

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

https://doi.org/10.1007/978-981-32-9915-3_26

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

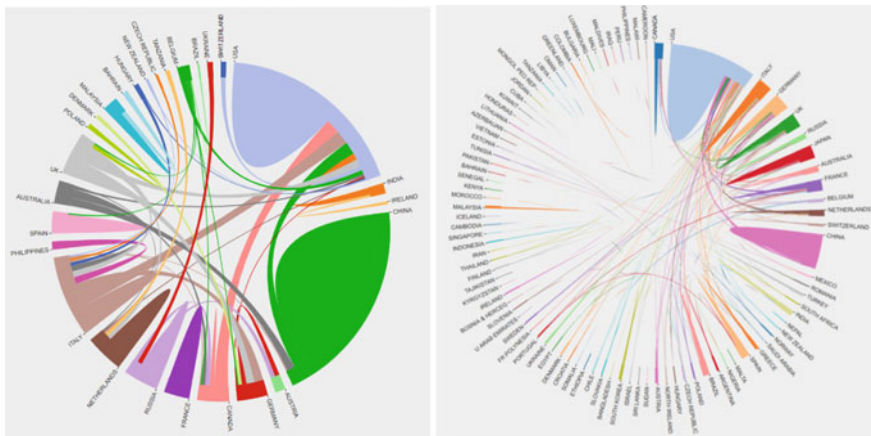


Fig. 26.1 Digital Earth research came from many countries in the world. The area shown for each country corresponds to its percentage contribution, and the linkages show the collaborations between different countries. China and the U.S. are in the top tier, with many cross-country collaborations

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-disciplinary 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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