

# Chapter 1

## Understanding Digital Earth



Zhen Liu, Tim Foresman, John van Genderen and Lizhe Wang

**Abstract** In the two decades since the debut of the Digital Earth (DE) vision, a concerted international effort has engaged in nurturing the development of a technology framework and harnessing applications to preserve the planet and sustain human societies. Evolutionary threads can be traced to key historic and multidisciplinary foundations, which were presciently articulated and represented at the first International Symposium on Digital Earth hosted by the Chinese Academy of Sciences in 1999. Pioneering groups in government, industry, and academia have cultivated this fertile futuristic conceptual model with technological incubation and exploratory applications. An array of space-age developments in computers, the internet and communications, Earth observation satellites, and spatially oriented applications sparked an innovative discipline. The *Beijing Declaration on Digital Earth* is recognized for its role in promulgating the series of International Symposia on Digital Earth to promote understanding of the impacts of DE technology and applications on behalf of humankind. Combinations of industrial, academic, and government organizations have rapidly advanced the technological components necessary for implementing the DE vision. Commercial leaders such as Google have accelerated the influence of DE for large segments of society. Challenges remain regarding requisite collaboration on international standards to optimize and accelerate DE implementation scenarios. This chapter provides an overview of the DE initiative and basic framework, the global response to DE, the evolution of DE, its relationship to key global science initiatives, and the response to global challenges.

---

Z. Liu (✉)

Secretariat of International Society for Digital Earth, Beijing, China

Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China

e-mail: [liuzhen@radi.ac.cn](mailto:liuzhen@radi.ac.cn)

T. Foresman

International Center for Remote Sensing Education/Earth Party, Elkridge, MD, USA

J. van Genderen

Department of Earth Observation Science, University Twente, Enschede, The Netherlands

L. Wang

School of Computer Science, China University of Geosciences, Wuhan, China

© The Editor(s) (if applicable) and The Author(s) and European Union 2020

H. Guo et al. (eds.), *Manual of Digital Earth*,

[https://doi.org/10.1007/978-981-32-9915-3\\_1](https://doi.org/10.1007/978-981-32-9915-3_1)

**Keywords** Digital Earth initiative · Basic framework · Global response · Evolution · Global challenge

## 1.1 The Digital Earth Initiative

Three years after a human first stepped on the moon's surface, the space and information age launched with the Landsat series of Earth observation satellites. Beginning in 1972, Landsat data kick started the big-data epoch by capturing imagery of the whole Earth's surface every two weeks. From these space-age origins, a multitude of technologies have developed to address data storage, preprocessing, classification, interpretation, analysis, integration with computational models, and visualization in digital image processing workflows. Digital image processing has spread across science, medical, computer, gaming, and entertainment fields, creating multitudes of new industries. With the booming development of Earth observation, considered the first wave of big data, massive amounts of digital data about the Earth's surface and near-surface have been collected from an ever-growing constellation of various satellites and sensors. Increased information technology capacity, following Moore's Law, has fostered disruptive changes regarding applications of Earth system data within the scientific community, relevant industries, and by consumer citizens. 'Digital' refers to more than the electronic format of the data in bits and bytes or the automated workflow used to manage the data. The Digital Era encompasses the much wider and greater societal and technological transformations facing humans. "Digital Earth is the inevitable outcome of the space era in the history of information society development" (Chen 2004). Digital Earth captures this phenomenal extension to harness the 'digital' world in which we live.

The concept of Digital Earth, first coined in Al Gore's book entitled "*Earth in the Balance*" (Gore 1992), was further developed in a speech written for Gore at the opening of the California Science Center in 1998. In this speech, Digital Earth was described as a multiresolution and three-dimensional visual representation of Earth that would help humankind take advantage of geo-referenced information on physical and social environments, linked to an interconnected web of digital libraries (Gore 1999). The concept of Digital Earth was further explained as the use of "digital technologies to model Earth systems, including cultural and social aspects represented by human societies living on the planet. The model is a multidimensional, multiscale, multitemporal, and multilayered information system. Digital Earth is envisaged as a common platform to support national and international cooperation for global sustainable development, and a newly developing point of economic growth and social well-being" (International Society for Digital Earth 2012).

Digital Earth theories and relevant technologies have flourished across a range of disciplines and applications worldwide (Chen 1999; Goodchild 1999, 2008; Foresman 2008; Guo et al. 2009; Annoni et al. 2011; Craglia et al. 2012; Goodchild et al. 2012). This momentous turn in the histories of cartography, meteorology, and geography was made feasible by the confluence of enabling information technologies in

computational science, mass storage, satellite imagery, broadband networks, interoperability, metadata, and unprecedented ‘virtual reality’ technologies. Powered by advances in semiconductor devices networked to telecoms, navigation, and Earth observation satellites, a new era of spatially enabled technologies transformed and fused multiple disciplines in the 21st century. As a system of interconnected systems, Digital Earth should be fully empowered with multiple sources of geospatial information, a 3D representation platform of the Earth, and a user interface, and act as the framework that combines these domains. As stated in the *Beijing Declaration on Digital Earth*, “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.” (International Society for Digital Earth 2009).

In addition to being a global strategic contributor to scientific and technological developments, Digital Earth was regarded as an approach for “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” (International Society for Digital Earth 1999). It is “a catalyst in finding solutions to international scientific and societal issues” (International Society for Digital Earth 2009). Contemporary local and global issues can be characterized as complex and interrelated. Solutions to challenging problems remain elusive under conventional governance. In this dynamic environment, better methods for organizing vast data and managing human affairs are sought at all organizational levels. While not a panacea, Digital Earth has been regarded as the most effective approach, organizing metaphor, or model, to turn raw and disaggregated data into understandable, visualized information to gain knowledge about the Earth and human influence (Goodchild et al. 2012). Consequently, it can aid in the sustainable development of all countries and regions (Chen 2004). Thus, Digital Earth plays “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” (International Society for Digital Earth 2009).

## 1.2 Basic Framework of Digital Earth

Digital Earth is described as a virtual globe constructed of massive, multiresolution, multitemporal, multityped Earth observation data and socioeconomic data combined with relevant analysis algorithms and models (Goodchild 2013; Grossner et al. 2008). From a scientific point of view, the basic implication of Digital Earth includes two aspects. First, Digital Earth represents a huge data and information system that aggregates and presents data and information related to the Earth. In addition, Digital Earth

is a virtual Earth system that can perform reconfigurable system simulations and decision support for complex geoscience processes and socioeconomic phenomena (Guo et al. 2014).

### ***1.2.1 Basic Scientific Problems***

The basic scientific problems concerning Digital Earth comprise three aspects:

- (1) How to construct Digital Earth provided that we have massive, multiresolution, multitemporal, multitype Earth observation data and socioeconomic data? And how to organize, map, and compute these data to generate the data ecosystem—a harmonious, multidimensional, multiscale, multitemporal, and multilayered information system for Digital Earth?
- (2) How to discover knowledge in Digital Earth? Assuming a data ecosystem has been built well, the next task is to compute, analyze, and mine the data for knowledge discovery to understand the Earth system using physical models (e.g., climate change models, Earth system models) or artificial intelligence algorithms (machine learning, data mining, deep learning, etc.).
- (3) How to operate and utilize Digital Earth? As various of types of Digital Earth exist, coordinating and operating multiple subsystems of a Digital Earth platform to deliver flexible, efficient and user-friendly service for Digital Earth users and applications is a basic scientific problem.

### ***1.2.2 Theoretical and Methodological Framework***

To target the aforementioned scientific problems, we need a theoretical and methodological framework for Digital Earth:

- (1) The theory and methodology of Digital Earth construction and implementation

This task is to generate the data and computer systems to produce a basic platform and infrastructure for a Digital Earth. The related theories and methods include remote sensing, geography, cartography, Earth information science, database theory, cloud computing, information networks, software engineering, and information theory.

- (2) The theory and methodology of Digital Earth knowledge discovery

This task is to comprise implementation of the change from data to knowledge to understand the Earth system, for example, how Earth has changed, what the next change is and how human activities affect the Earth system. The related theories and methods include information theory, artificial intelligence, data mining, and Earth system science.

### (3) The theory and methodology of Digital Earth operation and utilization

This task is to comprise management of the Digital Earth system and a whole and delivery of services to users and applications. The related theories and methods includes software engineering, cloud computing, Earth Information science, visualization, and information networking.

## 1.3 Global Response to Digital Earth

Responding to the vision for Digital Earth, the US government established a NASA-led Interagency Digital Earth Working Group in 1999 (Foresman 2008). Although this working group lost momentum and government support after 2001, its influence remained, with many stakeholders maintaining keen interest in pursuing this initiative.

### 1.3.1 *International Society for Digital Earth*

In 1999, the first International Symposium on Digital Earth to promote Digital Earth as a global initiative was held in Beijing, China, sponsored by the Chinese government and hosted by the Chinese Academy of Sciences. More than one thousand scientists, engineers, educators and governors from nearly 40 countries worldwide attended. The attendees approved a milestone document for the movement, the *1999 Beijing Declaration on Digital Earth*. This symposium laid the foundation for the development of Digital Earth at the global scale, and kicked off the worldwide responses to the Digital Earth initiative.

During the symposium, an International Steering Committee of the International Symposium on Digital Earth was established to organize subsequent symposia in the coming years. In 2006, the International Society for Digital Earth (ISDE) was formally established with the secretariat hosted by the Chinese Academy of Sciences. The ISDE is a nonprofit international scientific organization that principally coordinates and promotes academic exchange, education, science and technology innovation, and international collaboration towards Digital Earth.

Following the 1999 symposium, a symposium has been held every two years at different locations around the world. In addition, since 2006, Digital Earth summits have been added to the biannual symposia schedule to focus on specific academic themes that have been identified as important. After 20 years of development, ten symposia and seven summits have been hosted in 11 different countries. The upcoming symposium will be held in Italy in 2019 and the summit will take place in Russia in 2020.

Important to the professional standing of the ISDE is the addition of an international peer-reviewed academic journal, the *International Journal of Digital Earth*

(IJDE). The highly rated journal is published jointly by the ISDE and the Taylor & Francis Group. Inaugurated in March 2008, the IJDE was accepted for coverage by the Science Citation Index. Expanded in August 2009, the journal had an impact factor of 2.746 in 2018, ranking 13th out of 30 remote sensing journals, and has been included in 12 large international citation databases.

The Digital Earth initiative fits within many global organizations' missions through sharing knowledge and ideas about Digital Earth and seeking global benefits using Digital Earth technology. In 2009, the ISDE joined the Group on Earth Observations (GEO), the world's largest intergovernmental organization on using geospatial data. The ISDE also has established partnerships with the Committee on Data for Science and Technology (CODATA), the International Eurasian Academy of Sciences, the Global Spatial Data Infrastructure Association, and the African Association of Remote Sensing of the Environment. In 2017, the ISDE was recognized as a member of the International Council for Science (ICSU, now is the International Science Council). In August 2019, ISDE becomes a member of the United Nations Committee of Experts on Global Geospatial Information Management—Geospatial Societies (UN-GGIM GS). The ISDE is now widely recognized globally as a leadership organization in geospatial information science research.

### ***1.3.2 Group on Earth Observations' Membership***

In 2005, delegations from nearly 60 countries endorsed a ten-year Implementation Plan for the 2005–2015 Global Earth Observation System of Systems (GEOSS) and further established the intergovernmental Group on Earth Observations (GEO) to implement the plan. The ISDE's membership in the GEO guarantees organizational and scientific harmonization with all major international communities.

One of the GEO's missions is to implement GEOSS to “better integrate observing systems and share data by connecting existing infrastructures using common standards” ([https://www.earthobservations.org/geo\\_community.php](https://www.earthobservations.org/geo_community.php)). “GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS links these systems to strengthen the monitoring of the state of the Earth. It facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organizations within GEO. Further, GEOSS ensures that these data are accessible, of identified quality and provenance, and interoperable to support the development of tools and the delivery of information services. Thus, GEOSS increases our understanding of Earth processes and enhances predictive capabilities that underpin sound decision making: it provides access to data, information and knowledge to a wide variety of users” (<https://www.earthobservations.org/geoss.php>). GEOSS currently contains more than 400 million open data resources from more than 150 national and regional providers such as NASA and ESA, international organizations such

as the World Meteorological Organization (WMO), and groups in the commercial sector such as Digital Globe (now Maxar) ([https://www.earthobservations.org/geo\\_community.php](https://www.earthobservations.org/geo_community.php)).

### ***1.3.3 The Australian Geoscience Data Cube***

The Australian Geoscience Data Cube (AGDC) 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 the usefulness of Earth observation data. The AGDC is a collaborative initiative of Geoscience Australia, the National Computational Infrastructure (NCI), and the Australian Commonwealth Scientific Industrial Research Organisation (CSIRO). The AGDC was developed over several years as researchers sought to maximize the impact of Land surface image archives from Australia's first participation in the Landsat program in 1979. There have been several iterations, and AGDC version 2 is a major advance on previous work. The foundation and core components of the AGDC are (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) (Lewis et al. 2017).

A growing number of examples demonstrate that the 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, such as extracting the intertidal extent and topography of the Australian coastline from a 28-year time series of Landsat observations. Sagar et al. outlined an automated methodology to model the intertidal extent and topography of the Australian coastline that leverages a full time series of Landsat observations from 1987 to 2015 managed in the Australian Geoscience Data Cube (AGDC) (Sagar et al. 2017). The Australian Government established a program to improve access to flood information across Australia. As part of this, a project was undertaken to map the extent of surface water across Australia using the multidecadal archive of Landsat satellite imagery. The "initial scoping of the full processing time required for the analysis indicated that one analysis of the entire Landsat archive for surface water was over four years. The analysis as conducted on the AGDC was completed in under 8 h, making it feasible to review and improve the algorithms, and repeat the analyses many times, where previously such an analysis was essentially not feasible" (Mueller et al. 2016).

The AGDC vision is of a 'Digital Earth' (Craglia et al. 2012) composed of observations of the Earth's oceans, surface and subsurface taken through space and time and stored in a high-performance computing environment. A fully developed AGDC

would allow for governments, scientists and the public to monitor, analyze and project the state of the Earth and will realize the full value of large Earth observation datasets by allowing for rapid and repeatable continental-scale analyses of Earth properties through space and time. To enable easy uptake of the AGDC and facilitate future cooperative development, the AGDC code is developed under an open source Apache License, version 2.0. This open source approach is enabling other organizations including the Committee on Earth Observing Satellites (CEOS) to explore the use of similar data cubes in developing countries (Lewis et al. 2017). It creates the potential for expansion of the AGDC concept into a network of data cubes operating on large geoscientific and geospatial datasets, colocated in suitable HPC-HPD facilities, to address global and national challenges.

### ***1.3.4 CASEarth Data Bank***

The Earth observation community has entered into the era of big data. The CASEarth Data Bank, part of the Project on Big Earth Data Science Engineering (Guo 2018), provides big Earth data infrastructure that focuses on Earth observation data.

With new computing infrastructures, technologies and data architectures, the CASEarth DataBank system aims to meet the data management and analysis challenges that arise from the huge increase in satellite Earth observation data. The CASEarth DataBank system is designed to increase the value and impact of Ready to Use (RTU) products by providing an open and freely accessible exploitation architecture to broaden their applications for societal benefit (Guo 2018).

The CASEarth DataBank system is an intelligent data service platform that provides RTU products from multisource spatial data, especially satellite remote sensing data, and big Earth data analysis methods and high-performance computing infrastructure.

The CASEarth Databank consists of three main parts:

- (1) Standardized long time-series RTU products from Earth observation data including (1) Chinese satellite data: ZY, GF, HJ, CBERS, FY, HY, and CASEarth satellites, with spatial resolutions from one km to submeter; (2) Landsat data received by the China Remote Sensing Satellite Ground Station since 1986, with 12 RTU products including digital orthophoto maps, regional image maps, top of atmosphere reflectance, land surface reflectance, top of atmosphere brightness temperature, land surface temperature, normalized difference vegetation index, ratio vegetation index, global environment monitoring index, normalized burnt ratio, normalized difference water index, and pixel quality attribute; and (3) other big Earth data sources: DEM, vector, and social data (He et al. 2015, 2018a, b). These RTU products provide consistent, standardized, multidecadal image data for robust land cover change detection and monitoring across the Earth sciences.



- (2) **The Software Environment.** For the data engine, a databox was developed for time series data management and global tiling. For the CASEarth Data Bank system, a global subdivision grid was designed to effectively manage, organize and use long-term sequential RTU data and facilitate the integration and application analysis of multisource and multiscale geospatial information. The global subdivision grid was designed for RTU data based on the national standard of China (GB/T 12409-2009) (Guo 2018).

The computation engine consists of time series data analysis, computational modeling and data integration, middleware and tool modeling, data-intensive computing technologies, data-driven innovation, advanced manufacturing and productivity. It provides basic data analysis algorithms, a distributed parallel computing mechanism, and intelligent analysis solutions for big Earth data.

The visualization engine aids in data visualization in a pictorial or graphical format. With rich, interactive visuals such as graphs and charts, it is easy to discover insights hidden in the data due to the way the human brain processes information. It enables decision makers to see analytics presented visually. A visualization engine is being developed to better understand the data in the CASEarth Databank.

- (3) **Infrastructure and services.** It provides a high-performance computing environment and services with 50P storage and 2PF computing capability. The infrastructures and systems of datafication for big Earth data include storage, management, computing, optimizing cloudification, architectural features, stateless processing, microservices, containers, open software and inherent orchestration.

## 1.4 Evolution of Digital Earth

Fundamental changes in society have occurred since the Digital Earth concept was proposed 20 years ago. Along with these social changes, technology advances have been incrementally achieved, resulting in the evolution of Digital Earth.

### 1.4.1 Visionary Incubation of Digital Earth

Based on command and control technologies, there are several virtual globe platforms, or geobrowsers, with associated visualization applications. Among them, the three major categories are location-based commercial platforms, science platforms based on Earth system sciences, and public platforms oriented towards regional sustainable development and decision support (Guo et al. 2017).

In 2001, based on a 3D Earth geographic teaching software ‘Atlas 2000’ by Microsoft, an original prototype of the Earth system was developed, which integrated large-scale remote sensing imagery and key point datasets into a global 3D model.

Following that, ESRI launched ArcGIS Explorer, and Google Earth was launched in 2005. These early geobrowsers were supported by geospatial tessellation engines operated within desktop computers using 3D technology. When integrated, these Digital Earth systems allowed for querying, measurement, analysis, and location services based on massive geospatial data (Grossner and Clarke 2007). Since then, a number of virtual globes have been produced, including WorldWind, Skyline Globe, GeoGlobe, and Bing Maps 3D. Keyzers (2015) provides comparative descriptions of 23 virtual globes, demonstrating the early breadth of Digital Earth technology. This implies that the technology of virtual globes is not yet completely mature.

In addition, many other countries' governments and institutes have produced Digital Earth platforms for specific research purposes. The Chinese Academy of Sciences started research on a Digital Earth Prototype System in 1999 and released the Digital Earth Science Platform (DESP/CAS) in 2010 (Guo et al. 2009). The Jet Propulsion Laboratory created Eyes on the Earth to visualize in situ data from a number of NASA's Earth orbiting spacecraft (NASA 2009). The Australian government explored Blue Link and Glass Earth to observe and simulate the ocean and explore the top kilometer of the Australian continent's surface and its geological processes. A consortium of Japanese institutes developed the Earth Simulator to support environmental change research (Yokokawa 2002).

In 2011, a group of experts from the International Society for Digital Earth gathered at the "Digital Earth Vision to 2020" workshop in Beijing to discuss the developing trends of Digital Earth. This workshop discussed the achievements of Al Gore's first generation of the Digital Earth vision. Goodchild et al. (2012) indicated that the existing generation of Digital Earth (or Virtual Globes) represented great progress in Gore's vision. In Gore's vision, 3D representation of the Earth tops the list in realization of Digital Earth. 3D technology is derived from computer and 3D graphic technologies supported by the film and video game industries and is involved in the representation of the Earth, hence the name Digital Earth. Digital Earth is regarded as a "disruptive approach to the methods of geospatial analysis and visualization currently employed within the field of GIS that uses a virtual (3D) representation of the globe" and as a spatial reference model to visualize, retrieve, and analyze geospatial data at different levels (Mahdavi-Amiri et al. 2015). Data (including imagery, elevation data, vector data, 3D geometric data, and statistical data) are mostly assigned to discretized and hierarchical cells of the Earth, which is a structure known as Discrete Global Grid Systems (DGGs) that serves as the backbone of the Digital Earth system (Goodchild 2000; Sahr et al. 2003). The first generation of these systems could also be extended and adapted to different user requirements, i.e., displaying the oceanography, atmosphere, or geomorphology of the surface and near-surface of the Earth. However, some aspects fall short of Gore's vision, such as the exploration of historical and future scenarios of the Earth, as well as limitations in the storage, retrieval, and sharing of the huge amount of collected information related to the Earth, and in visualization of the Earth (Goodchild et al. 2012).

### ***1.4.2 Digital Earth in Support of Data-Intensive Knowledge Discovery***

With the tremendous growth of the geospatial data collected from satellite-based and ground-based sensors, a fourth paradigm of science was required to characterize data-intensive knowledge discovery. High-performance computing capacity, international collaboration, and data-intensive analysis using high-end visualization have been developed to deal with the multisource data management hurdles. New awareness of the challenges Digital Earth could face has attracted attention to theoretical and scientific innovations in data-intensive geoscience knowledge discovery methods, massive data convergence and service models, and data-intensive geoscience computing and knowledge discovery (Goodchild 2013).

Various types of observation data represent essential foundations for the development of Digital Earth. Massive amounts of geospatial data including satellite-borne data are being processed, exploited and combined with other massive data sources, and delivered in near-real time to users in highly integrated information products. In the context of the widespread use of massive geospatial data, Digital Earth prototypes, popularly represented by Google Earth, began to use the internet to provide the world with high-resolution digital rendering services beginning in 2005. Google's game-changing Earth tessellation engine enabled the public to realize free and convenient access to conduct geo-spatial inquiry and mapping operations on Earth-related data using their personal computers (Goodchild 2013). The challenges inherent in intensive data provide Digital Earth an opportunity to play a significant role in scientific knowledge discovery.

### ***1.4.3 Digital Earth with Multisource Data***

As a complex system, Digital Earth increasingly embraces massive multi-resolution, multitemporal and multitype Earth observation data and socioeconomic data as well as relevant analysis algorithms and models (Guo 2012; Grossner et al. 2008). Data acquisition, organization, analysis and application all reflect the importance and necessity of effectively handling massive volumes of scientific data. With the rapid development of internet, mobile 5G network, and Web 2.0 technologies, significant improvements occurred in the collection of multisource spatial data. The availability of data providers is increasing as digital citizens are no longer limited to government agencies or professional companies. Ordinary civilian users can participate in and cooperate with others to maintain and update geographic information data. The idea that everyone can serve as a data collection sensor has become a reality. Goodchild (2007) termed this new geographical era neogeography. New sources of data from both citizen science and smartphone activity enable the public to become mass providers of data. Concepts that embrace this new public data collection, such as volunteered geographic information (VGI) (Goodchild 2007), crowdsourcing geospatial

data (Giles 2006; Howe 2006; Heipke 2010), and generalized geographic information (Lu and Zhang 2014), have been highlighted. Although the concepts vary, all of them emphasize the transformation of geospatial data acquisition. The bottlenecks in acquisition due to reliance on traditional, professional or government mapping have been uncorked using diversified and increasingly accurate active or passive data provided by the public.

The aforementioned “Digital Earth Vision to 2020” workshop led to two scientific papers: *Next-Generation Digital Earth* published in the *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* (Goodchild et al. 2012) and *Digital Earth 2020: Towards the Vision for the Next Decade* published in the *International Journal of Digital Earth (IJDE)* (Craglia et al. 2012). Goodchild et al. (2012) proposed that inevitable new developments in internet communications and API services, multidimensional representation, and Earth observation visualization technologies would accelerate fulfillment of the Digital Earth concept and expand the potential of Digital Earth for all stakeholders. The next generation of Digital Earth is not projected to be a single system and will likely be multiple interconnected infrastructures based on professional standards for open access and horizontal participation across multiple technological platforms. Client-friendly and customized platforms will drive the growth of different audiences. One metaphor proposed Digital Earth as a digital nervous system for the globe, actively informing users about events happening on or near the Earth’s surface by connecting to sensor networks and situation-aware systems (Foresman 2010). de Longueville et al. (2010) believed that Digital Earth is a powerful metaphor for accessing the multiscale 3D representation of the globe but, due to its non-self-aware feature, the inclusion of temporal and voluntary dimensions would be more helpful in a description of the real world. Craglia et al. (2012) articulated the main policy, scientific and societal drivers for the development of Digital Earth. These papers help illustrate the multifaceted nature of next-generation Digital Earth. The growth of Digital Earth is predicated in part on emphasizing its usefulness to the public. Continued development and evolution of internet bandwidth and improved visualization techniques can be expected to maintain the growth of Digital Earth applications. Equally important for public applications are social developments and the widespread adoption of social networks, which serve as key ways to communicate and turn citizens into force multipliers as providers of information.

#### ***1.4.4 Digital Earth in Big Data Era***

Entering the big data era, national and regional governments responded by releasing relevant strategies accordingly. For example, in 2011 the European Commission announced a statement on “Open Data: An Engine for Innovation, Growth and Transparent Governance”. In 2012, the United States released the “Big Data Research and Development Initiative” to enhance the capability of knowledge discovery through big data (<http://www.whitehouse.gov/sites/default/files/microsites/>

[ostp/big\\_data\\_fact\\_sheet\\_final\\_1.pdf](#)). Australia published “The Australian Public Service Big Data Strategy” in 2013. Subsequently, the Chinese government began emphasizing big data as one of the strategic resources of social development in 2013 and issued the “The Action Plan for Promoting Big Data Development” in 2015, including a proposal for “Developing Science Big Data”. In 2012, the UN Global Pulse published “Big Data for Development: Opportunities and Challenges” to promote the significant role of big data in responding to climate changes. The International Council for Science (joined in 2017 with the International Social Science Council to form the International Sciences Council) published their “Strategic Plan 2012–2017”, which emphasized the importance of data management in new knowledge discovery.

Big data has created a new computational perspective in the use of continuously collected data from various sources to explore trends in large volumes of data and to better understand world dynamics. Such advances bring great opportunities for Digital Earth to play its visionary role in integrating the massive amount of multi-dimensional, multitemporal, and multiresolution geospatial data as well as socio-economic data in a framework for comprehensive analysis and application systems about the Earth.

Digital Earth has evolved into a new connotation of ‘big Earth data’. Big Earth data incorporates the litany of powerful tools requisite to understanding and explaining the Earth system and to investigating sustainable global development. It focuses on the synthesis and systematic observation of Earth, as well as data-intensive methods for studying Earth system models with the goal of increasing knowledge discovery. Big Earth data can be expected to promote the Digital Earth vision by connecting multiple satellites and geographical information centers that rely on national spatial infrastructures and high-speed internet to complete the acquisition, transmission, storage, processing, analysis, and distribution of spatial data.

## **1.5 Relationship with Other Initiatives**

### ***1.5.1 Geospatial Information Infrastructures***

The United States pioneered the development and implementation of the National Spatial Data Infrastructure (NSDI) in the 1990s. Clearly defined, the NSDI is the sum of the technologies, policies, standards, human resources, and related activities necessary to collect, process, publish, use, maintain, and manage geospatial data from all levels of government, private and nonprofit organizations, and academic communities. The NSDI makes existing and accurate geospatial data more accessible, greatly facilitates the collection, sharing, distribution and utilization of geospatial data, and has played an active role in economic growth, environmental quality and protection, and social progress in the United States.

The NSDI model has been accepted and adopted to fit the needs of many other countries that have implemented their own spatial data infrastructure plans. The federal government of Canada implemented the GeoConnections program in 1999, a national program of partnerships involving the federal government, provincial (district) governments, municipal and local governments, research institutes, universities, and private companies. The main role of GeoConnections is to establish the Canadian Geospatial Data Infrastructure (CGDI) and enable online access to Canadian geospatial databases and services. The CGDI is the sum of the policies, technologies, standards, access systems and protocols necessary to coordinate all geospatial databases in Canada and make them available on the internet. For more than a decade, the implementation of GeoConnections has enabled online access to Canadian geospatial databases and services, and effectively coordinated partnerships, investments and developments between federal, provincial, local government, private and academic communities.

In 2007, the Infrastructure for Spatial Information in Europe (INSPIRE) Directive came into force (<https://inspire.ec.europa.eu/about-inspire/563>). This directive established a web-based infrastructure to make more visible, shareable and usable environmental and geospatial information necessary to support European environmental policies that affect the environment such as transport, agriculture, and marine policy. INSPIRE is decentralized, i.e., the infrastructure builds on those set up and maintained by the 28 EU member states. It does not require the collection of new data and develops the technical, and organizational arrangements to achieve interoperability among the infrastructures in the member states and among the 34 data themes falling in the scope of the directive. INSPIRE will take more than 12 years to implement, from 2007 when the directive was adopted to 2019–20 and beyond. As this process takes place, it is important to consider the technological and policy developments that will shape the future data infrastructures so that the investments of today are open to the developments of tomorrow.

### ***1.5.2 Earth Observation Program***

Earth observation has become a major part of many countries' environmental and defense programs since the final decades of the last century. Nations were influenced by the Planetary Mission of NASA's Earth Observation Program. The program was developed for the scientific research of the Earth systems. Its goals were to collect sufficient data on the Earth's systems to enable whole planetary assessments and conduct comprehensive research on the Earth. NASA's program consists of three parts: the scientific plan, Earth observation platforms, and data information systems.

A new generation of space-Earth observation continues and has been extended to incorporate observations of the land, atmosphere, ocean, ecosystem processes, water and energy cycles, and solid Earth.

The Global Monitoring for Environment and Security (GMES) program was jointly established by the European Space Agency (ESA) and the European Commission in 2003. The ESA created a series of next-generation Earth observation missions, including the Copernicus program. To meet the operational needs of the Copernicus program, the ESA developed the Sentinel program to replace older Earth observation missions. Each Sentinel mission is based on a paired satellite model to provide datasets for Copernicus Services and focuses on different aspects of Earth observation, including atmospheric, oceanic, and land monitoring.

Earth observations have expanded rapidly around the globe, as demonstrated by the fact that the GEO now has more than 100 member nations. Bringing Earth observation down to Earth with an ever-increasing number of Earth observation satellites with increasing spatial, temporal and spectral resolutions represents a critical data input to the Digital Earth concept.

### ***1.5.3 National/Regional Digital Earth Programs***

Dozens of countries such as Australia, China, Japan, Singapore, South Africa, and the European Commission have generated their own Digital Earth-related programs. There has been important progress in these efforts, such as Digital Earth Australia established by the Australia federal government in 2017, the Geoscience Australia Data Cube (supported by the Commonwealth Scientific and Industrial Research Organization, the National Computational Infrastructure, and the National Collaborative Research Infrastructure Strategy of Australia), Digital China promoted by the Chinese government, the Key Laboratory of Digital Earth Sciences established by the Chinese Academy of Sciences, and the IDEAS (International Digital Earth Applied Science Research Center) at Chubu University in Japan, as well as those at several universities with Digital Earth departments or laboratories (e.g., Austria and Malaysia). Some of these are described in detail in Part III of this manual.

## **1.6 Digital Earth in Response to Global Challenges**

Correlated with and a derivative of many sciences dealing with the surface and near-surface of the Earth, Digital Earth was envisioned as an initiative for harnessing the Earth's data and information resources. With powerful tools to quantitatively describe a science-based representation of the planet, Digital Earth could serve as a tool to map, monitor, measure, and forecast natural and human activities. The prowess of the Digital Earth technology was envisioned as requisite to assist nations, organizations, and individual citizens in addressing the problems humans are facing in the 21st century. These challenges for all nations, such as climate change, natural disasters, and sustainable development, require the comprehensive scope and analytical capacity of Digital Earth technology.

### ***1.6.1 Response to Climate Change***

Since the middle of the 20th century, large-scale, high-intensity human activities and the rapid growth of the population and social economy have compounded global change problems such as global warming, air pollution, water pollution, land degradation, rapacious resource exploitation, and biodiversity decline. Global change threatens national security and all aspects of our lives, including economic and social development conditions from social, economic, living, and health perspectives. Sustainable development is now recognized as the most serious challenge facing human society.

The United Nations, in partnership with various intergovernmental coalitions, has organized and implemented a series of environmental research programs on global or regional scales, such as the World Climate Programme (WCP), the Man and the Biosphere Programme (MAB), and the International Biosphere Programme (IBP). Within the International Geosphere Biosphere Programme (IGBP), each country is challenged to address the natural resource and environmental issues caused by global change as a primary means to achieve sustainable approaches for socioeconomic development.

Global change is recognized as a significant threat to sustainable development worldwide. To address these multidisciplinary issues at a global scale, global change research faces the unpredicted challenge of obtaining copious data from the interacting subsystems of the Earth for analytical modeling and generating management decisions (Chen 1999; Shupeng and van Genderen 2008). Thus, it is important that Digital Earth facilitates the collection of data from various elements of the Earth system through monitoring the progress of global change in large-scale, long-term sequences, and aids in data processing, analysis, and simulation.

The Paris Agreement, which was negotiated by representatives of 196 countries, was endorsed at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in LeBourget, France on 12 December 2015. The Paris Agreement's long-term goal is to "strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius." The agreement states the need to "strengthen the ability of countries to deal with the impacts of climate change" as well as reduce the risks and effects of climate change (<https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>). Under this agreement, starting in the year 2020, a litany of financial policies and new technology frameworks will be put into action to support the realization of greenhouse gas emission mitigation, adaptation, and finance. Increasingly, scientists are documenting that the impacts of temperature increases in the polar regions indicate that our collective actions may be too little, too late.

Big Earth data should provide a wide range of long-term sequences and multiple spatiotemporal scales to cover all of Earth's systems including the atmosphere, cryosphere, hydrosphere, lithosphere, and biosphere. To stock Digital Earth with big



Earth data requires the only known science approach, which is to amass a space-air-ground integrated Earth observation system and a global near-real time, all-weather Earth data acquisition network. Through continuous and long-term monitoring of the Earth system, scientists can use advanced geospatial processing technologies to simulate and analyze Earth's dynamic surface processes and reveal spatiotemporal change mechanisms. Stakeholders will need to formulate scientific strategies and take progressive actions to respond to global change for sustainable development at varying local and regional scales. In this sense, big Earth data provides strong support to the Digital Earth vision, which will hopefully strengthen new approaches to global change research.

### ***1.6.2 Response to the UN SDGs***

In September 2015, the United Nations General Assembly adopted “Transforming our World: The 2030 Agenda for Sustainable Development” (United Nations 2015). This international milestone provides a blueprint for action for all countries and stakeholders. This agenda defines 17 Sustainable Development Goals (SDGs) and 169 targets and creates a global indicator framework until 2030. The 2030 Agenda for Sustainable Development provides a new insight into the global actions and transformative policies necessary to guide our collective pursuit of sustainable development.

Achieving sustainable development presents all countries with a set of significant development challenges. These challenges are inherently embedded with spatial-temporal complexities, that is, they are almost entirely geographic in nature. Many of the structural issues impacting sustainable development goals can be analyzed, modeled, and mapped using Earth observation data, which can provide the integrative and quantitative framework necessary for global collaboration, consensus and evidence-based decision making.

Digital Earth is closely interrelated with the global sustainable development challenges and processes, as evidenced through national Earth observation agencies' efforts to connect and integrate big Earth data into the application of many social and environmental programs. Earth observation data provide a substantial contribution to the achievements of the SDGs in support of decision making by monitoring impacts and results, improving the standardization of national statistics, addressing cross-cutting themes such as climate and energy, and facilitating countries' approaches to working across different development sectors (Anderson et al. 2017).

At the United Nations World Geospatial Information Congress (UNWGIC) held in Deqing, Zhejiang Province in China from 19 to 21 November 2018, attention was paid to strengthening national geospatial information management and systems and national implementation of the 2030 Agenda for Sustainable Development (<https://www.unwgic2018.org/>). It has become important to the science and governance communities to understand, analyze and discover knowledge from huge geospatial data resources. This must be accomplished in a collaborative way among nations to

effectively address local, regional, and global challenges and to share big Earth data worldwide as prerequisites to meet the requirements of sustainable development.

Effective transfer of all relevant technologies and Earth-related data represents an important challenge (Scott and Rajabifard 2017). However, under the Digital Earth framework, there are immense opportunities for digital transformation and sharing of resources. Achieving sustainable development will entail significant advances in overcoming political and technical bottlenecks to smooth the digital divide. Internet-based infrastructure with advancing 5G communication shows promise for expanding Digital Earth technologies to all nations.

### ***1.6.3 Response to Disaster Mitigation***

Addressing natural and human-caused disasters remains the highest priority of all nations. Climate change experts are in agreement that global warming will increase the frequency and intensity of storms and disruptive weather patterns. Therefore, application of the Digital Earth framework and technology for disaster response and mitigation is of paramount importance.

Recently, the Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) was adopted by the UN member states in March 2015 at the World Conference on Disaster Risk Reduction held in Sendai, Japan, and endorsed by the full UN General Assembly in June 2015. This 15-year development framework agenda contains seven targets and four priorities for action. The United Nations International Strategy for Disaster Reduction (UNISDR) has been tasked with supporting the implementation, follow-up and review of the Sendai Framework. The framework's central aim is to “reduce disaster risk... and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries” with the efforts of local governments, the private sector and other stakeholders within a voluntary, nonbinding agreement (<https://www.unisdr.org/we/coordinate/sendai-framework>).

Notably, disaster-related applications have been prominent since the inception of the Digital Earth community. Chen's (2004) comprehensive review of Digital Earth science in China includes examples of research on flood, coastal, river, and other disasters. The International Society for Digital Earth has sponsored or cosponsored many disaster-oriented workshops and symposia. Importantly, the collaboration with UNISDR, GEO and CODATA and other international associations has been anchored by the common commitment to collaboration and focus on applications for disaster response. Chapter 15 addresses these applications.

## 1.7 Conclusions/Structure of the Manual

In this manual, the Digital Earth vision has been introduced in the first chapter. Part I has eleven chapters about various Digital Earth technologies; Part II has seven chapters describing the role of Digital Earth in multidomain applications; and Part III contains four chapters showing how the Digital Earth concept has developed from Al Gore's original vision to its current implementation as employed around the world through four regional/national chapters of the International Society for Digital Earth. Part IV considers Digital Earth education and ethics. The concluding chapter of this Manual of Digital Earth describes some of the key challenges and future trends for the development of Digital Earth over the coming years.

Digital Earth is an evolving concept that is strongly influenced by the evolution of technology and the availability of new data. In a couple of years, the Earth will be revisited several times a day by the new generation of satellites, and real-time observation will no longer be a chimera. As we look to the future, it is unlikely that a unified vision of Digital Earth will capture all the perspectives of all stakeholders. A one-size-fits-all Digital Earth would not be appropriate for all nations and cultures. The current social and technological trends expressed in the literature prescribe a robust and comprehensive list of likely characteristics for an updated version for Digital Earth, which closely follows the original vision. There will be a series of connected perspectives of Digital Earth based on varying priorities and applications of the same framework data sources operating with different user-specified functionalities. In the future, the concept and vision of Digital Earth will evolve with the development of science and technology.

## References

- Anderson K, Ryan B, Sonntag W et al (2017) Earth observation in service of the 2030 agenda for sustainable development. *Geo-Spatial Inf Sci* 20(2):77–96
- Annoni A, Craglia M, Ehlers M et al (2011) A European perspective on Digital Earth. *Int J Digit Earth* 4(4):271–284
- Chen S (2004) *Geo-information science and Digital Earth*. Science Press and Science Press USA Inc, Beijing
- Chen S (1999) The 'Digital Earth' as a global strategy and its master point. *J Remote Sens* 3(4):247–253
- Craglia M, de Bie K, Jackson D et al (2012) Digital Earth 2020: towards the vision for the next decade. *Int J Digit Earth* 5(1):4–21
- de Longueville B, Annoni A, Schade S et al (2010) Digital Earth's nervous system for crisis events: real-time sensor web enablement of volunteered geographic information. *Int J Digit Earth* 3(3):242–259
- Foresman TW (2008) Evolution and implementation of the Digital Earth vision, technology and society. *Int J Digit Earth* 1(1):4–16
- Foresman TW (2010) Sustainability and an Earth Operating System for Gaia. In: Crist E, Rinker BH (eds) *Gaia in turmoil*. MIT Press, Cambridge, MA, pp 243–253
- Giles J (2006) Wikipedia rival calls in the experts. *Nature* 443(7111):493

- Goodchild MF (1999) Implementing Digital Earth: a research agenda. In: Xu G, Chen Y (eds) *Towards Digital Earth: proceedings of the International Symposium on Digital Earth*. Science Press, Beijing, pp 21–26
- Goodchild MF (2000) Discrete global grids for Digital Earth. In: *Proceedings of 1st international conference on discrete global grids*, Citeseer, California, Santa Barbara, pp 26–28
- Goodchild MF (2007) Citizens as sensors: the world of volunteered geography. *GeoJournal* 69(4):211–221
- Goodchild MF (2008) The use cases of Digital Earth. *Int J Digit Earth* 1(1):31–42
- Goodchild MF (2013) The quality of big (geo)data. *Dialogues Hum Geogr* 3(3):280–284
- Goodchild MF, Guo H, Annoni A et al (2012) Next-generation Digital Earth. *Proc Natl Acad Sci U S A* 109(28):11088–11094
- Gore A (1992) *Earth in the balance: ecology and the human spirit*. Houghton Mifflin, Boston
- Gore A (1999) *The Digital Earth: understanding our planet in the 21st Century*. *Photogramm Eng Remote Sens* 65(5):528–530
- Grossner KE, Clarke KC (2007) Is Google Earth, “Digital Earth?” – defining a vision. [https://www.researchgate.net/publication/254735434\\_Is\\_Google\\_Earth\\_Digital\\_Earth\\_Defining\\_a\\_Vision](https://www.researchgate.net/publication/254735434_Is_Google_Earth_Digital_Earth_Defining_a_Vision). Accessed 10 Mar 2019
- Grossner KE, Goodchild MF, Clarke KC (2008) Defining a Digital Earth system. *Trans GIS* 12(1):145–160
- Guo H (2012) China’s earth observing satellites for building a Digital Earth. *Int J Digit Earth* 5(3):185–188
- Guo H, Fan X, Wang C (2009) A Digital Earth Prototype System: DEPS/CAS. *Int J Digit Earth* 2(1):3–15
- Guo H, Liu Z, Jiang H et al (2017) Big earth data: a new challenge and opportunity for Digital Earth’s development. *Int J Digit Earth* 10(1):1–12
- Guo H, Wang L, Chen F et al (2014) Science Big Data and Digital Earth. *Chin Sci Bull* 59(12):1047–1054
- Guo H (2018) A project on big earth data science engineering. *Bull Chin Acad Sci* 33(8):818–824
- He G, Wang L, Ma Y et al (2015) Processing of earth observation big data: challenges and countermeasures. *Chin Sci Bull* 60(5–6):470–478
- He G, Zhang Z, Jiao W et al (2018a) Generation of ready to use (RTU) products over China based on Landsat series data. *Big Earth Data* 2(1):56–64
- He G, Wang G, Long T et al (2018b) Opening and sharing of big earth observation data: challenges and countermeasures. *Bull Chin Acad Sci* 33(8):783–790
- Heipke C (2010) Crowdsourcing geospatial data. *ISPRS J Photogramm Remote Sens* 65(6):550–557
- Howe J (2006) The rise of crowdsourcing. *Wired Mag* 14(6):1–4
- International Society for Digital Earth (1999) Beijing Declaration on Digital Earth. Approved at the First International Symposium on Digital Earth. <http://www.digitalearth-isde.org/society/56>. Accessed 10 Mar 2019
- International Society for Digital Earth (2009) Beijing Declaration on Digital Earth. Approved at the Six International Symposium on Digital Earth. <http://www.digitalearth-isde.org/society/56>. Accessed 10 Mar 2019
- International Society for Digital Earth (2012) Statutes of the International Society for Digital Earth. <http://www.digitalearth-isde.org/statues>. Accessed 10 Mar 2019
- Keyesers JH (2015) Digital globe review 2015, published by the Australia and New Zealand cooperative research centre for spatial information. <http://www.crcsi.com.au/assets/Uploads/Globe-review-paper-March-2015.pdf>. Accessed 10 Mar 2019
- Lewis A, Oliver S, Lymburner L et al (2017) The Australian geoscience data cube—foundations and lessons learned. *Remote Sens Environ* 202:276–292
- Lu F, Zhang H (2014) Big data and generalized GIS. *Geomat Inf Sci Wuhan Univ* 39(6):645–654
- Mahdavi-Amiri A, Alderson T, Samavati F (2015) A survey of Digital Earth. *Comput Gr* 53:95–117
- Mueller N, Lewis A, Roberts D et al (2016) Water observations from space: mapping surface water from 25 years of Landsat imagery across Australia. *Remote Sens Environ* 174:341–352

- NASA (2009) New vision for 'eyes on the earth'. [http://www.nasa.gov/topics/earth/features/Eyes\\_1.5.html](http://www.nasa.gov/topics/earth/features/Eyes_1.5.html). Accessed 10 Mar 2019
- Sagar S, Roberts D, Bala B et al (2017) Extracting the intertidal extent and topography of the Australian coastline from a 28 year time series of Landsat observations. *Remote Sens Environ* 195:153–169
- Sahr K, White D, Kimerling AJ (2003) Geodesic discrete global grid systems. *Cartogr Geogr Inf Sci* 30(2):121–134
- Shupeng C, van Genderen J (2008) Digital Earth in support of global change research. *Int J Digit Earth* 1(1):43–65
- Scott G, Rajabifard A (2017) Sustainable development and geospatial information: a strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-spatial Inf Sci* 20(2):59–76
- United Nations (2015) Transforming our World: The 2030 Agenda for Sustainable Development. Sustainable Development Goals Knowledge Platform. <https://sustainabledevelopment.un.org/post2015/transformingourworld> Accessed 18 Mar 2019
- Yokokawa M (2002) Earth simulator system. [http://www.thocp.net/hardware/nec\\_ess.html](http://www.thocp.net/hardware/nec_ess.html). Accessed 6 Mar 2019

**Zhen Liu** received her Ph.D. degree in Cartography and Geographical Information System from the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. She is now the Executive Director of the secretariat of the International Society for Digital Earth and the Managing Editor of the *International Journal of Digital Earth*.

**John van Genderen** is a Professor from the ITC, who has been involved in Digital Earth since the first ISDE Symposium in Beijing in 1999. His main research is in Remote Sensing Image Fusion, and in transfer of technology to Less Developed countries. He has carried out EO projects in some 140 countries.

**Lizhe Wang** is a “ChuTian” Chair Professor at School of Computer Science, China University of Geosciences (CUG). Prof. Wang received B.E. & M.E. from Tsinghua University and Doctor of Eng. from University Karlsruhe (Magna Cum Laude), Germany. His main research interests include remote sensing image processing and spatial data processing.

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

