; Robinson et al. 2018) for use in discussions with the EC. Several governments of EU Member States and public organizations actively support CS, particularly environmental protection agencies. One example is the Scottish Environment Protection Agency (SEPA), which fosters CS initiatives with a large support infrastructure, including best-practice guidance to support public authorities (Pocock et al. 2014). CS platforms and capacity-building initiatives increase the visibility of projects and help cultivate networks in the CS community (Hecker et al. 2018b). They produce training materials, distribute new developments and establish contacts to policy makers, scientists and stakeholders (Bonn et al. 2016, Richter et al. 2018). Examples of such platforms are *Bürger schaffen Wissen* (www.buergerschaffenwissen.de, Germany), *Österreich forscht* (www.citizen-science.at, Austria), *Schweiz forscht* (www.schweiz-forscht.ch, Switzerland), *Observatorio de la Ciencia Ciudadana en España* (http://ciencia-ciudadana.es, Spain) and the *Scottish Citizen Science Portal* (https://envscot-csportal.org.uk/, Scotland). A consortium of the nonprofit research associations Helmholtz and Leibniz, together with university partners, leads the *Bürger schaffen Wissen* (GEWISS) program in Germany. It published the green paper Citizen Science Strategy for 2020 (Bonn et al. 2016), which describes the understanding, requirements and processes of CS in Germany. For an extensive overview of European CS projects, we refer the reader to the *Inventory of citizen science activities for environmental policies* (EC 2018e) and the accompanying report (Bio Innovation Service 2018).

20.5 Digital Europe and Horizon Europe

To support future digital innovation (a fundamental prerequisite for effective implementation of DE in the coming years) in the framework of the next long-term EU budget for 2021–2027, the Commission is proposing two major programs: Digital Europe and Horizon Europe (EC 2018f, 2019c).

Digital Europe builds on the Digital Single Market strategy launched in May 2015 with the main objectives of increasing the EU's international competitiveness and shaping Europe's digital transformation for the benefit of citizens and businesses. The program will promote the large-scale deployment of digital technologies across economic sectors and will support the digital transformation of public services and businesses (EC 2019c). With a budget of €9.2 billion, Digital Europe will boost frontline investments in key relevant contexts:

- *high-performance computing*: €2.7 billion will be invested in projects aimed at strengthening supercomputing and data processing in Europe, with a goal of deploying a world-class supercomputer and data infrastructure with exascale capabilities (i.e., billion calculations per second) by 2022–2023 and post-exascale facilities by 2026–2027;
- *artificial intelligence (AI)*: €2.5 billion will be allocated to activities supporting the uptake of AI across the European economy and society, taking into account all the correlated socioeconomic changes and ensuring an appropriate legal and ethical framework. The idea is to create open 'European libraries' of algorithms to support both the public and private sectors to identify the most suitable solutions for their needs. The establishment of digital innovation hubs across the EU will also make it possible for small business and local innovators to access testing facilities;

- *cybersecurity*: €2 billion will be dedicated to boosting cyber defense and the EU's cybersecurity industry. This will be carried out by financing state-of-the-art cybersecurity equipment and infrastructure as well as by supporting the development of the necessary knowledge and skills;
- *advanced digital skills*: €700 million will be invested to form the current and future workforce through training courses and traineeships aimed at providing the necessary advanced skills to access supercomputing, artificial intelligence and cybersecurity; and
- *ensuring wide use of digital technologies*: €1.3 billion will support the digital transformation of public administration and related services, as well as their interoperability within the EU. Digital innovation hubs will become "one-stop shops" for both public administrations and small/medium-sized enterprises by providing access to technological expertise and experimentation facilities.

In addition to Digital Europe, financing for research and innovation in next-generation digital technologies will continue and be reinforced under the upcoming Horizon Europe program. Horizon Europe is the successor of H2020 and will be the biggest research and innovation funding program ever, with an overall budget of approximately €100 billion (EC 2018f). The new program will reinforce the Union's scientific and technological bases to help address major global challenges and contribute to achieving the United Nations SDGs; moreover, at the same time, it will boost the Union's competitiveness, including that of its industries. Horizon Europe will help deliver on the Union's strategic priorities and support the development and implementation of its policies. The program is designed around three main pillars: (i) the *Open Science* pillar, which supports researchers through fellowships, exchanges, and funding to projects defined and driven by researchers; (ii) the *Global Challenges* pillar, which directly supports research addressing societal challenges; and (iii) the *Open Innovation* pillar, which aims to make Europe a front runner in market-creating innovation.

Horizon Europe is expected to generate the following:

- new (and more) knowledge and technologies, promoting scientific excellence and impact. It will continue facilitating cross-border collaborations between innovators and top scientists, as well as allow for trans-national and cross-sector coordination between public and private investment in research and innovation;
- positive effects on growth, trade and investment flows as well as on quality jobs and international mobility for researchers in the European Research Area. The program is expected to increase the GDP by an average of 0.08–0.19% over 25 years (which corresponds to a potential return of up to €11 for each euro invested over the same period); and
- significant social and environmental impacts created by translating scientific results into new products, services and processes, which will help successfully deliver on political objectives, as well as social and eco-innovation.

The Digital Europe and Horizon Europe programs will work hand-in-hand: Horizon Europe provides key investments in research and innovation, and Digital Europe builds on these results to create the necessary infrastructure and support deployment and capacity building, which will provide input for future research in AI, robotics, high-performance computing and big data.

AI is foreseen to become the main driver of economic and productivity growth and will contribute to the sustainability and viability of the industrial base in Europe. Accordingly, the Union aims to develop trusted AI based on ethical and societal values, building on its Charter of Fundamental Rights; people should trust AI and benefit from its use for their personal and professional lives. Thus, the Communication "Artificial Intelligence for Europe" of 25 April 2018 proposed a dedicated strategy that supports the ambition for Europe to become the world-leading region in developing and deploying cutting-edge, ethical and secure AI (EC 2018g). Furthermore, in the related coordinated Action Plan of 7 December 2018, the Commission explicitly proposed the development and deployment of dedicated AI capacities, taking direct advantage of Copernicus data and infrastructure to foster geo-location-based services to support agriculture, air quality, climate, emissions, the marine environment, water management, security and migration monitoring, and citizen science (EC 2018h). These will be accompanied by initiatives supporting AI-based exploitation of EO data and information in both the public and private sectors.

20.6 Conclusions

Most of the visionary features of the original DE view formulated by Al Gore in 1998 were implemented in practice only 10 years later in several web-mapping platforms and desktop virtual globes. This led to an evolution of the DE concept, in light of the concurrent advancements in technology and research, as well as changes in society. DE expanded its role in other fields (e.g., related to global climate change, natural disaster prevention and response) and transformed into a more practical system design to fulfil the demand for information sharing and overcome the socioeconomic inequality in accessing and using the data. In a few years, Europe became one of the key players in DE at the global level. Through the INSPIRE Directive, it created a legal framework for the establishment of a European SDI relying on single NDSIs. By jointly supporting data discovery, access and harmonization, INSPIRE has become a model in the world and its complete entry into force in 2021 will become a milestone for the implementation of transnational services. Furthermore, the EO mass data collected within the Galileo and Copernicus programs place Europe at the forefront of the big data from space paradigm. Galileo will enable higher precision positioning, with consequent key improvements in a variety of applications (especially once full operation begins in 2021). Moreover, its SAR and signal authentication features will improve people's security and safety in many fields. Copernicus provides continuous monitoring of our planet through a comprehensive set of sensors mounted onboard the Sentinel satellites (whose families will grow in the next decade) as well as a number of environmental local measurements. From such a wealth of data, the ultimate goal of the program is to generate key information for the users; this is directly carried out by the different core services and made possible through novel cloud-based platforms such as the DIAS and the TEPs. The last 5 years saw the increasing emergence of CS in Europe, which proved to be an effective tool to support researchers and society at large, with hundreds of projects and initiatives funded throughout the different EU Member States. The implementation of dedicated platforms facilitated the uptake of CS in different fields and raised awareness of environmental and societal challenges. Further advancement is expected in the near feature, e.g., by giving citizens the possibility of collecting and contributing real-world data through novel (and connected) sensors directly immersed in their environments. Europe has clear plans for the future and is creating a basis to establish an overall framework in which DE will gain even more importance. This will be possible by means of the Horizon Europe and Digital Europe programs. The former will support research and innovation by strengthening the scientific and technological bases of the Union and fostering its global competitiveness and innovation capacity; the latter will procure high-tech resources and skills for use by European businesses and the public sector. In both cases, the effective integration of cutting-edge AI will be one of the main challenges in the next years.

In conclusion, the European experience illustrates that big data from satellites are a fundamental aspect for the future of DE, as they will allow for analyses that were unimaginable just few years ago. To maximize their benefit, the implementation of processing platforms that enable advanced processing are essential (the integration of novel AI-based methodologies is one of the priorities), as well as the establishment of effective SDIs to share derived products and guarantee access to them beyond national borders. In this framework, the role of citizens can become a key asset through their involvement in directly collecting and sharing data and actively providing feedback.

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Chapter 21
Digital Earth in Australia

Zaffar Sadiq Mohamed-Ghouse, Cheryl Desha and Luis Perez-Mora

Abstract Australia must overcome a number of challenges to meet the needs of our growing population in a time of increased climate variability. Fortunately, we have unprecedented access to data about our land and the built environment that is internationally regarded for its quality. Over the last two decades Australia has risen to the forefront in developing and implementing Digital Earth concepts, with several key national initiatives formalising our digital geospatial journey in digital globes, open data access and ensuring data quality. In particular and in part driven by a lack of substantial resources in space, we have directed efforts towards world-leading innovation in big data processing and storage. This chapter highlights these geospatial initiatives, including case-uses, lessons learned, and next steps for Australia. Initiatives addressed include the National Data Grid (NDG), the Queensland Globe, G20 Globe, NSW Live (formerly NSW Globe), Geoscape, the National Map, the Australian Geoscience Data Cube and Digital Earth Australia. We explore several use cases and conclude by considering lessons learned that are transferrable for our colleagues internationally. This includes challenges in: 1) Creating an active context for data use, 2) Capacity building beyond 'show-and-tell', and 3) Defining the job market and demand for the market.

Keywords Digital infrastructure · Data cube · National computational infrastructure · National collaborative research infrastructure strategy · Queensland globe

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21.1 Introduction

In this chapter, the authors demonstrate the need for local, champion-based initiatives to support mainstreaming, integration and take-up globally. This includes progress made in the digital earth agenda, and the creation of a repository that can be used by researchers, policy makers, decision-makers and the community at large. The chapter describes the lessons learned in Australia, which are likely to be immediately transferrable and of benefit to other initiatives around the world. The chapter outlines precedents and examples of innovation arising from the need to better manage local resources, and addresses the complexities of environmental stewardship and the extraction and processing of natural resources.

In the global move towards automation, employment and productivity (Manyika et al. 2017), Australia must overcome a number of challenges to meet the needs of its growing population in a time of increased climate variability, from sustainably managing and restoring natural environments to developing resources and optimizing our agricultural potential. Increasingly frequent environmental extreme events such as chronic drought, extreme bushfires, and flooding have catalyzed internationally regarded innovation in this field, in addition to the requirement for large-scale infrastructure planning along the eastern seaboard and in northern Australia (Australian Government 2015), and the national need to report on performance—in relation to people and planetary systems—through the United Nations Sustainable Development Goals (Griggs et al. 2013). Within this context, senior mentors in the field Steudler and Rajabifard reflect that sharing information through a spatial data infrastructure (SDI) can facilitate improved decision-making, where themed images and temporal overlays can quickly engage different communities in common understanding and appreciation of issues and potential solutions (Steudler and Rajabifard 2012; Rajabifard and Crompvoets 2016).

Fortunately, Australians have unprecedented access to current and historical data about land and the built environment that is internationally regarded for its quality. Australia has been at the forefront in the development and implementation of Digital Earth concepts over the last two decades (Woodgate et al. 2017). In recent years, several key national initiatives have also formalized the Australian digital geospatial journey, shaping its world-leading initiatives and credentials in digital globes, open data access and quality:

- The Cooperative Research Centre for Spatial Information (CRCSI), launched in 2003 and recently transitioned to 'FrontierSI', has driven numerous initiatives in research and technological innovation, market and product development, workforce planning and preparedness, and outreach. Three seminal *Global Outlook* reports (Woodgate et al. 2014; Coppa et al. 2016, 2018) provide excellent content for a more detailed exploration of the Australian geospatial progress, in addition to a White Paper on the context and priorities of the future of spatial knowledge infrastructure (Duckham et al. 2017).
- The National Innovation and Science Agenda (NISA), launched in 2015, comprises 24 initiatives. With a AUD $1.1 billion direct allocation of federal funds,

it influences approximately AUD $10 billion per annum in government-related expenditure on innovation (Coppa et al. 2018:6).

- The 2026 Agenda (co-chaired by Cockerton and Woodgate 2016, 2017, 2019), developed from extensive consultation, provides the vision and direction to enable the geospatial community to deliver national and global services supporting the NISA. This landmark initiative involved the CRCSI (now FrontierSI), the Spatial Industries Business Association-Geospatial Industry Technology Association (SIBA-GITA), the Australia New Zealand Land Information Council (ANZLIC—Australia and New Zealand's peak government Council for spatial matters), the Australian Earth Observation Community Coordination Group, Data61 (CSIRO), Landgate, Geoscience Australia, Department of Natural Resources and Mines (Queensland Government), and the Department of Prime Minister and Cabinet.
- Substantial digital infrastructure projects in broadband services around the country, including the National Broadband Network (NBN) and Australia's Academic and Research Network (AARNet), owned by the Australian universities and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which provides internet services to the Australian education and research communities and their research partners. AARNet is widely regarded as the founder of the internet in Australia and is renowned as the architect, builder and operator of a world-class high-speed, low-latency network for research and education (AARNet 2018).

Domestically, the country has directed efforts towards world-leading innovation in big data processing and storage (for example, see Dhu et al. 2017), without ownership of substantial resources in space (AAS 2009) and with only-recent establishment of a Space Agency. Furthermore, Australia is large enough for the Earth's curvature to be important, and its tectonic movement is significant enough to require a dynamic cadaster. Hence, Australia's digital earth history has been grounded in an emphasis on a planar geometry—where geodetic coordinates (latitude and longitude) are mathematically projected onto a two-dimensional plane using a Universal Transverse Mercator system—in comparison with other chapters in this manual that emphasize the globe.

Within this context, in 2017 the federal government established Digital Earth Australia (DEA), building on the Geoscience Australia 'Data Cube' supported by CSIRO, the National Computational Infrastructure (NCI), and the National Collaborative Research Infrastructure Strategy (NCRIS). This includes funding of AUD $15.3 M/year going forward within the federal budget. When completed, it will provide 10-meter resolution image data nationwide, allowing for multitemporal analyses throughout the stack of co-registered data for as far back as 30 years and as detailed as 16-day intervals.

Looking ahead, Australia has identified its most promising growth sectors for the spatial industry: transport, agriculture, health, defense and security, energy, mining, and the built environment, with the environment requiring special consideration (ACIL 2015; Cockerton and Woodgate 2017). ***A significant challenge concerns building capacity for widespread uptake of geospatial technologies and tools across***

these key growth sectors, where open-data use, real-time crowd-sourcing of information, and visualization are integrated within core decision-making processes.

Within this context, this chapter provides commentary on key geospatial initiatives, case-uses, lessons learned, and next steps for Australia, drawing primarily from published material in the public domain and experiences of the Authors. The chapter presents a summary of a number of initiatives, including the National Data Grid (NDG), the Queensland Globe, G20 Globe, NSW Live (formerly NSW Globe), Geoscape, the National Map, the Australian Geoscience Data Cube and Digital Earth Australia. It also highlights key products and projects currently being undertaken by Digital Earth Australia. The chapter includes exploration of several use cases in agriculture, property, education and training, and disaster management, and concludes with a consideration of lessons learned and next steps in Australia.

21.2 An Historical Context of Geospatial Initiatives

It has been a busy two decades for the Australian geospatial community, with a number of key products developed by state and federal governments. As illustrated in Fig. 21.1, these initiatives are indicative of a growing awareness of and appetite

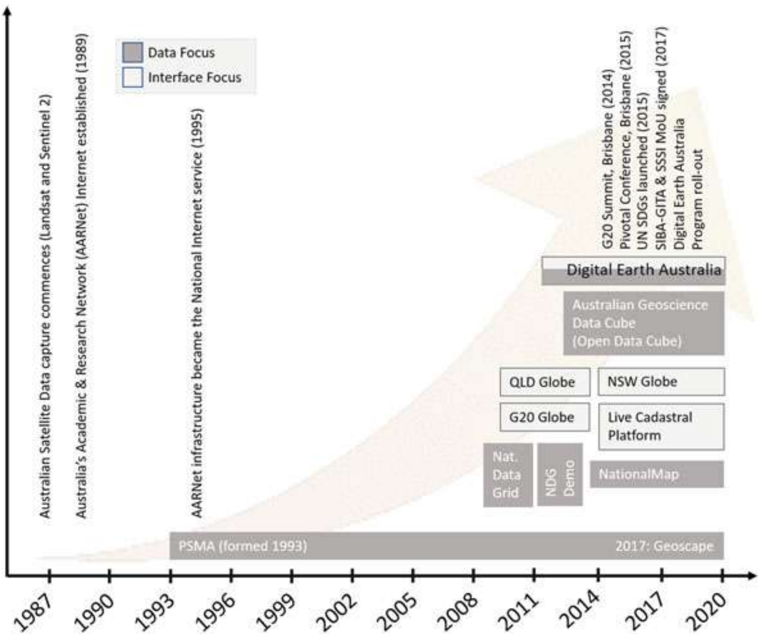

Fig. 21.1 Illustration of the history of digital earth in Australia

for access to data that can result in meaningful decision-making, addressing three important principles for Digital Earth (Desha et al. 2017):

(1) Open data: Harnessing the potential of open, transparent, rapid access to comprehensive data and information to harvest the plethora of data sets for meaningful problem solving. Australia ranked first on the Global Open Data Index that measures how well nations publish open government data against 14 key categories (Wallace 2017a).
(2) Real-world context: Decision-making support frameworks that integrate spatial information and sustainable development aspirations, including the United Nations' sustainable development goals. Australia's Open Data Cube (ODC) objectives include building the capacity of users to address these goals in addition to those of the Paris and Sendai agreements (Coppa et al. 2018:84).
(3) Informed visualization for decision support: i.e., making visual sense of the complex, dynamic and increasingly interrelated systems of today and the future. Among the world's 23 unique virtual globe platforms and four virtual globes that are visualization applications only, Australians have access to an expanding array of support tools (Keysers 2015), with exciting prospects for user functionality improvements.

In the following paragraphs, we briefly introduce the features of these products, how they have evolved over time, how they are being used to increase end-user take up of geospatial products and services, and the contributions that led to the formation of Digital Earth Australia (Sect. 21.3). Several use cases are also provided in Sect. 21.4.

21.2.1 National Initiatives

21.2.1.1 2008–2010: CRCSI's National Data Grid (NDG)

The National Data Grid (n.d.) was developed by the CRCSI to support the spatial enquiry needs of modelers and decision support systems, as conceptualized in Fig. 21.2. The developers had a vision to develop a shared infrastructure that could provide an economical and effective means to integrate spatial information from a variety of sources and formats to support commonly required query, analytical and modeling tasks.

The resultant NDG was essentially an integrated data platform that adopted a grid cell (i.e., raster) based approach to managing spatial information, which could assist professionals with little or no knowledge of geospatial science in performing simple and replicable spatial queries and analyses. It included three components (CRCSI 2009):

- National Nested Grid: a set of standard nested grids with an innovative indexing system to facilitate and promote spatial consistency in a cost-effective manner.

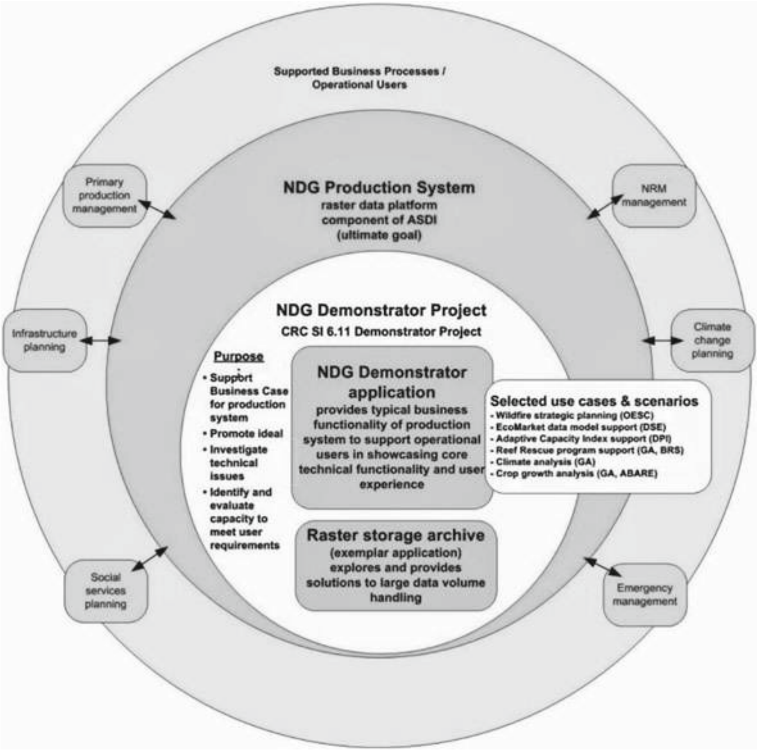

Fig. 21.2 A conceptualization of the national data grid (*Source* CRCSI 2011)

- National Data Grid Demonstrator Application: a publication data store with a web-based function, rich data querying and data visualization environment for users to access and publish grid cell data.
- National Data Grid Raster Storage Archive: a high-capacity backend data store for efficient and cost-effective storage and management of large datasets.

To raise awareness about the full potential of the NDG, the CRCSI funded the development of an online proof of concept 'NDG Demonstrator' (Spatial Vision 2011). Built upon an earlier collaboration into a 'Platform for Environmental Modeling Support' (Chan et al. 2008), several scenarios including crop growth, a biodiversity index and climate evaluation were used to showcase the core technical components and opportunities to interact with the product for national and jurisdictional agencies and the public, and opportunities to address scalability issues (CRCSI 2011). IP created in the NDG project was also subsequently used in a pivotal \$3.4 M initiative funded by the Australian Space Research Program to build Earth observation infrastructure enabling processing of the national LANDSAT imagery archive of more than 30 years of data.

21.2.1.2 2014: NICTA's NationalMap

National ICT Australia (NICTA) developed 'NationalMap' for the Department of Communications and Geoscience Australia as a public tool for accessing and mapping open data and users' private data (National Map, n.d.). The NationalMap provides a map-based view of data but does not store data. Selected data viewed on the map is typically accessed directly from the relevant government department or agency.

The initiative was designed with a focus on interoperability and open source code, supporting the government's commitment to policy visualization and open data (NAA, n.d.). It was developed as open source software (available as a GitHub project) using user-centered design methods. Now managed by the Department of the Prime Minister and Cabinet, the open source software is available as a GitHub project. The web front-end uses NICTA's TerriaJS software, which was initially developed by Data61 for NationalMap and has subsequently been used for other projects.

An example of NationalMap use documented in Australia's Digital Continuity 2020 Policy is the Australian Renewable Energy Mapping Infrastructure (AREMI) platform owned by the Australian Renewable Energy Agency (NAA, n.d.). AREMI uses NationalMap to create an open-source, three-dimensional mapping platform to convert and visually display information that works in any modern browser without plug-ins or specialized software on the user's computer. It facilitates evaluation of renewable energy project developments through gathering relevant spatial datasets in one location at the same time. End-user flexibility is key; financiers and investors can ascertain the potential viability of ventures, and project developers can freely access ground and resource measurements to assist with site assessment and design. State and local governments can also use the information to assist with community and stakeholder engagement, tracking and promoting projects, and reviewing and assessing environmental and regulatory planning approvals.

NationalMap requires data to be formatted in a particular way to be machine readable and presented spatially. The Australian Government is continuing to work with agencies to assist with data formatting requirements and compatibility with Australian and international data standards, and have produced the AusGEO CSV standard as a guide to provide consistent formatting.

21.2.1.3 2017: PSMA's Geoscape: Australia's National 3D Data Set

PSMA Australia is an independent and self-funded entity, formed in 1993 by the state governments of Australia to collate, transform and deliver the national government's geospatial data as national datasets (PSMA 2009). The company undertook its first major initiative in 1996, supporting the national Census by providing Australia's first digital national map at the street level.

In 2017, the company launched Geoscape as a suite of digital datasets that represents buildings, surface cover and trees across urban and rural Australia, as shown in Fig. 21.3. Using a reliable geospatial base, the national dataset spatially represents

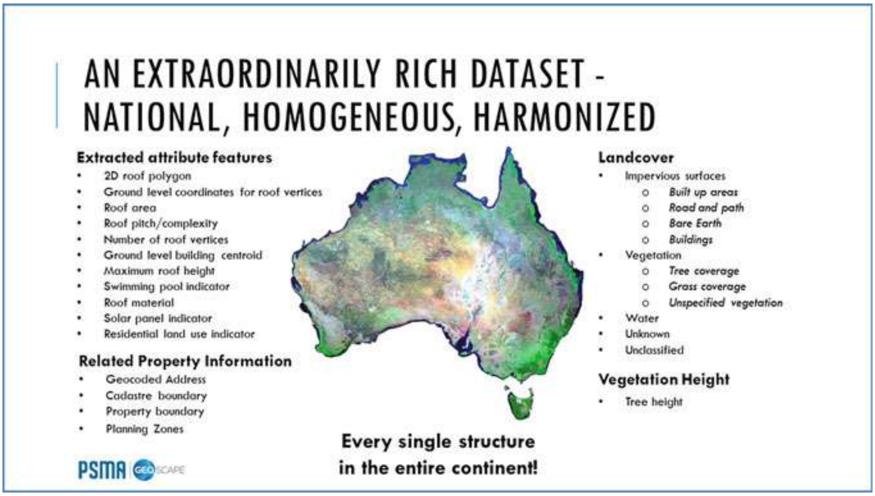

Fig. 21.3 Geoscape product summary (*Source* Paull and Rose 2017)

every building with a roof area greater than 9 m^2, for use by industry and government. This is equivalent to approximately 15 million buildings spanning 7.6 million km^2 across the entire country (Schubert 2017).

The data set links numerous land and property features related to physical structures, land and vegetation, and geographical locations. This includes links to important geospatial reference datasets including geocoded addresses, property data, administrative boundaries, 3D building attributes, land cover details, tree heights, and information on roof materials, swimming pools, and solar panels. It is regularly updated, providing a narrative of the changing landscape, and has links to other PSMA products including G-NAF (addresses), Cadlite (cadastre and property) and Administrative Boundaries (suburb/localities). As PSMA's CEO Dan Paull reflects in a Geoscape Blog (2017), *"Time and location-stamping have moved data from position to precision, giving a more accurate reflection of the built environment. Organisations can now make sharper decisions with more efficiency and greater confidence."*

Working in partnership with DigitalGlobe for satellite imagery, the company has used a combination of satellite imagery, crowd-sourcing and machine learning to develop a new process for recognizing and extracting insights from images. The result is an analytics-ready product that is globally replicable and depicts the full built environment (PSMA 2017a). At the time of writing, the roll-out of mapped locations was underway (see https://www.geoscape.com.au/rollout/).

The following are two examples showcasing the capabilities of Geoscape:

- The Greater Launceston Transformation Project: Geoscape provides the essential foundational data to enable a cost-effective, accurate solution for smart cities and smart suburbs in the Tasmanian city of Launceston. The *Sensing Value* company is layering datasets including Geoscape to provide scenario modeling capabilities and visual representations of entire land areas. This is being used to, '*model, understand and demonstrate the impact of development decisions, mobility patterns, energy consumption, land use and other strategic and operational insights for urban and regional planning*' (PSMA Australia 2017b).

- GeoVision™: Developed in collaboration with *Pitney Bowes*, this product is a suite of datasets including Geoscape that combines information on the 3D built environment with information such as addresses, postcodes and ABS Census data. (PSMA Australia 2017c). End users include retail, utilities and construction clients seeking to accelerate decision-making and increase efficiency as well as banking, financial services and insurance users. It aids insurers in risk modeling for setting insurance premiums and assists with telecommunications infrastructure planning.

21.2.1.4 2017: Australian Geoscience Data Cube—'Open Data Cube' (ODC)

The Australian Geoscience Open Data Cube—otherwise known as the Open Data Cube, (ODC)—aims to realize the full potential of Earth observation data holdings by addressing the big data challenges of volume, velocity, and variety that otherwise limit its usefulness (Lewis et al. 2016). The result of several years of iterations of partnership between Geoscience Australia (GA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the National Computational Infrastructure (NCI), it is the first case in which an entire continent's geographical and geophysical attributes have been made available to researchers and policy advisors. (NCI Australia 2018). It provides users with access to free and open data management technologies and analysis platforms, with the ability to observe historical changes in land use and patterns over time using the infrastructure shown conceptually in Fig. 21.4.

The foundations and core components of the AGDC are (Lewis et al. 2016):

(1) Data preparation, including geometric and radiometric corrections to Earth observation data to produce standardized surface reflectance measurements that support time-series analysis and collection management systems that track the provenance of each Data Cube product and formalize reprocessing decisions;
(2) The software environment used to manage and interact with the data; and
(3) The supporting high-performance computing environment provided by the Australian National Computational Infrastructure (NCI).

This data cube approach allows for analysts to extract rich new information from Earth observation time series, including through new methods that draw on the full spatial and temporal coverage of the Earth observation archives. As noted in the introduction, due to the size of Australia, the Earth's curvature is important and its tectonic movement is fast enough to require a dynamic cadastre. With an emphasis on a planar geometry, the Data Cube's flat base is actually an illusion that enables a useful platform to engage with the data.

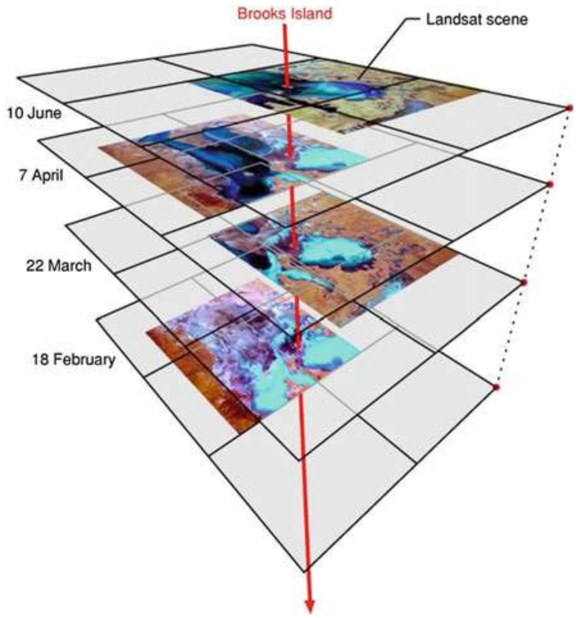

Fig. 21.4 Conceptual illustration of the data cube, showing Landsat scenes reformatted as spatially consistent tiles of data (*Source* Lewis et al. 2016)

To enable easy uptake and facilitate future cooperative development, the code was developed under an open-source Apache License, Version 2.0. This approach enables other organizations including the Committee on Earth Observing Satellites (CEOS) to explore the use of similar data cubes in developing countries. Advances in cloud computing and the availability of free and open technologies such as the Open Data Cube (ODC) mean that developing countries without the local infrastructure to process large volumes of satellite data can access data and computing power to build relevant applications and inform decision making.

21.2.2 State Initiatives

21.2.2.1 2013: The Queensland Globe and G20 Globe

The Queensland Globe was created in 2013 by the Queensland Government's Department of Natural Resources, Mines and Energy and was released by the Department as part of the State's open data initiative aimed at increasing the number of publicly available datasets (https://qldglobe.information.qld.gov.au/). As the first Australian example of combining Google Earth and government spatial data into a standalone application, it used the familiar Google Earth viewer to find and download free reports and information such as cadastral maps and coal seam gas well and water bore reports.

Subsequently, Google announced they were no longer going to support Google Earth Enterprise, and the new Queensland Globe was developed using the Esri JavaScript API 4.x and Esri REST web services application hosted on Amazon Web Services (AWS) Beanstalk. Its web services were published using ArcGIS Server from departmentally hosted servers. The Globe currently includes 652 data layers from almost every Queensland Government department and is now accessed straight from a browser, so users are no longer required to download Google Earth.

An adaptation of the Queensland Globe, the G20 Globe was produced for the G20 Summit held in Brisbane in 2014. Profiling Queensland to world leaders including Barack Obama and Vladimir Putin, the G20 Globe illustrates the global economic ecosystem from the perspective of Queensland. It shows the value of spatial technology for exploring economic activity in our globally interconnected world across six economic sectors, including agriculture, construction, resources, tourism, science and innovation and education and training. As an exemplar, the G20 Globe reveals the opportunities and competitive advantages in agriculture, construction, resources, tourism, science and innovation in Queensland. It demonstrates the value of open data and the capacity to merge it with digital technology so users can follow economic stories that begin with domestic supply chains and are linked to expansive market demands around the world.

At the time of the G20 summit, Queensland University of Technology went a step further than the Queensland Globe and G20 Globe, developing a state-of-the-art interactive digital display called the CUBE (Fig. 21.5) to teach school children geography and science in an innovative way. Consisting of 48 multi-touch screens across two stories, the Cube is open to the public to view and facilitates opportunities for discovery, visualization and contribution to research projects as 'citizen scientists' by experiencing real project scenarios and exploring 21st century challenges (QUT, n.d.).

Fig. 21.5 QUT's CUBE interactive displays, launched in 2014 and used for community engagement

21.2.2.2 2018: NSW Globe and Live Cadastral Platform

In New South Wales, the state government's Spatial Services initiated NSW Globe and a cloud-based 'cadastre as a service' platform to upgrade its maintenance of the NSW cadastre, including an application that lets the public access cadastral data in real time (Bishton 2018). The new API-based system is targeted at the automated backbone of the development application submission process for councils, reducing duplication of data and effort. Previously, plans were accepted in hard copy and manually scanned whereas the new submission process automatically extracts data and metadata from digital plans, and images are converted to validated LandXML. The DCDB remains the system of record, updated via the new API, and the LandXML and GeoTIFF files are stored in the cloud.

The system is part of a digital transformation of the surveying industry, and the benefits of this system include more efficient land subdivision and reduced cost of development to market. The public will also be encouraged to contribute data to the platform, which supports the NSW Government's spatially digital agenda. Other initiatives such as dMarketplace, a sharing place for data, include a rating scheme for data sources (Wallace 2017b).

21.3 Digital Earth Australia

In 2017, the Australian government launched *Digital Earth Australia* (DEA) to implement the open source analysis platform developed as part of the ODC initiative discussed above. The DEA program contributes code, documentation, how-to guides, tutorials, and support to domestic and international users of the Open Data Cube. As a platform, it uses spatial data and images recorded by orbiting satellites to detect physical changes in unprecedented detail.

Drawing on data from as far back as 1987, DEA translates almost three decades of Earth observation satellite imagery into information and insights about the changing Australian landscape and coastline, providing a ground-breaking approach to organizing, analyzing, and storing vast quantities of data (DEA 2017). Using high-performance computing power provided by the National Computational Infrastructure and commercial cloud computing platforms, DEA organizes and prepares satellite data into stacks of consistent, time-stamped observations that can be quickly manipulated and analyzed to provide information about a range of environmental factors such as water availability, crop health and ground cover. By preparing the data in advance, DEA reduces the cost and time involved in working with the vast volumes of Earth observation data. This analysis-ready data (ARD) are made freely available to users and will enable businesses to innovate and develop information products and applications that can be applied to global challenges.

21.3.1 Product Development for Enhanced Access

DEA provides a suite of information products to the Australian government and businesses. Table 21.1 provides a summary of key products and the following paragraphs describe some of them in more detail (report extracts) to illustrate how, by providing easy access to Earth observation data, DEA can help unlock innovation and capability in government, industry, and the research community (DEA 2018). In the future, there are many opportunities to include other data sets that may be in the public or private domains, such as data collected by sensors installed in machines used by farmers.

Severe floods are a feature of the Australian climate and landscape and are likely to continue with increasing regularity and severity. Water Observations from Space (WOfS) helps understand where flooding may have occurred in the past, which allows for mitigation measures to be considered for reducing future impacts, including proper disaster planning and initiatives supporting communities' preparedness and disaster resilience. WOfS is also an invaluable information source for the Australian Flood Risk Information Portal, which enables flood information held by different sources to be accessed from a single online location.

The fractional cover (FC) product can provide insights for land managers regarding which parts of a property show heavier grazing. DEA is working with the Australian Bureau of Statistics to explore whether this product can provide useful information for land accounting and environmental reporting, and with the Clean Energy Regulator to incorporate FC into its monitoring of Emissions Reduction Fund projects and in potential future ground fraction products that may be of use to industry partners such as FarmMap4D (FarmMap4D Spatial Hub 2018).

Changes in the NDVI over time can be used to identify areas where there has been a sudden decrease or increase in the amount of vegetation. Sudden decreases in the NDVI can be caused by a range of processes including tree clearing, cropping, or severe bushfires. Sudden increases in the NDVI can result from vegetation responding to increased water availability, crop growth, or greening of irrigated pasture.

The knowledge provided by products such as those highlighted in Table 21.1, can contribute to a broad range of applications, including environmental monitoring for migratory bird species, habitat mapping in coastal regions, hydrodynamic modeling, and geomorphological studies of features in the intertidal zone. The surface reflectance tool allows for a more accurate comparison of imagery captured at different times, by different sensors, in different seasons, and in different locations. It also indicates where the image contains missing data, is affected by clouds or cloud shadow, or has been affected in other ways.

Table 21.1 An overview of key DEA products developed in Australia, drawing on data gathered since 1987

Product	Description summary	Key References
Surface Reflectance (Landsat and Sentinel 2)	• Starting point for many analyses, translating information recorded by an Earth-observing satellite into a measurement of the characteristics of the surface of the earth	Li et al. (2012); Geoscience Australia (2018e), (2018f)
Fractional Cover (FC)	• Identifies areas of dry or dying vegetation and bare soil, and allows for mapping of the living vegetation extent (e.g., where animals spend time grazing). • Informs a broad range of natural resource management issues	Scarth et al. (2010); Geoscience Australia (2018b)
Water Observations from Space (WOfS)	• The world's first continent-scale map of the presence of surface water. • Provides insight into the behavior of surface water over time. • Highlights where water is normally present, seldom observed, and where inundation has occasionally occurred	Mueller et al. (2016); Geoscience Australia (2018a)
Normalized Difference Vegetation Index (NDVI)	• Assesses the extent of living green vegetation. • Provides valuable insight into the health and/or growth of vegetation over time. • Supports the mapping of different land cover types across Australia	Geoscience Australia (2018c)
Intertidal Extents Model (ITEM)	• Information regarding the extent and relative elevation profile of the exposed intertidal zone (between the highest and lowest tide). • Complements existing data with a more realistic representation and understanding	Sagar et al. (2017); Geoscience Australia (2018d)
High and Low Tide Composites (HLTC)	• Mosaics produced to allow for visualization of the Australian coastline and reefs at high and low tides	Geoscience Australia (2018g)
Dynamic land cover dataset	• Nationally consistent and thematically comprehensive land cover reference for Australia	Geoscience Australia (2018h)

Source References shown in table

21.3.2 Implementing Projects to Enhance Take-up

The DEA platform enables anyone, anywhere, to use the data to inform better decision-making. The platform has the potential to contribute immediate and direct economic benefits to companies, organizations and individuals conducting feasibility studies and assessments, evaluations, monitoring and management activities. A number of high-impact projects have used this platform, and GA aims to increase its use by the wider community, including in regional and remote Australia. The spectrum of Geoscience Australia's current projects is illustrated in Table 21.2, synthesized from the Geoscience Australia Road Map (GA 2018).

21.4 Australian Use Case Examples

In this section, we highlight several use cases spanning agriculture, education and training, and disaster management, including initiatives within the capacity-building work of the ISDE Australia chapter research node. For each use case, we highlight the project objectives, lessons learned and opportunities going forward.

21.4.1 Agricultural Sector—FarmMap4D

The FarmMap4D (formerly known as the NRM Spatial Hub) property management planning platform demonstrates how world-leading time-series remote sensing of ground cover through an online interface can optimize grazing pressure and land conditions, and allow for land managers to make better, more informed decisions. Managers can use the product to view and overlay map layers and generate maps and reports to support more effective land management and planning.

This single source of information is accessed by project managers, contractors, and property managers. The Hub combines the latest geospatial mapping technologies with time-series satellite remote sensing of ground cover in a novel way. For the first time, the sheep and beef industries can use and compare their own data paddock data with government data in a consistent and interactive way, as illustrated in the screenshot of the interface in Fig. 21.6.

Russell-Smith and Sangha (2018) provide an overview of how FarmMap4D can be used to consider emerging opportunities for developing a diversified land sector economy in Australia's northern savannas.

Table 21.2 Current and future DEA projects

Project category	Key current projects	Future projects 'on the horizon'
Land cover & Land use	UN land cover classification system feasibility study Forest cover; Dynamic land cover dataset; Fractional cover; Review of current crop mapping approaches; Irrigated versus Nonirrigated crop extents; Water quality monitoring for sustainable development goals	Water observations from space, Sentinel-2; National intertidal digital elevation model; National wetlands extents map; National land use map integration with DEA; Irrigated versus Non-irrigated crop extents; Broad commodity type crop mapping; NEXIS enhancement; Land degradation Monitoring; NRM requirements analysis; Urban features; Groundwater-dependent ecosystems
Marine & Coastal	National mangrove mapping; Shallow water habitat mapping	Marine turbidity; Ocean color statistical summary; Sea surface temperature statistical summary; Coral bleaching; Coastal change characterization
Change detection	Current projects; Change detection for CER land projects; New approaches to statistical analyses of time series data; Burn extents	–
Analysis-ready data	Sentinel-2 surface reflectance; Landsat ARD Intercomparison and sensitivity analysis; Landsat surface brightness temperature; Surface reflectance validation; Aquatic surface reflectance; Observation density quality assessment; Improving the location accuracy of synthetic aperture radar	Sentinel-1 ARD; Himawari-8 ARD; Sentinel-3 ARD; MODIS ARD; VIIRS ARD; Climate Data; Evapotranspiration
Platform improvement	Automation and orchestration; Cloud storage drivers; Scalability and performance; Documentation; Science algorithm portability	–

(continued)

Table 21.2 (continued)

Project category	Key current projects	Future projects 'on the horizon'
Data visualization & Delivery	NEII viewer extension; Data publication governance; User experience design; ODC web services development; NCI web services development; GSKY services for national map	Virtual products Web processing Data dashboard
Data management	Collection Upgrade and transition analysis; Automation of the landsat processing pipeline; Cloud computing architecture pilot; Regional copernicus data hub development	Collection one upgrade (actual upgrade); DGGS support; DGGS implementation support; Near real-time landsat processing
Government engagement	Department of the environment and energy needs analysis; Tasmanian government transition to DEA	Interdepartmental grad program
Industry & community engagement	Industry and economic value strategy	FarmMap4D need analysis
International engagement	Support for the group on earth observations; Support for the committee on earth observation satellites; Support for regional development projects; Cambodia open data cube; Open data cube community development	–

Source Adapted from Geoscience Australia (2018)

21.4.2 Education Sector—Research Group (ISDE Research Node, Australia)

Griffith University's researchers (in Queensland) are working to connect digital-spatial ('place based') design and decision-making enquiry for resilient and regenerative cities, building capacity to collectively address planning and governance for future resilience in the face of unprecedented pressures (see Smith et al. 2010; Steffen et al. 2011), including climate change, population dynamics and resource scarcity. Building upon research and experience in sustainable development and engineering, the researchers draw on a strong multidisciplinary research capacity and strengths in educational pedagogy, rapid capacity building and education for sustainable development. The group includes educational and behavioral psychology researchers,

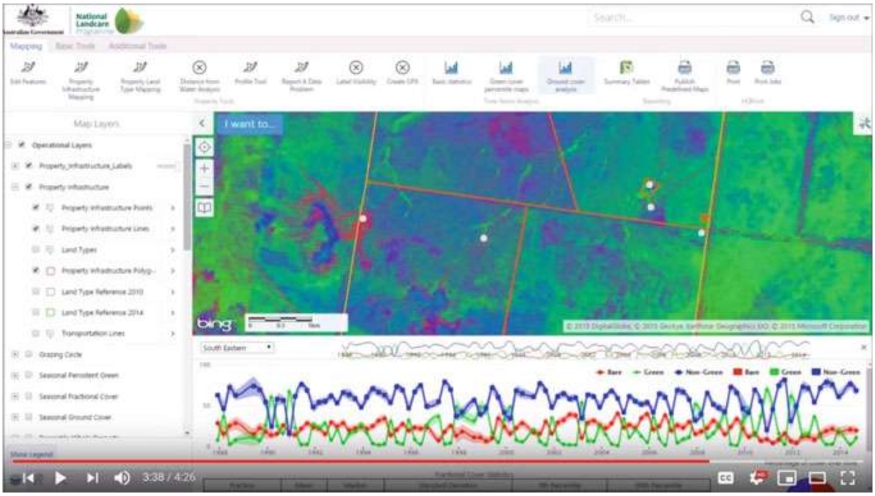

Fig. 21.6 Screenshot of the FarmMap4D interface (*Source* https://www.farmmap4d.com.au/)

industry-facing laboratory technical and management staff, and a growing team of doctoral (PhD) candidates.

21.4.2.1 Capacity-Building System

The Cities Research Institute (CRI) is collaborating with the International Water Centre (IWC) to create an innovative approach to capacity building for Digital Earth products and services, building on the IWC's success with the water modeling community in Queensland. With an aim of effectively disseminating Digital Earth knowledge and the benefits of use to the Australian professional community for business development and growth, the team is developing a 'Digital Earth Capacity System' through which participants can learn about new and emerging capabilities of Digital Earth globally and in Australia, as well as importance, relevance and applications, as illustrated in Fig. 21.7.

Participants engage with Digital Earth experts on trends and opportunities for Australian organizations and 'learn from doing' by working with Digital Earth Australia data to assess problems over time. The courses also include case studies of real examples of Digital Earth tools and applications that helped solve complex problems and enhance sustainability. It ranges from introductory courses to advanced support. Building on the data that has been created, participants develop the capacity to understand and use DEA data for applications including the development of evidence-based policies and developing visual aids for strategic decision-making.

Fig. 21.7 Illustrative photos of capacity-building environments within a community of practice context

The expected benefits for government collaborators include the following:

- Coursework being aligned with priority themes and focused on relevant topics
- Independent courses available to wider professional and public policy audiences
- Direct feedback from participants on the best ways to access and apply the tools
- Effective dissemination of knowledge and upskilling of the workforce to facilitate enhanced use of the available high-quality data.

Potential learning outcomes for participants include the following:

- Live interaction via remote immersive collaboration
- Practice in visualizing, interpreting and communicating big data sets
- The ability to engage in professional development from remote locations
- Remote, always-available access to learning resources about using products.

21.4.2.2 Remote Immersive Collaboration Spaces—DENs

The same group of researchers are prototyping two unprecedented cost effective and interactive "Digital Earth Node (DEN)" rooms, facilitating remote-immersive collaboration where the data itself stays local to the users (utilising image rather than data transfer) while collaboration occurs anywhere. In an increasingly connected world, it is a challenge to create virtual meeting spaces to facilitate deep thinking and decision-making that overcome the need to travel, where people can generate, harvest, interpret and share data as though they were physically side by side.

In response to this challenge and in liaison with colleagues in the International Society of Digital Earth (ISDE), 'Digital Earth Node' (DEN) engagement spaces have been designed to promote productive thinking and timely decision-making. The following paragraphs summarize the 'preto-typing' (i.e., conceptual) and 'prototyping' (i.e., pilot) undertaken to conceptualize, design and build the pilot facilities on two Griffith University campuses in Queensland, Australia, and connect them with other facilities elsewhere (see also Desha et al. 2018). The achievements to date are highlighted with regard to building the potential for immersive thinking environments, as well as next steps for future space development and refinement.

Smart visualization and communication are critical components of any effort to ensure that decision-makers have timely access to complex information and enable holistic problem solving. This has been documented by authors such as Van Wijk (2005) and the ISDE network (Goodchild 2010; Goodchild et al. 2012; Craglia et al. 2012; Roche 2014) and discussed within the geospatial and geo-design communities by seminal speakers including Dangermond (2010), Benyus (2014) and Scott (2017).

Table 21.3 summarizes the key differences that the research team have defined to date in the Digital Earth Node (DEN) rooms and other regularly used interactive video-conferencing tools and facilities. Essentially, the DEN rooms use readily available hardware that is also used for video conferencing, including web cams, audio feeds, touch screens and interactive technologies. However, a breakthrough in software has resulted in the software 'doing' the heavy lifting, resulting in almost no differences in the delay for the end-users and unprecedented flexibility in the extent of potential real-time editing and review.

A schematic of the room layouts is shown in Fig. 21.8. The individual room designs are mirrored as closely as possible to provide the user with an 'extended room' experience.

Table 21.3 Scope distinctions between conventional video conferencing and the DEN rooms

Video conferencing facility	Digital Earth Node (DEN) rooms
Interactive viewers	Immersive layout *with* interactive viewers
Remote connection "feels like you are really *there*"	Sense of proximity "feels like you are really *here*"
Catered to short interactions (usually up to 2 h)	Catered to long interactions (up to many hours)
Heavy hardware + share-screen software	Light hardware + heavy-lifting software

Source Desha et al. (2018)

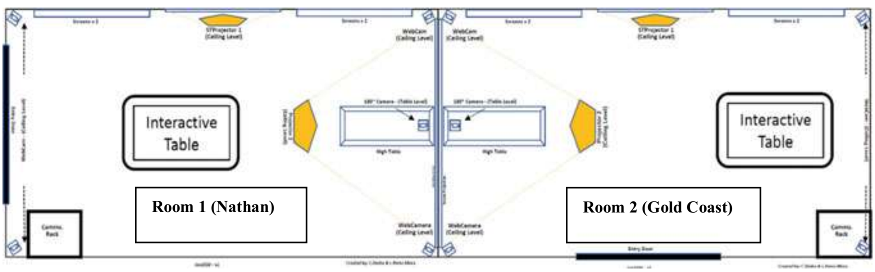

Fig. 21.8 DEN prototype configuration showing 'Room 1 (Nathan)' and 'Room 2 (Gold Coast)' (*Source* Desha et al. 2017)

Looking ahead, society must transition towards multidisciplinary and multinational approaches to address the planet's increasingly complex challenges. This requires a process change in collaboration around the world, without further impacting greenhouse gas emissions from the collaboration (primarily through travel). Considering the *Pivotal Principles* for such problem solving in the 21st century referred to in the Introduction to this chapter, the next logical step is to provide Digital Earth Node (DEN) facilities around the world that create 'remote but realistic' personal experiences between researchers and decision-makers to facilitate deep thinking and problem solving.

Efforts towards this end-goal include using the prototypes to inform the installation of a Disaster and Resilience Management Facility (DRMF) within a new building on Griffith University's Nathan Campus (Brisbane) by connecting the prototype DENs with ISDE chapters internationally and focusing on two primary research agendas to engage with the DEN rooms to explore how this technology and scientific knowledge could be harnessed for human and ecological wellbeing:

- Green infrastructure: Using nature and learning from nature to inform the design of resilient cities through analysis of geospatial data sets.
- Crisis communication in disaster management: using technologies to improve response times to optimize the allocation of resources.

We anticipate that this network of global nodes will connect academics, leaders and decision-makers around the globe in a fast, reliable and immersive manner. Colleagues around the world will be able to engage in pragmatic, real-time and rigorous enquiry into challenges and opportunities facing humanity, with application opportunities spanning sectors including education, research, emergency services, crisis management and global communication. This innovative network will be instrumental in developing spatial capabilities to catalyze human and planetary wellbeing. Such precedents of the possibilities will have immediate implications for deep-thinking engagement internationally and provide remote collaboration opportunities that are engaging and better for the planet.

21.4.3 Disaster Management—NSW Volunteer Rescue Association

With the reality that one minute can mean the difference between life and death, the New South Wales Volunteer Rescue Association (NSW VRA) has been exploring opportunities to make the most of existing 'state of the shelf' and emergent geospatial technologies to improve outcomes with regard to what is anecdotally referred to as, 'the right person and/or the right resources being in the right place, at the right time' (Desha and Perez-Mora 2018). This includes recognition that there may be associated critical infrastructure disruption during disasters that makes rescue more critical, including disabled communication networks, internet, and limited or no access to power. Such circumstances require creative solutions to manage the timely collation and exchange of conventionally ‘heavy’ data files such as video, photos, location-based mapping assistance and real-time or near-real-time management of large databases.

In 2017, the researchers were introduced to VRA personnel through the Griffith University EcoCentre. Inspired by the Digital Earth agenda and the work of researchers including Van Wijk (2005), Craglia et al. (2012), and Goodchild et al. (2012), they visited other researchers in Japan (Chubu University) and Europe (Joint Research Centre) to experience precedents and discuss possibilities for improving communication in disaster response.

Seeking a solution to these challenges, the researchers and their Digital Earth Node technical team have been working on developing software solutions to improve the way hardware is used and leased, including engaging researchers in different areas to generate better ways to use hardware in the form of a more efficient communication tool. In collaboration with the NSW VRA, data from a number of different sources have been collated and analyzed, including the organization’s database and historical anecdotal and solicited feedback from members of the volunteer community of professional volunteers and highly trained emergency management personnel. These data were used to ground-truth potential software solutions, allowing for the team to test solutions for improving the way personnel communicate in remote areas, how personnel deploy information and how personnel manage others in times of need.

Following software development, the first stage of deployment occurred in July 2018 when the team developed a software solution to improve the communication between executive managers and key decision-making personnel and their squads and squad members. This software now allows for the NSW VRA to collect data while in the field during a call out.

The data arising from deployment will be analyzed and processed to establish the next stage of this complex project, the deployment of a DEN (Digital Earth Node) remote immersive collaboration facility in regional NSW (Dubbo). This immersive tool will allow for decision making personnel to locate units or key personal in the field while they are being deployed during challenging times such as floods and bushfires. This will provide better ways to analyze what is happening in the field and aid in deployment of resources to the right locations at the right time. The system will also be able to track activities in real-time and with accuracy to ensure the safety of these professional volunteers.

The data will also be analyzed in an event block to enable a comprehensive report at the end of each incident response. Drawing on the analysis of the data collected by the DEN and devices in the field, the NSW VRA will be able to generate precise reports based on the human behaviors and decisions made. The findings will also allow for the Association to understand how they should improve the way they train their decision-making personnel and prevent mistakes during future events.

The research team is connecting with colleagues in international chapters of the International Society of Digital Earth (ISDE) to ensure that best practices are shared around the planet with other emergency management response teams. Thus, professional international expertise to fix unsolved or permanent challenges will reach remote areas of Australia. Ultimately, everyone, everywhere should have access to a fully comprehensive system that allows for our 'local heroes' to save more lives and provides them with the best safety approach during their high-risk activities.

21.5 Conclusions

This chapter highlighted achievements and opportunities for Australia considering three decades of data capture and enquiry, from local and largely champion-based ad hoc initiatives to mainstreamed integration and take-up globally. This included an historical exploration of practices and experiences in Australia arising from the need to manage local resources better, addressing the complexities of environmental stewardship. With regard to data management and interfaces for meaningful end-user engagement and enquiry, a number of initiatives stand out as exemplar projects for potential adoption elsewhere.

Australian current and future priorities were summarized through a text analysis of the Geoscience Australia roadmap, and two examples from the Australian ISDE chapter highlight the imperative of enhancing end-user take up of the Digital Earth technology through strategic capacity-building initiatives. The authors discussed the mechanisms and challenges of harnessing interoperable information in the form of geospatial data and through systems and processes to add value to the information. Considering these experiences, the benefits of open data and data sharing are realized through careful planning, design and integration, with a focus on upfront iterative design and end-user engagement. Releasing high-value data is an iterative process that requires collaboration and communication with agencies to show the benefits of open data and to support useful data sharing.

Reflecting on the history and examples provided, several 'turnkey' capability (workforce and market) considerations are summarized here for Australia's future and for non-Australians considering their own Digital Earth:

(1) ***Challenges in creating an active context for data use***: Decision-makers and researchers are currently grappling with how to harness the common repository to create saleable products (apps and APIs), where analytics is a well-established and supported opportunity for industry, beyond delivering funding for such initiatives via government grants (i.e., teaching the people how to fish).
(2) ***Challenges in capacity building beyond 'show-and-tell'***: In a rapidly emergent industry, it is critical to create the demand for products and services as well as build the capacity to deliver these goods and services. Trust is paramount in this process and must be prioritized when governments test and pilot products and services. There is a need for industry buy-in and for industry investors. In Australia, there is currently no public-private-partner (PPP) model in data adoption beyond advocating for industry to 'look how good the tool is.'
(3) ***Challenges in defining the job market and demand for the market***: In a country where the number of geospatial professionals is insufficient, capacity building is critical and must be addressed urgently (FrontierSI 2018). This includes public

and private sector considerations with regard to the types of skills required and the need for a capacity-building framework to aid in data utilization. We need to find demand for the market, potentially through the development of an active 'Community of Practice' across different key sectors, to enable more serious business workflow integration around technology, for example, for farm and water management.

In addition, several considerations relating to efforts and investments made on data and technologies are summarized:

(1) **Considering open source versus business continuity**: The initial version of the Queensland Globe was created using a Google open source platform, then could no longer be supported by Google. It took time for the Queensland government to find a reliable partner and Esri (proprietary software) was chosen to support the continuity of the project. In hindsight, a hybrid approach could take advantage of open source and proprietary platforms.

2) **Sharing knowledge within the context of an open source platform**: Despite progress, most end-users—whether government, business or citizens—do not have the knowledge and/or skills to find, download and use open data directly. This Digital Earth platform relies on a number of technologies and, although the code developed is open source, there is no community of practice to enable or coordinate technical expertise. Hence, coordination and capacity building are needed to help practitioners access and work with the data.

3) **Measuring the success of Digital Earth products**: This chapter provided numerous examples of products and the utilization of such products must be evaluated beyond the initial excitement and celebration of their existence. Ways to measure utilization are being explored, including conducting economic benefit analyses. Such metadata about utility is important to demonstrate value and ensure continued maintenance and updating of the Digital Earth Platform to meet the future needs of the community.

4) **Enabling access and utility remotely**: In a globally connected world, remote immersive collaboration has the potential to create communities of practice with reduced cost of travel and greenhouse gas emissions, in addition to ensuring data security in discussions and collaboration. This is particularly important when governments internationally are interested in using Australia's Digital Earth platforms to communicate decisions, upgrade infrastructure, and oversee the safety and wellbeing of citizens.

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Chapter 22
Digital Earth in China

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Abstract In the promotion of economic digitalization as an important force driving the realization of development through innovation, countries around the world have made forward-looking arrangements in frontier technology research and development, open data for sharing, privacy security protection, and personnel training. China also attaches great importance to the development of Digital Earth technologies and applications. In this chapter, we introduce the development of Digital Earth in China in recent years and provide readers a broad overview of Digital Earth technologies and applications in China.

Keywords Digital Earth in China · Big data · New generation information network · Internet + · Cloud computer · 5 Generation

22.1 Introduction

Research on technologies related to Digital Earth has been the focus of attention in fields such as science and technology, the economy and society. Many countries have raised Digital Earth and big data research to the national strategic level. In the promotion of economic digitalization as an important force driving the realization of development through innovation, countries around the world have made forward-looking arrangements in frontier technology research and development, open data

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for sharing, privacy security protection, personnel training and other areas. China also attaches great importance to the development of Digital Earth. In 1999, the first Digital Earth Symposium was held in Beijing, which began Digital Earth research all over China. In 2006, the Chinese National Committee of the International Society for Digital Earth (CNISDE) was established. As the national member of the ISDE, the CNISDE promotes the ISDE's ideals for national acceptance. Since 2006, Digital Earth has experienced high-speed development in China. Focusing on the development of Digital Earth in China caters to and promotes information technology development and acts as an endogenous driving force to promote economic transformation and upgrading as well as sustainable development.

22.2 China's Digital Earth Strategy and Policy

In recent years, the Chinese government has attached great importance to information technology development, especially for Digital Earth technologies. It has strengthened the top-level design and overall layout and made a strategic decision on building Digital Earth in China. Digital Earth is a new strategy for information technology development in the new era, a new measure to meet the people's growing demands for a better life, and a new driving force leading high-quality economic development. Digital Earth in China covers information technology construction in various fields such as the economy, politics, culture, society and ecology. In his congratulatory letter to the first Digital China Summit held in April 2018, President Xi Jinping noted that the information technology innovation in today's world is changing with each passing day, and in-depth development of digitalization, networking and intelligence plays an increasingly important role in promoting economic and social development, modernizing the state's governance systems and capabilities, and meeting the people's growing demands for a better life.

As Digital Earth development in China enters a peak period, the digital economy will also naturally add momentum to China's economic development. To speed up the development of Digital Earth in China, China will continue to improve the policy environment by formulating and introducing a series of policy documents on the development of Digital Earth in China. Information technology has become a major force for the government to serve the people and adds new momentum for economic development. The development of Digital Earth in China has brought changes to people's daily lives and the production of enterprises.

22.2.1 National Macro Strategic Plans for Digital Earth in China

In recent years, relevant departments in China have successively issued major strategic plans for national information technology development to indicate a road map and timetable for the development of Digital Earth in China and clarify that the general goal of Digital Earth development in the new era is to adhere to and achieve the synchronous promotion of the "Two hundred-years Goals" to fully support the development of the causes of the country, to promote balanced, tolerant and sustainable economic and social development and to provide solid support for the modernization of the national governance systems and capacities. The development plans note that China must adhere to people-centered development thinking and take the improvement of the people's well-being as the starting point and foothold for the development of Digital Earth in China, to better benefit the people. The three strategic tasks of Digital Earth in China are to greatly enhance the ability of information technology development, focus on improving the level of information technology development in economic and social fields and continuously optimize the environment for information technology development.

(1) ***"Broadband China" Strategy***. On August 17, 2013, the government of China issued the "Broadband China" strategy implementation plan and deployed the broadband development goals and paths for the next 8 years, meaning that the "Broadband Strategy" went from a departmental action to a national strategy, and broadband became the national strategic public infrastructure for the first time. By 2020, China aims to finish the construction of a high-speed and smooth broadband network infrastructure with advanced technology to cover urban and rural areas and offer convenient services.

(2) ***Outline of the National Information Technology Development Strategy***. The outline is a regulation formulated to promote modernization through information technology development and to build network power. The outline stipulates that, by 2020, the core key technologies will reach the international advanced level, the international competitiveness of the information industry will be greatly improved, the digitalization, networking and intelligence will make significant progress in key industries, the networked collaborative innovation system will be fully formed, e-government affairs will firmly support the modernization of national governance systems and capacities, and information technology development will become a leading force driving the modernization construction (The State Council 2016). The internet bandwidth for international export will reach 20 Tbps to support the implementation of the "Belt and Road" initiative and achieve network and information connection with neighboring countries. The China-ASEAN Information Port will be built and the online Silk Road will be established to significantly improve the international competitiveness of information and communication technologies and products and internet services.

(3) ***"Thirteenth Five-Year" National Information Technology Development Plan***. Aiming to implement the Outline of the Thirteenth Five-Year Plan and the

Outline of the National Information Technology Development Strategy, the plan is an important part of the “Thirteenth Five-year” national planning system and an action guide for information development work in various regions and departments during the “Thirteenth Five-year.” It was issued and implemented by the government of China on December 15, 2016. The plan noted that by 2020, “Digital Earth” development will achieve remarkable results, the level of information technology development will rise sharply, the information capability will rank among the top in the world, and the information industry ecosystem with international competitiveness and security under control will be in place. Information technology and economic and social development will be deeply integrated, the digital gap will be significantly narrowed and the digital dividend will be fully released. Information technology development will fully support the causes of the government and the country, promote balanced, tolerant and sustainable economic and social development and provide solid support for the modernization of the national governance systems and capacities (Gov.cn 2016).

(4) ***Big Data Strategy***. Data are basic national strategic resources. China attaches great importance to the role of big data in economic and social development. The government proposed the “implementation of the national big data strategy” and the issued the Outline for Actions Promoting Big Data Development to fully promote big data development and accelerate data development to strengthen the state. The Big Data Industry Development Plan (2016–2020) was also formulated, proposing that the income from big data-related products and services will exceed RMB 1 trillion by 2020, with an average annual compound growth rate of approximately 30%; 10 internationally leading core enterprises in the industry of big data will be cultivated; 10–15 comprehensive big data pilot areas will be built; and 1–2 open source communities with standardized operation and an international influence will be established.

(5) ***Network Power Strategy***. The network power strategy includes three aspects, namely, network infrastructure construction, new development of the information and communication industry and network information security (Chen 2016). The proposal for the “Thirteenth Five-Year” Plan approved by the government proposed implementation of the network power strategy and the closely related “internet +” action plan. Accelerating the network power strategy has a direct effect in improving China’s international competitiveness and contributes to the economic and technological development and transformation of China.

22.2.2 Policies and Plans for Development of Digital Earth in China

(1) ***White Paper on China’s Digital Economy Development (2017)***. On July 13, 2017, the China Academy of Information and Communications Technology released the White Paper on China’s Digital Economy Development (2017) at the 16th China

Internet Conference. The white paper noted that, in the next few years, China will deploy 5G, next-generation internet, the Internet of Things (IoT), industrial internet and other technologies on a large scale. With the construction of various network infrastructures and the application of related technologies, development of Digital Earth in China will enter a peak period. It will lay the foundation for development of the digital economy, industrial transformation and upgrading, and the integrated development of various industries in China (China Academy of Information and Communications Technology 2017).

(2) ***Action Plan for Promoting Large-Scale Deployment of Internet Protocol Version 6 (IPv6)***. On November 26, 2017, the government issued the Action Plan for Promoting Large-scale Deployment of Internet Protocol Version 6 (IPv6), proposing that in the next five to ten years, China will form a next-generation internet independent technology system and an industrial ecology, build the world's largest IPv6 commercial application network, realize deep integration and application of next-generation internet in various economic and social fields, and become an important leading force in development of the world's next-generation internet.

(3) ***"Internet +" Action Plan***. The development of the plan was led by the National Development and Reform Commission and the Ministry of Industry and Information Technology. China introduced and is still developing a series of policies for promoting innovative development of information technology and e-commerce. In the government work report on the two sessions in 2015, Premier Li Keqiang proposed the requirement of "developing an internet + action plan" to promote the integration of mobile internet, cloud computing, big data, and the Internet of Things with modern manufacturing and the sound development of e-commerce, industrial internet and internet finance as well as to guide internet companies to expand the international market (Ning 2015). Representing a new economic form, "internet +" supports industrial intelligence, enhances the momentum of new economic development and promotes improvements in quality and efficiency and the upgrading of the national economy.

(4) ***Three-Year Action Plan for Cloud Computing Development (2017–2019)***. In April 2017, the Ministry of Industry and Information Technology developed and issued the Three-Year Action Plan for Cloud Computing Development (2017–2019). The targets of the plan are for China's cloud computing industry to reach a worth of RMB 430 billion, make breakthroughs in a number of core technologies, achieve cloud computing service capability at an international advanced level and significantly drive the development of the new-generation information industry. The international influence of cloud computing enterprises will be significantly improved and two or three leading enterprises with a large share in the global cloud computing market will emerge. The capability of guaranteeing cloud computing network security will be significantly improved, and the network security supervision systems and laws and regulation systems will be gradually improved (The Ministry of Industry and Information Technology 2017).

(5) ***"Thirteenth Five-Year" Special Plan for Scientific and Technological Innovation in the Information Sector***. The special plan formulated the implementation plan for "Scientific and Technological Innovation 2030—Major Projects" and started

the implementation of major new-generation artificial intelligence projects (Gov.cn 2017). It steadily promoted major projects such as the space-terrestrial integrated information network and big data and launched the IoT and smart city initiatives, broadband communications, new types of networks and other key projects (The State Council 2015). China will accelerate the implementation of the Outline for Promoting National Integrated Circuit Industry Development and advance system innovation in the information industry. The core technology innovation in the information field will illustrate the new situation of catching up with the leaders at a faster speed, more shoulder-to-shoulder development and new leaders emerging.

22.3 Infrastructure for Digital Earth in China

The development of Digital Earth in China is inseparable from the support of network and information technology. The development of the entire infrastructure and related digital technologies is of great significance to the development of Digital Earth in China.

Currently, relevant new technologies, such as 5G, IPV6, cloud computing, big data and artificial intelligence, are continuously being applied in the infrastructure of Digital Earth in China. Related technologies including artificial intelligence, cloud computing, big data, and blockchain are also developing rapidly. China has introduced many new related policies, and many industrial alliances have been formed to add new impetus to Digital Earth in China. The infrastructure construction manifested as follows:

(1) ***Deployment of New-Generation Information Network Technology***. 5G network technology has made important breakthroughs in R&D, testing and verification (Fig. 22.1). In the implementation of the national major science and technology project "new-generation broadband wireless mobile communication network," the design and R&D of a 3Gsps 12-bit ADC/DAC, PA, a wide-area hot-spot baseband chip and a low-delay baseband chip was completed, and the R&D of key technologies such as the 5G core network and ultradense networking based on SDN/NFV is being advanced. 5G R&D and testing work is advancing rapidly; the first batch of specifications for the third phase of testing has been released and the development of the global unified 5G standard is being promoted. The bearing and capacities of the radio and television networks have been improved. The two-way access strategy for radio and television and telecommunications services is being promoted throughout the country. The second stage of an experimental pilot of the cable, wireless and satellite integration network for radio and television is being advanced at a faster speed, and the experimental technology solution and establishment of three standards for the integration network in 11 provinces have been approved. The number of China's IPTV users has reached 122 million. IPv6 is evolving comprehensively and being upgraded at a faster speed. The implementation of the Action Plan for Promoting

Fig. 22.1 5G network framework (from http://www.freep.cn/zhuangxiu_6/News_1937545.html)

Large-scale Deployment of Internet Protocol Version 6 (IPv6) accelerated the construction of next-generation internet with high speed, wide popularity, full coverage and intelligence.

(2) ***Innovative Construction of Cloud Computing Infrastructure***. The implementation of Opinions on Promoting Innovative Development of Cloud Computing and Cultivating a New Format of the Information Industry and the Three-Year Action Plan for Cloud Computing Development (2017–2019) in China has promoted the popularization of cloud computing applications, optimized the layout of cloud computing data centers, enhanced the usage rate and intensification level, and formed an industrial system with international competitiveness. Breakthroughs have been made in key technologies such as large-scale concurrent processing, massive data storage, and data center energy conservation. Cloud computing platforms with international competitiveness have emerged, such as Alicloud's Apsara platform, Baidu Brain and the WeChat open technology platform. In 2016, the proportion of large and ultralarge data centers increased to 25% from less than 8% in 2010. There are 295 enterprises with large data centers and cross-regional internet data services. The Internet of Things has been deeply integrated, and the pace of generic application has been sped up. The R&D and deployment of NB-IoT are being sped up, and China Telecom has built the world's first commercial NB-IoT network with the widest coverage and synchronous upgrading of the entire network of 310,000 base stations. The NB-IoT technology solution proposed by Huawei has been approved by 3GPP and become an international standard. The NB-IoT is being expanded to public facilities management, production and life at a faster speed to accelerate the intelligent transformation of power grids, railways, highways and other infrastructure.

(3) ***Localization of the GIS Platform***. During the development of Digital Earth in China, geographic information systems (GIS) have played a very important role in promoting Digital Earth in China. After 30 years of hard work, China's GIS

technology has made remarkable achievements. In the early stage of Digital Earth development, it was mainly based on two-dimensional visualization applications and lacked three-dimensional analysis capabilities. In response to the demand of Digital Earth in China, China has proposed and developed GIS technology that integrates two and three dimensions to gradually form the GIS software covering data models, scene modeling, spatial analysis and two- and three-dimensional software forms. With the development of data acquisition technology, Digital Earth in China has integrated traditional 3D modeling, oblique photography, laser-point clouds, BIM and other three-dimensional technologies based on two- and three-dimension integration technology to develop the new-generation three-dimensional GIS technology, which has realized three-dimensional modeling of multisource heterogeneous data, object-level 3D spatial analysis and visualization of nonvisual information, extending the research scope of Digital Earth in China from the Earth's surface to the entire space. Three-dimensional spatial data specifications have been formed to solve the sharing and interoperability problems inherent in such heterogeneous data in applications to bring real and convenient 3D experience to digital applications. Cloud GIS technology and cloud computing have greatly improved the data resources and computing resource capabilities of Digital Earth in China and expanded its range of applications. Cloud GIS technology has realized the interconnection and intercommunication of information and functions between cloud GIS (servers) and various terminal GIS (desktop GIS, mobile GIS, WebGIS), making applications and services ubiquitous. A client (such as WebGL) that is as thin as possible can also be used advantageously in cloud computing to reduce the client installation and maintenance costs in digital applications. As a result, the network-based intergovernmental and interdepartmental collaborative development of the "Digital Belt and Road" will be promoted.

As the "GIS core" for software platform construction in Digital Earth infrastructure, China's GIS basic software represented by SuperMap GIS has played a unique role. Through multisource heterogeneous data integration, it integrates, shares, analyzes, manages and mines data, and ultimately serves global change research, disaster reduction and prevention, new energy development, new urbanization, and agricultural food safety to aid in the development of Digital Earth in China.

(4) ***The Big Data Platform***. Big data has begun to significantly influence global production, circulation, distribution, and consumption patterns. It is changing humankind's production methods, lifestyles, mechanisms of economic operation, and country governance models. Big data occupies strategic high ground in the era of knowledge-driven economies, and it is a new strategic resource for all nations (Guo 2017).

In an initiative led by Guo Huadong, president of the Committee on Data for Science and Technology (CODATA) of the International Council for Science (ICSU), CODATA has worked with other international science organizations and initiatives to explore the value of big data in scientific research and to reinforce the crucial role of science in the development of big data. After the June 2014 "International Workshop on Big Data for International Scientific Programmes: Challenges and Opportunities" sponsored by CODATA in Beijing and cosponsored by the ICSU World Data System, Future Earth, Integrated Research on Disaster Risk, the Research Data Alliance, the Group on Earth Observations, the International Society for Digital Earth, and the Chinese Academy of Sciences Institute of Remote Sensing and Digital Earth, CODATA and others developed a joint statement of recommendations and actions [6]. This statement emphasized providing a better understanding of big data for scientific research, and strengthening international science for the benefit of society by developing research, policies, and frameworks related to big data. Since then, a series of meetings on big data for science has been organized or coorganized by Guo's research team. These have included the "Xiangshan Science Conference on Frontiers of Scientific Big Data," "The Academic Divisions of the Chinese Academy of Sciences Forum on Frontiers of Science and Technology for Big Earth Data from Space," and the "Exploratory Round Table Conference on Big Data in Natural Sciences, Humanities and Social Sciences." It is our opinion that scientific big data will play a key role in promoting scientific development (Guo 2017).

22.4 China's Experience in the Development of Digital Provinces and Cities

Digital cities refer to the use of spatial information to build a virtual platform that acquires and loads information such as that on natural resources, social resources, infrastructure, culture, and economics of provincial units or city units in the digital form to provide a wide range of services for governmental and social users to improve city management efficiency, save resources and promote the sustainable development of cities.

22.4.1 Digital Fujian

In 2000, when President Xi Jinping was in the position of governor of Fujian Province, China, he initiated the "Digital Fujian" project. He clarified the development connotation and development mode of "Digital Fujian" and proposed the development goal of being "digital, networked, visualized and intelligent." In 2001, the "Digital Fujian" Plan was launched, including one plan ("Digital Fujian" Tenth Five-Year Plan), three projects (Fujian Public Information Platform, Fujian Government Information Network Project and Spatial Information Research Center of Fujian) and one policy (Fujian information sharing policy). Fujian began to build three basic supportive platforms: a unified government affairs network, an information exchange system and an information security system to realize facilities sharing, platform sharing and data sharing, which established the overall framework of "Digital Fujian." Over the past 18 years, "Digital Fujian" has drawn up four five-year special plans using the top-level design as the guiding ideology for the overall coordination and planning of the information technology development of the whole province, to ensure that the construction of "Digital Fujian" moves forward in a phased, focused and orderly manner.

With the top-level design plan and long-term plans as guides, Fujian Province has advanced the construction of "Digital Fujian" in an orderly manner through the development goals, frameworks, mechanisms and development ideas that were determined in the initial years. The construction of "Digital Fujian" is close to people's livelihood, enterprises and society. The e-government practice of "Digital Fujian" comprises the joint development and sharing of data in all government systems, acceleration of the digital upgrading of tourism, transportation, taxation, medical treatment, education systems and other areas of people's livelihood, and reducing the "multiple leadership" in e-government. The new ideology makes "Digital Fujian" a new model that benefits the people. By 2020, the digital economy of Fujian will exceed RMB 400 billion with an annual growth rate of over 20% and a proportion of over 45% of the GDP, forming a development pattern with advanced digital infrastructure, efficient e-government collaboration, integrated and innovative digital economy and a secure, independent and controllable network and information, realizing the goal of being "digital, networking and intelligent." Fujian will actively promote the establishment of the Digital Earth Core Technology Industry Alliance, add to "Belt and Road" digital economy development funds and Digital Earth development funds, speed up the construction of a number of new smart city platform projects, strengthen organizational leadership, and optimize the development environment.

22.4.2 Digital Hong Kong and Digital Macao

The construction of Digital Earth has penetrated China's economy, society, and people's lives and has resulted in remarkable achievements in improving government management, promoting industrial development and serving people, especially the construction of Digital Hong Kong and Macao.

(1) ***Development History***: The government has been the main promoter of digital city construction and actively supports the digital development of cities. Since 1990, the Hong Kong government has spent 6 years establishing the first large land information system using geographic information systems (GIS) technology in Hong Kong and successfully applied it to land usage, cadastral maps and town plans. In 2009, the Hong Kong Transport Department launched a transport information system based on a central database, which provides four major services: a road traffic information service, Hong Kong eRouting, Hong Kong eTransport and an intelligent road network. In addition, the Hong Kong Lands Department is actively expanding smart city infrastructure and environmental detection applications based on mobile measuring vehicles.

In 2000, the government of the Macao Special Administrative Region (SAR) officially launched an environment geographic information system, which was jointly developed by the Cartography and Cadastre Bureau and Macao Environmental Protection Bureau (DSPA). The system draws a mathematical model to study the environmental conditions and perform evaluations through the comprehensive collection and analysis of existing and new environmental data in Macao, providing services for the urban environment quality evaluation, natural resources analysis, city planning, emergency warning systems and disaster assessment. In addition, to facilitate citizens' access to information on historical urban areas and cultural property reserves, the Macao Cartography and Cadastre Bureau launched the local Cadastral Information Network to include historical heritage and cultural conservation information, contributing to the protection of Macao's historical, cultural and architectural property.

(2) ***Preliminary Results***: At present, the construction of Digital Hong Kong and Macao has resulted in many achievements, covering disaster monitoring, urban construction, residents' lives, government management and other aspects.

On August 4, 2017, the Macao SAR signed the Framework Agreement on Strategic Cooperation in the Construction of a Smart City with the Alibaba Group. The government of Macao SAR will make full use of Alibaba's relevant leading technological capabilities, such as cloud computing and the application of big data, to promote the pace of the construction of a smart Macao, to widen the context of the SAR data, improve the modes of economic and social operation, and promote the development of the smart city. In the long term, Macao will be developed into a smart city that is "leading technology by digital development and serving people's livelihood with intelligence."

The construction of Digital Hong Kong and Macao show a good trend of "connecting every place and everything, handling everything on internet, and innovating every business." With the advances in technologies including cloud computing, big data, and the IoT, the deepening cooperation between the government and high-tech companies, the integrated development of different smart platforms, and the continuous improvement of the strategic guarantee system for integrated ground and air information technology, Digital Hong Kong and Macao will develop further and play a more important role in promoting urban economic development and improving the quality of life of urban residents.

22.5 Development of Digital Earth Applications in China

The wide application of Digital Earth technology has resulted in significant and far-reaching impacts on various economic and social areas in China. With the development of LiDAR, microwave and multispectral remote sensing technologies, great progress has been made in Digital Earth applications in China. The applications can be summarized in three aspects.

22.5.1 Digitalization: Drawing and Depicting China

To "Draw and Depict China with Digital Earth Technology" means to use digital technology to summarize and present the phenomena and laws that exist but are difficult to find using traditional administrative and technical means. Regardless of whether digital technology is used or not, these phenomena or laws exist objectively, but it is difficult to find or describe them without digital technology.

(1) ***Big Earth Data for Digital Earth***. "Big Earth data" is a fundamental aspect for Digital Earth. Big Earth data, including the huge datasets derived from satellite observations, ground sensor networks, and other sources, are characterized as being massive, multisource, heterogeneous, multitemporal, multiscale, high-dimensional, highly complex, nonstationary and unstructured. It provides support for data-intensive research in the Earth sciences (Guo 2017).

As an example, global change research demands the systematization of the Earth and comprehensive observations and has led to the rapid development of ground observation technology. Modern Earth science requires globally established, quasi-real time, all-weather Earth data acquisition capabilities and has developed an integrated space-air-ground observation system with high spatial, temporal, and spectral resolutions. Global change research focuses on global sustainable development and deals with key multidisciplinary challenges, including global change process monitoring, simulation analysis, and response strategies. These studies rely on big Earth data such as long-term, multispatiotemporal Earth observation data, accurate, continuous ground station observation data, and experimental data based on theoretical speculation and estimations. Therefore, big Earth data can provide a new approach to the development of global change research. As a tool in cross-disciplinary research, big Earth data has the potential to provide a virtual Earth that can be used in the Earth sciences and has close relations to information science, space science, technology, the humanities, and the social sciences. Generally, big Earth data include the main features of big data.

(2) ***Digital Agriculture***. "Digital agriculture" refers to intensive and information-based agricultural technologies supported by geoscience space and information technology. As an important symbol of agriculture in the 21st century, the development of "digital agriculture" and related technologies is an inevitable choice to support the development of modern agriculture in China.

One of the outstanding manifestations of the applications of information technology is the application of the Digital Earth platform in the field of digital agriculture, in breeding, crop growth, farmland management, and agricultural information (Meng et al. 2011). With the rapid development of Earth observation technology, research on and application of "digital agriculture" has been gradually deepened, providing more diversified information for digital agriculture and promoting the comprehensive development of agricultural information technology (Li 1992). In China, Digital Earth technology is widely applied in the acquisition of farmland plot information, agricultural measures, farmland environments and other information and has been successfully applied to monitor crop growth, soil moisture, crop water stress, crop nutrients, and crop disasters and in the estimation of the per unit yield of crops and agricultural irrigation guidance. Digital agriculture plays an important role in Chinese food security (Wu 2004).

22.5.2 Digitalization to Make China Different

"Digitalization to make China different" refers to a series of changes in the way that society operates and how people live through the extensive use of digital technology. "Digital Earth in China" has gradually led to revolutionary changes in people's daily behaviors and communication methods, allowing for people to enjoy the digital dividend.

(1) ***Disaster Monitoring and Prevention***. Digital disaster reduction technology has integrated the advantages of remote sensing, GIS, navigation systems, mobile terminals, and the internet and other technologies to comprehensively acquire and analyze disaster information. Compared with the traditional observation methods, the rapid, accurate and macro acquisition of information by digital disaster reduction technology using Earth observation technology, which is its core constituent technology, has played an irreplaceable role due to its all-weather, all-day, multiangle and highly efficient performance.

At present, digital disaster reduction research has abundant aerospace observation data sources, but there is an urgent need to develop the ability to quickly identify knowledge and obtain effective disaster information from massive data. With the advent of the era of big data, cutting-edge disaster reduction technology supported by big Earth data has brought new opportunities for the development of China's research on digital disaster reduction. It is expected to make breakthroughs in the bottleneck problem of open data for sharing. By integrating remote sensing satellite data, aviation monitoring data, navigation positioning data, ground survey data and social statistics data, integrated analysis of interdisciplinary and multitype disaster reduction data can be accomplished through the big Earth data platform to reduce the time cost of carrying out collaborative analyses of disasters based on multisource data and improve the ability to rapidly mine disaster information.

(2) ***Monitoring and Protection of Natural and Cultural Heritage***. Digital heritage refers to the applications of digital technology with spatial information technology as the core in the fields of cognition, protection and utilization of cultural and natural heritage. The applications of remote sensing, GIS, modern measurement technology and VR technology in the fields of heritage discovery, protection, display and utilization are the key endeavors. Entering the 21st century, digital heritage has entered a fast lane. Relevant national projects are being carried out one after another, such as the national project on exploring the origin of Chinese civilization and monitoring of the Chinese Grand Canal and Great Wall. In 2016, Guo Huadong established a "Protection and Development of Natural and Cultural Heritage Along the Belt and Road" project in the Digital Belt and Road (DBAR) research initiative. In 2017, a research team led by Bi Jiantao went deep into the Angkor Wat and Preah

Vihear temples in Cambodia to implement the monitoring and protection of natural and cultural heritage and realized the acquisition and modeling of centimeter-level 3D architectural cultural heritage data in a country along the Belt and Road for the first time. In 2018, a research team led by Wang Xinyuan found 10 archaeological sites of ancient Rome in Tunisia. The continuous implementation of these projects marks the beginning of a new development stage of digital heritage research.

(3) ***Applications in the Digital Mountain Field***. As a scientific subset and application example of Digital Earth, digital mountain research is the unification of spatial information methods and tools for mountain science research and integrated mountain management. It provides reliable basic data, analyzes solutions and simulates lab environments for mountain research through the integration of data, models, and analytical methods. Recently, a new phase of progress has begun in fields such as mountain cover mapping, digital terrain analysis and digital watershed construction. The development of the digital mountain observation and experiment platform needs to comprehensively consider the terrain gradient, vegetation gradient and multiscale nested observation methods to build a ground-air-space three-dimensional observation system with the help of UAV remote sensing platforms, to obtain multisource and multiscale surface observation data sets to support breakthroughs in mountain remote sensing theory and application research on digital mountain science.

(4) ***Research and Education***. Since the beginning of this century, China has established institutes, national and provincial key laboratories, and companies relevant to Digital Earth and Digital China. These include the Institute of Digital China, Peking University (IDC-PKU), founded in 2004, and the Beijing Key Laboratory of Environmental Remote Sensing and Digital City, founded in 2002. China has also hosted symposiums, summits, and workshops to discuss topics relevant to Digital Earth and Digital China, such as the Digital China Forum organized by PKU held annually from 2004 to 2018.

China has developed Digital Earth-related education activities for undergraduate students, graduate students and teenagers. Universities offer courses covering Digital Earth and Digital Cities, such as 'Introduction of Digital Earth' at Peking University (PKU) and 'GIS and Digital Earth' at Zhejiang University. Institutions and universities also offer large public science popularization activities for Digital Earth. For example, the Institute of Remote Sensing and Digital Earth (RADI) has 'Poster Walls' to show the development of Digital Earth technologies in China; the China Association for Science and Technology (CAST) and PKU host the annual 'BeiDou Cup' Youth Science Creation Competition to award achievements in the 'BeiDou Navigation Satellite System (BDS) and Digital China' field. Textbooks about Digital Earth have been published by professors from universities since the 1990s, and a variety of popular science books have been published since the beginning of the 2000s.

(5) ***Digital Geographical Names***. The public service project regarding geographical names includes four tasks: geographical name specification, geographical name marks, a geographical names plan and digital geographical names. The digital geographical names project comprises the informatization of geographical name services. The construction of geographical name information services can further

enhance the scientific and standardization level of geographical name management and achieve multidata collection. The rational use of these data and the development of various geographical name information services will transform such resources into enormous social and economic benefits. Digital geographical name technology makes full use of electronic maps, remote sensing images and other technical means in the field of Digital Earth and expands the use of the internet, big data and other technical methods to achieve the combination of geographical name information, map imagery, geographical name query and statistical analysis.

Relying on the geographical name database, telecommunications technology, the internet and other media will be used for a geographical name informatization service via a toponymic website, toponymic hotline, toponymic disc (electronic map), and a toponymic touch screen as the main contents to realize the sharing of geographical name information with all of society. The public can obtain accurate geographical name information quickly, conveniently and in a timely manner.

22.5.3 Digitalization to Drive and Promote China's Development

"Digital Earth to drive and promote China's development" means the essential improvement of production modes, production efficiency and product quality brought by the application of digital technology in the field of spatial information technology. In addition to the extensive application of digital technology in auxiliary aspects such as R&D, management, marketing, warehousing and logistics, an increasing number of technologies such as the IoT, artificial intelligence, industrial internet and industrial robots have been directly introduced into production to enable improvements in the production of enterprises and to provide a solid foundation to guarantee personalized customization and intelligent manufacturing. Currently, China is vigorously promoting "Made in China 2025" and "building a manufacturing power." This is a key direction of research and promotion of the ISDE Chinese National Committee to study how to strengthen the role of digital technology in the process.

(1) ***Digital New Technologies, New Industries, New Formats and New Models Are Constantly Emerging***. In 2017, China's digital economy reached RMB 27.2 trillion, showing a yearly growth of 20.3% and accounting for 32.9% of the GDP, and became an important engine to drive economic transformation and upgrading. The electronic information manufacturing industry, software and information services industry and communications industry continued to develop rapidly. In 2017, the information industry had a revenue of RMB 22.1 trillion, showing a yearly growth of 14.5%. In 2017, China's information consumption increased to RMB 4.5 trillion, a yearly growth of 15.4%, which was approximately twice the growth rate of final consumption during the same period. It accounted for 10% of final consumption and contributed more than 0.4% to GDP growth. The overall strength and global competitiveness of the network and information technology enterprises in China

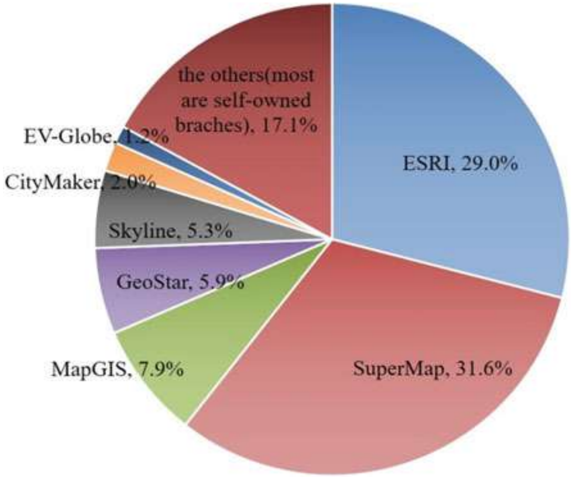

Fig. 22.2 GIS software market share in China (2015)

have been continuously improved (see Fig. 22.2), and seven internet enterprises rank among the top 20 in the world in terms of their market values.

(2) ***Digital Information Technology Promotes Changes in the Quality, Efficiency and Power of Economic Development***. The Guiding Opinions on Deepening the Integrated Development of the Manufacturing Industry and Internet and the Guiding Opinions on Deepening "Internet + the Advanced Manufacturing Industry and Developing Industrial Internet" have been implemented to promote the in-depth integrated development of the manufacturing industry and the internet. The implementation has been defined by software, driven by data, supported by platforms, added value to services and led by intelligence (Figs. 22.3 and 22.4). With the rapid development of industrial internet, a number of industrial applications for complex products such as high-speed trains and wind power have been developed and initially achieved commercialized applications. The pace of rural and agricultural information technology has been obviously sped up by fully implementing the project to deliver information into villages and households and offer services for the convenience of 233 million people. A number of demonstration templates for digital agriculture have been created to continuously improve intelligent agricultural production, business based on networks, and online services. "Internet + convenient transportation" has been promoted at a faster speed to develop intelligent transportation and facilitate passenger travel. A national transportation and logistics public information platform has been built and improved to promote the sharing of logistics information and promote cost reduction and efficiency improvements in logistics.

(3) ***E-government Has Been Advanced***. At the national level, the National General Plan for E-government was released to establish an overall coordination mechanism for national e-government, organize the implementation of national comprehensive e-government pilots, deepen the applications of e-government and explore the

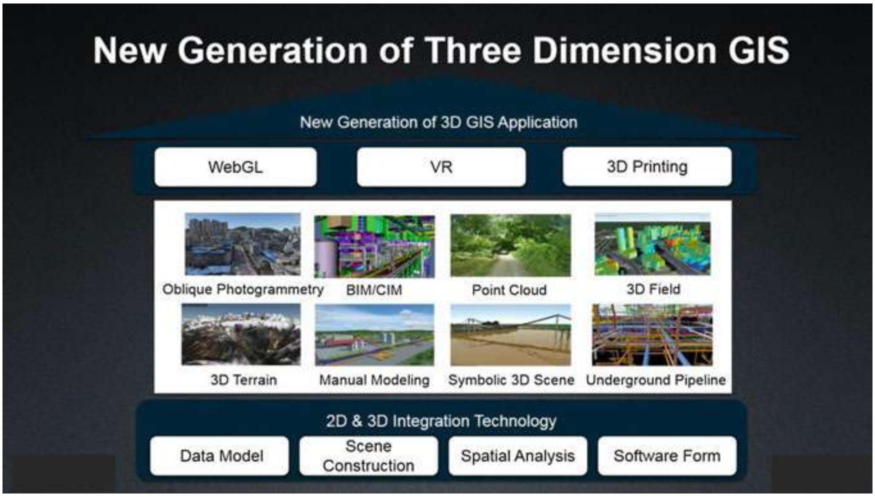

Fig. 22.3 The new generation of 3D GIS technology

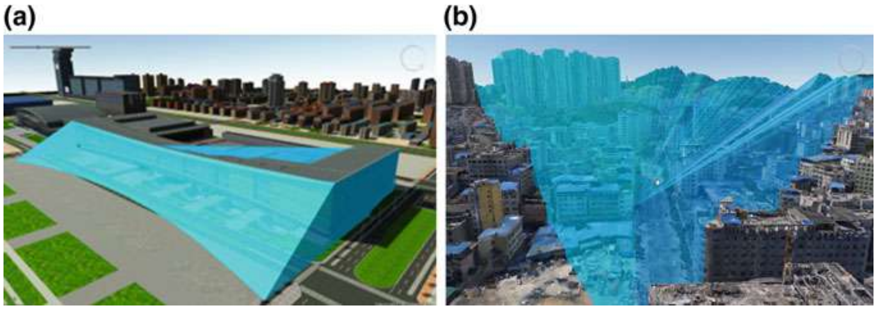

Fig. 22.4 Using a 3D entity model to describe abstract 3D objects: **a** 3D of shadow, **b** 3D of visibility

development of a comprehensive e-government pilot to promote the modernization of national governance systems and capabilities.

The government of China issued the Implementation Plan for the Integration and Sharing of Government Information Systems to accelerate the integration and sharing of government information systems, promote network communication, data communication and business communication, and continuously extend e-government services to the grassroots governments. E-government media have flourished. Party and government organizations and group organizations at all levels actively use Weibo, WeChat, other clients and new media to publish government affairs information, respond to social concerns, provide convenient services and promote collaborative governance, creating effective platforms for building an online and offline community and practicing the government's mass line. Public security organizations have accelerated the application of new technologies and continuously improved their ability and level of prevention and control, mass service, and social governance. The construction of the social credit system has achieved remarkable results. The national credit information sharing platform has been linked to 39 ministries and commissions and all provinces, autonomous regions and municipalities. The total amount of credit information collected has exceeded 6.5 billion items, and the system of joint punishment for dishonesty and joint incentives for honesty between departments has been improved.

(4) ***Information Services to Benefit the People and Add Convenience***. To develop the network and information technology businesses, it is necessary to implement people-centered development thinking. Regions and departments should regard information technology as an important means to safeguard and improve people's livelihood and should vigorously develop information services such as online education, telemedicine, network culture, "internet + public legal services" and "internet + public security" so that people can have a greater sense of gain in terms of sharing the results of internet development.

"Internet + education" expands the coverage of high-quality education resources. Significant progress has been made in the construction and application of the "three accesses and two platforms (network access for each school, resource access for each class and space access for each person, and the educational resource service platform and the educational management service platform)," the level of educational information technology has been significantly improved, and the promotion mechanism for the participation of all society has been continuously improved. Applications benefiting the people have been rapidly popularized. The interconnection of national transportation cards has been advanced rapidly. China has actively promoted the model of "internet + public security" and built the "internet + government service" platform for public security to improve the service efficiency and extend the service range. Many areas have expanded applications in other government public service areas including resident health, civil assistance, and financial subsidies, and initially established a mechanism for the coordination and sharing of pension services and community services.

(5) ***International Cooperation in the Digital Economy***. International cooperation in the digital economy has become a new highlight. China has promoted the launch of the G20 Digital Economy Development and Cooperation Initiative and the Initiative for International Cooperation in "Belt and Road" Digital Economy, actively promoted negotiations on nearly 20 e-commerce topics of free trade agreements such as regional comprehensive economic partnerships, deepened pragmatic cooperation in cyberspace, and promoted the joint construction and sharing of the Digital Silk Road. The system for serving enterprises that work overseas has been continuously improved. The channels for acquiring overseas enterprise information services have been expanded, and the release of early warning safety information has been strengthened. The "Belt and Road" big data service system has taken shape to actively provide effective information and services for relevant enterprises, organizations and individuals involved in construction of the "Belt and Road".

22.6 Summary

The goal of building Digital Earth in China is to provide crucial information technology and support resources for promoting China's economic, political, cultural, social and ecological civilization construction progress. The Chinese government has attached great importance to and strengthened the top-level design for long-term planning and specific implementation steps for Digital Earth in China. With the rapid development of basic theory and innovations in common key technology and information infrastructure in spatial information technology, Digital Earth in China has experienced explosive development, such as in digital agriculture, digital disaster reduction, and digital heritage. Digital Earth in China has been a model for the digital economy in some countries but not in other countries. This may be due to several reasons, but the social system and government organization are important aspects for the rapid development of Digital Earth in China. Although it has been successful, there are also many problems regarding the future development of Digital Earth in China, such as privacy, politics, possible access to government data by the public and data sharing. The Chinese government must work to overcome these issues and continue to focus on the development of Digital Earth in China

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Chapter 23
Digital Earth in Russia

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Abstract A brief overview of the history of Digital Earth in Russia, its current status and prospects for further development are proposed and discussed in this chapter. The anticipation of the concept of Digital Earth in Russian culture is demonstrated and explained. Conclusions about the specificity of the development of the concept of Digital Earth in Russia due to its geographical, historical and cultural characteristics are drawn, and development factors are revealed. The vital need for the concept in ensuring the effective governance and sustainable development of the country is emphasized. Theoretical and applied results achieved by the Russian Digital Earth community are presented. Special attention is paid to the outreach of the Digital Earth vision to state governance, business, society and education. The key importance of international cooperation for the successful implementation of Digital Earth in Russia is explained.

Keywords Digital Earth · Russia · Precursor · Sustainable development · Neogeography · Effective governance

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23.1 Introduction

As a new geospatial principle and interdisciplinary research area, Digital Earth addresses the most fundamental problems of concern to all mankind—ensuring precise decision making, sustainable development, and efficient use of limited resources. These problems are particularly evident in large and diverse countries such as Russia. Two main factors determine the strong interest in the concept of Digital Earth in Russia. The first factor is the vastness. From a geospatial point of view, Russia is a big landmass with extremely unevenly distributed population, resources, and infrastructure. For more than four hundred years, Russia has been the biggest undivided country in the world, and national stability and sustainable development highly depend on the quality of governance. Therefore, sustainable managing of vast and diverse territories with the help of increasingly complicated hierarchical governing structures was recognized as a vital problem many centuries ago. Sustainable development of Russia depends highly on consistent and comprehensive geospatial data with a wide range of scales and the flawless integration of geospatial data of different scales and different origins into a single heterogeneous dataset. As a geospatial approach with radically new properties, Digital Earth is very attractive and promising, especially for Russia.

The second vital factor that creates a strong interest in the concept of Digital Earth in Russia is the predominance of space exploration in the national mentality. Russia has the longest history of space exploration in the world. Applied space research, especially the idea of holistic, non-mediated, direct representation of our planet using remote sensing data instead of maps has become very popular and commonplace for at least two generations of Russians since the beginning of the space age in the second half of the 1950s. Wide usage of satellite remote sensing for decision making, management and governance of all kinds and levels was very popular in the beginning of the twenty-first century, and thus Digital Earth as new scientific, technological and social initiative was met with great enthusiasm—Russian society was mentally prepared for a new scientific revolution.

In 2005, the Google Earth online service was started, following the geoportal Google Maps. This event marked the beginning of a great geospatial revolution in Russia. As a bright embodiment of the Digital Earth concept, Google Earth was almost instantly recognized in Russia, and new geospatial approach was widely appreciated with remarkable speed. New, highly demanded, colored high-resolution satellite images were recognized by Russian users as an invaluable resource for decision making. However, the implementation of Digital Earth in Russia was a rather long and controversial process. Understanding Digital Earth and the rapid expansion of detailed satellite data triggered a long process of adaptation of national legislation and management practices to the new technological reality. In the second half of the 2010s, the process of adopting Digital Earth reached its culmination: in 2017, the Russian government proclaimed Digital Earth as a new ideology of national space remote sensing. In addition, a critical review of national goals and space assets was initiated. The digital economy has been recognized as a new and ultimate goal for Russia's technological development. Under these circumstances, Digital Earth was gradually anticipated as a pivotal element of national command and control infrastructure due to its organic compatibility with digital economy. Currently, the synergy of both "digital" concepts is becoming an important factor in the development of national industry, national technologies and the nation itself.

23.2 Prehistory and Precursors of Digital Earth in Russia

The importance of Digital Earth for Russia and its visible scientific significance raised the question of its prerequisites in national history. There are indications that the essence of Digital Earth, as a new geospatial approach that was visibly different from other geospatial approaches, was anticipated in Russia many years and even centuries before the current geospatial revolution, and the concept of a universal, direct representation of Earth has repeatedly manifested in Russian culture.

23.2.1 Cultural Precursors of Digital Earth in Russia

The official history of Digital Earth started in the eve of the 20th century, when Vice President of the USA Al Gore introduced and described a new, promising type of geospatial information systems—so-called "Digital Earth"—in his book "Earth in the balance" (Gore 1992) and in a famous speech given at the California Science Center in Los Angeles on January 31, 1998 (Gore 1998). Digital Earth was described as a comprehensive, three-dimensional and multi-scaled model of Earth that could be used as an ultimate collector of spatially localized information. However, this core idea of Digital Earth was anticipated many times in different countries, including Russia. One of the most unbelievably accurate descriptions of an informational system that envisioned the future Digital Earth was made by the great Russian and Soviet writer Mikhail Bulgakov (1891–1940). In his mystical novel "Master and Margarita" (Bulgakov 1967), written between 1928 and 1940, he described a so-called 'Globe of Woland'—a magic globe that demonstrated and emphasized the ability to visualize all events in any place of the Earth immediately, interactively, completely and in full detail. The main features of the 'Globe of Woland' described in detail in the novel accurately and comprehensively anticipated the basic features of the Digital Earth approach—a three-dimensional, scale-independent, dynamic model of Earth. Moreover, Bulgakov envisioned avoiding mapping signs to improve the quality of perception, consciously anticipated and described in detail the basic principles of the future Digital Earth with unbelievable accuracy nearly 60 years before Digital Earth was manifested and interdisciplinary research was initiated.

Bulgakov's 'Globe of Woland' also had a predecessor. There is opinion (Sokolov 1988) that the idea of the magic Globe was borrowed from the novel 'War and Peace' (Tolstoy 1869) written by Russian writer Leo Tolstoy (1828–1910). The novel depicted an 'alive and vibration globe without any dimensions' (in original Russian text) that the hero saw in a dream. This kind of impossible object could be regarded as a metaphorical description of the idea of scale-independency. Notably, in the English translation of the novel, this paradoxical property of the Globe was reduced to a more imaginable form—an 'alive and vibration globe without fixed dimensions.'

Therefore, we assume that a representation of our planet as a scale-independent and projection-independent, sign-less, space-temporal replica of real Earth was anticipated, understood and popularized in Russia long before the establishment of Digital Earth as a scientific paradigm, technological and social initiative.

23.2.2 Technological Prerequisites of Digital Earth in Russia

With the beginning of the Space Era a new, holistic vision of our planet as a live Globe became widespread globally. The first image of Earth from outer space was produced in 1947 with the help of the US-launched German missile V-2 (NASA 2017). The first satellite was successfully launched from the Russian space center (cosmodrome) Baikonur in 1957. The American satellites Explorer-6, in 1959, and TIROS, in 1960, provided the first photographic and television images of Earth, respectively. In 1959, the Soviet automatic station Luna-3 captured the first image of the far side of the Moon. In 1961, Soviet cosmonaut Yuri Gagarin made the first manned space flight (Afanasiev et al. 2005; Baturin et al. 2008). During his day-long orbital mission flight (August 6–7, 1961), the second cosmonaut, Gherman Titov, took the first photographical images and movies of Earth from space manually.

A new vision of Earth became very popular, especially in Russia as it was an initial leader of the space race. The numerous benefits and hidden potential of remote sensing were quickly understood. This trend was amplified by the new concept of state governing with the help of digital computer networks, proposed during the same time by famous Soviet cybernetic and mathematician, academician Victor Glushkov (1923–1982), the chief designer of the first Soviet small ('personal' of some kind) computer for engineering purposes 'Mir-1' (1966). He proposed and popularized the idea of a so-called 'OGAS' (Universal State Automated System, or All-State Automated System)—a net-centric, internet-like architecture intended for collecting, storing and processing information on the state level to improve decision making. The project was proposed in the 1950s, became very popular in the 1960s–1970s, and gradually died out after the death of V. Glushkov in 1982 and as the country entered a deep crisis in the end of the 1980s. OGAS was not centered on geospatial data, but the clear necessity of spatial and temporal localizations of data in a universal, scale-independent framework induced interest in new approaches to handling geospatial data. The widely appreciated and supported concept of OGAS contributed to the future explosive growth of common interest in the Digital Earth concept in Russia (Fig. 23.1).

The fragmentation of the Soviet Union into 15 independent countries in 1991 and the severe, prolonged economic and political crisis significantly limited the scientific

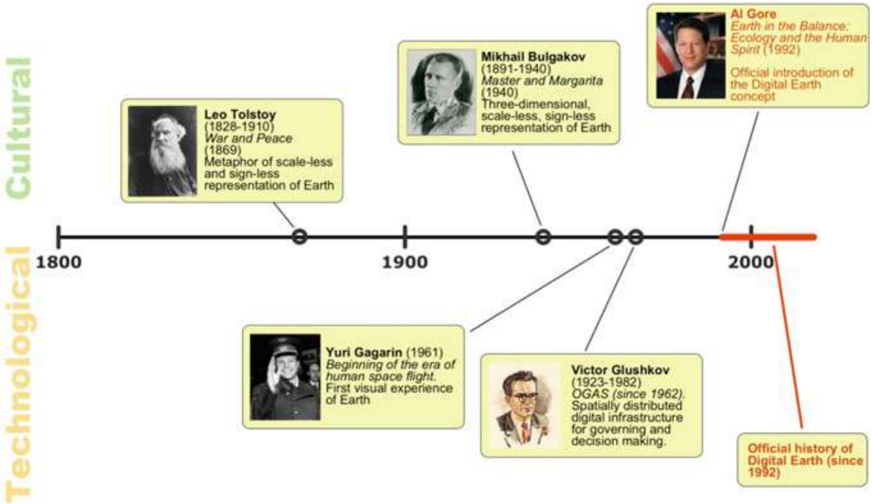

Fig. 23.1 Cultural and technological precursors of Digital Earth in Russia

potential of Russia and demands for innovations in the 1990s, and led to the shutdown of many promising projects. In the eve of the new millennium, the manifesting of Digital Earth in 1998 by Vice President of the USA Al Gore attracted the attention of the Russian scientific community. A real breakthrough came in the middle of the 2000s, following the start of the Google Earth online service in 2005, establishment of the International Society of Digital Earth (ISDE) in 2006, and proposition of the neogeography concept the same year.

23.3 Introducing Digital Earth in Russia

One of the first forerunners of Digital Earth in Russia was the virtual globe ArcGlobe—a software module and 3D viewing environment for the popular software ArcGIS (ESRI). ArcGlobe was introduced in the beginning of the 2000s and became popular as an effective new approach for integration of geospatial 3D data into the virtual globe. For the first time, ArcGlobe allowed for a user to immerse data into a rich geospatial context formed by global mosaic satellite images, and interact with it. However, the low spatial resolution of contextual geospatial data provided on DVD in the absence of online services and standalone applications as well as the relatively high cost prevented the wide usage of this interesting product. However, ArcGlobe ignited discussion about the future directions of GIS development and generated expectations for the emergence of a new type of geospatial product in the near future. The first products that incorporated the same approach to varying extents (e.g., NASA WorldWind, Microsoft Encarta, etc.) were introduced around same time, but were not widespread. For example, there are no mentions of NASA WorldWind in the articles registered in the Russian national scientific electronic library until 2005. The next big step toward understanding and assessing the new paradigm in Russia was made by Google.

The start of the Google Earth online service in the first half of 2005 provided an inspiring and thought-provoking effect and triggered the process of adopting the Digital Earth paradigm in Russia. Due to relatively good broadband access across the country and free access to Google Earth in its basic configuration, the high reliability, very rich contextual data and pressing demand for correct and unmediated geospatial data in the country resulted in amazingly rapid proliferation of the use of Google Earth in Russia. In 2007, the first open Russian model of a Russian city for Google Earth became accessible through the web site (Wolodtschenko et al. 2015). The model was based on a previous GIS-based model (Fig. 23.2a, b).

The model of Protvino was followed by others. They were increasingly used for urban and regional planning, education, and monitoring of social processes in urban environments (Fig. 23.3a, b).

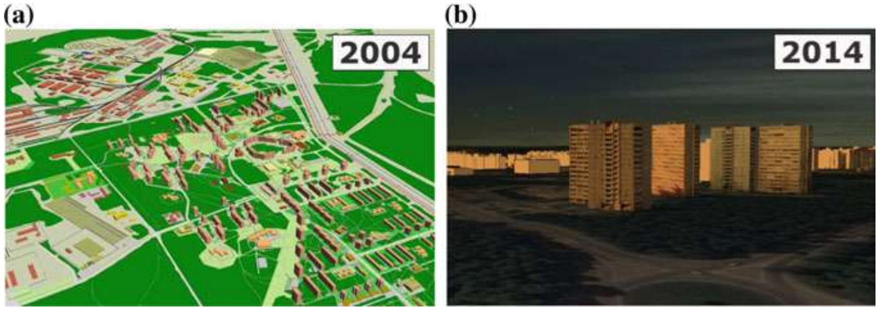

Fig. 23.2 **a, b** Left to right: evolution of the 3D model of the city of Protvino (Moscow region, Russia) during the adoption of the Digital Earth concept. **a** GIS-based 3D model of Protvino created in 2004, **b** realistic dawn view of Protvino generated using a photorealistic 3D model of Protvino based on the Digital Earth paradigm (2014)

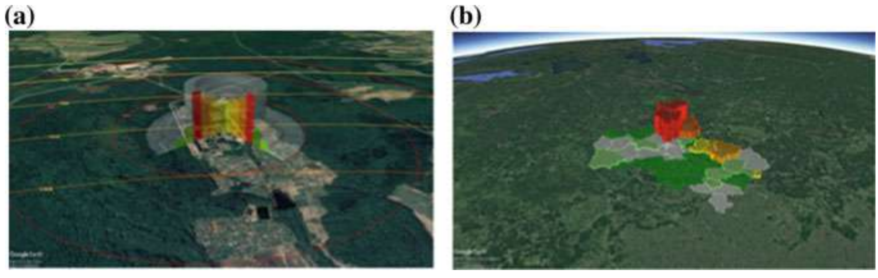

Fig. 23.3 **a, b** (From left to right) Visualizations of statistical and social data on urban (**a**) and regional (**b**) levels in the Digital Earth environment in Russia in 2005–2014

In 2008, the first software tools for Google Earth developed in Russia were proposed (Blogru.geoblogspot.com 2008). The scientific novelty of Google Earth and its advantages were obvious, leading to discussion about the nature of new approaches for working with geospatial data. In Russia, this discussion was induced by a comparative analysis of 'Geography' and 'Neogeography', initiated by A. Turner in his book 'Introduction into Neogeography' (Turner 2006). In Russia, neogeography was recognized and studied as a new scientific paradigm and quantum leap in cartography. Therefore, it was eventually identified with Digital Earth as an advanced geospatial approach, with Google Earth as its embodiment. Digital Earth was regarded as a significant innovation and promising achievement in a variety of geospatial products that emerged, especially after 2005. This vision stimulated the search for scientific, not solely technological, foundations of a new approach. In 2008, the first Russian intensional definition of neogeography, later adopted for the Digital Earth, was proposed (Eremchenko 2008). The fundamental interconnection between Digital Earth and the concept of situational awareness has also been identified and studied (Boyarchuk et al. 2010). The philosophical effects of the new geospatial paradigm were discussed in a comprehensive analysis based on the 'Noosphere' concept (Lepsky 2013). In 2008, a range of conferences dedicated to new approaches in cartography began to be held in Russia annually, and a growing number of scientific articles have been published each year.

In 2012, the book 'Virtual Geographic Environments' (Lin and Butty 2009) with the chapter 'Concept of "Digital Earth"' was published in Russia. The first scientific article with the term 'Digital Earth' (in Russian) in its title registered in the Russian official scientific database E-Library was published in 2013 (Lisitsky 2013). In 2015, a common vision of Digital Earth and neogeography was proposed (Eremchenko et al. 2015). In 2016, the first scientific event was held in Russia (Novosibirsk), organized by the ISDE as part of the annual Interexpo GEO-Siberia 2016 international conference (ISDE 2016).

The number of Digital Earth-related articles (Fig. 23.4) has grown annually. The growing interest in Digital Earth stimulated its transfer to different areas. The Digital Earth concept began to be perceived by a wide audience, especially among government officials. To some extent, 2017 was the watershed year.

At the 10th International Symposium on Digital Earth held in Sydney, Australia, in 2017, the Russian "Neogeography Group" was recognized as one of the founders of the Digital Silk Road Alliance (DSRA). The DSRA will build a cooperative network and a geospatial 'think tank' for the Silk Road countries and support the advancement of geo-spatial information and sustainable development through international cooperation within the Digital Earth paradigm (ISDE 2017).

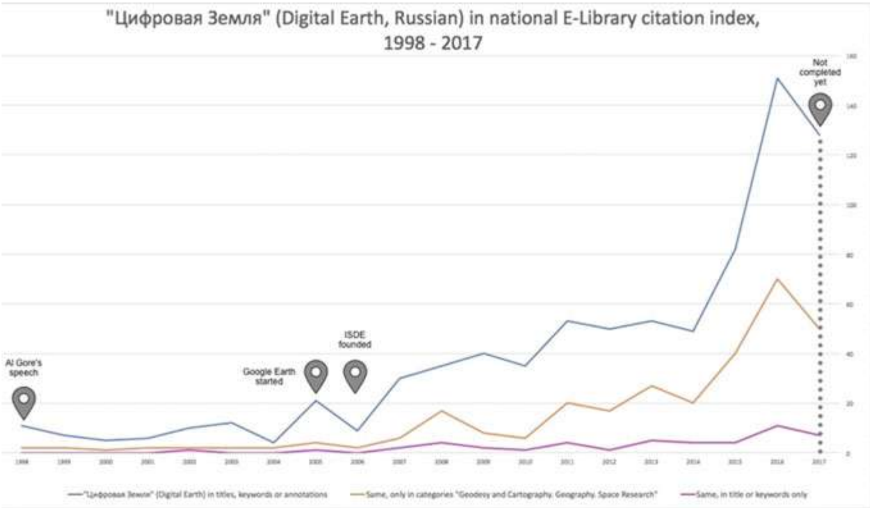

Fig. 23.4 Number of scientific papers and books about Digital Earth (in Russian), indexed in the Russian national scientific citation index E-Library from 1998 to 2017. Note that the term 'Digital Earth' was also widely used in hardware engineering to describe the ground potential of digital equipment

23.4 Establishing the Digital Earth Russia Community

The understanding, development and adoption of the Digital Earth vision in Russia were organized in an interdisciplinary manner from the beginning. A significant part of the efforts of the Russian Digital Earth community was dedicated to outreach and the projection of the Digital Earth vision into different disciplines, industries, and social groups to address vital problems of society. Conferences and meetings were organized in different Russian cities (Fig. 23.5) for different groups of participants.

Discussion of the Digital Earth concept occurred during the annual Neogeography conferences held in Moscow in 2008–2011, as well as at a long list of conferences organized and supported by famous Russian scientist and expert in scientific visualization, visual analytics, situational awareness and neogeography, Prof. Stanislav Klimenko (1941–2018). In 2009, 2014 and 2016, the Digital Earth Vision was presented and discussed at the Annual International Conferences "Information and Mathematical Technologies in Science and Governance" held in Irkutsk and Baikal (Siberia). In 2014, the Russian Digital Earth community helped organize a special session on the semiotics aspects of geospatial visualization, "Neogeo-Semiotic Synthesis", at the 12th World Congress of Semiotics in Sofia, Bulgaria (Semio2014.org 2014). Since 2016, the Digital Earth concept has been presented during the annual InterCarto/InterGIS conferences organized in different locations in Russia and abroad. From 2017, activity in the Russian Digital Earth community began to increase. For example, in 2017, the Digital Earth Vision was presented by

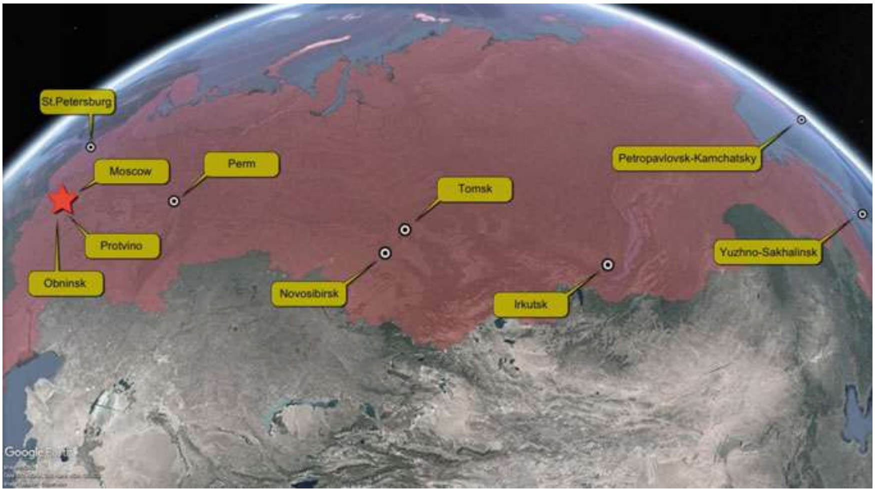

Fig. 23.5 Spatial distribution of Russian Digital Earth centers and the locations of the most significant scientific Digital Earth conferences and other events in Russia since 2008

Russian supporters at more than half a dozen scientific conferences in different fields: philosophy, visual analytics, governance, innovative economics, the Silk Road and Belt Initiative, geography and GIS, monitoring and security, scientific visualization and big data, aerospace and remote sensing, and cartography.

At some conferences, the Digital Earth sessions have become traditional (Neogeography.ru 2017, 2018). The Russian Digital Earth community has also focused on outreach as a vital way to proliferate Digital Earth expertise and provide a synergy effect in the scope of Silk Road infrastructure projects and a Digital Turn in the economy (Eremchenko et al. 2017).

The positive dynamics and fast recognition of the Russian Digital Earth community attracted the attention of colleagues abroad. At the 7th Digital Earth Summit held in Al-Jadida, Morocco in 2018, the council of the ISDE decided to organize the next (2020) 8th Digital Earth Summit in Russia. It will be held in Obninsk—a well-known scientific and university center with a history of being affordable. The selection of the relatively small (approximately one hundred thousand inhabitants) university town Obninsk with very diverse industry and science as the host of a Digital Earth Summit emphasizes the interdisciplinary and outreach goals of this forum and demonstrates the significance of Digital Earth in the Silk Road and Belt project because Obninsk is a Russian hub of the Silk Road.

Establishing a national corpus of relevant scientific journals is also a key factor for the successful development of disciplines, especially interdisciplinary ones. Scientific articles about different aspects of Digital Earth are published in various journals. In addition, the proceedings of the annual GraphiCon and InterCarto/InterGIS conferences, the annual almanac Geocontext, and other sources of information are relevant. To share the Digital Earth vision, internet portals, social networks, and media are actively used. Many reviews, news, and outreach-oriented discussion materials are published on the internet portal NeoGeography.ru. Notably, Digital Earth in Russia was developed mainly within the Russian linguistic context and terminology, therefore the constant coordination of discourse and results and harmonization of research with the international community is a significant issue.

Also in 2018, preparation for a Russian chapter of the ISDE was initiated (DERussia.ru 2018).

23.5 Exploration of Digital Earth in Russia

A key factor of success in technological development is a clear understanding of the nature of Digital Earth as a scientific paradigm and new approach for processing geospatial information. Since the introduction of the Google Earth geoservice in 2005, the discussion about Digital Earth in the Russian scientific community has focused on fundamental issues, primarily on the problem of developing a scientific definition of Digital Earth. Special attention was also paid to its paradoxical properties, primarily semiotic ones.

The following are the main directions of research of the Digital Earth phenomenon in Russia (Eremchenko 2017):

- development of an intensional definition of Digital Earth;
- proposal of a typology of geospatial visualization methods;
- discussion of the semiotic implications of Digital Earth, including introduction of the 'zero sign' concept;
- proposing and discussing the concept of georhetorics; and
- studying the concept of Digital Earth in the context of situational awareness, the digital economy, visual analytics, and smart city concepts.

Digital Earth is also used in Russia to observe social processes in the urban environment with unprecedented spatial and temporal resolutions.

23.6 Digital Earth: Russian Government Initiatives

In May 2017, less than two months after the 10th International Symposium on Digital Earth was held in Australia and two weeks after announcement of the Digital Earth Australia project, a similar Digital Earth-based concept of new space remote sensing policy was officially adopted by the Russian government (Kremlin.ru 2017). At the presidential meeting on developing the space sector held on May 22, 2017, the concept of Digital Earth was proposed and approved as a core idea of new national policy in space. The Russian Space Agency provided information about the "Digital Earth" project focused on stimulating development of the Russian economy in accordance with new "digital" trends and an innovative "digital economy". Digital Earth in Russia should become a central element of a highly effective national command and control system to ensure sustainable development in Russia. The main declared goals of the "Digital Earth" project are the creation and regular updating of a seamless raster coverage for the entire globe with 1 m accuracy (or better) and formation of a family of new geospatial services focused on the urgent demands of business, government, and society. Commercialization manifested as a fundamental approach to satellite remote sensing. One specificity of the Russian policy in the field of remote sensing is the desire to ensure independence and autonomy in space. In accordance with this policy, the country is developing all the elements of the infrastructure of the future Digital Earth.

Development of Digital Earth in Russia and its infrastructural elements was supported by regulatory documents such as "The concept of development of the Russian space system of remote sensing of the Earth for the period up to 2025", resolution of the Government of the Russian Federation No. 326 on 28 May, 2007, "On the procedure for obtaining, using and providing geospatial information", Bases of the state policy of the Russian Federation in the field of space activity for the period till 2030 and further prospect, approved by the President of the Russian Federation on April 19, 2013 № ПР-906, the state program of the Russian Federation "Space activities of Russia for 2013–2020" approved by the government of the Russian Federation on April 15, 2014 № 306, and others.

23.7 Infrastructure of Digital Earth in Russia

The concept of Digital Earth naturally integrates achievements in the fields of space exploration, advanced technologies, promising areas of fundamental scientific research, establishment of an appropriate infrastructure backbone, and social, industrial and governmental demands. The need to revise the existing principles of obtaining, accumulation, processing and use of geospatial data in accordance with the internal logic of scientific and technological development was realized in Russia in the first decade of the twenty-first century.

In Russia, this state-of-the-art system consists of number of components and national assets such as a remote sensing satellite constellation, global navigational satellite system (GLONASS) and a unique project of a common geographically distributed information system of remote sensing (ETRIS DZZ).

23.7.1 Remote Sensing Constellation

Satellite remote sensing capabilities are fundamental to a Digital Earth-based information system. Russia has long and bright history of remote sensing, though the present constellation and its potential are rather modest. At the beginning of 2019, it consisted of the high-resolution (better than 1 m) satellites of the "Resurs" family and moderate resolution (2.5 m) satellites of the "Kanopus-B" family, the meteorological satellites "Meteor-M" and "Electro-L", as well as hydro-meteorological and experimental satellites. Increasing the number of satellites and the capacity of the national constellation of remote sensing satellites is considered a major national task. A plan to increase the number of national remote sensing satellites from 8 (2017) to 20 by 2025 was revealed (Roscosmos.ru 2017). Highly reliable "Kanopus-B" satellites work in the common constellation with the identical Belorussian satellite BKA. As of May 2019, there were 7 satellites in the common "Kanopus-B" constellation (6 Russian satellites and 1 Belorussian satellite).

23.7.2 National Global Navigation Satellite System

Global Navigational Satellite System (GLONASS) is a key national space resource. A core element of GLONASS is a space segment that consists of 24 satellites that are evenly distributed on 3 orbital planes (8 satellites in each plane). Like GPS, GLONASS provided two free worldwide navigational signals (L1 and L2). Development of GLONASS was initiated in 1976. The deployment of the first experimental satellites of the "Uragan" family began in 1982. The system began limited operation in 1993, deployment of the full GLONASS constellation (24 satellites) was successfully completed in 1995, and full-scale operation of the system began. However, the system degraded due to a lack of resources and incoherent national space policy.

Rehabilitation of GLONASS was stimulated by a federal special purpose program initiated in 2002. Through this program, the orbital segment of the system was eventually recovered, and in 2009 GLONASS was redeployed and returned to full-scale operation as a second global navigational satellite system for the world. Now, the orbital segment of the system is based on "Glonass-M" satellites. GLONASS development is regulated by RF Government Ordinance No. 189 "Supporting, developing and using of GLONASS for 2012–2020" dated March 3, 2012. Development of a new "Glonass-K2" satellite with improved specifications, deployment of navigational satellites with new types of orbits, and creation of a wide-area augmentation system are planned.

In conjunction with another navigational systems like GPS, BeiDou and GALILEO, GLONASS is actively used for creating new digital infrastructure in Russia. One prominent example is the ERA-GLONASS system intended to generate rapid information about car incidents. Since January 1, 2017, all new cars in Russia and other countries of the Eurasian Custom Union must be equipped with ERA-GLONASS car modules. A similar system, eCall, was developed in the EU and will be technologically compatible with ERA-GLONASS.

23.7.3 The International Global Aerospace System (IGMAS)

Historically, the first predecessor of the modern Digital Earth Russia system can be considered, was the IGMAS (International Global Aerospace System) project proposed in 2009 (Menshikov 2009). IGMAS was proposed as a "special space system", or system-of-systems, comprising space, aerial and ground segments and intended for "real-time monitoring of asteroid and comet hazard… continuous incoming of real-time forecast monitoring information on the occurrence of natural and manmade disasters on a global scale, as well as timely detection of asteroid and comet hazard and availability of such information to a wide range of consumers" (Kuzmenko et al. 2010). The IGMAS project remained unrealized but contributed to the idea of creating a unified global information system that met Digital Earth requirements.

23.7.4 The ETRIS-DZZ System

The "Digital Earth Russia" project that has been developed by the Russian Space Agency since 2017 includes a new state-of-the-art ground segment system as a key element—a 'common geographically distributed information system of remote sensing' (ETRIS DZZ). The new system, developed by the "Russian Space Systems" holding, was successfully tested and recommended for operation in 2016 (RussianSpaceSystems.ru 2016). ETRIS DZZ consists of 13 centers distributed throughout Russia and abroad, including in the Arctic and Antarctic. Compared with the existing single-point reception, the deployment of a system with a multi-point reception organization will significantly improve the efficiency of the use of existing and planned Russian remote sensing satellites due to the timely discharge of accumulated information from satellite memory on most orbital turns.

23.7.5 The SPHERE Project

The ambitious SPHERE project was announced by the president of Russia on June 7, 2018. The project envisages the deployment of an extensive (approximately 640 satellites) LEO constellation aimed at solving three main tasks: communication and internet access, remote sensing, navigation and geopositioning. There are three stages of deployment of the system: 2022, 2024, and 2028 (Kremlin.ru 2018). The specifications of the future SPHERE system and information about the satellites is not accessible yet.

23.7.6 Services and Applications

Remarkable visualization of Earth with the help of state-of-the-art computer systems is a prominent aspect of the Digital Earth paradigm. Historically, the Russian scientific community has focused on the study of Digital Earth as a scientific paradigm based on existing practical realizations (NASA WorldWind; Google Earth, ERDAS Titan, etc.). In addition, the range of palliative, 2D geoportals such as Google Maps was developed in Russia—Maps.Yandex.ru, Kosmosnimki.ru, etc. However, the limited capabilities of map-based geoportals are obvious and the demand for a real Digital Earth-like solution persists.

In 2010, the 'Geoportal of Roscosmos' (https://gptl.ru) was presented; it was promoted as an innovative, updated daily global coverage made using satellite images. Low-resolution images are free of charge and accessible for any user, higher-resolution images can be purchased. The cost of developing the 'Geoportal of Roscosmos' was estimated at approximately $300,000. Nevertheless, the need to create a fully featured Digital Earth was obvious due to the practical needs of the vast country.

The first national geospatial product that met the requirements of the Digital Earth paradigm was the NeoGlobus software, developed in VNIIEM Corporation, a leading aerospace enterprise specializes in producing satellites, including the remote sensing satellite families "Meteor" and "Kanopus-B". In 2010, NeoGlobus was presented at the seventh international industrial forum "GeoForm+2010" as an 'innovative environment for integration of geospatial data' based on a global seamless mosaic of satellite images (VNIIEM 2010). NeoGlobus was proposed and implemented as an environment for long-term planning and tasking for Russian remote sensing satellites of the "Kanopus-B" family, and therefore its market niche was limited.

23.8 Digital Earth Russia: Private Business Initiatives

Russian private business was also involved in Digital Earth R&D. One of the most successful Russian Digital Earth services that was implemented at the same time and is increasingly being used in various fields is Sputnik GIS, developed by Russian privately owned company Geoscan Group.

A predecessor of the Sputnik GIS project was started in June 2009 as a 3D globe based on NASA WorldWind SDK, intended for spatial data visualization. Later, Sputnik GIS developed by Geoscan emerged. The history of development is interesting because it is well-suited for the specific demands of the national Russian market.

Sputnik GIS is based on the Digital Earth paradigm but has a substantially and gradually expanded functionality compared with most widespread solutions such as Google Earth. From the beginning, Sputnik GIS was oriented for use by emergency services for UAV monitoring. The first versions had few features:

- Visualizing UAV flight trajectories;
- Visualizing SRTM as a 3D surface on the globe; and

- Visualizing UAV-borne data (orthophotos).

The next step in the evolution of Sputnik was creating a Ground Control Station (GCS, Geoscan Planer) for the Geoscan UAV. The Geoscan GCS used a fully 3D environment and had the ability to plan flight with respect to the local terrain, modelled using the SRTM or other sources.

The third big step in Sputnik GIS evolution was releasing support for the Agisoft PhotoScan *.tls format. This feature made Sputnik GIS a unique software solution for 3D modelling, visualization and analysis of cities. Along with *.tls format support, basic measurements tools such as ruler, corner ruler and area were released. At the same time, Geoscan finished the project of creating a Tomsk city 3D model (Fig. 23.6). It was a rather ambitious project, because Tomsk is a big Siberian city with a population of more than half a million. In addition, Tomsk is well-known for its very rich and unique urban heritage, especially wooden architecture, which is very difficult to model in 3D. Nevertheless, the project was completed in a short term with exceptional, unprecedented quality. Since 2014, the Tomsk city administration has used Sputnik GIS intensively and successfully. Later, similar models were created for other big Russian cities: Khabarovsk, Vladivostok, Kazan, Tula, Veliky Novgorod (Sputnik.Geoscan.aero 2018). Moreover, the practical possibility of creating high-precision photo-visual 3D models of cities and entire regions has been demonstrated. For example, a 3D model of the Tula region in central Russia (an area of more than 25 thousand square kilometers, with a population of approximately 1.5 million inhabitants) was successfully created.

Geoscan also developed and released new versions of Sputnik GIS with a number of features including change detection, volume calculation, section generation,

Fig. 23.6 View of a photorealistic detail of a 3D model of the city of Tomsk, created and visualized in Sputnik GIS

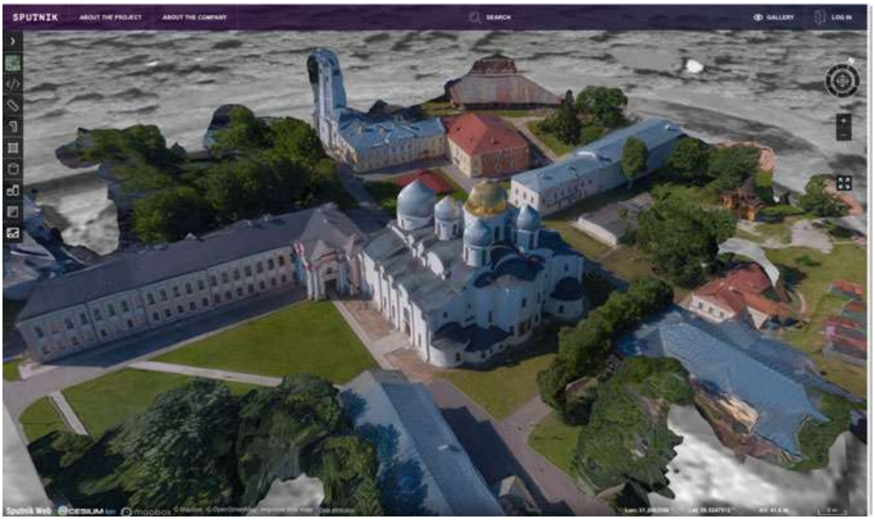

Fig. 23.7 Precise 3D model of historical Sofia Cathedral in Novgorod, Russia, created and visualized in Sputnik WEB GIS

contour generation, slope maps, creation and visualization of the NDVI, thermal maps and more. With the idea of involving UAV technologies in different industries, Geoscan developed the Sputnik GIS product family:

- Sputnik GIS—for surveyors and urban planners;
- Sputnik Agro—for agricultural companies and individual farmers;
- Sputnik PTL—for energy companies; and
- Sputnik WEB—a web implementation of Sputnik GIS with cloud photogrammetry features (Fig. 23.7).

Sputnik GIS has a long (nearly 10 years) history of development and is a mature, versatile, functional, multipurpose Russian Digital Earth service, oriented toward the specific needs of national and international (Arza-García et al. 2019) customers and developed dynamically. Due to the user-oriented approach, significant upgrading capabilities and full integration with state-of-the-art UAVs, Sputnik GIS became an effective replacement for Google Earth as a nationwide Digital Earth platform.

23.9 Conclusions

The Digital Earth paradigm has been actively investigated in Russia since 2005 and was anticipated many decades before. This anticipation originated from the vital necessity of a global, scale-independent, three-dimensional, unified, unmediated representation of geospatial context. Digital Earth is natural geospatial approach for all cultures and nations, especially for Russia.

Russian studies of Digital Earth were mainly focused on its fundamental issues. A range of applications and online services, inspired by Google Earth, was created in Russia and actively used, especially in state governance and emergency services. The culminating point of the process of adopting the Digital Earth Vision was its manifestation as a core ideology of national space remote sensing in 2017. The process of harmonizing national activities with the International Society for Digital Earth through the establishment of the Russian Chapter of the ISDE has been finalized.

Some fundamental issues and effects of the Digital Earth paradigm, unveiled by the Russian Digital Earth community, are fruitful and could impact a wide range of disciplines. The process of harmonizing geospatial data within the new framework of the 'Silk Road and Belt' and technological development of new generation of geospatial services should also be fruitful. The future of Digital Earth in Russia looks promising, bright and full of scientific and technological achievements.

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Part IV
Digital Earth Education and Ethics

Chapter 24
Digital Earth Education

Cuizhen Wang, Camelia M. Kantor, Jerry T. Mitchell and Todd S. Bacastow

Abstract Digital Earth (DE) education provides students with geospatial knowledge and skills to locate, measure, and solve geographic problems on Earth's surface. The rapid development of geospatial technology has promoted a new vision of DE to embrace data infrastructure, social networks, citizen science, and human processes on Earth. The high demand for a geospatial workforce also calls for an ever-changing, diverse form of learning experiences. Limited efforts, however, have been made regarding DE education to adapt to this changing landscape, with most interventions falling short of expectations. This chapter gives an overview of current teaching and learning structures with DE technologies. Successes and obstacles for K-12 education are explored first, followed by classroom technologies and experiential learning and outreach exercises such as academic certificates and internships in higher education. Taking the geospatial intelligence model from the U.S. Geospatial Intelligence Foundation (USGIF) as an example, recent advancements in DE education for professional careers are described via its geospatial competencies, hierarchical frameworks, and credentials. In alignment with the principles of DE development, future DE education calls for an integrated learning framework of open data, real-world context, and virtual reality for better preparedness of our students in the geospatial world.

Keywords K-12 · Higher education · Internships · Geospatial competency · Credentials

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24.1 Introduction

The vision of Digital Earth (DE), initially presented by former U. S. Vice-President Al Gore in 1998 (Gore 1999), has been to build a multi-resolution, three-dimensional representation of the planet in a system that allows users to navigate through space and time and to support decision-makers, scientists, and educators (Grossner et al. 2008; Goodchild et al. 2012). With recent technological advances, the system is now much closer to reality by utilizing vast amounts of geographic information. In the Big Data era, new visions for DE are emerging to take into account the developments in web-enabled sensors and opportunities provided by social networks and citizen-contributed information. Advances in information technology, data infrastructures and Earth observations, and the scientific and societal drivers for the next-generation of DE have been highlighted in recent literature (e.g., Craglia et al. 2012; Goodchild et al. 2012; Guo et al. 2017).

Little of the DE development focus, however, has been cast on education. The descriptor of user(s) is generically defined or refers to, at best, a few professional organizations. Nowhere in this particular vision of users does the *learner* appear even though education has caught the attention of DE proponents in the past (Kerski 2008; Donert 2015). The focus of this chapter is on the *learner* and the education/training structures that support teaching and learning with DE technologies. K-12 successes and obstacles are identified first, followed by higher education, professional credentialing opportunities, and finally the future of DE education and professional development.

24.2 Digital Earth for K-12

A variety of geospatial technologies are currently used in K-12 classrooms, and how to best do so has been pondered for some time (Fitzpatrick 1993; Nellis 1994). A keyword analysis of the *Journal of Geography*—a journal primarily dedicated to teaching and learning in geography—found first-time article keyword entries for remote sensing in 1990, computers in 1991, global positioning systems in 1993, geographic information systems in 1993, and Google Earth in 2007, indicating a steady progression of interest in these tools for education (Mitchell et al. 2015). More attention has been placed on educational uses of Geographic Information Systems (GIS) generally (Kerski 2008; Kerski et al. 2013), but concern for remote sensing (Kirman 1997), Google Earth (Patterson 2007; Zhu et al. 2016), and other virtual globe representations (Schultz et al. 2008) also is evident.

Classroom use of GIS began to appear in the 1990s (Kerski et al. 2013) and scores of research articles related to its educational use have appeared since in journals such as *International Research in Geographical and Environmental Education*, *Journal of Geography*, and *Cartography and Geographic Information Science*, among others. There are far too many sample articles to acknowledge in this short overview, but topics have included GIS and elementary school map skills (Shin 2006), bridging GIS teaching and learning between high school and college (AP GIS&T Study Group 2018), and GIS teacher training (Hohnle et al. 2016; Hammond et al. 2018). This interest was driven in large part by the ability to harness GIS for problem-based learning and the study of real-world phenomena and concerns (Milson and Kerski 2012).

Several examples illustrate this last point. In the United States, Mitchell et al. (2008) worked with middle school students to map hurricane storm surge and a chemical spill in relation to vulnerable populations such as children and the elderly; young people in 4-H clubs created trail maps and plotted locations for industrial development (Baumann 2011); and The Geospatial Semester offered secondary students the opportunity to learn about geospatial technologies and increase their spatial vocabularies by working on local problems such as siting a solar farm (Kolvoord et al. 2019). Elsewhere, students have used the technology to design a high-speed railway loop (France), map invasive flora (Canada), and identify locations for street lights to enhance public safety (Japan) (Kerski et al. 2013).

Whether and how GIS is used in instruction varies globally. The various structures that govern education and curriculum-making are important drivers in this regard. In countries where GIS has been made a part of the national curriculum, the spread of GIS in education has been faster (Kerski et al. 2013; Rød et al. 2010; Lam et al. 2009). These countries include China, Finland, India, Norway, South Africa, Taiwan, Turkey, and the United Kingdom. Note that, save for the Americas, these locations span the globe.

These achievements aside, most advocates would be quick to admit, however, that the promise of geospatial technology use in the K-12 classroom has fallen far short of expectations (Collins and Mitchell 2019). Some of the original obstacles plaguing greater use of geospatial tools by K-12 students remain depending on location; these include the inaccessibility of computers such as in South Africa (Breetzke et al. 2011) and Turkey (Demirci 2011) and not having a teacher and/or an educational context whereby tool use is well-taught and encouraged (Mitchell et al. 2018). As previously noted, educational standards also vary considerably internationally, meaning curricular integration of the technology can be equally variable. Improvements have included a decrease in software and hardware costs and a much greater availability of data—especially local data—for use in class projects. A focus on the student necessitates an emphasis on their teachers as well. Three important aspects apply, here. First, before a teacher embraces DE technologies they should also understand *geography* as a discipline for the unique contribution a spatial perspective brings (Bednarz and Ludwig 1997; Bednarz and van de Schee 2006). Too many teachers hold a narrow and information-oriented view of geography that is limiting for instruction (Bourke and Lidstone 2015). Second, a teacher must perceive DE technologies as useful and able to create learning opportunities not afforded by other methods (Lay et al. 2013). Finally, after fostering this positive mindset, DE teacher professional development (PD) must include several key components.

In order for teacher's DE PD to be successful, to have a "stickiness" (in other words, staying power and continued classroom use), the learning experience must be of sufficient duration. Too often geospatial training workshops are short in duration with little ongoing support (Baker et al. 2015). Successful teacher implementation requires long-term support instead of one-time PD. For example, Walshe (2017) showed that pre-service geography teachers with "*gradual yet repeated exposure to GIS with increasing complexity across the [school] year*" better developed their practice. Professional learning communities also sustain DE use. A strong cohort of learning peers can result in teachers from different disciplinary areas assisting and working with each other (Mitchell et al. 2018). Encouragement by school administration is crucial. Devoting new resources and allowing teachers to try something out of the norm: these are DE features where administrative support is necessary (Hong and Melville 2018). The best DE PD brings together diverse subject matter expertise and connects the learning to the existing curriculum to elevate the relevance of the tools to existing instruction (Hong 2014). Finally, extensive feedback and coaching, from improving classroom delivery to growing teacher confidence in using some of the more powerful features of DE tools when teaching their students, is a necessary support. Importantly, these findings are supported by work with educators across many countries, including Germany (Hohnle et al. 2016), the United States (Mitchell et al. 2018), the United Kingdom (Walshe 2017), and Hong Kong, China (Lam et al. 2009), suggesting that common teacher-training approaches in DE could be useful. A well-trained teacher corps that is mindful of how DE can be deployed in pedagogically appropriate ways (Mishra and Koehler 2006) can lead to a student population ready to connect DE technology with a problem-focused approach to learning.

24.3 Digital Earth for Higher Education

In a geospatial world, "geo" is fundamental in preparing students with geographical knowledge and skills to locate, measure, and quantify geographic phenomena (Medina and Hepner 2017). In DE higher education, students are expected to build on a firm math, science, and geography foundation with specialized courses in surveying, cartography, photogrammetry, remote sensing, and geographic information systems. The civil and governmental sectors of our society also are placing an ever-increasing reliance on the ability to build, query, analyze and communicate geospatial information to support a myriad of world issues.

24.3.1 Instructional Technologies

Pedagogical approaches for DE have developed rapidly, accompanying transformational changes such as crowdsourcing, cloud computing, and artificial intelligence (AI) that impact geospatial technologies. At many universities, introductory level GIScience courses are now taught online. Joyce et al. (2014) presented a remote sensing computer-aided learning (RSCAL) program released in 2013 in Australia, which utilized interactive online tools to facilitate students' active learning in classrooms. As a freely available online tool, the program interacts with a range of visualization, animation, and audio to enhance learning of the fundamentals of remote sensing. Torres et al. (2017) utilized WebGIS tools to enhance personalized learning in landscape education, in which students learn the landscape as a diversity of spatial elements and a complex system of physical and human factors. Many schools also are making significant efforts to infuse their GIS curriculum with a variety of commercially available or open-source technologies such as QGIS (QGIS Development Team 2018) and geospatial course materials developed by Boundless, a geospatial technology firm.

Since the debut of geobrowsers such as Google Earth in May 2005 (Fig. 24.1), these new geospatial tools make spatial data easily available worldwide and mark an evolutionary point for the DE community (Foresman 2008; Bearman et al. 2016). An increasing number of courses have adopted geobrowsers and virtual globes for classroom use. A compilation of similar geobrowsers and virtual globes released by a variety of private and public sectors all over the world is shown in Table 24.1. These user-friendly digital platforms are visually appealing to students and present a useful device for faculty to create a virtual Earth environment for interactive learning and enhanced student spatial thinking. By interacting with the real and digital Earth and within collaborative environments, students not only use and analyse data,

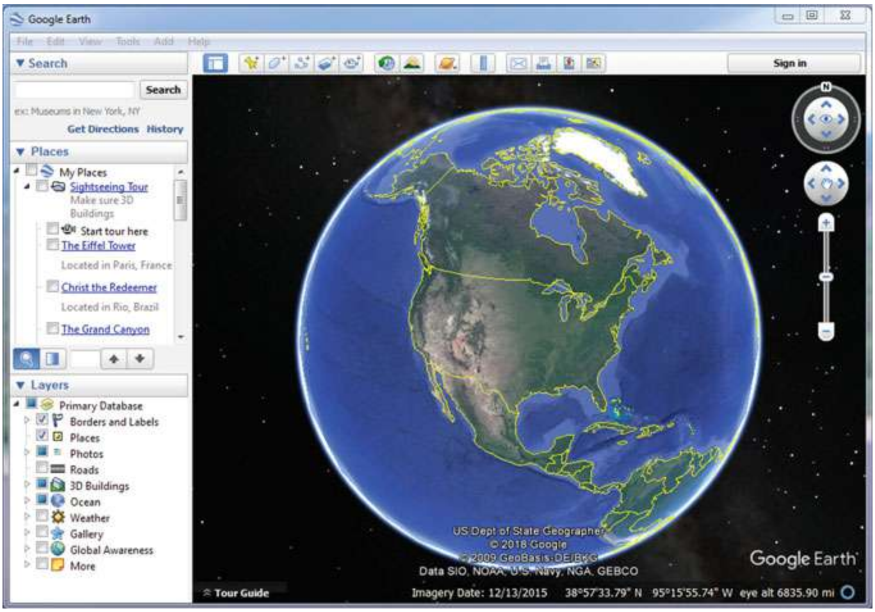

Fig. 24.1 The interface of Google Earth (Earth version 7.3.2, DigitalGlobe, Inc.)

Table 24.1 A list of geobrowsers and virtual globe platforms worldwide

Name	Source	Website
Google Earth	Digital Globe, USA	https://www.google.com/earth/
OpenStreetMap	OpenStreetMap Project, USA	https://www.openstreetmap.org
WorldWind	NASA[a], USA	https://Worldwind.arc.nasa.gov
Censium	Analytical Graphics, USA	https://cesium.com/ion
GBDX	DigitalGlobe, USA	https://platform.digitalglobe.com/gbdx
Bing Maps	Microsoft, USA	https://www.bing.com/maps
ArcGIS Explorer	ESRI, USA	www.esri.com/software/arcgis/exploer
SkylineGlobe	Skyline Software Systems, USA	http://skylineglobe.com
Open Data Cube	Digital Earth Australia, Australia	https://www.ga.gov.au/dea/odc
Géoportail	DGME[b], France	https://www.geoportail.gouv.fr/
Digital Earth Science Platform	Chinese Academy of Sciences, China	http://english.radi.cas.cn/ (to be released in late 2019)

[a]NASA: National Aeronautics and Space Administration
[b]DGME: French General Directorate for State Modernisation

but contribute to its collection, processing, and integration with other freely available platforms. DE is becoming an educational tool and a medium to facilitate our improved understanding of both natural and human processes on Earth (Annoni et al. 2011; Patterson 2007). Geo-media, for example, is a recently emerging concept that links geoinformation, online mapping, mobile APPs and volunteered geographic information for multimedia representation in classroom usage (Donert 2015).

Rapidly evolving geospatial platforms, open-source programs, and citizens-as-sensors (Goodchild 2007) allow for a higher level of spatial data adaptation in classrooms. These widely available geoportals, however, have their own limitations in DE pedagogy. On the one hand, they put pressure on educators to continually update their curriculum. Gaps between classroom learning and workplace frontiers are often observed when educators cannot stay abreast of all new changes in the market. On the other hand, some argue that while students can easily access spatial data using these tools, the level of spatial literacy they gain can be reduced and their critical spatial thinking skills can be endangered (Bearman et al. 2016). Most recently, numerous geo-“hackathons” have been conducted around the globe where geo-enthusiasts capture geo-tagged information or data using a variety of tools (GPS, WPS, RFID, etc.) which is then analyzed using GIS. The hackathon concept is intended to encourage digital innovation with existing assets and resources (Briscoe and Mulligan 2015).

While hackathons provide opportunities for collaboration and field work and allow students to learn and manipulate the tools, limited timing and focused technologies may have students entirely miss the geographic context and its principles.

24.3.2 Academic Curricula

As presented by the United Nations Educational, Scientific and Cultural Organization (UNESCO), education fulfils its valuable role of providing foundational knowledge and skills, engaging critical thinking, and building students positive attitudes to become active participants in a world characterized by diversity and pluralism (UNESCO 2018). Within a "credentialism" concept framework built in the 1970s, academic credentials continue to be the basic requirement for any professional occupation. However, both industry and academic professionals have concerns over the ability of academia being able to keep up with rapid industry changes. Graduating students also worry that the skills and abilities gained are not job-market oriented. Efforts currently are being made by academia, industry and government departments tasked with education and training to search for the right mix of competencies from across industries rather than from discipline-specific degrees.

As a consequence, DE concepts are offered in a multi-disciplinary education infrastructure by departments that are more cross-disciplinary in nature. Educating a student as a qualified geospatial analyst requires coursework in image interpretation, geographic information systems, open-source information, geospatially referenced data representation, management, and analytical skills. In the United States, more than 50% of GIScience courses are offered in geography and environmental science departments (ASPRS 2004); offerings also appear in other academic departments such as forestry, oceanography, engineering, or even public health and political science. The applied context of DE is positioned at multiple spatial scales and is interconnected among these disciplines. In a survey of 163 GIScience education programs at U.S. institutions in 2007–2008, Kawabata et al. (2010) reported that, while geography departments were the major provider of GIScience curricula, 40% of the GIScience degrees or certificates in these institutions involved multiple disciplines and nearly 20% interacted with more than three.

Unfortunately, there is no standardized DE pedagogy. The DE curriculum has complied with the systematic body of knowledge in GIScience for the collegiate teaching community. Since the early 1990s, the National Center for Geographic Information and Analysis (NCGIA) has recommended a core curriculum for GIS (Goodchild and Kemp 1992) and remote sensing (Estes et al. 1993; Foresman and Serpi 1999). Current GIScience curriculum has three primary concentrations:

- Cartography/surveying,
- Photogrammetry/remote sensing, and
- Geographic information systems/spatial analysis.

Crossing academic boundaries, DE curriculum also is undertaken by industry geospatial players in collaboration with or independently from academia. Students now have much better access to hardware, software, course materials and data via memorandum of understanding (MOUs), grants, challenges and scholarships, and partnerships between individuals, industry, and schools. For example, Esri offers GIS access to K-12 schools throughout the world, and the United States Geospatial Intelligence Foundation (USGIF) has established agreements with Digital Globe Foundation, Boundless, and Hexagon Geospatial to offer free software, data support and high-resolution imagery for classroom usage. However, the formula for seamlessly transitioning across different DE concepts is still lacking. While those out of academia focus more on technical and industry specific skills, universities continue to hold the primary role in forming a well-rounded learner who graduates with both a liberal arts background and technical, software agnostic knowledge.

The motivation to develop DE pedagogy and curriculum originates in a variety of disciplines and is driven by various stakeholders. With increasing computing power, the focus of DE has been moving toward the automation of tasks and dynamic visualization of historic or real-time data. Making sense of data has led to a shift of geospatial analysis from maps to models (spatiotemporal analytical methods; statistical, numerical, mathematical models) running on high performance computing. These are now developed and used to understand complex adaptive systems found in the natural or built environments as well as in health, political, social or economic systems on Earth (Galvani et al. 2016). With advances in computer-processing and broadband internet, geobrowsing has brought DE to the fingertips of people worldwide (Craglia et al. 2012). All these technological advances lead to changes in the workforce and in the nature of how organizations operate and interact with each other. This in turn requires re-imagining geospatial education in an excessively digital world as a customized and customizable package that takes into account rapid shifts in technology (Kantor 2018).

But DE is more than GIScience and technological development. Critical spatial thinking is a key aspect in geography as a discipline (Whyatt et al. 2011). Goodchild (2012) proposed that DE represents the full integration of geospatial technologies into the human activities of our daily life. In this sense, two learning objectives should be amended to the skill-based GIScience curriculum above:

- Critical spatial thinking, and
- Problem solving.

Thinking spatially enables better interpretation of a digital world to reach a solution: space (where); representation (what); reasoning (why); and analytics (how). Uttal and Cohen (2012) explored the relationship between spatial thinking and students' performance and attainment in science, technology, engineering and mathematics (STEM) disciplines. Similarly, it is integral to everyday life and fundamental to DE education. Without critical spatial thinking, students often ignore the context setting of spatial problems when using GIS and remote sensing software (Bearman et al. 2016). They may know very well how to run the models, but they also could have a difficult time understanding the extracted geo-information and therefore lack the ability to truly answer the complex spatial problems facing our world today. Unfortunately, many universities still organize their GIScience courses based on the transmission of knowledge rather than on questioning and problem solving (Cachinho 2006). With skills-based lectures and lab settings, the involvement of student's critical thinking in current GIScience curricula has been limited. As outlined in Bearman et al. (2016), DE educators can teach students to understand spatial issues in three aspects: spatial data, spatial processing, and spatial outputs and communication. This systematic set of training eventually links to a positive attitude of problem solving.

The challenge of developing DE curricula within such a rapidly changing technological environment has created the need to develop curriculum frameworks made of standards, guidelines, and building blocks that can be shared and transferred across educational providers, namely universities or private or government training agencies tasked with workforce development (Malhotra et al. 2018). Reasonably, DE education is restructuring from a skills-based to a competency-oriented model to meet the rapid evolution of societal and workforce needs (Schulze et al. 2013). Reflecting a variety of competencies, a number of geographic information science and technology (GIS&T) bodies of knowledge (BoK) have been identified to guide GIScience curricular development. For example, the University Consortium for Geographic Information Science Body of Knowledge (UCGIS BoK) has been adopted by the American of Association Geographers as a set of standards of GIScience learning (DiBiase et al. 2006). DE education could follow a similar curriculum framework from essentials to advanced functions. Its breadth of knowledge equips students with geospatial and problem-solving skills to assist human activities in our society (Kantor 2018).

Even with these frameworks, challenges still remain in preparing qualified personnel for both today and tomorrow. To leverage them, external activities for experiential learning such as internships have become common in academic and professional development. These activities are crucial in shaping a student's career pathway and their implementation should start as early as high school.

24.3.3 Experiential Learning: Academic Certificates and Internships

While academic degrees are still recognized as valuable for geospatial careers, the complexity of the digital world, the fast-paced workforce environment, and continuous technology innovation have all led to a focus on competencies. Good course performance toward academic degrees, however, may not directly fulfil specific workforce needs, especially in the Big Data era with rapid technological change (Kantor et al. 2018). By the time the technologies are taught, there is little time left for critical thinking, problem solving, and integration. Academic certificates and internships are then adapted to prepare students for their geospatial careers. By interacting with targeted communities, experiential learning activities enhance community engagement and foster critical spatial thinking of students in exploring cultural and political issues (Sinha et al. 2017). This, then, meets the ultimate goal of problem solving in DE development.

Academic certificates

Academic certificate programs are usually a series of courses provided by an educational institution. The certificate is granted as a proof that the coursework is taken and completed in a satisfactory manner. GIScience certificates, for example, have been offered as a suite of courses (12–21 credit hours) at numerous universities. The course sequence matches the learning outcomes of the geospatial curriculum framework.

The USGIF Geospatial Intelligence Certificate Program is an excellent example of academic certificates in the scope of DE. Currently there are seventeen USGIF accredited institutions in the United States and Europe offering a geospatial intelligence certificate or degree. Their course curricula bridge classroom learning and professional training and offer future decision-makers actionable insights about Earth and its people for business, humanitarian, security, and defense-related decisions. In general, current geospatial intelligence certificate/degree programs address three overarching educational objectives:

- to provide traditional students with a broad base of the knowledge, skills, and abilities requisite to work in the geospatial industry at an analyst level or higher;
- to offer a means of educating the non-traditional workforce by balancing work-related training provided in formal collegiate education; and
- to leverage education, training, and work experiences to obtain industry recognized credentials (certification and licensure).

Aside from technical and discipline-specific applied courses, all students seeking the geospatial intelligence certificate or degree also are required to complete a capstone project/experience. As an example, the following outlines the capstone requirements at Delta State University (Mississippi, USA), the first institution to offer an undergraduate geospatial intelligence degree:

- Applied projects: The program of work must demonstrate the use of geospatial technologies to improve workflow efficiencies, consequence analysis, new applications or methods, or improve return on investment.
- Applied geography: The program of work associated with an applied geography project must focus on improving the understanding of a geographic region through the use of geospatial technologies.
- Geospatial education: The program of work must demonstrate a need for the creation of educational materials pertaining to a common challenge encountered when using geospatial technologies.

Academic certificate programs have been in effect in various countries. A good example of international efforts is UNIGIS Distance Learning, a worldwide network of universities from nine countries and regions including Austria, Portugal, Spain, Hungary, Poland, Netherlands, United Kingdom, Latin America, and the United

States (https://unigis.net/). Initiated in 1990, UNIGIS offers professional diplomas, postgraduate certificates, and master's degree programs in six languages within its global network of fifteen Study Centers. All of these programs are in the fields of GIS, Geoinformatics, geospatial intelligence, and geospatial leadership.

Internship Programs

Traditional learning theories in academic curricula educate students for critical thinking, but often lack hands-on training to prepare them for authentic career work. To fill in this gap, many institutions have established internship programs to build a flexible learning environment for students to meet the rapidly evolving geospatial landscape. For example, the University of South Carolina (South Carolina, USA) offers an internship course—GEOG 595 (Internships in Geography)—as an experiential study for geography majors and minors. Through a semester-long internship contract with community partners, this 3- to 6-credit course prepares students for the workplace and give students an opportunity to explore career options and to put their skills into practice. For students in DE education, their internships engage with private and public partners in the geospatial community to support personalized learning. To establish a common ground for the program, it is crucial to build a community network across competencies that share mutual interests in geospatial analysis. The network comprises geospatial agencies and industries at local, state, regional, and national levels to support interns with activities that vary in terms of skill requirements and learning objectives.

The internship programs utilize a personalized curriculum and education metric. The evaluation of an intern's learning is job-specific. Given the diversity of internship activities for different interns, the learning outcomes cannot be quantified using traditional assessment schemes such as quizzes, homework, and exams. Kantor et al. (2018) propose discipline-based education research (DBER) in geospatial intelligence to better educate students to think about and understand their location-based tasks and to reflect back with improved outputs (Colom et al. 2010). The DBER strategy can be embedded in the internship courses. With job tasks and learning outcomes outlined in each internship contract, the intern perceives, understands, and embraces the critical connections between geospatial competencies and the degree-offering discipline. In this way, the curriculum is specifically designed to fit different student learning styles (Dolan et al. 2017).

The personalized curriculum adaptively helps an intern gain human intelligence on problem solving by observing, measuring, assessing and reporting the problems, and improving the individual abilities needed to cope with challenging situations. Human intelligence points to the fundamental difference between humans and machines when programming has reached its limits and run out of data (Hawkins and Blakeslee 2005). This type of adaptive learning (Posner 2017) is fundamental in DE curriculum development, but has been a major drawback in traditional unified curricula in classrooms.

Aside from the regular, full-time students in experiential learning, there is a growing student population formed of adult learners seeking to complete their degrees or to earn academic certificates. Many of these students return to school with work experience within the field and are looking to gain recognized credentials that would help them advance their careers. Among various skills programs, one good example is the Postgraduate Training Program operated by the Center for Spatial Data Infrastructures and Land Administration (CSDILA) at the University of Melbourne (Melbourne, Australia). The Center attracts world class postgraduates to gain specialized supervisory expertise in spatial data infrastructure. These students are motivated and informed (with experience), expect to apply newly gained knowledge and skills the next day, and thus create a different type of pressure on collegiate curricula. "Experience" is now expressed in various forms, carries a multitude of names (i.e. internship, apprenticeship, experiential learning, field-based training, and working knowledge), and has become part of the collegiate educational journey.

24.4 Digital Earth Education to Professional Careers

The rapid development of geospatial technology enables considerable employment growth in the geospatial technology industry as well as DE-related service employment sectors and fields. Geospatial technology has been identified as one of the three (along with nanotechnology and biotechnology) most important emerging and evolving fields with the highest number of new jobs (Gewin 2004). The U.S. Department of Labor reported an annual growth of 35% in the geospatial workforce (USDOL 2005). Upon a worldwide study by Oxera (commissioned by Google), the global geospatial services sector generated $150–270 billion per year (NSDI 2013). Various efforts, from academia to workforce, have been made to maximally prepare students for the ever-evolving geospatial world. For example, the Spatial Industry Business Association (SIBA), an association in Australia and New Zealand, has established an educational initiative, Geospatialscience, to build an interactive network that bridges school-age students with DE-related careers in the geospatial industry.

This section presents an example of DE education to professional careers in the field of geospatial intelligence, which has developed competencies to better complement DE by illustrating its real-world application. The geospatial intelligence model can serve as a catalyst for making the DE vision a reality via tools, expertise, and techniques, and integrate them into a new interconnected platform. Geospatial intelligence can bring these tools and perspectives forward to help extract actionable information from vast amounts of geographic data. Closely related to this chapter's topic, geospatial intelligence already has a framework for teaching and learning that could leverage DE education.

24.4.1 Geospatial Competency-Based Models

As early as 1999, Lucia and Lepsinger (1999) offered this definition of a competency: "… *a cluster of related knowledge, skills, and attitudes that affects a major part of one's job (a role or responsibility), that correlates with performance on the job, that* *can be measured against well-accepted standards, and that can be improved* via *training and development*." This definition leads to a formula where competencies (C) are proper subsets of well-accepted industry standards (IS), training (T), and performance on the job (PJ):

$$C \subset IS + T + PJ \tag{24.1}$$

This is a formula for training, but competencies also are becoming a major focus in education. Competency-based education provides the foundational knowledge, skills, and, most importantly, attitudes towards a profession. The purpose of "education" is to ensure the attainment of these specified knowledge, skills, and "attitudes" (Banathy 1968). Attitudes in particular are very volatile competencies and depend on external influences and self-motivation. They also are very difficult to assess and thus improve. In education, the previous formula would look different as it would need to incorporate these attitudes as essential in teaching students why to use the system and how to improve it (at the graduate level), not just how to build and operate it (technical training). Thus, the education formula is where competencies (C) are proper subsets of well-accepted (industry) standards (IS), education (E), and apprenticeship (A):

$$C \subset IS + E + A \tag{24.2}$$

Both education and apprenticeship help build not only knowledge and skills, but also attitudes designed and assessed according to industry standards. With changing demographics in student populations (e.g., an increase in adult learners), as well as changes in the modes of delivering educational and training content, attitudes are becoming an important competency to consider in both education and training.

24.4.2 Geospatial Frameworks

Looking back at the geospatial credentials market, despite all the societal advances in technology and connectivity, the 1999 view on competency-based training remains unchanged while education continues to grow more interconnected with industry standards. The major shifts in both have been witnessed by industry standards and attitudes which in turn have impacted knowledge and skills or abilities expected from the workforce. In building the geospatial workforce, several organizations have been using collaborative and cross-industry efforts to identify job specific competencies that are then followed by developing geospatial frameworks for competency-based collegiate (4 year and vocational) and training offerings.

Two prominent frameworks are the Geospatial Technology Competency Model (GTCM) designed by the National Geospatial Technology Center of Excellence (GeoTech Center) and the Geospatial Intelligence Essential Body of Knowledge (EBK) designed by USGIF. Both competency-based models have been developed with help from subject matter experts (SMEs) from across industry, government, and academia. The results should reflect the competencies needed by today's geospatial professionals and guide both educational and training curriculum development.

The GTCM was submitted to the U. S. Department of Labor (USDOL) in August 2018 and a working version was released in September 2018 (GeoTech Center 2018). The GTCM has become an important resource for defining the geospatial industry and a valuable tool for educators within the domain of geospatial technology. The University of Southern Mississippi's Geospatial Workforce Development Center conducted an initial effort in the early 2000s to define skills and competencies, an effort that led to the first draft of the GTCM. Work continued under the direction of the Geographic Information and Technology Association (GITA), the American of Association Geographers (AAG), and the Wharton School of Business at the University of Pennsylvania (DiBiase et al. 2006) but it remained a draft. In early 2009 the GeoTech Center became involved in the effort to complete the GTCM. A broad-based panel of geospatial experts were convened and suggested including two industry-related technical competencies: industry-wide and industry-specific, in the model. Public comments were sought, and comments were addressed with a final GTCM draft submitted to the U. S. Department of Labor's Employment and Training Administration's (DOLETA) Geospatial Technology Competency Model. The draft was approved by DOLETA in 2010. The industry has continued to evolve and grow and the GeoTech Center has undertaken the work to update the 2010 version of the GTCM. Partnering with DOLETA, the GeoTech Center updated the GTCM in 2014. The USDOL prefers that competency models are updated every four (4) years (GeoTech Center 2018). The 2018 GTCM update focuses on Tiers 1–5 as defined below:

- Industry-Related Technical Competencies:

  Tier 5—Industry-Specific Technical Competencies
  Tier 4—Industry-Wide Technical Competencies

- Foundational Competencies

  Tier 3—Workplace Competencies
  Tier 2—Academic Competencies
  Tier 1—Personal Effectiveness

USGIF produced the Geospatial Intelligence EBK by conducting a cross-industry job analysis to identify the knowledge, skills, and abilities critical to the geospatial intelligence workforce in consultation with psychometric consultants and the geospatial intelligence community. Qualified Subject Matter Experts (SMEs) from government, industry, and academia participated in each phase of the job/practice analysis to ensure an accurate reflection of geospatial intelligence practices. The Geospatial Intelligence EBK was revised in 2018 and published in 2019 with major additions and improvements. The GEOINT EBK describes geospatial intelligence competency and practice in terms of key job tasks and essential knowledge, skills, and abilities required for a professional to be successful. These are organized into four competency areas as described below.

- Competency I: GIS & Analysis Tools describes the knowledge necessary to ensure the various elements and approaches of GIS and analysis are properly understood in order to successfully capture, store, manage, and visualize data that is linked directly to a location.
- Competency II: Remote Sensing & Imagery Analysis describes the knowledge necessary to generate products and/or presentations of any natural or human-made feature or related object of activity through satellites, airborne platforms, unmanned aerial vehicles, terrestrially based sensors, or other similar means. This competency area contains the knowledge necessary to synthesize technical, geographic, and intelligence information derived through the interpretation or analysis of imagery and collateral materials as well as the processes, uses, interpretations, and manipulations of imagery for dissemination.
- Competency III: Geospatial Data Management describes the knowledge required to acquire, manage, retrieve, and disseminate data to facilitate integration, analysis, and synthesis of geospatial information.
- Competency IV: Data Visualization describes the use of cartographic and visualization principles to generate products that represent information about the physical environment that can be easily understood by decision-makers.

The Geospatial Intelligence EBK also includes cross-functional knowledge areas. These are necessary when there are widely accepted knowledge, skills, and abilities that transcend specific core competencies or where competencies are found across the full scope of practice. Cross-functional geospatial intelligence knowledge, skills, and abilities generally reflect:

- Qualitative “soft skills” used in geospatial intelligence,
- Unique aspects of the universal geospatial intelligence tradecraft applicable to the majority of practitioners and,
- Common geospatial intelligence knowledge and practices that, if followed, will improve the performance of a practitioner (USGIF 2018).

The Geospatial Intelligence EBK was initially developed for working professionals, not geared towards an academic curriculum. With the growth in the number of academic institutions offering geospatial intelligence credentials (certificates and, more recently, degrees), the EBK needed to be restructured for its broader audience. To make it more “academic friendly”, USGIF has invested in recent updates of the Geospatial Intelligence EBK to include learning objectives at four different experience levels and designed with regards to Bloom’s Taxonomy levels and psychometrics. Faculty will now be able to devise and maintain a master course map with formative and summative learning objectives as well as improve teaching and learning assessments. Assessment data, captured by faculty, will be used to evaluate student success with respect to each competency at the end of each semester. The academic certificates are expected to provide a basal measure of competency across the full spectrum of the Geospatial Intelligence EBK topics aimed at an “Essentials” exam (already piloted during Spring of 2019) level that will allow students who pass the exam to enter the professional world and gain an entry-level certification.

A geospatial intelligence degree is expected to provide the knowledge and skills required at the Certified GEOINT Professional (CGP) exam level. Institutionally designed frameworks for assessing student mastery is expected to be incorporated into their existent learning management systems (i.e. Blackboard, Moodle, Canvas) and the resulting data will be used to guide self-improvement. Student success rates with credentialing exams taken post-graduation and job placement also could serve as a secondary means of assessing program effectiveness. The 2018–2019 revision and updating of the Geospatial Intelligence EBK started from a "matrix" tool that was developed for each competency in the current EBK, followed by the identification of Emerging Geospatial Intelligence Competencies. Each matrix includes competency specific topic areas in the left column, as well as questions pertaining to each proficiency level (i.e., Prerequisites, Foundation, Application, Mastery/UGP) in the subsequent columns. The questions read as:

- Question 1: What do you need to know to be ready to learn about the Topic Area at a fundamental level?
- Question 2: What do you need to learn about the Topic Area at the fundamental level?
- Question 3: What do you need to know to apply the Topic Area?
- Question 4: What do you need to know to advance fundamental knowledge in the Topic Area?

The SMEs were then assigned a specific matrix to author, and added content indicating the knowledge and skills necessary to adequately address each topic area at the specified proficiency levels. Then, learning objectives for each matrix subtopic (i.e., knowledge and skills) were generated by the SMEs (Table 24.2).

Therefore, the new EBK features the following:

- Vetted learning objectives for each subtopic identified during the "deep dive" process.
- A numbering scheme for the EBK to facilitate easy communication and identification of learning objectives.
- A progression of subtopic knowledge necessary to grow and advance within a given competency.

The new EBK format is significantly more academic curriculum friendly and helps guide the pathway into geospatial intelligence learning starting from high school, moving into college, and then into the professional workforce. In addition, the newly updated Geospatial Intelligence EBK has identified and recognized the importance of a number of emerging areas, namely: Data Science, Use of varied datasets, Machine Learning, Virtual reality, Neural networks/AI, small Unmanned Aerial Systems (sUAS), Automation, and Critical thinking. Therefore, geospatial intelligence has both human and technical scopes. People are essentially trained to utilize various technical tools to understand human geospatial behaviour.

Today, the geospatial intelligence academic programs initially built upon the GTCM are shifting their curriculum towards the Geospatial Intelligence EBK to better reflect the program's growth, maturity, and establishment as a standalone

Table 24.2 An example competency area (prerequisites) of remote sensing and imagery

Matrix subtopic	Learning objective(s)
Basic computer literacy	Execute basic computer tasks including typing, use of commercial software products, navigating file systems, reading and writing computer files, internet navigation, downloading and uploading files
Basic digital image processing	Summarize the steps taken to perform basic digital image processing Explain why digital image processing is performed
Remote sensing software package	List the common remote sensing software packages and their uses
Basic remote sensing process and components	Outline the basic remote sensing processes List the components that coincide with each remote sensing process
High school physics	Integrate high school physics principles (e.g., the electromagnetic spectrum, principles of light and optics, statics and kinetics etc.) with other areas of study (e.g., math, other science)
High school math (algebra, geometry, trigonometry, and statistics)	Explain how advanced math principles (e.g., algebra, trigonometry, geometry, and statistics) apply to other fields, such as science

geospatial discipline. Efforts are being made and there is a strong ongoing partnership between the GeoTech Center and USGIF to leverage the use and fusing of both frameworks for the benefit of the greater geospatial community. These frameworks are being updated so that all the programs of study can maintain currency and relevance to the discipline. To provide a balance of theory, technical skills development, and ethical reflection, the presentation of knowledge required to achieve professional competency would be sequential and interlocking. Programs of study should aim to first orient students to fundamentals before embarking on specialization, whereas specialization should serve as a means of broadening knowledge rather than limiting practice.

In addition to the GTCM and Geospatial Intelligence EBK, the National Science Foundation also has supported various projects aimed at the development of job/occupation specific Developing a Curriculum (DACUM) frameworks (e.g., GeoTech Center produced a DACUM for GIS & Remote Sensing, Northland Community College DACUM for the sUAS maintenance technician, etc.). These newly updated competency models demonstrate a movement towards making them more "education friendly" via the introduction of learning objectives and outcomes as well as a separation into levels of expertise based on Bloom's Taxonomy. This again demonstrates the need for a continuum between education and training in building career pathways.

24.4.3 Geospatial Credentials: Certificate Versus Certification

Despite significant efforts towards establishing, maintaining, and updating the competency models in the geospatial community, the geospatial credentialing market use of the terms certificate and certification is confusing. There is ambiguity over the terms as well as the credit value between course-based academic certificates offered by numerous universities and those certificates and certification obtained after attending an hour, a half-day, a full-day, or several days/weeks/months of training in person or online.

The Cambridge Dictionary defines certification as "*a proof or document providing that someone is qualified for a particular job, or that something is of good quality*". It then goes further to imply that, for example, more adult workers are going back to school for a certification to improve their job opportunities. Based on the current credentialing market, the rule of thumb is that certifications are geared towards to-be-certified professionals; that individuals are at least at the journeyman level with a balanced combination of educational credentials and hands-on, practical work experience; and that the credential needs to be maintained through Continuing Education of Professional Development Units. One exception is Esri's Technical certification that does not require maintenance because it is largely focused on Esri's software as opposed to the software agnostic certifications offered by the aforementioned professional organizations.

In comparison, an academic certificate does not require maintenance once students complete the required courses. Therefore, certifications and certificates can be divided into three different major categories, all functioning under a larger "credentials" umbrella (Fig. 24.2).

The American Society for Photogrammetry and Remote Sensing (ASPRS), the GIS Certification Institute (GISCI), the National Geospatial Intelligence Agency (NGA) GEOINT Professional Certification (GPC), and the USGIF Certified

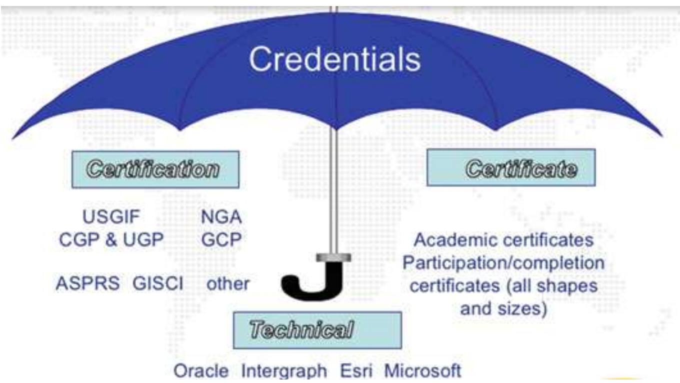

Fig. 24.2 Geospatial credentials

GEOINT Professional (CGP) and Universal GEOINT Professional (UGP) are major players in the professional geospatial certification arena (Fig. 24.2). These groups are making significant efforts to maintain software agnostic credentials. These credentials can be earned by documenting relevant educational achievements, professional experience, contributions to the profession, and by affirming a commitment to ethical practices.

In brief, ASPRS is a scientific association serving thousands of professional members around the world with the mission "to advance knowledge and improve understanding of mapping sciences to promote the responsible applications of photogrammetry, remote sensing, geographic information systems (GIS) and supporting technologies" (ASPRS 2004). ASPRS offers ten certifications (Table 24.3) geared towards photogrammetrists, mapping scientists, and technologists. GISCI is a non-profit organization that provides the GIS community with a certification program leading to GISP® (Certified GIS Professional). NGA offers the government a focused GEOINT Professional Certification (GPC) program as part of a broader Under Secretary of Defense for Intelligence (USD(I)) initiative to further professionalize the Department of Defense Intelligence Enterprise (DIE) workforce (NGA 2018).

USGIF is a more recent addition to the professional certification community, but the only one to offer a sequence of geospatial intelligence credentials that range from rigorously evaluated academic curricula via USGIF accreditation of certificates and degrees to the offering of an Essentials (entry-level) exam and professional certifications. The USGIF accredited programs offer certificates that require at least 18 (undergraduate) or 12 (graduate) credits of coursework, including a capstone project resulting from research, internship, or apprenticeship work. The value of these certificates is considered superior to that of other "certificate" credentials given the depth and breadth of required curricula. With the spring 2019 planned introduction of its Essentials exam and its ongoing K-12 curricula development efforts, USGIF intends to bridge the gap between high school prerequisites, collegiate credentials, and professional certifications in a continuum of building blocks based on the Geospatial Intelligence EBK (USGIF 2018).

The Open Geospatial Consortium (OGC) "*provides a consensus process that communities of interest use to solve problems related to the creation, communication and use of spatial information*" through the OGC Standards Program and, lately, its own certification and training (Open Geospatial Consortium 2018). OGC's standards are used by its community of interest which includes those in aviation (air travel safety and operational efficiency), built environment and 3D (open standards to support productivity across the supply chains of the building design, physical infrastructure, capital project and facilities management industries), energy and utilities, emergency response and disaster management, business intelligence, and defense and intelligence. In academia, OGC provides a fertile environment in which university geomatics, computer science, geography, and geoscience departments can modernize and advance their curricula.

Table 24.3 Examples of professional certifications

Specification	Professional certifications	Technical certifications
GIS (and Spatial Analysis)	ASPRS (Photogrammetrist, Mapping Scientist-Remote Sensing, Mapping Scientist-GIS/LIS, Lidar, UAS)	ASPRS (Photogrammetric Technologist, Remote Sensing Technologist, GIS/LIS Technologist, Lidar Technologist, UAS Technologist)
Geospatial Technology	URISA/GIS Certification Institute-Certified GIS Professional (GISP)	ESRI Technical Certification
Geospatial Science	NGA-GEOINT Professional Certification (GPC)	ORACLE Spatial Essentials
Geospatial Intelligence	USGS—Digital Aerial Certification	Microsoft technical certifications
Remote Sensing	USGIF Certified GEOINT Professional—GIS & Analysis Tools (CGP-G), Remote Sensing & Imagery Analysis (CGP-R), Geospatial Data Management (CGP-D) and Universal GEOINT Professional (UGP) designation	
UAV, UAS (Unmanned Aircraft Systems Maintenance Technician	Federal Aviation Administration (FAA)—Unmanned Aircraft Systems certification	
Web (CSW), Geopackage, Geography Markup Language, KML, Sensor Observation Service, Simple Feature Access, Web Coverage, Web Feature and Web Map Service	Open Geospatial Consortium (OGC)	
Other	Mississippi Enterprise for Technology (MsET)- SPACE and STARS Certifications	

As evidenced in this section, there have been significant advances in the geospatial educational and professional communities. Most organizations agree that competencies are best learned by following updated frameworks that are in line with industry standards as well as through experiential educational practices which include practicum, cooperative learning, internships, and that have no cost limitations. The geospatial intelligence community has achieved significant partnerships and shared credentialing but is still working to achieve full collaboration. A shared understanding of the end value is needed to reduce the uncertainty of value and disruption in academia.

24.4.4 Geospatial Intelligence Bridging Academic and Professional Connections

The rapidly evolving geospatial intelligence field demands that academic education and professional training complement each other. The community educates students in critical spatial thinking and the conceptual use of technology to solve unstructured problems, while training focuses on increased performance in described circumstances (Kantor et al. 2018). The critical balance of academic education and practical skills training, which is necessitated throughout a geospatial intelligence professional's career, is illustrated by the age-old adages of individuals "*being educated but poorly trained*" or "*well-trained and poorly educated*" (Burrus 2016).

The core of geospatial intelligence includes providing geospatial insights to decisionmakers about human needs and potentially addressing the impact of false geospatial information that arises in a competitive environment. As a meta-discipline, it entails a view of professional know-how unbounded by typical academic and organizational limits and barriers. This is to say, geospatial intelligence is not simply a collaboration of fields, but rather a fundamental merging of disciplines in theoretical and practical ways. This implies that for one to legitimately be an expert in geospatial intelligence and DE, the individual must have know-how in many traditional domains including the technical, the human, and the problem's domain.

Geospatial intelligence also is polymorphic which explains the discipline's definitional challenge. This elusive explanation is similar to that described in the Indian parable of the blind men trying unsuccessfully to identify an elephant by touching just one of its different parts. As the poet Godfrey Saxe (1816–1997) wrote, "…, *each was partly in the right, they all were in the wrong*" (Saxe 1963).

Geospatial intelligence is a sub-discipline of geography being offered in forms of certificates and academic degrees at universities in the United States and Europe and is also cross-disciplinary in nature. It is still evolving. Moving beyond defense-related issues, the field now is leading the integration of concepts and practices in oil and gas, health, business, precision agriculture, and emergency response to name a few. It benefits engineers who build and improve weather satellites, scientists who gather measurements of atmospheric, terrestrial, and oceanic conditions, database managers, Big Data analysts, business analysts who conduct cost and marketing analyses, political scientists involved in national and international conflict resolution, law enforcement in their efforts to not only reduce but mitigate crime, and even farmers seeking the best options to increase their yields.

While some are still hesitant to embrace geospatial intelligence because of its historic association with the U. S. intelligence community, there is growing understanding that geospatial intelligence, like DE, brings a unified geospatial approach to addressing the human and environmental challenges of today and tomorrow. It has been practiced by many nations although often different terminology is used. Research on the United Kingdom and Russia highlights the lesson that success in geospatial intelligence is the combination of the utilitarian aspects of technology mixed with a sophisticated understanding of the mental maps of our self, our partners, and our rivals (Bacastow 2019). Geospatial intelligence's evolution offers a model of how DE could leverage education and training to advance the perspective where politics and culture are resistant. Geospatial intelligence's experience offers DE an example of how a cohesive curriculum can advance and help to define value.

24.5 The Future of Digital Earth Education

Based upon a decade of dialogue hosted by the ISDE, three Pivotal Principles have been identified to guide DE development in the 21st Century: open data, real-world context, and informed visualization for decision support (Desha et al. 2017). These principles call for higher accessibility and a broader, interdisciplinary context of Big Earth Data and advanced analytical visualization skills for sustainable governance and decision making. This is necessary for building an overarching framework for future DE education from K-12 to professional careers.

24.5.1 DE Future in K-12

DE technologies show great promise and growth potential in K-12 education, however, a number of impediments remain. Some obstacles are technical while others are institutional. As technology penetrates classrooms more readily as infrastructure and hardware costs decrease (more so in developed rather than less developed countries), it is the latter problem—institutional—that requires greater intervention. Focusing on improving pre-service teacher training programs to include more geography and DE technologies can encourage greater use and application. This will need to be followed with intensive feedback and coaching with established teachers. Research has shown that these concerns appear across the globe (Germany, Hong Kong, United States, United Kingdom, elsewhere); time and monetary resources will need to be put in place to effect substantive change. A second necessity will be to include DE technologies within academic standards. These agreed upon learning objectives drive curriculum, and if DE is specifically included then usage will rise. A number of countries have successfully done so already, but these are countries with centralized national curricula. Countries with decentralized education systems will likely remain fragmented in their K-12 DE development. In sum, K-12 DE use currently remains scattershot and spatially variable. Although exciting projects appear in a few special cases, large-scale implementation has been elusive, and DE's K-12 potential remains untapped.

24.5.2 Micro-credentials

Credentials, in the form known by us today, may be very different in the future. Customization may include different time frames and delivery formats, as well as learning content that is narrower and focused on specific technologies and competencies, and delivered via transportable and transparent credentials and by traditional (universities) and/or less traditional (industry) institutions. Ultimately, all credentials should serve a larger purpose—that of building a networked human society ready to tackle the environmental, social, and economic challenges that lie ahead.

To address the rapid changes in technology and workforce competency needs, the future seems to favor a combination of credentials, from the micro-credentials enhanced by digital badges to degrees and certificates. More recent on the credentialing market, a micro-credential is a digital currency that recognizes competency in a specific task, knowledge, or skill and that the individual can use and share across various outlets (e.g., LinkedIn, Facebook) to enhance their marketability and give them a competitive edge (e.g. it can be combined with digital badges). Created as self-paced, shorter modules, micro-credentials can be more easily designed to mirror changing market trends. Also, they can be more affordable and easily digested by potential students, especially by the adult learners. Micro-credential requirements vary significantly from credential to credential since anyone can grant them and there are no official requirements.

Typically, micro-credentials are shorter than other credential options like college degrees or certificate programs; however, that is not always the case since the requirements are usually determined by the credential-granting institution. Because of the lack of consensus in terms of format and definition of what micro-credentials should entail, the reputation of the institution offering them still plays a major role in one's decision to pursue these credentials.

If carefully designed and implemented, they represent creative ways to bridge the gap between traditional higher education and 21st century technology and beyond. However, while designed for a specific purpose, micro-credentials should be thought of and planned in sequences and represent milestones in one's educational pathway (e.g. used toward a certificate and/or degree) and professional development. The existent geospatial models should be used as frameworks in the design of DE credentials to reflect annual changes and create a common language across the geospatial community.

24.5.3 Challenges and Opportunities for DE Education and Professional Development

Today, it is not surprising that DE-related credentials support the acquisition, understanding, management, analysis, visualization and (to some extent) ethics of data. According to Grossner and Clarke (2007), the term DE has come to represent a global technological initiative, but also "an intellectual movement." While the human aspects of DE were articulated by Foresman (2008), the current DE focus is still on the technical issues of the problem without much regard to its human aspects. The vision of DE should not be solely about space and spatial relations but also about place, culture and identity, spanning the entire physical and virtual space (Craglia et al. 2012). This new vision is still only slowly being adopted and there is uncertainty related to the needed competencies required in the preparation of future DE specialists. The future of DE should be planned on several important pillars:

- Education: provides a liberal arts background, methodologies, and depth as well as breadth of thinking. The human is ultimately where knowledge work is done and those insights are produced in geospatial intelligence. It is dependent on the geospatial analyst's meta-knowledge.
- Training/Professional development: built on education and expanding the knowledge base for increased performance. The training and professional development should focus on the human-machine team where there is a focused effort to develop information about relationships among disparate objects and events.

DE education and professional development can be implemented in several subsets as below:

- Competencies: industry-based but also focused on improving attitudes towards the discipline and the understanding of its larger, community implications.
- Technology: seen as a needed but also ubiquitous tool where abilities improve with experience and require flexibility to adjust to rapid changes;
- Leadership: the capacity to have a balanced combination of education and training/professional development to gain a holistic understanding of the problem beyond technology, combined with vision, a positive attitude, and strategic thinking.
- Research: the capacity to have a higher level of education and training/professional development coupled with imagination, creativity and positive attitudes to further contribute to the advancement of geospatial theory and knowledge as well as new improved technologies and innovative ideas.
- Education research: discipline-based education research (DBER) focused on better understanding the science of teaching and learning within and across geospatial disciplines and with sufficient resources to contribute to improved pedagogy and andragogy.

These subsets can fit under both education and training/professional development in various forms and shapes. While there is a classic continuum of education moving into training/professional development, the future movement may not be linear, but circular in nature. Certificates, certifications, and micro-credentials can be customized to fit individual pathways at different times in one's career. High levels of flexibility, creativity, positive attitudes, and time-relevant education research and implementation will be vital in a society rapidly embracing the Digital Earth. We have been deeply transformed by a (geo)digital revolution, reaching a moment where technology is becoming a commodity more so than a skill. The future will (hopefully) bring us back to what makes us intelligent creatures on Earth, ones capable of innovation, creativity, imagination, and ethical conduct.

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Chapter 25
Digital Earth Ethics

Yola Georgiadou, Ourania Kounadi and Rolf A. de By

Abstract Digital Earth scholars have recently argued for a code of ethics to protect individuals' location privacy and human dignity. In this chapter, we contribute to the debate in two ways. First, we focus on (geo)privacy because information about an individual's location is substantially different from other personal information. The compound word (geo)privacy suggests that location can be inferred from people's interests, activities, and sociodemographics, not only from traditional geographic coordinates. (Geo)privacy is a claim of individuals to determine for themselves when, how, and to what extent location information about them is communicated to others. Second, we take an interdisciplinary perspective. We draw from (geo)computing to describe the transformation of volunteered, observed, and inferred information and suggest privacy-preserving measures. We also draw from organization studies to dissect privacy into ideal types of social relationships and privacy-preserving strategies. We take the point of view of Alice, an individual 'data subject' encountered in data protection legislation, and suggest ways to account for privacy as a sociocultural phenomenon in the future. Although most of the discussion refers to the EU and the US, we provide a brief overview of data protection legislation on the African continent and in China as well as various global and regional ethics guidelines that are of very recent vintage.

Keywords Ethics · Geoprivacy · Spatial data · Inference attacks · Privacy-preserving measures

25.1 Introduction

The previous chapters of the Manual of Digital Earth describe remarkable progress to date. Key technologies envisioned by Vice President Gore in 1998 are now in place for the first-generation and next-generation Digital Earth (DE). Similar progress in DE ethics is not yet evident despite the early ethical stirrings in the geographic community. As early as 1990, at a roundtable on *Ethical Problems in Cartography*,

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Brian Harley wondered whether cartography was out of step with other disciplines. He suggested that the real ethical priority is for a map to be a socially responsible representation of the world: *"Can there be an ethically informed cartography and what should be its agenda? [S]hould we be concerned with transcendental values that go to the heart of social justice in the world at large?"* (Harley 1991, p. 9). In this chapter, we update Harley's vocabulary for the current era of datafication of everyday life (Cukier and Mayer-Schoenberger 2013) and explore the *Ethics of Where* instead of the ethics of cartography. This leads us to recent debates on data justice—fairness in the way people and their resources are made visible, represented and treated as a result of their digital data production (Taylor 2017).

In 2012, DE scholars observed that any effort to develop a next-generation Digital Earth will require a principle of privacy protection that minimally guarantees control over any individual's locational privacy and the ability to turn it on or off at will. They noted, *"there is also room for a Digital Earth code of ethics that could set standards for behavior in a complex, collaborative enterprise […] necessary to tackle the growing issues of privacy and ethics that are associated with access to fine-resolution geographic information"* (Goodchild et al. 2012, pp. 11092–3). In 2014, some of the authors of the previous paper reiterated the call for privacy and reaffirmed the need for a code of DE Ethics. They argued that *"technological advancements have to be accompanied by the development of a DE code of ethics that ensures privacy, security, and confidentiality in a world where everybody can be connected to everybody else and everything all the time. Without solving this critical dilemma and allowing people to decide whether or not they want to be connected and how much of their thoughts and emotions they want to share, the dream of a wonderful virtual future may well turn into DE nightmare"* (Ehlers et al. 2014, p. 13). They boldly suggested that Digital Earth should follow the Kantian ethics of personal autonomy and human dignity in composing its code.

An obvious source of inspiration and lessons for such a code are the practices of the Association for Computing Machinery (ACM), which represents and regulates the behavior of a global computing community of approximately 100,000 members. In 2018, the ACM updated its Code of Ethics and Professional Conduct to address the significant advances in computing technology and the growing pervasiveness of computing in all aspects of society (ACM Code Task Force 2018). The responsibility to respect privacy, one of the seven general ethical principles in the ACM Code of Ethics, applies to computing professionals in a profound way. The ACM urges computing scholars and professionals to become conversant in the various definitions and forms of privacy and understand the rights and responsibilities associated with the collection and use of personal information. The ACM appeals to all computing professionals, including current and aspiring practitioners, instructors, students, influencers, and anyone who uses computing technology in an impactful way. Given that big computing companies have a significant impact on society, we should explore how their views on privacy have diverged over time from the current ACM ideal and how they contest privacy as a concept. Some consider privacy irrelevant. As early as 1999, Scott McNealy, the founder and CEO of Sun Microsystems, declared *"you have zero privacy … get over it,"* a statement some in the privacy industry took as tantamount to a declaration of war (Sprenger 1999). Others consider it an evolving social norm. In 2010, Mark Zuckerberg claimed that *"people have really gotten comfortable not only sharing more information and different kinds, but more openly and with more people," he said. "The [privacy] social norm is just something that has evolved over time"* (Johnson 2010). Others such as Apple CEO Tim Cook note that *"the poor privacy practices of some tech companies, the ills of social media and the erosion of trust in [Cook's] own industry threaten to undermine "technology's awesome potential" to address challenges such as disease and climate change"* (Romm 2018).

Privacy is a contested concept for good reasons. First, the etymology—the history of linguistic forms—reveals how privacy changed meaning from derogatory to laudatory. The ancient Greek word ἰδιώτης (pronounced idiōtēs) originally meant a private man, an ignoramus, as opposed to δημόσιος (pronounced dēmosios; meaning 'of the people'), a person of public distinction (Liddell and Scott 1940). Currently, the stem of idiōtēs forms the word idiot and dēmos is one of the two stems of democracy. The word private in Latin meant 'deprived' of public office–privacy designated a (negative) state of deprivation. For instance, a private in the army is a person with no rank or distinction and very little privacy (Glanville 2018). Second, privacy is contested because it can be portrayed in various competing ways—as a positive or negative right (Floridi 2014); as an instrument for Kantian ethics—human dignity and personal autonomy; and as an instrument for Aristotelean virtue ethics—personal development and human flourishing (van der Sloot 2014). The watershed US Supreme Court case, *Kyllo v. United States*, reported in Mulligan et al. (2016) and reproduced in the box below, is an example of how a seemingly simple case of home privacy violation was contested by the defendant, the federal government and the Supreme Court in 2001. The five to four decision of the Supreme Court eventually upheld the Fourth Amendment—the right of an individual to retreat into his own home and be free from unreasonable governmental intrusion, in this case, free from the intrusion of a thermal imaging device deployed by a federal agent to scan the outside of Kyllo's home (US Supreme Court 2001).

> *Kyllo v. United States involved an investigation of a marijuana cultivation and distribution operation in which a federal agent used a thermal imaging device to scan the outside of Kyllo's home. The resulting thermal image was used to obtain a warrant to search the house. Kyllo moved to suppress the evidence recovered from the search of his home, arguing that the use of the thermal imaging device to scan it was an invasion of his reasonable expectation of privacy. In a five to four decision, the Supreme Court held that 'obtaining by sense-enhancing technology any information regarding the interior of the home that could not otherwise have been obtained without physical "intrusion into a constitutionally protected area", constitutes a search—at least where (as here) the technology in question is not in general public use'.*

The Kyllo case was contested at every level. The parties disagreed over the object of privacy under contention. The government argued that Kyllo had no expectation of privacy in 'the heat emitted from the home', while Kyllo argued that what privacy protected was the 'private activities' occurring within the home. The five justices who made up the majority determined that the case was about the 'use of technology to pry into our homes', the related matter of the sanctity of 'private lives', and the need to draw a not only 'firm but also bright' line to protect the sanctity of the home and the activities occurring within it. During oral argument, the justices drew attention to evidence provided to the appellate court revealing that a thermal image reading could 'show[ed] individuals moving . . . inside the building' to emphasize that what was at risk was not data, but 'what's going on in the house'.

The dissenting justices drew a distinction between 'through-the-wall surveillance that gives the observer or listener direct access to information' and 'inferences from information in the public domain' explaining that inferences drawn from 'gathered data exposed on the outside of petitioner's home' did not intrude on privacy. Justice Stevens's writing for the dissent explained, 'it would be quite absurd to characterize [the police's] thought processes'—the inference they drew from the data that seeped through the walls—as 'searches'. The majority justified its decision to prohibit the use of thermal imagers absent a warrant in order to protect the privacy of in-home activities on the basis that 'at the very core' of the Fourth Amendment 'stands the right of a man to retreat into his own home and there be free from unreasonable governmental intrusion'. The ruling was justified by the need to limit the Government's access to individuals' private lives.

Currently, the dissenting judges' claim that inferences drawn from thermal imagery of Kyllo's home were not an intrusion of his privacy but only the *'police's thought processes'* and the government's assertion that *'the heat emitted from the home'* is not private seem normal. In the Netherlands, heat detection from police helicopters is not considered systematic government observation (Hennepadvocaat 2019) and thus constitutes legal proof. Our location and movement, tweets, emails, photos and videos, purchases, our every click, misspelled word, and page view—are routinely observed by government and big tech via mobile phones, surveillance cameras, drones, satellites, street views, and corporate and government databases to draw inferences that can control, predict and monetize our behavior. Siegel (2013) notes that an individual's data can be purchased for approximately half a cent, but the average user's value to the Internet advertising ecosystem is estimated at $1,200 per year. Wall Street values tech giants, not because of the services they provide but for the data they collect from individuals and its worth to advertisers (Halpern 2013). Ironically, these data may be emitted by millions of automated accounts, each sold by obscure companies many times over, or celebrities, businesses or anyone desiring to exert influence online, according to a New York Times investigation (Confessore et al. 2018).

These facts have not escaped the public's attention. The Snowden revelations (Greenwald and MacAskill 2013) and the Cambridge Analytica scandal (The Guardian 2018) were probably the biggest contributors to citizens' changing perceptions of privacy, though not in the way Zuckerberg predicted in 2010. People care now more about privacy, and liberal governments responded accordingly. A 2018 survey by The Atlantic found that in the USA, *"overall, 78.8 percent of people said they were "very" or "somewhat" concerned about the privacy of their information on social media, and 82.2 percent said they self-censor on social media"* (Beck 2018). In 2018, legislation was passed in Vermont to regulate data brokers and California gave its residents the right to be informed about the kinds of personal information companies have collected about them, as well as the right to request that their personal information be deleted. Colorado-based companies will be required to, among other things, dispose of certain kinds of personally identifying information. The different types of information prone to compromise individual privacy are explained in detail in Sect. 25.2. Overall, two thirds of Americans are now eager to see stricter privacy laws (Halpern 2018). On May 25, 2018 the General Data Protection Regulation (GDPR) came in force to protect individuals in the 28 member countries of the European Union, even if their data is processed elsewhere. The GDPR applies to publishers, banks, universities, most Fortune 500 companies, ad-tech companies and the Silicon Valley tech giants. With the GDPR, *"companies must be clear and concise about their collection and use of personal data like full name, home address, location data, IP address, or the identifier that tracks web and app use on smartphones. Companies have to spell out why the data is being collected and whether it will be used to create profiles of people's actions and habits. Moreover, consumers will gain the right to access data companies store about them, the right to correct inaccurate information, and the right to limit the use of decisions made by algorithms"* (Tiku 2018).

Ethical issues arising in studies of our planet, as a system involving natural, man-made and hybrid processes, are enmeshed with scientific or industrial practices. Professional codes of ethics safeguard the public good by requiring honesty, trust and fairness, and the avoidance of harm. Respect for privacy and other people's work addresses concerns of intrusion and intellectual property. Studies involving geospatial information may be riddled with ethical ambiguity because professional responsibility requires acknowledging that the proposed methods may not travel well to other geographies. In short, location is burdened with contextual specifics. If such specifics are not parameterized, the earth sciences are vulnerable to the reproducibility crisis (Baker 2016). Ethics in Digital Earth methods are thus fundamentally important to study, and we expect open science approaches (Vicente-Saez and Martinez-Fuentes 2018) to mature in coming years and allow improvement of their methodical robustness.

In this chapter, we contribute to the *Ethics of Where* in two ways. First, we focus on information privacy, and location privacy, or (geo)privacy. This is necessary because information about an individual's location is substantially different from other kinds of personal information. The reasons for this include the ease of capturing an individual's location, the improvement of a service when the user shares their location with a service provider, and the potential to infer sensitive information about social, economic or political behavior from location history (Keßler and McKenzie 2018). Data inferred from an individual's location are socially constructed. If a society considers a given mode of personal behavior—e.g., political opinion, sexual orientation, religious or philosophical beliefs, trade union membership—to be socially legitimate, then these data are deemed personal and worthy of protection. We define privacy as a positive right concerning *"the claim of individuals to determine for themselves when, how, and to what extent location information about them is communicated to others"* because control of location information is the central issue in location privacy (Duckham and Kulik 2006, p. 36). Second, we complement other studies that describe the current state of the art and formulate challenges (Keßler and McKenzie 2018; Zook et al. 2017) or describe different scenarios concerning the development of geoprivacy (Wegener and Masser 1996) and revisit them (Masser and Wegener 2016) by taking an interdisciplinary perspective. We draw from the field of (geo)computing to describe the transformation of volunteered, observed, and inferred information (Sect. 25.2) and suggest privacy-preserving measures (Sect. 25.4). We draw from organization studies to dissect privacy into some ideal types of social relationships and strategies (Sect. 25.3), and draw from cultural theory to suggest future research (Sect. 25.5). The final section provides a brief overview of data protection legislation on the African continent and in China as well as various global and regional ethics guidelines.

We use the compound word (geo)privacy to suggest that, although control of location information is the central issue, location can be inferred from people's interests, activities, and sociodemographics, not only from 'traditional' location information, e.g., geographic coordinates (Keßler and McKenzie 2018). Further, we emphasize the distinction between privacy as a negative right (freedom from interference) and privacy as a positive right (freedom to control). This is because old, predigital technologies—such as the instantaneous photographs and newspaper tabloids in Brandeis and Warren's time—restricted individuals to claiming privacy as a negative right only, as freedom from interference or '*the right to be left alone*' (Warren and Brandeis 1890). New digital technologies can reduce or significantly enhance privacy as a positive right, i.e., the freedom to control (Floridi 2014), often in combination with social and/or organizational and/or legal measures/strategies (Mulligan et al. 2016).

25.2 Transforming Volunteered and Observed Data to Inferred Data

We distinguish three types of personal data: volunteered, observed and inferred data. These new types replace the old, 'personal, nonpersonal' data distinction, which has outlived its usefulness in the era of datafication. We define the three data types as suggested by the World Economic Forum (2011, p. 7): "*Volunteered data are created and explicitly shared by individuals, e.g. social network profiles. Observed data are captured by recording the actions of individuals, e.g. location data when using cell phones. Inferred data are data about individuals based on analysis of volunteered or observed information, e.g. credit scores.*" These three types involve both spatial and nonspatial data. We define spatial data as data that includes explicit coordinates interpretable in an open, well-known system. Examples are map coordinates, postal codes and street addresses. We do not think of mobile cell tower numbers as spatial data because special insight into the coding mechanism is required to understand their location.

To explain how volunteered and/or observed spatial data can be transformed into inferred data, we describe spatial data types with private or confidential components and provide examples of possible inference attacks on them. In principle, the subjects of these data types can be humans, organizations, groups of people, animals, nonliving physical objects such as buildings, or other confidential information with location attributes. Here, we focus on individual humans as data subjects. Hence, we drop the term 'confidentiality' and focus on 'privacy' because data classified as confidential (e.g., health records) is also private at an individual level. Similarly, inferences or inference attacks refer to private data that can be derived for each individual included in a spatial dataset.

We define a key identifier as an attribute that can be exploited with minimal effort to identify a subject. According to the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule, some common key identifiers are a person's name, telephone number, fax number, street address, electronic mail address, social security number, vehicle license plate, device identifier, biometric identifier, facial image, Internet protocol (IP) address, and web universal resource locator (URL) (U.S. Government Publishing Office 2009). Other potential key identifiers are account names on Internet platforms (e.g., in social media applications) and coordinate pairs of private information (e.g., location of households). In some cases, a key identifier links private information to a single individual only for a subset of the data. For example, in a dataset with locations of households, a small percentage corresponds to single-family houses (or detached houses) with only one occupant. The key identifier is a direct identifier for this subset. In other cases, a key identifier links private information to a small group of people closely related to the subject. This group may be family members who become emotionally traumatized if their private information is released or may be other house occupants that are incorrectly identified as the subjects. In addition, we define a quasi-identifier as an attribute that pinpoints a subject uniquely or almost uniquely, when combined with at least one other quasi-identifier attribute. A unique identifier (UID) is an attribute that allows for uniquely identifying single subjects. In some cases, a UID can be a key identifier (e.g., social security number, which identifies a subject), in others, its value may not be subject-specific, for instance, if it identifies a drug brand or a pharmaceutical factory process number, which cannot be used to disclose private information. Finally, a private attribute is any attribute that is not a key identifier, a quasi-identifier, or a UID, and contains other information about the subject from which inferences regarding privacy can be drawn.

The above data typology focuses on the usefulness of spatial or non-spatial data in inferences that affect privacy. Below, we discuss a second data typology that characterizes the roles of spatial and temporal attributes.

The simplest spatial data type is *'discrete location data'* (abbreviated *Dd*); it is a collection of one or more key spatial identifiers. The disclosure of this data type implies disclosure of subjects linked to the private information or to a small circle of possible subjects for each key identifier. Examples of *Dd* are the locations of domestic violence events and addresses of cancer patients. In both these cases, subjects can be identified as a person living at the disclosed location. As with all the data types discussed here, we assume that the data holder can interpret the data because they are aware of the contextual information that defines the search (e.g., "this is a collection of addresses of cancer patients").

A second data type is *'discrete location data with covariates,'* hereafter referred to as *Dd* + . The "+" symbol extends the notion of *Dd* by including additional attributes. The additional attributes are one or more quasi-identifiers. Quasi-identifiers are demographic, social, or economic attributes. A private attribute may or may not be present. An example of *Dd* + is a crime dataset of locations of offences (key identifier), the age of the victim (quasi-identifier), the ethnicity of the victim (quasi-identifier), and the type of the offence (private attribute). The location of offence is a key identifier, at least for that subset of the data collection where the type of offence occurs predominantly in residential addresses.

An inference attack on *Dd* and *Dd* + data types aims to identify (or re-engineer) the location of some subject(s). The data may not be disclosed but presented as a printed or a digital map. Such media can be geoprocessed to re-engineer the locations with considerable accuracy (Brownstein et al. 2006; Leitner et al. 2007). Multiple anonymized copies of the data can be disclosed, accompanied by specifications of the anonymization technique, for instance, for scientific transparency and reproducibility. This can provide hints to the attacker and, depending on the strength of the technique, locations can be re-engineered with the Gaussian blurring algorithm (Cassa et al. 2008).

A third data type is *'space-time data,'* hereafter referred to as *STd.* Data of this type contains location and timestamps for one or more subjects, which can be distinguished with a UID. Each location represents or approximates where a subject was at a particular time. Typical examples are call data records (CDR) and data used in location-based services (LBS). Unless the identity of the subject is known (e.g., when UIDs are real names), there is no key identifier or quasi-identifier. Nevertheless, the subjects' spatiotemporal whereabouts can be analyzed to draw a plethora of inferences such as their home address, work address, time spent away from work, and places visited during weekends (Alrayes and Abdelmoty 2014).

Gambs et al. (2010) analyzed GPS mobility traces of 90 taxi trails in San Francisco, US. They attempted to infer the home location of the drivers using a heuristic approach of the first and last recorded locations during working days. However, they did not have validation data to assess the accuracy of their approach. De Montjoye et al. (2013) focused on the uniqueness of spatiotemporal trajectories and analyzed mobility data from mobile phone interactions (calls and messengers) for approximately 1.5 million people. They found that four random locations are enough to uniquely characterize 95% of mobile users for a sample in which the location of a user is specified hourly, with a spatial resolution equal to that determined by the carrier's antennas.

The fourth and last data type is the *'space-time-attribute'* data, hereafter referred to as *STd* + . As with *Dd* + , the "+" symbol denotes an extended version of *STd*, which includes additional attributes that can be quasi-identifiers or private attributes. An example of *STd* + is the georeferenced data of a Twitter user. Twitter data contains spatial and temporal information as well as the short message text posted by the user. Inferences can be made similar to those for *STd*. Additionally, the textual or otherwise semantic information may reveal private matters about the sender such as interests, beliefs, and attitudes. For instance, Preoţiuc-Pietro and Cohn (2013) exploited the primary venue type in Foursquare check-ins (i.e., professional and other, travel and transport, residence, food, nightlife spots, university, outdoors, arts and entertainment, and shop and service) to cluster users by behavioral patterns and estimate their next activity based on the history of past venue visits. In another real-word but small-scale study, LBS network data of university volunteers was analyzed based on location similarity. Inferences were made to predict the users' demographics such as education level and gender (Li et al. 2018).

Participatory sensing data are data collected by volunteers, mainly for research, using mobile sensors such as biometric bracelets, smartwatches or smartphones. They include data from mobile devices such as sensors carried by 'humans as sensor operators,' sensors carried by 'humans as objective sensors,' and devices carried by 'humans as subjective sensors' (Kounadi and Resch 2018). Participatory sensing data are the *STd* + type. For example, participants in a participatory research campaign may use mobile apps that track their space-time information and report their level of stress (i.e., sensitive information) throughout their activity spaces (Zeile et al. 2011). In participatory sensing data, private attributes are observed or volunteered geoinformation whereas private attributes are also inferred geoinformation in LBS network data. Thus, due to the error of the inference process, the disclosure risk of LBS network data may be lower than that of participatory sensing data.

The four types of spatial data are illustrated in Fig. 25.1, where:

- $S_{1\ldots k}$ is the spatial attribute such as the coordinates, postal codes, or street addresses;
- $T_{1\ldots n}$ is the temporal attribute such as hour, date, or month; and
- $A_{1\ldots m}$ are quasi-identifiers and/or private attributes.

All spatial data types include a spatial attribute. Two of the data types contain a temporal attribute (*STd* and *STd* +) and two contain additional attributes (*Dd* + and *ST* +).

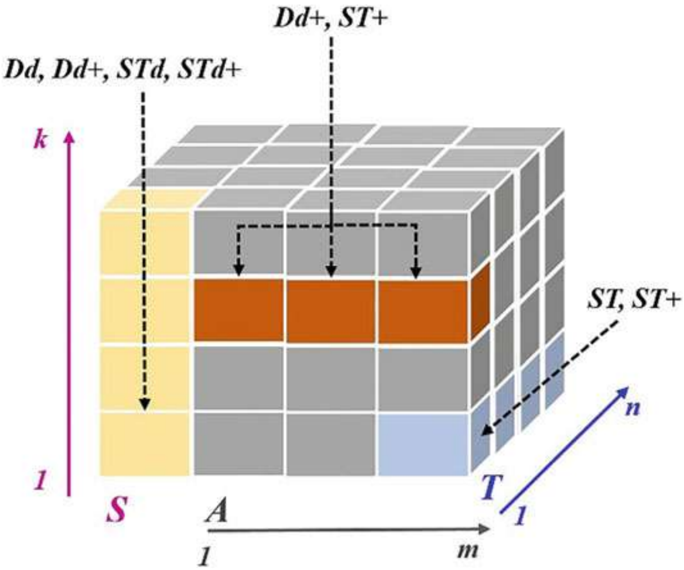

Fig. 25.1 Four spatial data types, Dd, Dd+, ST, ST+, and the types of attributes they contain (S, T, A)

25.3 A Typology for (Geo)Privacy

Privacy is always relational. It does not make sense for a lonely man on a desert island. At its simplest, privacy relates two parties—a human to a human, a human to a group of humans, a human to a private corporation or a human to a government institution. These relations can be arranged in a typology of (geo)privacy (Table 25.1). This grouping is a gross simplification of reality. For instance, LBS involve no less than thirteen human, machine and software parties—the mobile device, the hardware manufacturer, the operating system, the operating system manufacturer, the mobile application, the mobile application developer, the core application, the third-party software, the third-party software developer, the LBS, the LBS provider, the network operator and government (Herrmann 2016). Further, government institutions and private corporations often cooperate. The National Security Agency obtained direct access to the systems of Google, Facebook, Apple and other US Internet giants as part of the Prism program, which allows for officials to collect material including search history, the content of emails, file transfers and live chats (Greenwald and MacAskill 2013). Nevertheless, the four ideal types of relations help create a rough grid into which finer resolution grids may be inserted in future iterations.

At the heart of the typology is Alice. We may imagine her as a member of ACM who must comply with the ACM Code of Ethics or as a member of a (geo)computing department at a European university, which must comply with the GDPR. Alice values (geo)privacy as a positive right, a right that obliges action by individuals, groups,

Table 25.1 A typology of (geo)privacy relations

		Goal incongruity	
		Low(er)	*High(er)*
(Alice's) Ability to control human behavior, machine behavior, outputs	*Low(er)*	Cell (4) Alice—Government institution **Privacy strategy**: Compliance; lodge complaint to DPA in case of violation of the GDPR; anti-surveillance resistance	Cell (3) Alice—Private corporation **Privacy strategy**: Control behavior of corporation (via GDPR); lodge complaint to DPA in case of violation of the GDPR
	High(er)	Cell (1) Alice—Bob **Privacy strategy**: Right and duty of partial display	Cell (2) Alice–(Bob–Carol–Dan-etc.) **Privacy strategy**: Geoprivacy by design

or institutions to determine for themselves when, how, and to what extent information about them is communicated to others (Westin 1967). To transfer from Westin's times to the information age, Alice values privacy as the positive right of individuals, groups, or institutions *"to control the life cycle (especially the generation, access, recording, and usage) of their information and determine when, how, and to what extent their information is processed by others"* (Floridi 2014, p. 114). The relationality of privacy highlights the possibility that the privacy goals of two binary parties can be incongruous and results in the horizontal dimension of the typology in Table 25.1. Incongruity can be low or high. The vertical dimension refers to Alice's ability to control the transformation process of her volunteered, observed or inferred information or that of her research subjects. Her ability is high when she can control the entire transformation process—the behavior of humans (incl. herself) and machines and outputs. It is low when she can control some or none of these (Ouchi 1979; Ciborra 1985). Alice's ability (low or high) to control the transformation process results in the vertical dimension in Table 25.1.

In Cell (1), two humans (Alice and Bob) are interacting face-to-face in a private or public space. This is the archetypal human-to-human interaction. Both Alice and Bob are conscious of being observed by each other and other humans and have similar privacy goals—to uphold a tacit social code, the *'right and duty of partial display.'* The sociologist Erving Goffman (1957) described how all humans reveal personal information selectively to uphold this code while constructing their public personae. Hence, the low incongruity between Alice's and Bob's goals to protect their privacy—both strive to uphold this tacit social code, to protect (or curate) their public personae, and modulate it gradually over time, as the relation expands or shrinks. As Fried (1968) explains, Alice may not mind that Bob knows a general fact about her but may feel her privacy is invaded if he knows the details. For instance, Bob may comfortably know that Alice is sick, but it would violate her privacy if he knew the nature of the illness. If Bob is a good friend, he may know what particular illness Alice is suffering from but it would violate her privacy if he were actually to witness her suffering. Both control their behavior and the knowledge they share (outputs) about each other and may choose to modulate them over time. Goffman's theory applies in settings where participants can see one another face-to-face and has implications for technology-mediated interactions, e.g., in email security (Agre and Rotenberg 1997). When emailing each other, Alice and Bob may choose from a continuum of strategies to safeguard their privacy depending on context. They may refrain from emailing, they may email each other but self-censor, they may delegate privacy protection to mail encryption and firewalls, or they can work socially and organizationally to ensure that members of their community understand and police norms about privacy (Bowker et al. 2010).

Cell (2) describes the interaction of a human, e.g., Alice, the research leader of a participatory sensing campaign, with a group of campaign participants (Bob, Carol, Dan, Eric, etc.).

The goal incongruity between Alice and the group may be high if the group members are not aware of possible breaches to their privacy and their implications. As campaign leader, Alice has a high ability to control outputs and the behaviors of group members and machines and takes a series of privacy-preserving measures for the entire group before, during and after the campaign, a strategy Kounadi and Resch (2018) call *'geoprivacy by design.'* Kounadi and Resch (2018) propose detailed privacy-preserving measures in four categories, namely, 6 measures prior to the start of a research survey, 4 measures for ensuring secure and safe settings, 9 measures for processing and analysis of collected data, and 24 measures for safe disclosure of datasets and research deliverables. Table 25.2 provides illustrative examples in each category. Interestingly, measures to control human behavior include two subtypes:

Table 25.2 Examples of measures that control the transformation process

	Measures controlling human/machine behavior and outputs
Prior to start of campaign	human behavior (participation agreement, informed consent, institutional approval); outputs (defined criteria of access to restricted data)
Security and safe settings	human behavior (assigned privacy manager, trained data collectors); machine behavior (ensuring secure sensing devices, ensuring a secure IT system)
Processing and analysis	outputs (deletion of data from sensing devices, removal of identifiers from data set)
Safe disclosure	outputs (reduction of spatial and temporal precision, consideration of alternatives to point maps) human behavior (providing contact information, using disclaimers, avoiding the release of multiple versions of anonymized data, avoiding the disclosure of anonymization metadata, planning a mandatory licensing agreement, authenticating data requestors)

outreach measures, e.g., participation agreements, and measures of self-restraint, e.g., the use of disclaimers, avoiding release.

Cell (3) describes the interaction of Alice with a private corporation, as a user of a location-based service, of which Google Maps is the most popular and commonly used. Alice *volunteers* her location to the LBS to get directions to a desired destination (Herrmann 2016). In this case, the goal incongruity between Google and Alice is high, as evident from comparing Alice's commitment to (geo)privacy with that of Google's former executive chair Eric Schmidt. *"If you have something that you don't want anyone to know, maybe you shouldn't be doing it in the first place"* (Newman 2009). Alice's ability to control how her location information is used by LBS to infer other information about her is low. As an EU citizen, she can rely on the GDPR to (partly) control the behavior of the LBS provider. Another strategy is lodging a complaint to her national Data Protection Authority (DPA). DPAs are independent public authorities in each EU state that supervise application of the GDPR and handle complaints lodged concerning violations of GDPR. If the private corporation where Alice works systematically monitors its employees, including their workstations and Internet activity, a Data Protection Impact Assessment (DPIA) may be required.

Cell (4) describes the interaction of Alice with government institutions. Alice trusts that her government will respect her right to information privacy (thus the goal incongruity is low) but may be in the dark regarding the transformation process unless a whistleblower leaks a secret surveillance program (e.g., Greenwald and MacAskill 2013) or the abuse of private data (The Guardian 2018). Further, if the public organization where Alice works engages in processing that is likely to result in a high risk to the rights and freedoms of individuals, Alice may lodge a complaint to the DPA and request a DPIA. Such processing may include the systematic and extensive evaluation of personal aspects of an individual, including profiling, the processing of sensitive data on a large scale, or the systematic monitoring of public areas on a large scale.

Another strategy for Alice is collective, e.g., participating in popular resistance to unpopular government action. When the government of the Federal Republic of Germany announced a national census on 27th April 1983, German citizens protested so strongly that a dismayed German government had to comply with the Federal Constitutional Court's order to stop the process and take into account several restrictions imposed by the Court in future censuses. Asking the public for personal information in 1983, the fiftieth anniversary of the National Socialists' ascent to power, was apparently bad timing, to say the least (Der Spiegel 1983). When the census was finally conducted in 1987, thousands of citizens boycotted (overt resistance) or sabotaged (covert resistance) what they perceived as Orwellian state surveillance (Der Spiegel 1987).

Notably, these remarkable events took place in an era where the government was the only legitimate collector of data at such a massive, nationwide scale and at a great cost (approx. one billion German marks). Currently, state and corporate surveillance are deeply entangled. In response, technologically savvy digital rights activists have been influential in several venues, including the Internet Engineering Task Force (IETF) and the Internet Corporation for Assigned Names and Numbers

(ICANN), through the Noncommercial User Constituency (NCUC) caucus. However, their efforts have largely remained within a community of technical experts ('tech justice') with little integration with 'social justice' activists (Dencik et al. 2016).

25.4 Measures to Preserve Geoprivacy

In Sect. 25.2, we characterized various data types that deserve specific scrutiny when privacy is concerned. This characterization was motivated by the perspective of a variety of attackers' strategies (either theoretically possible or practically realized) to identify private information on a subject. Below, we describe geoprivacy-preserving measures to counter such attacks. Section 25.3 highlighted the relationality of privacy and described the four fundamental relations that are critical to understanding privacy as a societal phenomenon. In real life, the social graph is not bipartite and humans cannot be bluntly labeled as either 'attacked' or 'attacker'. Relations are often transitive and privacy-relevant information may travel along longer paths, which implies that intermediate agents may have dual, possibly frictional, roles. One rather regulated, yet much-discussed case, is that of patients whose hospital visits are covered by health insurance companies. Geoprivacy may be related to the living or working conditions of the patient. The patient's typical direct relation with the insurance company does not make this case less trivial. A second example that played out recently in the Netherlands was that of a citizen with a tax dispute, and the national museum foundation that had issued an annual pass to that person (van Lieshout 2018). The tax office accessed the person's museum visit details to prove that he actually lived in the Netherlands, and not abroad, as he claimed.

To identify core geoprivacy measures, we must define the landscape of variables and the values they take, and explore their interrelationships. Six *fundamental variables* are discussed below, along with their values, and are summarized in Table 25.3. The first variable is the 'attacked', who is any subject in a dataset that may be harmed from potential inferences. The attacked is an individual such as Alice—i.e., aware of privacy risks and subscribing to the ACM code of Ethics—or someone who is unaware of privacy risks and relevant legislation and regulations. The second variable is the *'attacker'*, who could use the data for a malevolent purpose. The attacker may be a government institution, corporation, researcher, or other individual. The third variable is the *'data type'*, any of the four types discussed in Sect. 25.2 (i.e., *Dd*, *Dd*+, *STd*, or *STd* +). The fourth variable is the *'purpose of attack'*, which may assume two values: (a) private attribute(s) of the attacked are identified (attribute(s) is unknown but the attacked is known) and (b) the attacked who has certain private attribute(s) is identified (attacked is unknown but the attribute(s) is known). In attacks of the first category, the attacker knows that the attacked's details are contained in a dataset and the attacker aims to draw inferences on the attacked. In those of the second category, the attacker knows the private information and aims to infer the identity of the attacked.

Table 25.3 Fundamental geoprivacy variables and their associated values

Variable	Values
Attacked	1. Any individual
Attacker	2. Government/Institution 3. Corporation 4. Researcher 5. Any individual
Spatial data types	1. Discrete location data (*Dd*) 2. Discrete location data with covariates (*Dd*+) 3. Space-time data (*STd*) 4. Space-time-attribute data (*STd*+)
Purpose of attack	1. Identify private attribute(s) of the attacked 2. Identify the attacked who has certain private attribute(s)
Attacker's strategy	1. Key-identifier exploitation 2. Combine to uniqueness 3. Re-engineering locations 4. Analyzing locations 5. Homogeneity attack 6. Background attack 7. Composition attack
Privacy-preserving measures	1. Pseudoanonymity 2. K-anonymity 3. Spatial *k*-anonymity 4. *l*-diversity 5. Differential privacy

We have used terminology from Sects. 25.2 and 25.3 to define four of the six fundamental variables. Two more variables in the geoprivacy landscape are discussed next. The fifth is the *'attacker's strategy'* (also referred to as "*inference attacks*") that can take seven forms: (a) key-identifier exploitation, (b) combine to uniqueness, (c) re-engineering locations, (d) analyzing locations, (e) homogeneity attack, (f) background attack, and (g) composition attack.

The simplest type of inference is *key-identifier exploitation*. It requires the presence of key identifiers in the dataset. The accuracy of such inferences range from low to high depending on the relationship type that the data represents (i.e., one-to-many or one-to-one). For example, a location representing a block of flats links it to many households (and even more people) whereas an address in a single-family residential area only links the location to a small number of family members. Other key identifiers represent a strict one-to-one relationship (e.g., a fingerprint or iris scan). Datasets collected by a governmental institution are more likely to contain such key identifiers, while subjects such as Alice have little control over the inferences that the institution can draw about them.

Individuals may be identified if the data comprise a combination of quasi-identifiers in the dataset that allows for the unique identification of subjects (i.e., *combine to uniqueness*). Unlike pseudonyms, quasi-identifiers are real attributes such as sex and age, which can be further processed or linked to external data to disclose the subject's identity. Such disclosure may occur if hospitals share their medical records with governmental institutions such as a country's census bureau (Cell (4) relation). A hypothetical *Dd* + contains attributes such as the date of visit, age, gender, occupation, municipality of residence, and final diagnosis. A data analyst from the census bureau can identify a unique combination of quasi-identifiers in which there is a visitor diagnosed with a given disease who is male, lives in a known municipality, and has a known professional occupation. The combination of such facts in a certain municipality may lead to unique subject identification with a simple Internet search. However, only a fraction of the subjects may be identified in this way.

As explained in Sect. 25.2, in examples regarding *Dd* and *Dd* +, *re-engineering of locations* is performed using geoprocessing and spatial analysis techniques. When these locations represent private information, re-engineering of location implies identification of the attacked. For example, a researcher publishes a map of the distribution of pregnant teenagers in a study area as dots on a map (a Cell (2) relation). The map is georeferenced to a known coordinate system, and the dots are digitized as circles. Then, the centroid of each circle can be extracted as a single location. Geocoding can be used to reveal the addresses of the studied teenagers.

The analysis of locations of individuals may yield various inferences including the location of their home, which is a key identifier for a data subject. When key identifiers are inferred or re-engineered, the risk of identification is typically lower than when the key identifier is available in the dataset because of possible errors and inaccuracy in the inferencing processes. For example, an LBS stores the time and location of all user service requests (a Cell (3) relation). An attacker who has access to data on service requests may wish to infer the home locations of the users. First, the attacker excludes all service requests during working hours and weekends and splits the dataset by user. The remaining datasets represent sets of possible home locations for each user—requests sent at night and during weekdays, where people are more likely to be at home. The following analysis may be repeated for each user separately: (a) apply spatial clustering and identify the cluster with the highest density and (b) extract the point with the smallest accumulated distance to all other points (i.e., a point set centroid) within the highest density cluster. The extracted point is inferred as the home location of the user.

Anonymized data may disclose information if they yield homogeneous groups of subjects regarding their private attributes. This strategy is referred to as a *homogeneity attack* and requires that a dataset (either in its current form or after processing) includes a private attribute of categorical or ratio scale. For example, a researcher collects Twitter data during a three-month period (a Cell 2 relation). The home location of subjects is estimated using spatial analysis and the subjects' political preference (i.e., a categorical private attribute) is inferred using natural language processing and machine learning techniques. The researcher publishes the dataset in anonymized form, aggregating the home locations to zip code, including the political preference, and excluding all Twitter-relevant information (e.g., account names). An attacker knows a subject who uses Twitter frequently and where this person lives. However, all records associated with the zip code of the subject display a single political preference. Thus, that subject's political preference is disclosed due to a lack of diversity in the private attribute.

A *background attack* is possible when an attacker has knowledge (in the form of background information) on the distribution of a private attribute. For instance, mobile operators collect call data records that contain the location, time and a user identifier for each call (a random UID distinguishes users) (a Cell (3) relation). The operator can apply spatiotemporal analytics to infer the most visited venue during weekends for each subject. Anonymized copies of the data may be shared with another corporation for advertising purposes. The operator may have aggregated subject home locations by zip code (the home location is already known to the operator because of contract information), and may include visited venues during weekends in addition to other information. An attacker from the corporation knows that a subject is in the dataset and may know their home address. In the records of the zip code of the known person, it is possible that four different restaurants are revealed as frequently visited. The attacker knows that due to the subject's religion, three out of the four restaurants are unlikely. Thus, private information about the user is disclosed using background information.

The term *composition attack* refers to a privacy breach that occurs when exploiting independent anonymized datasets from different sources that involve overlapping subject populations (Ganta et al. 2008). A composition attack may build on the attacker's knowledge about a subject or the distribution of the private attribute and relies on the existence of further sources of auxiliary information. For example, in the mobile operator case, a subject may visit only two restaurants due to their eating habits. The data may have been anonymized to include the zip code and the most visited venues during weekends. Because the attacker also possesses Foursquare check-in data and knows that the subject is a frequent Foursquare user, they can search the venue results within the subject's zip code. There may be six distinct venues in the second dataset but only one appears in both datasets for the same zip code, and so the most visited venue by the attacked during weekends is disclosed.

The sixth variable is the *'privacy-preserving measures'* that mitigate an attack strategy by controlling the final digital outputs (Table 25.3). Data holders with full control of the transformation process may apply various privacy-preserving measures. Alice, as a sophisticated attacked, should consider the attacker's strategies and the privacy-preserving measures and intervene in her outputs by controlling, blurring, or censoring her digital behavior. The degree to which this is possible depends on her ability to control the transformation process (see Table 25.1). Next, we discuss five measures at her disposal, namely, (a) pseudonymity, (b) k-anonymity, (c) spatial k-anonymity, (d) l-diversity, and (e) differential privacy.

Pseudonymity is the use of pseudonyms as identifiers (or as key identifiers) (Pfitzmann and Köhntopp 2001). Unlinked pseudonyms are fake identities associated with data subjects. A pseudonym can be used to permit a subject's distinguishability, such as a UID as a random number. If distinguishability is not needed, given the use forms of the data, all key identifiers should be removed. However, if we consider that the attacker can apply strategies beyond *key identifier exploitation*, such as *combine to uniqueness,* pseudonymity mitigates but does not eliminate disclosure risk. *Combine* *to uniqueness* can be prevented with *k-anonymity*, which ensures that any subject is a member of a group of size k with the same values of the quasi-identifiers (Samarati and Sweeney 1998). Thus, a *key-identifier exploitation* attack is mitigated by a k level of anonymity. The larger the k, the more difficult it is to identify a subject.

A similar measure to k-anonymity is *spatial k-anonymity*, in which a location cannot be distinguished among k-1 other locations. This can mitigate the risk from analyzing locations, and its application varies depending on the data type. For example, to prevent re-engineering from a *Dd*, every location should be an approximation of k locations (such as residential addresses) within an area. In this case, randomly displacing residential addresses based on some uniform distribution is preferable over a normal distribution because the latter may provide hints to potential attackers (see Sect. 25.2). To prevent the inference of home locations from an *STd*, each subject's location should ambiguously map information to at least k other subjects for every moment in time. This approach can be done by decreasing the spatial resolution.

Machanavajjhala et al. (2006) showed that k-anonymity mitigates but does not prevent identification due to homogeneity and background attacks. The authors proposed the *l-diversity* privacy measure, which requires a k-anonymous dataset to have at least l 'well-represented' values for the *private* attributes in each equivalence class. The characteristic l is the minimum number of times a value of a private attribute appears in a dataset. The last measure is *differential privacy*, which guarantees that any disclosure from the data does not change significantly due to the absence or presence of a subject in the database (Dwork 2006). *Differential privacy* returns answers to aggregate queries and, according to Ganta et al. (2008), certain variations of the measure may satisfy conditions to prevent *composition attacks*.

25.5 Toward a Sociocultural Understanding of Privacy

In the previous sections, we explored the *Ethics of Where* from the point of view of Alice, an individual complying with the ACM Code of Ethics and/or the rules of a GDPR-compliant European university. Alice's technological sophistication enables her to control (part of) the transformation process (from volunteered/observed to inferred information) and preserve her privacy from attackers (Table 25.3), as well as the privacy of her research subjects (Table 25.2). Her knowledge of GDPR legislation reassures her that the behavior of corporations and government institutions is controlled by law and enforced by sanctions. GDPR instruments (e.g., DPIA) enable her to lodge complaints to preserve her privacy as a private or public sector employee. She may tackle perceived privacy breaches of the data protection legislation by alerting her representative in the legislature, by joining a collective movement of peaceful protest or by bringing a case of privacy violation to a court of law, as in *Kyllo v. United States*.

In the future, we should tackle privacy at the sociocultural level, starting from a basic premise in social theory, as Alice's (privacy) preferences and commitments are shaped by and shape the culture of her community and society (Georgiadou et al.

2019). Her individual preferences and the culture—i.e., the shared beliefs, attitudes, way of life, or world view—of the community or society in which she is socialized are deeply enmeshed and mutually reinforcing, and there is no way to determine the dependent and independent variables. This means that we should consider privacy a social construction to account for the substantial differences in social organization in countries around the world, each with different preferred ways of social organizing and different attitudes to privacy. We may distinguish four ideal types of social organizing—individualist, hierarchist, egalitarian, or fatalistic (Douglas and Wildavsky 1983). Each type is supported by (and supports) a 'cultural bias': a compatible pattern of perceiving, justifying, and reasoning about nature, human nature, justice, risk, blame, and privacy. These ideal types do not exist in unadulterated form, but can help us identify which hybrids may be most effective in which institutional settings, and how these hybrids change over time.

Individualists tend to frame information privacy as a product that can be exchanged in the marketplace for a fair price. An excellent recent example of this approach is the advocacy of the GenerationLibre think tank (Laurent 2018) to extend the private property paradigm to personal data. GenerationLibre aspires to change the way the digital ecosystem works by giving user-producers: *"(1) The possibility for e-citizens to negotiate and conclude contracts with the platforms (possibly* via *intermediaries) regarding the use of their personal data, so that they can decide for themselves which use they wish to make of them; (2) The ability to monetise these data (or not) according to the terms of the contract (which could include licensing, leasing,* etc.*); (3)The ability, conversely, to pay the price of the service provided by the platforms without giving away our data (the price of privacy?)"* (p. 7).

Hierarchists may be willing to surrender some of their privacy to a legal/rational authority (e.g., government) they trust in exchange for another public good they value, e.g., security or economic growth. The Chairperson of the German Social Democratic Party (SPD), Andrea Nahles (2018), framed the problem: *"Empires like Google and Amazon cannot be beaten from below. No start-up can compete with their data power and cash. If you are lucky, one of the big Internet whales will swallow your company. If you are unlucky, your ideas will be copied."* Her solution is a Data-for-all law: *"The dividends of the digital economy must benefit the whole society. An important step in this direction: we [the state] must set limits to the internet giants if they violate the principles of our social market economy. […] A new data-for-all law could offer decisive leverage: As soon as an Internet Company achieves a market share above a fixed threshold for a certain time period, it will be required to share a representative, anonymized part of their data sets with the public. With this data other companies or start-ups can develop their own ideas and bring their own products to the market place. In this setting the data are not "owned" exclusively by e.g. Google, but belong to the general public."* However, as Morozov (2018) argues, Nahles' agenda *"needs to overcome a great obstacle: citizens' failing trust in the state as a vehicle of advancing their interests,"* especially in a country such as Germany with a long history of data privacy activism.

Morozov (2018) argues for an egalitarian approach to privacy as constitutive of who we are and as radical citizen empowerment. *"We should not balk at proposing* *ambitious political reforms to go along with their new data ownership regime. These must openly acknowledge that the most meaningful scale at which a radical change in democratic political culture can occur today is not the nation state, as some on the left and the right are prone to believe, but, rather the city. The city is a symbol of outward-looking cosmopolitanism–a potent answer to the homogeneity and insularity of the nation state. Today it is the only place where the idea of exerting meaningful democratic control over one's life, however trivial the problem, is still viable."* Similarly, the Oxford-based *Digital Rights to the City* group proposes a deeper meaning to the right to information that amounts to the declaration that *"we will no longer let our information be produced and managed for us [presumably by the state or corporations], we will produce and manage our information ourselves"* (Shaw and Graham 2017). Fatalists are those persuaded by the abovementioned slogans *"you have zero privacy…get over it"* or *"if you have something that you don't want anyone to know, maybe you shouldn't be doing it in the first place."* However, as Snowden said, *"arguing that you don't care about the right to privacy because you have nothing to hide is no different than saying you don't care about free speech because you have nothing to say"* (Reddit 2015).

25.6 Toward Digital Earth Ethics: The Ethics of Where

In the previous sections, we mentioned privacy arrangements in the legal systems of two polities—the United States and the European Union—a serious limitation in a chapter on Digital Earth Ethics that encompasses the entire planet. However, it is possible to see how privacy is dealt with differently in these two cases. The word privacy is not mentioned in the US Constitution except indirectly in the Fourth Amendment, which protects the right of people to be secure in their persons, houses, papers, and effects against unreasonable searches and seizures. In contrast, in the European Union, privacy is a human right according to Article 8 of the European Convention on Human Rights: a *"right to respect for private and family life, home and correspondence."* This is largely due to the events around World War II, where personal information was often used to target individuals and groups and facilitate genocide. In 2018, we witnessed a serious shake-up of the treatment of privacy, data protection, and cybersecurity by legal systems around the world. The EU's GDPR, put in place in 2018, is a landmark development for privacy and how we perceive it. In this transitional period, a number of countries seem to follow a similar pathway as the GDPR: for instance, Canada, Japan, and India are looking at comparable extraterritorial privacy regimes. A common denominator between them is privacy as a constitutional right. Similar legislative developments are manifesting in China and the African continent.

In China, the Cybersecurity Law, the most important Internet legislation to be passed in the country thus far, came into effect on June 1, 2017. The law is intended to align China with global best practices for cybersecurity. Network operators must store select data within China and Chinese authorities may conduct spot-checks on a company's network operations. *"The Cybersecurity Law provides citizens with an unprecedented amount of protection to ensure their data privacy. The law defines "personal information" as information that can be used on its own or in conjunction with other information to determine the identity of a natural person, including but not limited to a person's name, birthday, identity card number, biological identification information, address, and telephone number. In other words, once such information is de-identified, it will no longer be subject to the requirement for personal information in the Cybersecurity Law"* (Lee 2018, p. 87). Other countries such as Korea and Singapore are less decided and may be consciously delaying their legislative moves until the scene becomes clearer.

In the African continent, approximately 40% of the countries have enacted data protection legislation that abides the OECD standards (1st generation), the EU DPD 1995 standards (2nd generation), or even features GDPR elements (3rd generation). The latter refers to Mauritius, one of Africa's dynamic but small economies, which updated its 2004 law in 2017 with a new Data Protection Act 2017 featuring elements of the GDPR. In June 2014, the African Union (AU) adopted the Convention on Cyber Security and Personal Data Protection, known as the Malabo Convention, the first treaty outside the EU to regulate the protection of personal data at a continental level. The Convention aims to establish regional and national legal frameworks for cybersecurity, electronic transactions and personal data protection, but its actual impact will depend on ratifications, which had not occurred by early 2016. In 2018, the AU created data protection guidelines that are broadly aligned with the GDPR for its Member States, with contributions from regional and global privacy experts including industry privacy specialists, academics and civil society groups (Georgiadou et al. 2019). On a global scale, there is a substantial imbalance in sensitive data flows, with mostly American Internet tech companies sourcing data globally. This imbalance is the substrate for a continuation of developments in technology, the legal scenery and contractual arrangements that we do not expect to be settled soon. Unfortunately, privacy and data protection as global goods intersect with cybersecurity and counterterrorism, which gives little hope for transparency and focus on solutions. Nevertheless, we should follow these developments closely (Raul 2018).

In addition to legislative efforts, global and regional institutions are busy developing ethical principles and guidelines. The *UNESCO Declaration of Ethical Principles in relation to Climate Change* addresses the responsibility to overcome the challenges and reinforces ethics at the center of the discussion on climate change. Member states have mandated UNESCO with promoting ethical science: science that shares the benefits of progress for all, protects the planet from ecological collapse and creates a solid basis for peaceful cooperation. The *Global Ethics Observatory (GEObs)*, a system of databases with worldwide coverage in bioethics and environmental ethics, science ethics, and technology ethics, helps researchers identify Who's Who in Ethics, Ethics Institutions, Ethics Teaching Programs, Ethics-Related Legislation and Guidelines, Codes of Conduct and Resources in Ethics. Other global actors in the responsible data movement, e.g., UN Global Pulse (2017), Red Cross/Red Crescent 510 (2018) and UNOCHA (2019), also develop data ethics guidelines as a cornerstone of their groundwork.

At the European Union level, the *High-Level Expert Group on Artificial Intelligence (AI HLEG)* proposed the first draft AI ethics guidelines to the European Commission in December 2018. These cover issues such as fairness, safety, transparency, the future of work, democracy and the impacts of application of the Charter of Fundamental Rights, including privacy and personal data protection, dignity, consumer protection and nondiscrimination. The *European Group on Ethics in Science and New Technologies (EGE)* provides the Commission with high-quality, independent advice on ethical aspects of science and new technologies in relation to EU legislation or policies. The EGE is an independent advisory body founded in 1991 and is tasked with integrating ethics at the international level, at the interinstitutional level with the European Parliament and the Council, and within the Commission itself. The *European Union Agency for Fundamental Rights (FRA)* is the EU's center of fundamental rights expertise. It helps ensure that the fundamental rights of people living in the EU are protected. Fundamental rights set minimum standards to ensure that a person is treated with dignity. The Agency seeks to instill a fundamental rights culture across the EU by collecting pertinent and timely data and information, by sharing evidence-based insights and advice with policy- and decision-makers, by raising rights awareness and promoting fundamental rights through cutting-edge communications, and by engaging with a wide array of diverse stakeholders from local and international levels.

However, requiring global and regional guidelines and principles to conceptualize ethics and privacy across diverse cultural and political contexts and to substitute for lacking or existing weakly enforced legislation (Taylor 2017) may further deplete local institutional capacity and harm citizens. The question of how to improve digital data flows between local and global institutions while maximizing the use of innovative geospatial technologies and protecting citizens' rights as well as local institutions is particularly relevant in view of the increasing use of artificial geospatial intelligence, mobile technology and social media to extract information about individuals and communities.

Finally, legal and social strategies and privacy-preserving technological measures should form the backbone of university curricula for students and working professionals. The advent of the GDPR in 2018 created a sudden educational demand for university courses, of which the massive open online course (MOOC) *'Privacy by Design and GDPR'*, designed by computer scientists at Karlstad University in Sweden, is a recent EU-focused example (Fischer-Hübner et al. 2018). The educational challenge is to gradually expand the content of such courses for a global audience of students from countries with emergent privacy and data protection legal frameworks, different understandings of privacy and different social organization as well as different levels of technological sophistication in countering privacy attacks, because *The Ethics of Where* should eventually be everywhere.

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Chapter 26
Digital Earth Challenges and Future Trends

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Abstract The previous 25 chapters introduced relevant technologies, applications, and other topics related to Digital Earth. Respective challenges and future research were also proposed by various authors. In this concluding chapter, we briefly review Digital Earth past and present, followed by a set of challenges and future trends, speculating on how Digital Earth may evolve over the coming years. Such challenges and trends are discussed in the context of science drivers, technological advances, application adoption, and relevant virtual—physical community building.

Keywords Geoscience · Big Data · Sustainable development · Climate change

26.1 Introduction

As mentioned in the introductory chapter, the concept of Digital Earth was first coined in Al Gore's book entitled "*Earth in the Balance*" (Gore 1992), and was further developed in a speech written for delivery by Gore at the opening of the

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California Science Center in 1998 (Gore 1998). And then the First International Symposium on Digital Earth was held in Beijing in 1999 (ISDE 1999). Since then, the symposium has been held every two years, and the International Society of Digital Earth (ISDE) registered in Beijing in 2006. With the establishment of the Society, rapid progress was made. The Society launched the *International Journal of Digital Earth* (IJDE) in 2008, and this journal was accepted by the Science Citation Index after only 18 months of existence. Started as a quarterly journal, it is now published twelve times a year, with almost 100 scientific papers being published per year. The *Big Earth Data* open-access journal was also established in 2017 to further advance the data aspect of Digital Earth. Now the Society organizes, besides its flagship event of the biannual symposium, a series of summits, which focus on a narrower set of topics and issues. The Society has now established several national and regional chapters and a national committee around the world, and more will no doubt follow over the coming years. Moreover, ISDE has become a Participating Organization Member of the Group on Earth Observations (GEO) and an Affiliated Member of the International Science Council (ISC) since 2009 and 2017, respectively. Also ISDE has been accepted as a new member of the United Nations Committee of Experts on Global Geospatial Information Management—Geospatial Societies (UN-GGIM GS) in August 2019.

By analyzing the Google and Web of Science (SCI-E) academic indexing systems, we found that: a) Google Scholar has indexed ~20,000 publications since 1992 on "Digital Earth" with a steady annual increase, and b) a more restrictive search of the Web of Science using "Digital Earth" as the topic and as all fields returned values of 553 (left of Fig. 26.1) and 6669 (right of Fig. 26.1), respectively (as of May 26, 2019). Publication numbers jumped during 2008−2010 when IJDE was officially launched and when it received the first SCI-E impact factor. The diversity of research

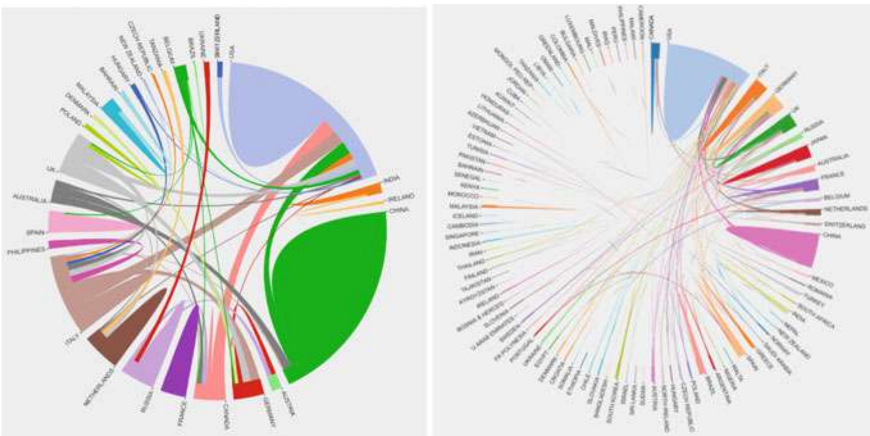

Fig. 26.1 Digital Earth research came from many countries in the world. The area shown for each country corresponds to its percentage contribution, and the linkages show the collaborations between different countries. China and the U.S. are in the top tier, with many cross-country collaborations

activities is reflected in the worldwide distribution, which has engaged all developed countries and many developing countries, with the U.S. and China as the top-tier contributors (Fig. 26.1). The collaboration between different countries also signifies the internationalization of the Digital Earth effort.

In the remainder of this chapter, we will look at a selection of the major challenges the Society will face, plus we shall do some crystal-ball gazing, and speculate on some of the major new trends in Digital Earth research over the coming years.

26.2 Major Challenges for Digital Earth

26.2.1 Big Data Management in Digital Earth

In discussing the challenges highlighted in earlier chapters of this manual, the authors have demonstrated the tremendous volume, variety, veracity, and velocity (the four Vs) challenges for Big Earth Data (Guo et al. 2017; Yang et al. 2017). The four Vs impose new requirements on computing, data management, information extraction, and knowledge discovery, as well as the detection of events of interest, needed to realize the value (the fifth V) of Big Earth Data for Earth science and applications (Guo et al. 2014; Lee and Kang 2015; Shu 2016;Yang et al. 2019).

According to Filchev et al. (2018), up to 95% of the Earth observation (EO) data present in existing archives has never been accessed, so the potential for increasing exploitation is very large. Many satellite agencies are now changing their data archive holdings to cloud-based or hybrid storage. Maintaining the balance of cost, usage, transmission, and analytical services in the cloud is quite a challenge (Yang et al. 2017).

In the new era of Big Earth Data, geoscience can only achieve its full potential through the fusion of diverse Earth observations and socio-economic data, together with additional information from a vast range of sources. Such data sources include observations obtained at different spectral and spatiotemporal resolutions, and observations from different platforms (e.g., satellite and in situ), orbits, and sensors, the Internet of Things, and also unmanned autonomous vehicles (UAVs) (Pohl and van Genderen 2014). Fusion, given the variety, veracity, and velocity challenges of the data, is only possible with well-designed architectures, reference systems, and standards. Hence, image and data fusion methods will require new and creative solutions to meet the needs of the next generation of Digital Earth, where social science aspects such as volunteered information, citizen science (public participation in scientific research), etc., will need to be fused with Earth observation data from space, air, ground, and subsurface (Pohl and van Genderen 2017). There are still many issues to be resolved first, such as how to ensure that data found in multiple data systems agree with one another. Accuracy of the data and information, currency, and reliability are all aspects likely to be investigated over the coming years in this field of image, data, and information fusion.

A major challenge for the next generation of Digital Earth is that of common standards for transforming the increasingly massive amounts of data (Bermudez 2017). The new Discrete Global Grid System (DGGS) specification of the Open Geospatial Consortium (OGC) provides a concrete way of addressing this challenge, but only addresses the spatial aspect; how the other aspects of orbits, sensors, and spectral and temporal resolution should be standardized still presents a challenge. These issues may demonstrate a path forward towards the realization of the "Digital Twin"—where our engagement and understanding of the physical Earth can seamlessly interact with the Digital Earth, and vice versa (see 5.1 in Chap. 2). Flexible solutions are also needed in the area of the Internet of Things (IoT) for, whilst many government and private organizations are starting to implement IoT solutions, developing an appropriate vision where things will work together, seamlessly and reliably is still a huge challenge (see Chap. 11).

As detailed in Chaps. 6 and 9, addressing the four Vs of Big Earth Data in order to obtain actionable information for end users is computationally intensive (Yang et al. 2008). Utilizing cutting-edge computing is desirable, and how to coordinate the process is a significant challenge. Cloud computing has been adopted in the past few years to address challenges and relevant issues (Yang and Huang 2013). GPU, MPI, Quantum, Edge, and Mobile computing may also assist Digital Earth computing. However, picking the best computing mode and transitioning between different computing modes to best leverage each of them for specific Digital Earth tasks is also still quite a challenge (Yang et al. 2013).

26.2.2 Large-Scale Digital Earth Platform Implementation and Construction

A major challenge for Digital Earth over the coming years will be to develop a new generation of Digital Earth science platforms in order to provide a new impetus for interdisciplinary, cross-scale, macro-scientific discoveries in the era of Big Data and to make planet Earth more sustainable. As Digital Earth platforms use geospatial information infrastructures, the speed of technological progress is one of the main challenges facing the further development of Digital Earth.

It is generally recognised that DE can flourish only if supported by a robust computing infrastructure and good-quality data. As to data, we argue in favour of learning from successful Internet companies, opening access to data and developing interactivity with the users rather than just broadcasting data. By adopting this paradigm (known as Datafication), we can develop ecosystems of public administration, firms, and civil society, enriching the data to make it fit for AI applications responding to DE needs (Craglia et al. 2018).

The Australian 2026 Spatial Industry Transformation and Growth Agenda finds that the age of "viewing everything through an application lens is coming to an end". Instead, platform architectures will be selected primarily to cope with soaring volumes of data and the complexity of data management, not for their ability to support applications. In the report, the authors show how the Digital Earth approach uses a variety of Earth observation data, from the global to the local scale. By using quantitative spatial analysis methods, Digital Earth allows a deeper understanding of global-change mechanisms, allowing us to evaluate global change from the perspectives of regional responses and zonal characteristics caused by the Earth's rotation. Furthermore, the Digital Earth approach enables us to display and demonstrate the global-change mechanisms and their temporal effects, in order to better inform decision makers of potential regional and global schemes for environmental protection.

26.2.3 Strengthening Fundamental Research for Digital Earth

As an evolving discipline, Digital Earth needs the following questions to be answered: What is the basic theory of Digital Earth? What are its core characteristics? What is the difference between Digital Earth and geospatial technology? And what is the relationship between Digital Earth and Big Earth Data? (Guo 2018).

With the development of Digital Earth, it is necessary to gain a profound understanding and make an in-depth analysis of the expanding scope of the concept of Digital Earth, as well as the impacts of Digital Earth on the interdisciplinary sciences and social progress.

We should pay attention to cross-disciplinarily research in the fields of Earth science, information science, space science and related technologies to broaden the research directions of Digital Earth, and so further help Earth system research reach new heights.

We should realize that Digital Earth is becoming ever more relevant as the world undergoes a profound digital revolution. The increasing volume of data being amassed by Earth system science and geo-information science is prompting experts to investigate and experiment with highly automated and intelligent systems in order to extract information from enormous datasets, thus driving future innovative research that will greatly benefit from developments in Digital Earth technologies and systems (Guo 2017).

It should be realized that Digital Earth can help to bridge the information gap for the general public by integrating data and information from multiple sources including those from space, social networks, and economic data. By developing intelligent models and data-intensive computing algorithms, Digital Earth can generate useful information and scientific knowledge to support the functioning of social services.

As we enter this new age, Digital Earth has been endowed with the new mission of integrating natural and social sciences so that it can respond to the challenges of global sustainability, environmental change and digital economic society that human beings are facing. Digital Earth is being pushed towards contributing to the discovery of new knowledge that can support our understanding of the planet and enable us to live on it in a sustainable manner (Guo et al. 2014).

26.2.4 Developing an Ecosystem for Digital Earth

For the development of Digital Earth systems, an ecosystem should include scientists, engineers for implementation, and users, as well as applications that make use of the Digital Earth system services. Furthermore, new aspects such as privacy, security, education, and training, which have often been ignored in the past, should be put on the "to-do-list".

Many Digital Earth datasets, such as volunteered geographic information (Goodchild 2007), raise issues of privacy, security of business, intellectual merit, or intelligence. It is a big challenge to provide proper access to such data and to protect such information from misuse by unauthorized users. The adoption of a datafication approach (i.e., shifting the focus from data sharing to intelligence generation in a collaborative way) promises to address these challenges.

All the challenges relating to the future of Digital Earth, as described above, plus the many new opportunities and trends described below, will demand a large increase in the number of scientists, academics, and business professionals to be trained and educated in the Digital Earth concept in all its many facets; none more so than in the field of citizen science, as explained and shown in the education chapter of the Manual. Young people are the key to developing solutions to meet such challenges. Especially challenging for ISDE will be the need to attract younger researchers and post-graduate students to become involved in defining how Digital Earth moves forward.

26.2.5 Addressing Social Complexities

The increasing complexity of the Digital Earth system, and the engagement of an ever-increasing number of people in building and using the system, will require a sophisticated approach for leveraging advances in the relevant social and natural sciences, to facilitate a sustainable rate of progress (see Chap. 12 Social Media and Social Awareness). The challenges include cross-cultural and cross-jurisdiction boundaries, disparate languages, interdisciplinary gaps, and potential misunderstanding (Lane et al. 2009). The engagement of social media and citizen science in providing more real-time and social data also pose privacy and related concerns (see Chap. 18 on Citizen Science in Support of Digital Earth). Engendering trust in the quality of data and information is a significant challenge when massive numbers of users are contributing data and the information extraction process passes through many steps that include human intervention. Developing proper models for the measurement of accuracy or quality is a key to ensure trust (Goodchild and Li 2012).

The advance of Digital Earth will expose many of the privacy concerns associated with Big Data, such as fine-resolution imagery and data on personal activities at fine spatiotemporal resolution. How to properly avoid the exposure of personal information to unauthorized users needs both research and policy attention. Ethical issues may also be brought up when such information is viewable across cultural and jurisdiction boundaries or across religious groups (Gross and Acquisti 2005). How to develop methods to measure privacy exposure and to protect privacy is a challenge presented in Chap. 25.

In addition to the social concerns raised by Digital Earth, other social challenges (such as counter-terrorism and presidential election analyses; Braha and de Aguiar 2017) can be addressed by developing new methodologies (such as social network analyses and social simulations) using a Digital Earth platform or systems. Such advances would also benefit initiatives of significant social complexity, such as the implementation of the United Nations' 17 sustainability goals.

26.2.6 Diversified Curricula Toward Digital Earth Education

With Digital Earth being embraced in our society, there has been a classic continuum of education (from K−12 to higher education) moving toward training/professional development such as internships, certificates and professional certifications (see Chap. 24 Digital Earth Education). Because of the difficulties related to data accessibility, interdisciplinary connections, and the natural as well as the social context of Digital Earth, it is challenging to build an overarching framework for the transformation.

There is a need in K−12 education to improve pre-service teaching training programs by including more geography and DE technologies in classrooms to better reflect this rapidly evolving geospatial world. Curriculum development is driven by up-to-date learning objectives and the encouragement of greater DE applications. In higher education, various curriculum development efforts such as experiential learning courses and certificates have been introduced. To promote professional development, the interaction and partnership between higher education, non-profit organizations and the geospatial industry are closer than ever. However, there remain discrepancies between academic education and the career readiness of the next generation. Misrepresentation of competencies and credentials in the curricula may make our students "*well educated but poorly trained*" or "*well trained but poorly educated*" (Burrus 2016). (A) diversified standard(s) is/are thus required to evaluate and guide future curriculum development, and to bridge the gaps between academia and industry, education and training, knowledge and skills, etc.

Reflecting the interdisciplinary nature of Digital Earth, we call for society-wide efforts within the ISDE to establish its unique body of knowledge (BoK). A hierarchical BoK structure may cover a wide range of knowledge from general geospatial education to skill-driven competencies. This BoK will provide fundamental guidance to future DE education.

26.3 New Opportunities and Future Trends in Digital Earth

26.3.1 New Technologies

(1) IoT

IoT has been developing rapidly in recent years, with billions of connected devices being developed and deployed in different domains and regions (such as urban traffic, ecosystem monitoring, and driverless cars). These devices not only sense essential elements of our Earth environment, but also provide processing capabilities at the edge of the networked environment, pushing innovative paradigms for distributed computing, such as edge and fog computing. As IoT matures it will be possible to link EO data with 3D data and with airborne, UAV, and both surface and underground data, just as Al Gore envisaged twenty years ago. IoT is becoming a global infrastructure, enabling advanced services through the interconnection of things that belong to both the physical and virtual worlds. IoT will significantly contribute to implementing a sort of "digital nervous system of the globe, actively informing on events happening on (or close to) the Earth's surface by connecting to sensor networks and situation-aware systems" (Craglia et al. 2012).

(2) Blockchain

Blockchain was developed to support the bitcoin currency, and has the characteristics of decentralization, persistence, anonymity, and auditability. These characteristics provide a potential solution to the data security and privacy problems in Earth data, and different aspects of these are being investigated to support Digital Earth. However blockchain relies on very intensive computing, and absorbs vast amounts of electrical energy. As such it is clearly not sustainable or scalable. The example of blockchain raises a fundamental question for Digital Earth: while it is a powerful way of addressing the sustainability problems facing humanity, it nevertheless requires growing investment in technology and growing power consumption, creating its own sustainability problem.

(3) Virtual Reality/Augmented Reality/Mixed Reality

The demand for all types of interactive experiences, whether from scientists, business people, government decision makers, or ordinary citizens, will continue to grow (notwithstanding the issues raised in the previous paragraph). The foundation of VR/AR/MR lies in geospatial technology. For example, geospatial technology is contributing to the market for wearable technology, which enables users to track their steps, heart rate, etc., and thus helps them to have a better understanding of their activities during the day.

(4) Artificial Intelligence

Artificial intelligence (AI), a broad term that includes deep learning, knowledge graphs, and brain-inspired computing, is one of the most prominent technologies currently being advanced. It is a hot topic for researchers and offers great opportunities for Digital Earth knowledge discovery, but is also raising a number of important concerns even among the world's greatest technological minds (Craglia et al. 2018). While generalizability across space and time has always been a requirement of basic science, AI requires a somewhat looser interpretation of the term, and its popularity may even have a fundamental effect on the conduct of science and its epistemological underpinnings. The strength of AI may lie in prediction, whereas science has long emphasized explanation and understanding. It is also far from clear what role the principles of geographic information science—spatial dependence, spatial heterogeneity, etc.—can play in an AI that is virtually theory-free.

The development of AI is strongly linked to an exponential increase in the availability and quality of data on which AI applications are built. The development of new connectivity via 5G, new computing infrastructure, and sensor networks in the Internet of Things offers major opportunities to create ecosystems of shared data across the public sector, commercial sector, and civil society so that AI applications address the most pressing needs of our planet and society, at both local and global levels (Craglia et al. 2018).

(5) Hyper-Connectivity

The volume of available data is now growing at an unprecedented pace. Worldwide, citizens, public administration, and private companies generate and store a vast volume of data daily. A driving factor behind this is certainly increasing Internet connectivity. In the past, the Internet evolved from a network of online resources—today, there exist more than 1 billion websites (Netcraft 2019) targeted by over 6 billion Google queries per day (Internet Live Stats 2019)—to a global social network, connecting people and communities worldwide. In 2018 there were more than 2.3 billion Facebook (Facebook 2019) and 321 million Twitter (Twitter 2019) active users monthly; every day, around 4 billion videos are viewed on Youtube (MerchDope 2019), and 95 million photos and videos are shared on Instagram (Instagram 2019). According to some global market experts, in 2025 each connected person will have at least one data interaction every 18 s (IDC and Seagate 2018). For example, digital payments are expected to hit 762 billion by 2020 (Capgemini and BNP Paribas 2018), while Internet devices carried by individuals (e.g., smartphones or wearable technology) will continuously record and upload to the Internet data on humans' behaviour (digital "footprints"), such as location, physical activity, and health status.

(6) 5G, Fog/Edge Computing

Many connected devices (including those using AI) require the transmission of huge amounts of data to the cloud for storage and processing. The advent of the 5G (the fifth generation of mobile wireless technologies) network will dramatically increase this demand in the next few years—and, in particular, demand for real-time processing services. Critical applications using IoT devices (for example in sectors like health, energy, or automobiles) will depend on the reliability of communication networks. In addition to time latency, this raises other important challenges, such as security, privacy, and energy efficiency for data moving and processing. For these reasons, novel data computing architectures have been introduced—in particular, fog and edge computing. The advent of 5G will be disrupting for mobile connectivity, because not only will it deliver faster broadband to consumers, it will also enable emerging technologies such as autonomous vehicles and the IoT to become a reality for both industries and consumers. Meanwhile, we should consider the environmental impact of 5G on energy consumption and human exposure.

(7) Progress in Computing and Microelectronics

Big Data analytics and AI require new types of computing to address emerging needs—for example, to support parallel and tensor processing, overcome the traditional computer architecture latency problem, embed machine learning, deploy processor-in-memory, 4D virtual reality and augmented reality, to visualize and, notably, to consume less energy. Traditional CPUs have been replaced by innovative (and green) processing technologies, often developed by big ICT companies (e.g., Google, Facebook, Apple, Intel, Tesla) that are better suited to AI. These technologies include GPU, TPU, cloud chips, neuromorphic computing, reversible computing, and quantum computing. Recent developments also include field-programmable gate arrays (FPGAs) and application-specific integrated circuits (ASICs) as the next primary chips for AI/ML. The main idea behind FPGAs is that they are reconfigurable: the chip hardware wiring can be changed as easily as writing code.

(8) In-memory Computing

In-memory computing stores data in RAM rather than in databases hosted on disks. This eliminates the I/O latency and the need to implement database transactions reliability and consistently. This technology speeds data access exponentially because RAM-stored data is available instantaneously, while data stored on disks is limited by network and disk speeds. In-memory computing requires that massive amounts of data be cached, enabling extremely fast response times, and that session data be stored to help achieve optimum performance; for instance, see HP in-memory solutions. This approach allows quick analysis of massive volumes of data in real time at very high speeds, and also supports the detection of patterns.

26.3.2 New Services

There are many new trends involving the development of innovative products by government departments, space agencies, and private companies. These offer fundamentally new services based on machine learning, and also integration with related services and technologies, such as navigation, geolocation, artificial intelligence, IoT, Big Earth Data, blockchain, and many others.

It is clear that the new, disruptive technology trends will transform many strategies across the globe. At the intersection of technology, government, science, and industry, clashes and resistance to change may impede progress in finding solutions to many of the world's most vexing problems. On the other hand, it is clear that new technologies can sometimes create more problems than they solve when not all of their consequences are anticipated.

26.3.3 New Applications

With advances in Earth system science, the need for sustainable development has been well understood in the scientific community, in government, and in human society. Digital Earth will serve as an enabling platform and system for Earth system science as well as research into global climate change.

With regard to the challenges facing the use of Digital Earth in studying climate and environmental changes, we have seen in earlier chapters of the manual (e.g., Chap. 14) that, due to cloud cover, aerosols in the atmosphere, seasonal snow cover, sensor failure, and limited observation geometry, existing remote sensing products suffer from noise, and time and space discontinuity. These defects severely constrain the study of land-surface processes and climate change simulations that are driven by spatial data parameters, and therefore reduce the reliability of climate-change projections. It is necessary to synthesize multi-sensor remote sensing data to obtain high-quality and spatiotemporally continuous data on land-surface parameters. This will allow more accurate evaluation of the spatiotemporal variation of climate-sensitive parameters, improve the accuracy of climate models, and also allow the accurate monitoring of the locations of disturbances, the extent of their impact, and the consequent future changes (e.g., Shupeng and van Genderen 2008). This challenge also applies to the utilization of Digital Earth to support most advances in geoscience (Yang and Huang 2013).

Digital Earth should evolve in a sustainable way by considering the vision, technology, workforce, policy, and many other aspects; for example, how to apply, adapt, and integrate the U.N.'s Sustainable Development Goals (SDGs) into the next Digital Earth system (Anderson et al. 2017; Scott and Rajabifard 2017). Among the 17 goals, at least 8 could be realized by benefiting in different ways from Digital Earth Data. These goals include clean water, affordable energy, sustainable cities, climate change, life below water, life on land, good health, and peace. Digital Earth can play a very important role in these fields (Guo 2017).

26.3.4 New Paradigms

The Web has seen many developments, connecting more and more elements of our society, and, all the time, creating new business intelligence. Today, the Web enables the externalization of practically any digital capability and service, moving most of society's transactions and processes onto the network by exploiting the platform economy, hyper-connectivity, and Cloud computing. IoT and 5G are promising to further expand the Web by connecting vast numbers of devices and generating new business intelligence. In the future, simple objects (e.g., devices), complex real-time systems (e.g., moving vehicles), and sophisticated analytical and forecasting models will all be online and exchanging information. Real-world objects (sensing and acting upon the physical world) will be represented in the virtual world, and their interconnection will enable advanced services. Enabling technologies include mobile technology (5G), cloud computing (virtual computing), big data, and AI (deep analytics).

This will lead to an ecosystem of diverse (Internet-based) platforms and domain applications, which is termed the Web of Things (WoT) by W3C. WoT aims to connect real-world objects and systems to the Web, creating a decentralized IoT where things are linkable, discoverable, and usable (W3C 2019). In such a framework, a promising interaction pattern is called a digital twin: a digital model of a real connected object or a set of objects representing a complex domain environment. Depending on its complexity, a digital representation (i.e., the twin) may reside in a cloud or on an edge system. A digital twin can be used to represent real-world things and systems that may not be continuously online, or to run simulations of new applications and services before they are deployed to the real world.

In the future, it might be possible to connect (in the virtual world) diverse digital twins representing extremely complex and vast domains, such as natural phenomena and social processes. Virtual forms of future digital twins might even be developed to model the Earth domain, a digital twin of our planet, or Earth twin. This paradigm would support the ISDE's vision of Digital Earth as "multiple connected infrastructures based on open access and participation across multiple technological platforms addressing the needs of different audiences".

26.3.5 New Challenges

(1) ***Sustainability challenges***

The digital transformation of our society is facing an increasing problem: the severe mismatch between the processing and storage needs of the escalating volumes of data available, and the need to have a sustainable energy footprint. A report prepared for Greenpeace (2012) claimed that if the cloud were a country, it would have the fifth largest energy demand in the world, while Vidal (2017) suggested that the data tsunami could consume one fifth of global electricity by 2025. Trust (including cyber-security) and ICT energy consumption will be two important determinants of the long-term sustainability of the next digital (r)evolution. The constant innovation in digital technologies promises to address sustainability issues; however, side and rebound effects must also be considered. For instance, while blockchain promises to address some important security and trust issues, ledger-based networks (like blockchain technology) still remain to be investigated, in particular, in terms of their energy consumption (Nascimento et al. 2018). Another valuable example is represented by the development of green (i.e., less energy- consuming) devices, which, as they become cheaper, will likely have the effect of increasing the number of devices being commercialized and the amount of time for which they are used. Finally, concerns have already been raised about the environmental impact of 5G technology, especially in relation to energy consumption and human health issues (Van Chien et al. 2016): unlike 4G networks, 5G uses extremely high frequencies that do not travel as far as 4G waves, and, therefore, requires much smaller cells and a higher density of transmitters.

(2) ***Ethical and security challenges***

It is important to think about how the digital transformation of our society (and in particular the adoption of AI) might bring new challenges in relation to individual human beings. In this context, it is crucial to consider how the concepts of autonomy and the identity of individuals as well as security, safety, and privacy issues might change. AI systems are currently limited to narrow and well-defined tasks, and their technologies inherit imperfections from their human creators, such as the well-recognised bias effect present in data. Ethical and secure-by-design algorithms are crucial to building trust in this disruptive technology, but we also need the broader engagement of civil society in the values to be embedded in digital transformation and future developments (Craglia et al. 2018).

(3) ***New governance challenges***

The development of DE and the digital transformation of our society provide many new opportunities for a deeper understanding of both physical and social phenomena, and new tools for collective action. As we see in the environmental domain, however, it takes a long time and a consistent effort to forge a shared view of both problems and solutions, and to reach agreements which, even then, are not without setbacks and challenges. Digital transformation adds a new dimension to the governance challenge because it reshuffles the power relationships between governments, the commercial sector, and civil society. Increasingly, the control of data conveys power. Whilst many governments have begun to realize that their ability to understand and govern society is diminishing, the IoT and AI revolution may bring new actors into the game: machine-to-machine data generation, elaboration, and autonomous action may give machines an agency as yet unforeseen, challenging further the ability to govern the system. This, therefore, requires a collective response by the international community, including the setting of new ground rules to ensure continued human control of the direction of travel and how to get there.

26.4 Conclusions

When the concept of Digital Earth was first mooted, it had several drivers, including scientific questions, technological developments, critical thinking about the domain, and our capabilities for content handling. The challenges of the concept have driven us to adopt new technologies and approaches, and to develop new solutions. All these new Digital Earth technologies and the multitude of new Earth observation data from satellites offer new possibilities for DE scholars to advance our understanding of how the ocean, atmosphere, land, and cryosphere operate and interact as part of an integrated Digital Earth system. They also bring both challenges and opportunities to career preparedness for the next generation, especially to curriculum development for education at all levels.

Since the vision put forward by Al Gore, which he illustrated by imagining a young girl experiencing the Earth through the medium of virtual reality, many advances have been made at various levels and in various aspects, but we are still some distance from the ultimate Digital Earth as envisioned by Gore. While technology has advanced in leaps and bounds, and an approximation to Digital Earth is now available to anyone through readily available devices, a host of new challenges present themselves. Technology which was once seen as a utopian solution to many human problems is now recognized as having the potential to create almost as many problems as it solves. Future research will need to focus not only on the technology and on the science that it makes possible, but also on its societal context: on its sustainability, on equity of access, and on the dystopias it can create alongside the utopias. Meanwhile we can expect that a steady stream of new technologies will sustain interest and ensure steady progress toward the dream of a Digital Earth.

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Appendix A
International Society for Digital Earth (ISDE) History and Milestones

In May 2006, the International Society for Digital Earth (ISDE) was officially inaugurated in Beijing, China. The 1st ISDE Executive Committee Meeting was held on May 21, 2006. ISDE is a non-political, non-governmental and not-for-profit international organization principally promoting academic exchange, science and technology innovation, education, and international collaboration towards Digital Earth.

On August 13, 2007, Mr. Al Gore was awarded the Special Advisor of the International Society for Digital Earth at the occasion of his visit to the Chinese Academy of Sciences in Beijing and gave a presentation entitled “Climate Change and Environmental Protection”.

In March 2008, the *International Journal of Digital Earth* was launched by the International Society for Digital Earth jointly with Taylor & Francis Group.

In August 2009, the *International Journal of Digital Earth* was accepted in the SCI-Expanded.

In November 2009, the International Society for Digital Earth was accepted as a new member of the Group on Earth Observations (GEO) at the Sixth Plenary Session of GEO, held on November 17–18, 2009 in Washington, becoming the 58th Participating Organization of GEO.

In 2010, the *International Journal of Digital Earth* gained its first Impact Factor of 0.864.

In August 2010, the third edition text book “Geographic Information Systems and Science” described the International Society for Digital Earth as a key international organization in Digital Earth field.

In November 2010, on behalf of the International Society for Digital Earth, Prof. Huadong Guo stated the ISDE’s future roles and actions in Global Earth Observation System of Systems (GEOSS) at the 7th Plenary Session of the Group on Earth Observations held in Beijing.

In March 2011, the “Workshop on Digital Earth Vision to 2020” organized by the ISDE secretariat was held in Beijing, China. The main achievements of this meeting were published in two important journals. One is the paper entitled “*Digital Earth 2020: towards the vision for the next decade*” published in the *International Journal*

H. Guo et al. (eds.), *Manual of Digital Earth*,
https://doi.org/10.1007/978-981-32-9915-3

of Digital Earth in 2011, and another paper is "*Next-Generation Digital Earth*" published in the *Proceedings of the National Academy of Sciences* in 2012.

In October, 2011, the International Society for Digital Earth and the ICSU Committee on Data for Science and Technology signed a Memorandum of Understanding of the CODATA Hand-in-Hand Program at the Centre of Earth Observation and Digital Earth (CEODE), Chinese Academy of Sciences in Beijing.

In 2015, the *International Journal of Digital Earth* received its Impact Factor of 3.291, ranking the 4th in Remote Sensing Category, and 7th in Geography category.

In January 2017, the International Society for Digital Earth has been formally admitted to be an International Scientific Associate Member of the International Council for Science (now is the International Science Council), becoming one of its 24 International Scientific Associate members, and one of its 167 members.

In December 2017, the International Society for Digital Earth published a new journal, namely *Big Earth Data*.

In February 2018, the inauguration ceremony of the *Big Earth Data* journal was held together with the launching ceremony of the Big Earth Data Science Engineering Project (CASEarth) of the Chinese Academy of Sciences.

In June 2019, The International Journal of Digital Earth received the highest SCI impact factor, 3.985, since its inauguration in 2008.

In August 2019, the International Society for Digital Earth is accepted as a new member of the United Nation Committee of Experts on Global Geospatial Information Management—Geospatial Societies (UN-GGIM GS).

Appendix B
International Symposium on Digital Earth and Digital Earth Summit

International Symposium on Digital Earth

From November 29 to December 2, 1999, the 1st International Symposium on Digital Earth was hosted by the Chinese Academy of Sciences in Beijing, with the theme of Towards Digital Earth. A milestone document—the *1999 Beijing Declaration on Digital Earth*, was officially approved at the symposium. The former Vice Premier of China, Li Lanqing, attended the opening ceremony and delivered a speech. More than 500 delegates from 27 countries attended this symposium. Prof. Yongxiang Lu was the Chair and Prof. Huadong Guo was the Secretary General of this Symposium.

On December 2, 1999, an International Steering Committee of the International Symposium on Digital Earth was established to organize the subsequent series of symposia in the coming years. Prof. Yongxiang Lu and Prof. Huadong Guo were elected the Chairman and Secretary General of the Committee, respectively. It was suggested that the International Symposium on Digital Earth be held every two years, rotating among countries.

In June 2001, the 2nd International Symposium on Digital Earth was held in New Brunswick, Canada, with the theme of Beyond Information Infrastructure. More than 700 delegates from 30 countries attended the symposium.

In September 2003, the 3rd International Symposium on Digital Earth was held in Brno, Czech Republic, with the theme of Information Resources for Global Sustainability. About 250 delegates from 34 countries participated in the symposium.

In March 2005, the 4th International Symposium on Digital Earth was held in Tokyo Japan, with the theme of Digital Earth as a Global Commons. About 350 delegates from 36 countries attended the symposium.

In June 2007, the 5th International Symposium on Digital Earth was held in Berkeley USA, with the theme of Bring Digital Earth down to Earth. About 390 delegates from 28 countries attended this symposium. The 2nd ISDE Executive Committee Meeting was held on June 4, 2007 at Regents Room in Durant Hotel, co-chaired by Dr. Marc D'Iorio and Prof. Milan Konecny.

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In September 2009, the 6th International Symposium on Digital Earth was held in Beijing, China, with the theme of Digital Earth in Action. The *2009 Beijing Declaration on Digital Earth* was fully adopted at the symposium. More than 1000 delegates from 40 countries attended this symposium. The 4th ISDE Executive Committee Meeting was held on September 9, 2009, Prof. Yongxiang Lu chaired the meeting.

To celebrate the 10th anniversary of Digital Earth, some individuals and organizations were rewarded for their special contributions to the development of Digital Earth at the opening ceremony. The "Digital Earth Science and Technology Contribution Award" was presented to the late Prof. Shupeng Chen, Prof. Guanhua Xu, and Prof. Michael Goodchild; the "Contribution Award for Enterprises in Digital Earth" was presented to Google Earth, Map and Local, and Google Inc.; the "Digital Earth Medal" was presented to Prof. John van Genderen; the "International Digital Earth Series Symposia and Summits Organization Award" was presented to the organizers of five International Symposia on Digital Earth, and two Digital Earth Summits.

In August 2011, the 7th International Symposium on Digital Earth was held in Perth, Australia, with the theme of The Knowledge Generation. Over 800 experts from worldwide attended the symposium. The 6th ISDE Executive Committee Meeting was held on August 22, 2011 at Landgate Cloister, chaired by Prof. John Richards.

In August 2013, the 8th International Symposium on Digital Earth was held in Sarawak, Malaysia, with the theme of Transforming Knowledge into Sustainable Practice. Over 360 experts and scholars from 35 countries and regions attended this symposium. The 8th ISDE Executive Committee Meeting was held on August 25, 2013 at Borneo Convention Centre, Kuching, Malaysia.

In October 2015, the 9th International Symposium on Digital Earth was held in Halifax, Canada, with the theme of Towards a One-World Vision for the Blue Planet. About 300 delegates of scientists, engineers, technologists, and environmental managers from 28 countries around the world gathered at the symposium. The 10th ISDE Executive Committee Meeting was held on October 4, 2015 at the World Trade and Convention Centre, Halifax, Canada, chaired by Prof. Huadong Guo.

In April 2017, the 10th International Symposium on Digital Earth was held in Sydney, Australia, with the theme of Digital Transformation – Our Future. More than 600 people from 27 counties participated in the event. The 12th ISDE Council Meeting was held on April 4, 2017 at the Sydney International Convention Center, Australia, chaired by Prof. Huadong Guo.

In September 2019, the 11th International Symposium on Digital Earth will be held in Florence, Italy, with the theme of Digital Earth in a Transformed Society.

Digital Earth Summit

In August 2006, the 1st Digital Earth Summit was held in Auckland, New Zealand, with the theme of Digital Earth Summit on Sustainability. The former New Zealand

Prime Minister, Rt Hon Helen Clark, delivered a speech at the opening ceremony. More than 380 delegates from 35 countries attended the summit.

In November 2008, the 2nd Digital Earth Summit was held in Potsdam, Germany, with the theme of Geoinformatics: Tools for Global Change Research. More than 120 delegates from 15 countries attended this summit. The 3rd ISDE Executive Committee Meeting was held on November 13, 2008 at Vortagsraum, Building A31, GFZ, Potsdam, Germany.

In June 2010, the 3rd Digital Earth Summit was held in Nessebar Bulgaria, with the theme of Digital Earth in the Service of Society: Sharing Information, Building Knowledge. There are nearly 100 researchers from 11 countries registered at this submit. The 5th ISDE Executive Committee Meeting was held at Arsena Hotel, Nessebar, Bulgaria on June 11, 2010, co-chaired by Prof. Huadong Guo and Prof. Milan Konecny.

In September 2012, the 4th Digital Earth Summit was held in Wellington, New Zealand, with the theme of Digital Earth and Technology. Around 200 delegates from more than 20 countries gathered at this summit. The 7th ISDE Executive Committee Meeting was held on September 1, 2012 at the Square Affair Suite, Wellington Town Hall.

In November 2014, the 5th Digital Earth Summit was held in Nagoya, Japan, with the theme of Digital Earth for Education Sustainable Development. More than 100 participants from 22 countries attended this summit. The 9th ISDE Executive Committee Meeting was held on November 8, 2015 in Nagoya.

In July 2016, the 6th Digital Earth Summit was held in Beijing, China, with the theme of Digital Earth in the Era of Big Data. About 300 delegates of scientists, engineers, technologists, and scholars from 30 countries attended the summit. The 11th ISDE Council Meeting was held on July 6, 2016 at Beijing International Convention Center, China.

To celebrate the 10th anniversary of ISDE, seven ISDE honors/awards were granted to those who made great contribution to the development of Digital Earth. The "ISDE Fellow" was granted to Prof. Yongxiang Lu and Prof. Michael F. Goodchild; the "ISDE Honorary Member" was granted to Mr. Yong Shang; the "ISDE Life Member" was granted to Prof. Yuntai Chen, Mrs. Davina Jackson, Prof. John van Genderen, Prof. Jean Sequeira, Dr. Gábor Remetey-Fülöpp, Prof. Shu Sun, Prof. Tim Foresman and Prof. Guanhua Xu; the "ISDE Special Contribution Award" was granted to Prof. Qinmin Wang; the "Digital Earth Science/Technology Contribution Award" was granted to Dr. Alessandro Annoni and Prof. Deren Li; the "ISDE Service Award" was granted to Prof. Changlin Wang, Prof. Milan Konečný, Dr. Mario Hernandez and Dr. Fred Campbell (Posthumously Awarded); the "ISDE Conference Organizing Award" was granted to Prof. Huadong Guo, Prof. Temenoujka Bandrova, Dr. Peter Woodgate, Dr. Richard Simpson, Prof. Mazlan bin Hashim, Prof. Hiromichi Fukui and Prof. Hugh Millward.

In April 2018, the 7th Digital Earth Summit was held in EI Jadida, Morocco, with the theme of Digital Earth for Sustainable Development in Africa. Around 200 attendees from worldwide participated in this summit. The 13th ISDE Council Meeting was held on April 16, 2018, chaired by Prof. Huadong Guo.

Appendix C
The Organization of the International Society for Digital Earth (ISDE)

ISDE Bureau (2015–2019)

President
Huadong Guo, Chinese Academy of Sciences, China
Vice President
Alessandro Annoni, Joint Research Center, Europe Commission
John Townshend, University of Maryland, USA
Secretary General
Mario Hernandez, Future Earth Engagement Committee, Mexico
Treasurer
Zaffar Sadiq Mohamed-Ghouse, Cooperative Research Centre for Spatial Information, Australia
Executive Director
Changlin Wang, Chinese Academy of Sciences, China
Other Member
Claudia Kuenzer, German Aerospace Center, Germany

ISDE Councilors (2015–2019)

Alessandro Annoni, Joint Research Center, European Commission
Changlin Wang, Chinese Academy of Sciences, China
Claudia Kuenzer, German Aerospace Center, Germany
Eugene N. Eremchenko, Lomonosov Moscow State University, Russia
Hiromichi Fukui, Chubu University, Japan
Huadong Guo, Chinese Academy of Sciences, China
Joel I. Igbokwe, Nnamdi Azikiwe University, Nigeria
John Townshend, University of Maryland, USA
Josef Strobl, University of Salzburg, Austria

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Mario Hernandez, Future Earth Engagement Committee, Mexico
Markku Kulmala, University of Helsinki, Finland
Richard Simpson, Meta Moto Pty Ltd, Australia
Stefano Nativi, Joint Research Centre, European Commission
Sven Schade, Joint Research Centre, European Commission
Temenoujka Bandrova, University of Architecture, Civil Engineering and Geodesy, Bulgaria
Zaffar Sadiq Mohamed-Ghouse, Cooperative Research Centre for Spatial Information, Australia

ISDE Executive Committee (2014–2015)

Officers
President
John Richards, Australian National University, Australia
Vice President
Milan Konečný, Masaryk University, Czech Republic
Secretary General
Huadong Guo, Chinese Academy of Sciences, China
Treasurer
Mario Hernandez, Future Earth Engagement Committee, Mexico
Executive Director
Changlin Wang, Chinese Academy of Sciences, China
Other Members
Peter Woodgate, Cooperative Research Centre for Spatial Information, Australia
Alessandro Annoni, Joint Research Center, Europe Commission
Yola Georgiadou, University of Twente, The Netherlands

Members
Alessandro Annoni, Joint Research Centre, European Commission
Bernhard Hoefle, University of Heidelberg, Germany
Changlin Wang, Chinese Academy of Sciences, China
Hiromichi Fukui, Chubu University, Japan
Huadong Guo, Chinese Academy of Sciences, China
Hugh A. Millward, Saint Mary's University, Canada
Jean Sequeira, University of Marseilles, France
Joel I. Igbokwe, Nnamdi Azikiwe University, Nigeria
John Townshend, Maryland University, USA
Josef Strobl, University of Salzburg, Austria
Manfred Ehlers, University of Osnabrueck, Germany
Mario Hernandez, Future Earth Engagement Committee, Mexico
Markku Kulmala, University of Helsinki, Finland
Milan Konečný, Masaryk University, Czech Republic

Parodi Luciano, Ministry of Foreign Affairs, Chile
Peter Woodgate, Cooperative Research Centre for Spatial Information, Australia
Rebecca Moore, Google, USA
Richard Simpson, Spatial Industries Business Association, New Zealand
Sven Schade, Joint Research Centre, European Commission
Temenoujka Bandrova, University of Architecture, Civil Engineering and Geodesy, Bulgaria
Tim W. Foresman, International Centre for Remote Sensing Education, Inc. USA
Vladimir Tikunov, Lomonosov Moscow State University, Russia
Zaffar Sadiq Mohamed-Ghouse, Cooperative Research Centre for Spatial Information, Australia

ISDE Executive Committee (2011–2014)

President
John Richards, Australian National University, Australia
Vice President
Michael F. Goodchild, University of California, Santa Barbara, USA
Milan Konečný, Masaryk University, Czech Republic
Secretary General
Huadong Guo, Chinese Academy of Sciences, China
Treasurer
Fred Campbell, Canada FC Consultant Ltd., Canada

Members
Alessandro Annoni, Joint Research Centre, European Commission
Armin Gruen, Federal Institute of Technology, Switzerland
Changchui He, FAO for Asia and Pacific Regions
Changlin Wang, Chinese Academy of Sciences, China
David Rhind, City University, United Kingdom
Gabor Remetey-Fülöpp, Hungarian Association for Geo-information, Hungary
Guanhua Xu, Ministry of Science and Technology, China
Hiromichi Fukui, Keio University, Japan
Jean Sequeira, University of Marseiles, France
John Townshend, Maryland University, USA
Ling Bian, University at Buffalo, State University of New York, USA
Luke Driskell, Louisiana State University, USA
Manfred Ehlers, University Osnabrück, Germany
Mario Hernandez, Remote Sensing Unit, UNESCO
Peter Woodgate, Cooperative Research Center for Spatial Information, Australia
Richard Simpson, University of Auckland, New Zealand

Temenoujka Bandrova, University of Architecture, Civil Engineering and Geodesy, Bulgaria
Terence van Zyl, University of the Witwatersrand, South Africa
Tim W. Foresman, International Center for Remote Sensing Education, USA
Vladimir Tikunov, Lomonosov Moscow State University, Russia
Yola Georgiadou, University Twente, The Netherlands
Yuntai Chen, State Seismological Bureau, China

ISDE Executive Committee (2006–2011)

President
Yongxiang Lu, Chinese Academy of Sciences, China
Vice President
Marc D'Iorio, Geological Survey of Canada, Canada
Milan Konečný, Masaryk University, Czech Republic
Secretary General
Huadong Guo, Chinese Academy of Sciences, China

Members
Adigun Ade Abiodun, United Nations Committee on the Peaceful Uses of Outer Space
Alessandro Annoni, Joint Research Centre, European Commission, Italy
Armin Gruen, Federal Institute of Technology, Switzerland
Changchui He, FAO for Asia and Pacific Regions
David Rhind, City University, United Kingdom
Fred Campell, Canada FC Consulting, Canada
Gabor Remetey-Fülöpp, Hungarian Association for Geo-information, Hungary
Guanhua Xu, Ministry of Science and Technology, China
Hiromichi Fukui, Keio University, Japan
Jean Sequeira, University of Marseiles, France
John L. van Genderen, ITC, the Netherlands
John Townshend, Maryland University, USA
Manfred Ehlers, University Osnabrück, Germany
Mario Hernandez, Remote Sensing Unit, UNESCO
Mike Goodchild, University of California, Santa Barbara, USA
Peter Woodgate, Cooperative Research Center for Spatial Information, Australia
Richard Simpson, University of Auckland, New Zealand
Shupeng Chen, Chinese Academy of Sciences, China
Tim W. Foresman, International Center for Remote Sensing Education, USA
Vincent Tao, Microsoft Corporation, USA
Werner Alpers, University of Hamburg, Germany
Yuntai Chen, State Seismological Bureau, China

National and Regional ISDE Chapters

Chinese National Committee of the International Society for Digital Earth
Established in Beijing in May 2006
Australian Chapter of the International Society for Digital Earth
Approved by ISDE Executive Committee in Nagoya, Japan, November 2014
European Chapter of the International Society for Digital Earth
Approved by ISDE Executive Committee in Nagoya, Japan, November 2014
Japan Chapter of the International Society for Digital Earth
Approved by ISDE Council in Sydney, Australia, April 2017
Russian Chapter of the International Society for Digital Earth
Approved by ISDE Council in El Jadida, Morocco, April 2018

ISDE Secretariat

Changlin Wang, Zhen Liu, Jingna Liu, Hao Jiang, Linlin Guan
Institute of Remote Sensing and Digital Earth
Chinese Academy of Sciences, China

Appendix D
Journals Published by the International Society for Digital Earth

International Journal of Digital Earth

The *International Journal of Digital Earth* (IJDE) is one of the academic journals of the International Society for Digital Earth, which is sponsored by the Institute of Remote Sensing and Digital Earth of Chinese Academy of Sciences and jointly published by Taylor & Francis Group. IJDE was launched in March 2008, and accepted for coverage in the Science Citation Index Expanded (SCI-E) in August 2009. Its latest Impact Factor is 3.985 for the year of 2018. The Editor-in-Chief is Prof. Huadong Guo, the Executive Editor is Prof. Changlin Wang, the editors are Dr. Zhen Liu and Dr. Linlin Guan.

IJDE aims to publish research findings on Digital Earth theories, technologies and applications, which improve the understanding of the Earth and support knowledge-based solutions to improve human conditions, protect ecological services and support future sustainable development for environmental, social, and economic conditions.

IJDE is an international peer-reviewed journal. It encourages submissions covering, but not limited to the following areas:

- Progress visions for Digital Earth frameworks, policies, and standards;
- Explore geographically referenced 3D, 4D, or 5D models to represent the real planet, and geo-data-intensive science and discovery;
- Develop methods that turn all forms of geo-referenced data, from scientific to social, into useful information that can be analyzed, visualized, and shared;
- Present innovative, operational applications and pilots of Digital Earth technologies at a local, national, regional, and global level;
- Expand the role of Digital Earth in the fields of Earth science, including climate change, adaptation and health related issues,natural disasters, new energy sources, agricultural and food security, and urban planning;
- Foster the use of web-based public-domain platforms, social networks, and location-based services for the sharing of digital data, models, and information about the virtual Earth; and

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- Explore the role of social media and citizen provided data in generating geo-referenced information in the spatial sciences and technologies.

Journal website: http://www.tandfonline.com/toc/tjde20/current.

Big Earth Data

The journal of *Big Earth Data* is an interdisciplinary, open access and peer-review academic journal. Launched in December 2017, this journal is published by the International Society for Digital Earth jointly with the Institute of Remote Sensing and Digital Earth of Chinese Academy of Sciences, the Big Earth Data Science Engineering Project of Chinese Academy of Sciences, the Taylor & Francis Group and the Science Press. The Editor-in-Chief is Prof. Huadong Guo, the Executive Editor-in-Chief is Prof. Changlin Wang, the editors are Dr. Linlin Guan and Dr. Zhen Liu.

Aiming to provide an efficient and high-quality platform for promoting 'big data' sharing, processing and analyses, thereby revolutionizing the cognition of the Earth's systems, the journal *Big Earth Data* was inaugurated. To showcase the benefits of data-driven research, submissions on the applications of 'big Earth data' in exploring the Earth's history and its future evolution are highly encouraged. *Big Earth Data* supports open data policy and serves as a direct link between the published manuscript and its relevant supporting data in the advancement of data sharing and reuse.

The journal publishes research topics on 'big data' studies across the entire spectrum of Earth sciences, including but not limited to Earth Observation, Geography, Geology, Atmospheric Science, Marine Science, Geophysics, Geochemistry and so on. It accepts original research articles, review articles, data papers, technical notes and software. Along with research papers and data papers describing data sets, the journal also publishes paper-related data sets deposited in the public repositories.

Big Earth Data is an Open Access electronic online journal.

Journal website: http://www.tandfonline.com/toc/tbed20/current.

Appendix E
The Digital Earth: Understanding Our Planet in the 21st Century

The Speech Delivered by the Former US Vice President, Al Gore at the California Science Center, Los Angeles, California, on January 31, 1998.

A new wave of technological innovation is allowing us to capture, store, process and display an unprecedented amount of information about our planet and a wide variety of environmental and cultural phenomena. Much of this information will be "georeferenced"—that is, it will refer to some specific place on the Earth's surface.

The hard part of taking advantage of this flood of geospatial information will be making sense of it.—turning raw data into understandable information. Today, we often find that we have more information than we know what to do with. The Landsat program, designed to help us understand the global environment, is a good example. The Landsat satellite is capable of taking a complete photograph of the entire planet every two weeks, and it's been collecting data for more than 20 years. In spite of the great need for that information, the vast majority of those images have never fired a single neuron in a single human brain. Instead, they are stored in electronic silos of data. We used to have an agricultural policy where we stored grain in Midwestern silos and let it rot while millions of people starved to death. Now we have an insatiable hunger for knowledge. Yet a great deal of data remains unused.

Part of the problem has to do with the way information is displayed. Someone once said that if we tried to describe the human brain in computer terms, it looks as if we have a low bit rate, but very high resolution. For example, researchers have long known that we have trouble remembering more than seven pieces of data in our short-term memory. That's a low bit rate. On the other hand, we can absorb billions of bits of information instantly if they are arrayed in a recognizable pattern within which each bit gains meaning in relation to all the others—a human face, or a galaxy of stars.

The tools we have most commonly used to interact with data, such as the "desktop metaphor" employed by the Macintosh and Windows operating systems, are not really suited to this new challenge. I believe we need a "Digital Earth". A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data.

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Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a "magic carpet ride" through a 3-D visualization of the terrain. Of course, terrain is only one of the many kinds of data with which she can interact. Using the systems' voice recognition capabilities, she is able to request information on land cover, distribution of plant and animal species, real-time weather, roads, political boundaries, and population. She can also visualize the environmental information that she and other students all over the world have collected as part of the GLOBE project. This information can be seamlessly fused with the digital map or terrain data. She can get more information on many of the objects she sees by using her data glove to click on a hyperlink. To prepare for her family's vacation to Yellowstone National Park, for example, she plans the perfect hike to the geysers, bison, and bighorn sheep that she has just read about. In fact, she can follow the trail visually from start to finish before she ever leaves the museum in her hometown.

She is not limited to moving through space, but can also travel through time. After taking a virtual field-trip to Paris to visit the Louvre, she moves backward in time to learn about French history, perusing digitized maps overlaid on the surface of the Digital Earth, newsreel footage, oral history, newspapers and other primary sources. She sends some of this information to her personal e-mail address to study later. The time-line, which stretches off in the distance, can be set for days, years, centuries, or even geological epochs, for those occasions when she wants to learn more about dinosaurs.

Obviously, no one organization in government, industry or academia could undertake such a project. Like the World Wide Web, it would require the grassroots efforts of hundreds of thousands of individuals, companies, university researchers, and government organizations. Although some of the data for the Digital Earth would be in the public domain, it might also become a digital marketplace for companies selling a vast array of commercial imagery and value-added information services. It could also become a "collaboratory"—a laboratory without walls—for research scientists seeking to understand the complex interaction between humanity and our environment.

Technologies Needed for a Digital Earth

Although this scenario may seem like science fiction, most of the technologies and capabilities that would be required to build a Digital Earth are either here or under development. Of course, the capabilities of a Digital Earth will continue to evolve over time. What we will be able to do in 2005 will look primitive compared to the

Digital Earth of the year 2020. Below are just a few of the technologies that are needed:

Computational science: Until the advent of computers, both experimental and theoretical ways of creating knowledge have been limited. Many of the phenomena that experimental scientists would like to study are too hard to observe—they may be too small or too large, too fast or too slow, occurring in a billionth of a second or over a billion years. Pure theory, on the other hand, cannot predict the outcomes of complex natural phenomena like thunderstorms or air flows over airplanes. But with high-speed computers as a new tool, we can simulate phenomena that are impossible to observe, and simultaneously better understand data from observations. In this way, computational science allows us to overcome the limitations of both experimental and theoretical science. Modeling and simulation will give us new insights into the data that we are collecting about our planet.

Mass storage: The Digital Earth will require storing quadrillions of bytes of information. Later this year, NASAs Mission to Planet Earth program will generate a terrabyte of information each day. Fortunately, we are continuing to make dramatic improvements in this area.

Satellite imagery: The Administration has licensed commercial satellites systems that will provide 1-meter resolution imagery beginning in early 1998. This provides a level of accuracy sufficient for detailed maps, and that was previously only available using aerial photography. This technology, originally developed in the U.S. intelligence community, is incredibly accurate. As one company put it, "It's like having a camera capable of looking from London to Paris and knowing where each object in the picture is to within the width of a car headlight."

Broadband networks: The data needed for a digital globe will be maintained by thousands of different organizations, not in one monolithic database. That means that the servers that are participating in the Digital Earth will need to be connected by high-speed networks. Driven by the explosive growth of Internet traffic, telecommunications carriers are already experimenting with 10 gigabit/second networks, and terrabit networking technology is one of the technical goals of the Next Generation Internet initiative. The bad news is that it will take a while before most of us have this kind of bandwidth to our home, which is why it will be necessary to have Digital Earth access points in public places like children's museums and science museums.

Interoperability: The Internet and the World Wide Web have succeeded because of the emergence of a few, simple, widely agreed upon protocols, such as the Internet protocol. The Digital Earth will also need some level of interoperability, so that geographical information generated by one kind of application software can be read by another. The GIS industry is seeking to address many of these issues through the Open GIS Consortium.

Metadata: Metadata is "data about data." For imagery or other georeferenced information to be helpful, it might be necessary to know its name, location, author or source, date, data format, resolution, etc. The Federal Geographic Data Committee is working with industry and state and local government to develop voluntary standards for metadata.

Of course, further technological progress is needed to realize the full potential of the Digital Earth, especially in areas such as automatic interpretation of imagery, the fusion of data from multiple sources, and intelligent agents that could find and link information on the Web about a particular spot on the planet. But enough of the pieces are in place right now to warrant proceeding with this exciting initiative.

Potential Applications

The applications that will be possible with broad, easy to use access to global geospatial information will be limited only by our imagination. We can get a sense of the possibilities by looking at today's applications of GIS and sensor data, some of which have been driven by industry, others by leading-edge public sector users:

Conducting virtual diplomacy: To support the Bosnia peace negotiations, the Pentagon developed a virtual-reality landscape that allowed the negotiators to take a simulated aerial tour of the proposed borders. At one point in the negotiations, the Serbian President agreed to a wider corridor between Sarajevo and the Muslim enclave of Gorazde, after he saw that mountains made a narrow corridor impractical.

Fighting crime: The City of Salinas, California has reduced youth handgun violence by using GIS to detect crime patterns and gang activity. By collecting information on the distribution and frequency of criminal activities, the city has been able to quickly redeploy police resources.

Preserving biodiversity: Planning agencies in the Camp Pendelton, California region predict that population will grow from 1.1 million in 1990 to 1.6 million in 2010. This region contains over 200 plants and animals that are listed by federal or state agencies as endangered, threatened, or rare. By collecting information on terrain, soil type, annual rainfall, vegetation, land use, and ownership, scientists modeled the impact on biodiversity of different regional growth plans.

Predicting climate change: One of the significant unknowns in modeling climate change is the global rate of deforestation. By analyzing satellite imagery, researchers at the University of New Hampshire, working with colleagues in Brazil, are able to monitor changes in land cover and thus determine the rate and location of deforestation in the Amazon. This technique is now being extended to other forested areas in the world.

Increasing agricultural productivity: Farmers are already beginning to use satellite imagery and Global Positioning Systems for early detection of diseases and pests, and to target the application of pesticides, fertilizer and water to those parts of their fields that need it the most. This is known as precision farming, or "farming by the inch."

The Way Forward

We have an unparalleled opportunity to turn a flood of raw data into understandable information about our society and out planet. This data will include not only high-resolution satellite imagery of the planet, digital maps, and economic, social, and demographic information. If we are successful, it will have broad societal and commercial benefits in areas such as education, decision-making for a sustainable future, land-use planning, agricultural, and crisis management.

The Digital Earth project could allow us to respond to manmade or natural disasters—or to collaborate on the long-term environmental challenges we face.

A Digital Earth could provide a mechanism for users to navigate and search for geospatial information—and for producers to publish it. The Digital Earth would be composed of both the "user interface"—a browsable, 3D version of the planet available at various levels of resolution, a rapidly growing universe of networked geospatial information, and the mechanisms for integrating and displaying information from multiple sources.

A comparison with the World Wide Web is constructive. [In fact, it might build on several key Web and Internet standards.] Like the Web, the Digital Earth would organically evolve over time, as technology improves and the information available expands. Rather than being maintained by a single organization, it would be composed of both publically available information and commercial products and services from thousands of different organizations. Just as interoperability was the key for the Web, the ability to discover and display data contained in different formats would be essential.

I believe that the way to spark the development of a Digital Earth is to sponsor a testbed, with participation from government, industry, and academia. This testbed would focus on a few applications, such as education and the environment, as well as the tough technical issues associated with interoperability, and policy issues such as privacy. As prototypes became available, it would also be possible to interact with the Digital Earth in multiple places around the country with access to high-speed networks, and get a more limited level of access over the Internet.

Clearly, the Digital Earth will not happen overnight.

In the first stage, we should focus on integrating the data from multiple sources that we already have. We should also connect our leading children's museums and science museums to high-speed networks such as the Next Generation Internet so that children can explore our planet. University researchers would be encouraged to partner with local schools and museums to enrich the Digital Earth project—possibly by concentrating on local geospatial information.

Next, we should endeavor to develop a digital map of the world at 1 meter resolution.

In the long run, we should seek to put the full range of data about our planet and our history at our fingertips.

In the months ahead, I intend to challenge experts in government, industry, academia, and non-profit organizations to help develop a strategy for realizing this vision. Working together, we can help solve many of the most pressing problems facing our society, inspiring our children to learn more about the world around them, and accelerate the growth of a multi-billion dollar industry.

Appendix F
1999 Beijing Declaration on Digital Earth and 2009 Beijing Declaration on Digital Earth

Beijing Declaration on Digital Earth

December 2, 1999

We, some 500 scientists, engineers, educators, managers and industrial entrepreneurs from 20 countries and regions assembled here in the historical city of Beijing, attending the first International Symposium on Digital Earth being organized by the Chinese Academy of Sciences with co-sponsorship of 19 organizations and institutions from November 29, 1999 to December 2, 1999, recognize that humankind, while entering into the new millennium, still faces great challenges such as rapid population growth, environmental degradation, and natural resource depletion which continue to threaten global sustainable development;

Noting that global development in the 20th century has been characterized by rapid advancements in science and technology which have made significant contributions to economic growth and social wellbeing and that the new century will be an era of information and space technologies supporting the global knowledge economy;

Recalling the statement by Al Gore, Vice President of the United States of America, on *Digital Earth: Understanding Our Planet in the 21st Century*—and the statement by Jiang Zemin, President of the People's Republic of China, on Digital Earth regarding trends of social, economic, scientific and technological development;

Realizing the decisions made at UNCED and Agenda 21, recommendations made by UNISPACE III and the Vienna Declaration on Space and Human Development, which address, among other things, the importance of the Integrated Global Observing Strategy, the Global Spatial Data Infrastructure, geographic information systems, global navigation and positioning systems, geo-spatial information infrastructures and modeling of dynamic processes;

Understanding that Digital Earth, addressing the social, economic, cultural, institutional, scientific, educational, and technical challenges, allows humankind to visualize the Earth, and all places within it, to access information about it and to understand and influence the social, economic and environmental issues that affect their lives in their neighborhoods, their nations and the planet Earth;

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Recommend that Digital Earth be promoted by scientific, educational and technological communities, industry, governments, as well as regional and international organizations;

Recommend also that while implementing the Digital Earth, priority be given to solving problems in environmental protection, disaster management, natural resource conservation, and sustainable economic and social development as well as improving the quality of life of the humankind;

Recommend further that Digital Earth be created in a way that also contributes to the exploration of, and scientific research on, global issues and the Earth system;

Declare the importance of Digital Earth in achieving global sustainable development;

Call for adequate investments and strong support in scientific research and development, education and training, capacity building as well as information and technology infrastructures, with emphasis, inter alia, on global systematic observation and modeling, communication networks, database development, and issues associated with interoperability of geo-spatial data;

Further call for close cooperation and collaboration between governments, public and private sectors, non-governmental organizations, and international organizations and institutions, so as to ensure equity in distribution of benefits derived from the use of Digital Earth in developed and developing economies;

Agree that, as a follow-up to the first International Symposium on Digital Earth held in Beijing, the International Symposium on Digital Earth should continue to be organized by interested countries or organizations biannually, on a rotational basis.

Beijing Declaration on Digital Earth
September 12, 2009

We scientists, engineers, educators, entrepreneurs, managers, administrators and representatives of civil societies from more than forty countries, international organizations and NGOs, once again, have assembled here, in the historic city of Beijing, to attend the Sixth International Symposium on Digital Earth, organized by the International Society for Digital Earth and the Chinese Academy of Sciences, with co-sponsorship of sixteen Chinese Government Departments, Institutions and international organizations, being held from September 9–12, 2009.

Noting
That Significant global-scale developments on Digital Earth science and technology have been made over the past ten years, and parallel advances in space information technology, communication network technology, high-performance computing, and Earth System Science have resulted in the rise of a Digital Earth data-sharing platform for public and commercial purposes, so that now Digital Earth is accessible by hundreds of millions, thus changing both the production and lifestyle of mankind;

Recognizing
The contributions to Digital Earth made by the host countries of the previous International Symposia on Digital Earth since November 1999, including China, Canada,

the Czech Republic, Japan and the USA, and by the host countries of the previous Summit Conferences on Digital Earth, including New Zealand and Germany, for the success of the meetings as well as further promotion of Digital Earth;

Further, that the establishment of the International Society for Digital Earth and the accomplishments of its Executive Committee, the launch of the International Journal on Digital Earth, and its global contribution to cooperation and data exchange;

That the themes of the previous seven meetings: Moving towards Digital Earth, Beyond Information Infrastructure, Information Resources for Global Sustainability, Digital Earth as Global Commons, Bring Digital Earth down to Earth, Digital Earth and Sustainability, Digital Earth and Global Change, and Digital Earth in Action, have laid out a panoramic scenario for the future growth of Digital Earth;

That Digital Earth will be asked to bear increased responsibilities in the years to come, in the face of the problems of sustainable development;

Further Recognizing

That Digital Earth should play a strategic and sustainable role in addressing such challenges to human society as natural resource depletion, food and water insecurity, energy shortages, environmental degradation, natural disasters response, population explosion, and, in particular, global climate change;

That the purpose and mission of the World Information Summit of 2007, the Global Earth Observation System Conference of 2007, and the upcoming United Nations Climate Change Conference of 2009, and that Digital Earth is committed to continued close cooperation with other scientific disciplines;

Realizing

That Digital Earth is an integral part of other advanced technologies including: earth observation, geo-information systems, global positioning systems, communication networks, sensor webs, electromagnetic identifiers, virtual reality, grid computation, etc. It is seen as a global strategic contributor to scientific and technological developments, and will be a catalyst in finding solutions to international scientific and societal issues;

We Recommend

(a) That Digital Earth expand its role in accelerating information transfer from theoretical discussions to applications using the emerging spatial data infrastructures worldwide, in particular, in all fields related to global climate change, natural disaster prevention and response, new energy-source development, agricultural and food security, and urban planning and management;
(b) Further, that every effort be undertaken to increase the capacity for information resource-sharing and the transformation of raw data to practical information and applications, and developed and developing countries accelerate their programs to assist less-developed countries to enable them to close the digital gap and enable information sharing;

(c) Also, that in constructing the Digital Earth system, efforts must be made to take full advantage of next-generation technologies, including: earth observation, networking, database searching, navigation, and cloud computing to increase service to the public and decrease costs;
(d) Further, that the International Society for Digital Earth periodically take the lead in coordinating global scientific research, consultations and popular science promotion to promote the development of Digital Earth;
(e) Expanding cooperation and collaboration between the International Society for Digital Earth and the international community, in particular with intergovernmental organizations, and international non-governmental organizations;
(f) Extending cooperation and integration with Government Departments, the international Scientific and Educational community, businesses and companies engaged in the establishment of Digital Earth;

We Call for

Support from planners and decision-makers at all levels in developing plans, policies, regulations, standards and criteria related to Digital Earth, and appropriate investments in scientific research, technology development, education, and popular promotion of the benefits of Digital Earth.