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Digital Earth 2020: towards the vision for the next decade[1]

Max Craglia[a]*, Kees de Bie[b], Davina Jackson[c], Martino Pesaresi[a],
Gábor Remetey-Fülöpp[d], Changlin Wang[e], Alessandro Annoni[a], Ling Bian[f],
Fred Campbell[g], Manfred Ehlers[h], John van Genderen[b], Michael Goodchild[i],
Huadong Guo[e], Anthony Lewis[j], Richard Simpson[k], Andrew Skidmore[b] and
Peter Woodgate[l]

[a]*European Commission Joint Research Centre, Ispra, Italy;* [b]*ITC, University of Twente,
Enschede, The Netherlands;* [c]*D_Citynetwork, Sydney, Australia;* [d]*Hungarian Association for
Geo-Information (HUNAGI), Budapest, Hungary;* [e]*Center for Earth Observation and Digital
Earth, Chinese Academy of Sciences, Beijing, China;* [f]*Department of Geography, University at
Buffalo, State University of New York, Buffalo, NY, USA;* [g]*Canada Centre for Remote Sensing,
Ottawa, ON, Canada;* [h]*Institute for Geoinformatics and Remote Sensing, University of
Osnabrück, Osnabrück, Germany;* [i]*Department of Geography, Center for Spatial Studies,
University of California, Santa Barbara, CA, USA;* [j]*Department of Geography and
Anthropology, Louisiana State University, Baton Rouge, LA, USA;* [k]*Nextspace, Auckland, New
Zealand;* [l]*Cooperative Research Center for Spatial Information, Australia and New Zealand
Land Information Council, Canberra, Australia*

This position paper is the outcome of a brainstorming workshop organised by the
International Society for Digital Earth (ISDE) in Beijing in March 2011. It argues
that the vision of Digital Earth (DE) put forward by Vice-President Al Gore 13
years ago needs to be re-evaluated in the light of the many developments in the
fields of information technology, data infrastructures and earth observation that
have taken place since. The paper identifies the main policy, scientific and societal
drivers for the development of DE and illustrates the multi-faceted nature of a
new vision of DE grounding it with a few examples of potential applications.
Because no single organisation can on its own develop all the aspects of DE, it is
essential to develop a series of collaborations at the global level to turn the vision
outlined in this paper into reality.

Keywords: Digital Earth; spatial data infrastructures; earth observation; GEOSS;
geobrowsers; voluntary geographic information

1. Introduction

Thirteen years ago, US Vice-President Al Gore articulated a vision of 'Digital Earth'
as a multi-resolution, three-dimensional representation of the planet that would
make it possible to find, visualise and make sense of vast amounts of geo-referenced
information on physical and social environments. Such a system would allow users to
navigate through space and time, accessing historical data as well as future
predictions (based for example on environmental models), and would support its
use by scientists, policy-makers and children alike (Gore 1999).

At the time, this vision of Digital Earth (DE) seemed almost impossible to achieve given the requirements it implied about access to computer-processing cycles, broadband internet, interoperability of systems and above all data organisation, storage and retrieval. Ten years later, geo-browsing (browsing digital geographic information (GI) over the web) has brought many of these elements of DE to the fingertips of hundreds of millions of people worldwide.

Today's users of the first commercial DE geobrowsers, Google Earth (and commercial alternatives including Bing and Digital Globe) are benefiting from innovative ways to organise and present data and from rapid advancements in hardware, software and data capture and processing. With this in mind, several authors (Craglia *et al*. 2008, Goodchild 2008, Grossner *et al*. 2008, Jackson 2008) have recently considered the extent to which the original vision had been achieved, and what gaps still existed that deserved attention.

Since 2009, the International Society for Digital Earth (ISDE) has been reflecting on the need for a new vision of DE, more in tune with the societal and technological changes that are expected to evolve exponentially in the current decade and beyond. From a European perspective, Annoni *et al*. (2011) identified three areas of particular interest in Europe:

(1) Developing dynamic information flows of social and environmental interactions by exploiting new developments in web-enabled sensors, and the opportunities provided by social networks and citizens'-contributed information.
(2) Establishing DE as a framework for addressing global sustainability research questions, and as a catalyst for advancing the GI science issues needed to turn the DE vision into reality.
(3) Raising awareness in Europe of the concept of DE, and coordinating the many activities, projects and funding streams that can contribute to the development of DE.

These priority areas were discussed at the ISDE Summit in Nessabar in 2010 and were felt to be generic enough to be included in a more global reflection on a new vision for DE. With this in mind, the ISDE organised a Vision 2020 brainstorming workshop in Beijing in March 2011, hosted by the Centre for Earth Observation and Digital Earth (CEODE) of the Chinese Academy of Sciences. The workshop aimed to identify the key elements to include in a revised vision for DE. This article is one of the outcomes of that meeting.

This article is organised as follows: after this brief introduction, Section 2 reviews the case for developing a new vision of DE to take into account key scientific questions, emerging societal needs and new opportunities to engage the public more fully in addressing the big challenges of our time. Section 3 reviews the growing literature on DE and identifies a range of complementary perspectives on DE that express its multi-faceted nature. In a networked society, it is unlikely that there will be only one DE; more likely we will see a series of connected views reflecting a system of systems logic, and plurality of stakeholder priorities. Section 4 identifies the key feature of the vision for DE, and Section 5 puts forward three examples of possible applications of DE in 2020 to reflect global-, regional- and individual-level viewpoints. Having sketched out these uses and complementary perspectives, Section 6

addresses the all-important issue of the partnerships that need to be established and cultivated to turn the vision into reality and sustain it in the long term. Section 7 concludes with a summary of key issues and priorities.

2. The case for DE

Goodchild (2008) explored the use case for DE. He argued that it is common practice in software engineering to build systems based on the analysis of the functionalities required by users. In the case of geographic information systems (GIS), the functionalities offered to address the main use cases for data query, analysis and visualisation. In the case of geobrowsers, however, this approach does not seem to have been followed. It appears to have been a case of 'build them and they will come'. Nevertheless, as Goodchild (2008) argues, this has become a very successful case because geobrowsers, with their emphasis on visualisation and ease of use appeal to humans' spatial thinking, 'which is one of the fundamental forms of intelligence needed to function in modern society'. Yet, in a forthcoming paper on the next generation of DE, Goodchild *et al.* (forthcoming) conclude that despite the progress of today's generation of virtual globes they still fall short of Gore's vision of a DE.

So, if one had to develop a use case for DE in 2020, what would that be? We frame this question from four points of view articulated below: the world in 2020, the science case, webs of citizens and sensors and the hierarchy of needs perspective.

2.1. The world in 2020

A number of reports have been published in recent years that try to identify the key issues and challenges facing us in the coming 10–20 years (Sheate *et al.* 2007, UNEP 2007, NIC 2008, OECD 2008). From these documents, there seems to be a large degree of consensus that at the global level we will see an increasing shift in economic wealth and power, particularly towards Brazil, Russia, India and China, resulting in a multi-polar world, and new challenges for governance and leadership.

Increased world population combined with increased economic wealth will put major pressures on strategic resources: energy, food and water. A consequence will be continued (or increased) disparities within countries and across continents (e.g. potential doubling of people with limited access to fresh food and water), and potential for conflicts, particularly in the developing countries. Western countries will not only face their specific challenges related to energy and the environment but will also be confronted with particular tensions in balancing competitiveness, cohesion, ageing populations and immigration.

Focusing specifically on the environment, there is a broad consensus that climate change, loss of biodiversity, water scarcity and the impact of chemicals and carbon emissions on air quality and public health will continue to be major issues in the next 20–30 years. Nevertheless, working towards a cleaner and more sustainable environment also provides an opportunity for many countries.

By investing further in information and environmental technologies, it is possible for some countries to become exporters of clean technologies and thus turn the environment into a new engine for competitiveness and growth, rather than a cost as currently perceived. Embedding environmental perspectives into social and economic policy requires a more holistic and cross-sectoral way of working, strengthening local

to global interactions and improving scientific understanding. In this respect, greater transparency about assumptions, shared access to data and better communication of scientific findings will become critical to gathering and retaining the support of society and policy-makers.

From these scenarios, the requirements for DE are to provide a framework for shared global access to information supporting the sustainable use and equitable distribution of scarce resources across regions and generations. Such a framework needs to support scientific research, but also public participation in science and in the strategic choices affecting our planet.

2.2. The science case

One of the most fundamental challenges facing humanity at the beginning of the twenty-first century is to respond effectively to the global environmental changes that are threatening humanity. The International Council for Science (ICSU) articulates this priority as follows:

> Over the next decade the global scientific community must take on the challenge of delivering to society the knowledge and information necessary to assess the risks humanity is facing from global change and to understand how society can effectively mitigate dangerous changes and cope with the change that we cannot manage. We refer to this field as 'global sustainability research.[1]

Through consultations with more than 1000 scientists from 85 countries in 2009–2010, ICSU has identified five scientific priorities, or Grand Challenges, in global sustainability research. These Grand Challenges include:

(1) Developing the *observation* systems needed to manage global and regional environmental change.
(2) Improving the usefulness of *forecasts* of future environmental conditions and their consequences for people.
(3) Recognising key *thresholds* or non-linear changes to improve our ability to anticipate, recognise, avoid and adapt to abrupt global environmental change.
(4) Determining what institutional, economic and behavioural *responses* can enable effective steps towards global sustainability.
(5) Encouraging *innovation* (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability.

ICSU also argued that tackling these grand challenges requires a stronger involvement and greater integration of the social sciences, health sciences, engineering and humanities, along with the natural sciences. In other words, there is a strong need to move from disciplinary research to multi-disciplinary research. Moreover, an effective response to global environmental change requires not only better science but also more focused collective action by all stakeholders. This entails two key priorities:

- Communicating science more effectively to close the gap with citizens and policy-makers.

● Engaging the public in the scientific process such as helping monitoring the environment, reporting observed and perceived changes and impacts for example via social networks.

The Grand Challenge of developing and maintaining global observation systems is the scope of the Global Earth Observation System of System (GEOSS) initiative. GEOSS is being developed through the voluntary efforts of 84 countries and 58 organisations participating in the Group on Earth Observations' 10-year implementation plan (2005–2015) (GEO 2005).

A major role of GEO is to promote scientific connections and interoperability between observation systems to address some of the scientific challenges identified by ICSU with a particular focus on nine societal benefit areas.[2] In particular, GEO is advancing collaborations across thematic domains, developing a technical infrastructure with agreed data sharing principles to facilitate access and use of available resources and building institutional capacity.

Similar initiatives to improve the knowledge base of policy and science are taking place at national and regional levels through the development of spatial data infrastructures (SDIs) based on the interoperability of systems, data and services. In Europe, INSPIRE (EC 2007) is leading the way in building a decentralised Infrastructure for Spatial Information, while the Global Spatial Data Infrastructures Association provides a platform to share related experiences in North and South America, Africa and Asia. The many initiatives in government and science under the banner of Open Data are also worth mentioning because they are gaining considerable momentum (see e.g. data.gov in the US, data.gov.uk in Europe, Open Science Data, the Science Commons and the Open Data challenge http://opendatachallenge.org/).

Although GEOSS and SDIs are important steps towards coordinating and sharing earth observation and geographic data, they generally fall short of meeting the challenges identified by ICSU. To do so, they would need to:

● Include multi-disciplinary models from both physical and social sciences to forecast change, and identify thresholds or 'tipping points' leading to non-reversible change. To make these models understandable and usable across disciplines would require a major effort in developing semantically rich descriptions of key concepts and processes, and underpinning assumptions.
● Include scenarios of possible policy responses and frameworks to measure their likely impact and consequences across environmental, social and economic domains.
● Include a participatory framework able to engage decision-makers and the public in the analysis of scientific evidence and possible scenarios, responses and impacts across geographical regions and social groups (who wins and who loses as a result of certain actions or non-actions). The serious controversy that arose in regard to the apparent certainty of projections made by some scientists associated with the 2007 report of Intergovernmental Panel on Climate Change (IPCC) led to major public debate in many countries. Therefore, the measurement and communication of uncertainty is also crucial.

Digital Earth should include all of the above to meet the challenge of global sustainability research. It should also exploit the new opportunities (not foreseen at the time of the Al Gore speech) offered by the massive deployment of sensors, and the rise of social networks to develop a truly participative and a near-to-real time nervous system for planet Earth (De Longueville *et al*. 2010).

2.3. Webs of citizens and sensors

Digital Earth involves multiple stakeholders and actors. While the roles of environmental and social scientists, technologists and decision-makers are widely acknowledged, those of citizens in the development, use and management of DE have yet to be articulated. There are several facets to this important issue, and we suggest giving priority to the following two:

- *Contributions of individuals as providers of data.* With over 10 billion social network accounts in 2010 (50% more than people on Earth) (Silicon.com 2011) (generating for example 65 million Tweets a day, www.twitter.com, and a store of over 4 billion photographs on Flickr www.flickr.com), the opportunities to harness this wealth of digital data for a variety of applications, from emergency management and response to risk assessment, quality of life and environmental monitoring, cannot be ignored (Goodchild 2007). Assessing the quality of this data is an important issue but the contribution they can make in narrowing the gap between science and the public is potentially very significant (Ostermann and Spinsanti 2011).
- *The impacts of DE on individuals and society.* This area includes research and ethical issues on privacy and confidentiality, openness and transparency versus security considerations, as well as the measurement of the social, economic and environmental costs and benefits of the deployment of DE. Research in this area has so far rightly focused on the potential negative consequences of a digital 'Big Brother' scenario, or of actions taking place in the grey zone that emerges when legal frameworks are unable to keep pace with rapid technological developments (see for example www.spatiallaw.com). However, new uses of social networks to mobilise the masses, and foster political change ought also to be studied in greater depth.

Whilst citizens' information provides new and exciting opportunities for collaborative and participative science, or Science 2.0 (Burgelman *et al*. 2010), the development of web-enabled sensors (Klopfer and Simonis 2009, Broering *et al*. 2010, De Longueville *et al*. 2010) adds a complementary dimension. During the last decade, we witnessed a tremendous development and uptake of low-cost miniaturised sensors and wireless sensor nodes, while standards such as the Open Geospatial Consortium (OGC) Sensor Web Enablement (Botts *et al*. 2008) make it possible to treat equally all sensor-like information. This has led to the concept of the 'Observation Web' with observations originating from humans, sensors or numerical (environmental) simulations (Butler 2006).

Integrating the Observation Web with a global system of systems would contribute to addressing at least part of the scientific challenges identified by ICSU. In particular, it would allow moving from an essentially static representation

of the Earth to one that is dynamic and interactive, and more responsive to the Grand Challenges. Moreover, integrating the quantitative measurements and observations from sensors with the richness of qualitative information provided by citizens, makes it possible not only to assess how the environment is changing but also how such change is perceived. These dimensions are crucial for the interface between policy, science and society.

As we consider these developments in a global context we also need to be mindful of different social and political context, and levels of development. To illustrate this point, we have developed a DE Index discussed in the following Section.

2.4. DE Index

The DE Index represents the state of digital development of each country. Using the 'hierarchy of needs' concept developed by Maslow (1943), we could consider the DE Index as a measure of 'digital needs'. The Index is shown in Figure 1. The *x*-axis has the rate of energy consumption (based on the DMSP-OLS Night-time Lights Time Series[3]) by population, which can be taken as a proxy for dependency on digital goods and equipment. The *y*-axis is the rate of Internet penetration reflecting a need for advanced technology use to strengthen individual opportunities. The *y*-axis has a natural log scale to accentuate discrepancies between countries. The hierarchy of the DE Index is interpreted as an inset, with a comparison to Maslow's hierarchy of needs.

The curve drawn in Figure 1 separates two areas. A balanced 'digital' needs fulfilment takes place when a country is positioned above the curve (left-top of the XY-plot): relatively little energy dependency while the use of advanced technology is comparatively sufficient. Countries below the curve consume high amounts of energy while the Internet penetration level remains very low. Clear differentiation between continents regarding their current state in 'digital' development is obvious. Africa is only at the start; Asia, Oceania and Latin America are well ahead, while Europe and North America have reached a high level in the hierarchy. Within continents, the status of individual countries often varies considerably, e.g. Asia and the Middle East.

Considering the mechanisms of the hierarchy of needs, societies will strive to maintain or improve their current status. Needs fulfilled in respect to 'digital' development are well protected and defended, while countries that have not satisfied such needs will strive to do so after fulfilling their more immediate physical needs. The interdependencies between digital and fundamental human needs, such as freedom, have become very evident in the early part of 2011 during the uprising in the Middle East. This also shows that having a relatively low level of the DE Index such as Libya does not mean that the available Information and Communications Technologies cannot be used to great effect to mobilise the masses. There is much to be gained by all countries in the development of DE, providing access and use is open to all.

The hierarchy proposed earlier can and will have additional higher levels not yet captured by the indices used. As new advances take place, new 'digital' needs will be felt. To cope with the increase in complexity of society and the environment, we need additional sensors, processing capacity and storage to make sense of the complexity of the information we face. Vice versa, DE will help deliver solutions to these needs
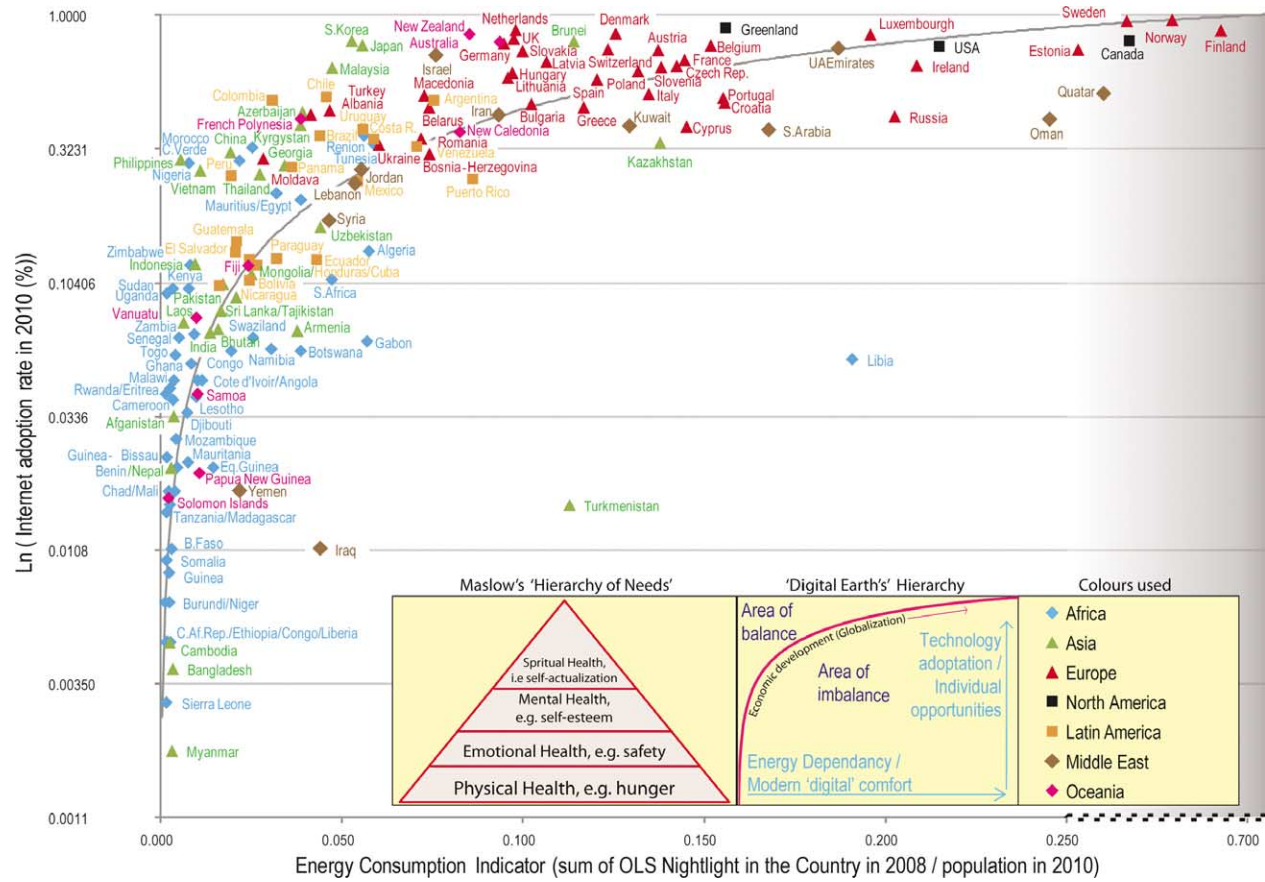
Figure 1. The Digital Earth (DE) Index of needs.

and will create for us an increased understanding on progress in the pyramid of 'digital' needs.

3. Perspectives on DE

The academic literature on DE has been growing steadily in recent years, encouraged by the ISDE. Since 1999, the ISDE has organised DE Symposia and Summits in alternate years, and launched in 2008 the *International Journal of Digital Earth,* now a highly ranked regular publication for academics interested in this area. Reviewing the literature on DE, it is possible to discern a few major streams of perspectives.

Digital Earth as a *research challenge*: in this stream Goodchild (1999) outlines research issues that arise from the vision of the Gore speech, in the areas of data structures, indexing schemes, data integration, semantic integration, cartographic technique and geovisualisation and institutional arrangements. Craglia *et al.* (2008) and Annoni *et al.* (2011) consider the major developments that have taken place in the 10 years since the Gore speech, and add new topics to the research agenda identified by Goodchild (1999). These new topics address the opportunities of sensor webs and volunteered GI in providing dynamic data flows on the state and responses of the environment.

Digital Earth as an *information system*: Grossner (2007) and Grossner *et al.* (2008) define a DE system as: 'a comprehensive, distributed geographic information and knowledge organization system' which would be based on participant systems that adhere to an agreed set of protocols and standards for data models, data formats and metadata, allowing it to function as a contributing node in a single, virtual computing system. This perspective comes close to the system of systems approach of GEOSS (2005). Similarities with the current work to implement GEOSS can also be seen in He (1999) reviewing the range of needs and systems being developed by the Food and Agriculture Organization (FAO), particularly in the context of the International Global Observing Strategy.

Digital Earth as a set of *applications, and an organising metaphor*. The global features of DE offer potential mainly for environmental applications such as global climate change environmental protection, disaster management, natural resource conservation and sustainable economic and social development (ISDE 1999, 2009). An example of applications related to the land use implications of switching to renewable energy resources is reported by Strobl (2006), while Fukui (2009) discusses monitoring glacial lake outburst floods as an example of applications of Digital Asia to assess the impact of global warming. Aside from these applications, Goodchild (2000) makes the point that DE is a much better metaphor to organise, search and retrieve the information necessary to understand the Earth phenomena than the office metaphor of most desktops based on filing cabinets, wastepaper bins and so on.

Digital Earth as a *strategic infrastructure* is a perspective advocated in China by for example Guanhua (1999) who focuses in particular on DE for sustainable development and management of natural resources but also as a catalyst for leap-frogging development in science and technology. The strategic nature of DE is also strongly put forward by Wu and Tong (2008) who argue that it is as strategic as 'the atom bomb, hydrogen bomb, and artificial satellites' (p. 4), while Guo *et al.* (2010) argue that 'possessing DE is equivalent to taking the highest control point in modern society' (p. 45). A similar, yet more tactical view of DE is put forward by Goodchild

(2000) who focuses on the concept of DE as a 'moonshot' that can motivate and mobilise cutting-edge research.

Counterbalancing these positive perspectives are a few authors who point to the *potential negative aspects of DE* like Curry (2000) who argued that GI systems traditionally had two dimensions: global (geographical) and local (e.g. planning and advocacy). The emerging debate on DE, like the transition from GI Systems to GI Science, strengthens the global discourse and reduces the spaces for local voices and needs to be heard. In a similar vein, Konecny (1999) argued that whilst DE is a powerful concept, it is important to ensure that all can partake in its development and use, and that opportunities and threats are recognised and addressed. These include decentralisation versus recentralisation and control (e.g. manufacturing and delocalisation), fragmentation of polity versus integration (e.g. online communities), homogenisation versus diversity (e.g. role of international media homogenising popular culture versus the assertion of inward-looking local identities).

As shown from this brief review of the literature on DE, there are multiple perspectives on what DE is or should be. It is unlikely therefore that a single (revised) vision of DE will capture all perspectives from all stakeholders. There is not going to be a one-size-fits-all DE, but there will be a series of connected views of DE based on the same sources of data and offering users different functionalities. Based on the current social and technological trends and the review of the literature, we can identify some likely characteristics of the revised vision for DE.

4. What will DE look like?

- It will look like a globe, as the globe is proving to be a very powerful mechanism for visualisation, and a metaphor for organising the world's information. From the globe view it will then be possible to see, in 3-, 4-and n-dimensions, inside buildings as well as what lies underground and under-water.
- It will visualise the present physical features of the Earth but also the past through historical data, and the future based on the outcome of integrated models. Time will be a critical dimension of understanding and analysis. Therefore, preservation of our digital past, as well as our present, will be an important feature.
- It will be dynamic and interactive exploiting the full range of information flows from sensors and people.
- It will synthetise heterogeneous information and provide metrics of quality and trust of both data inputs and outputs.
- It will be more participative as people will have a greater say in providing data but also in interpreting the data and shaping the construction of scientific 'evidence', and arguing the pros and cons of different policy choices. As a result, it will improve our collective understanding of how the Earth works, and how it may respond to both physical and social interventions.
- It will be not just about space and spatial relations but also about place, culture and identity, spanning the physical and virtual space. It will thus emphasise the analysis of networks and flows, and relationships between

places (e.g. cultural influences, links established through migratory flows or history) in addition to the traditional spatial analysis.

● It will be easy and fun to use with different levels of functionality available to different audiences to find out more about a place or issue, or interact with models and parameters.

● It will be an ubiquitous frame of reference as people and an increasing number of every day objects will be online at all times.

To understand better some of the functionalities that may be required and to help develop the vision of Digital Earth 2020, it is useful to define a few exemplary use cases as argued by Goodchild (2008). The section below shows both global examples of possible applications and common individual-level examples.

5. Examples of use in 2020

5.1. Global examples

5.1.1. Land use change and food production

The year is 2020. Farmers connect to DE to optimise their activity, close chronic yield gaps through improved management and have better coping mechanisms in case of disasters. The combination of field level weather forecasts, and sensors constantly measuring moisture and soil composition and acidity has made it possible to reduce the amounts of pesticides used by 50%. This has reduced significantly eutrophication, without loss of yield for the farmers. Instant information on markets, prices and delivery methods allows for rational crop rotation, and improved conservation of the resource base. Moreover, DE components specifically developed for farmers have automated some management operations through GPS and GNSS-based geo-location tools (precision farming), and improved management through investments, loans or barter trade, supported through micro-insurance schemes that can be subscribed to in a tailored-way. Farmers now use DE services to supply information on local crop status and yields in exchange for long-term risk-analysis on price fluctuations in different markets, consultancy from fellow farmers, advice from market analysts on new trends (e.g. marketing of bio-labelled food), and early warning on emerging dangers (droughts, fire, flooding, hail and storms, frost, locusts).

Increased communications and sharing of information among farmers and other actors in the processing and marketing chain has strengthened local communities and provided opportunities for better long-term planning. Speculation based on fragmented information and markets has thus been reduced. DE has enhanced our options to cater for the basic needs (food) of the ever-increasing global population. It has successfully helped remove poverty traps by creating safety nets, providing location and situation-based services, guidance and knowledge-packages, so that farmers are able to sustain our future.

5.1.2. Global human settlement layer

The year is 2020. A global symbolic representation of the built environment is available and integrated in the DE. The global human settlement layer (GHSL) is a

multi-scale volumetric information layer describing artificial spaces where people live, work and enjoy life. Physical components such as buildings, roads and open spaces are accurately described at each scale from single rooms or apartments, to rural villages, towns or mega cities and other urbanised regions. The widespread use of Lidar and digital photography has enabled the creation of this global layer in 3D, so that we can explore all built environments moving from the inside of buildings to the whole metropolis, including underground infrastructures and utilities. Digital histories of buildings and cities available in DE also allow navigation through time (4D), and new planning proposals are regularly debated based on realistic models portraying the evolution of the city in the future.

Sensor webs (exploiting satellite, aerial, ground and mobile sensors), connected to advanced pattern recognition algorithms and distributed processing capacities, produce an objective, globally seamless and constantly updated GHSL. Shared privacy rules protect private spaces, and people and households have the right to decide if and at which level of detail they are connected to the DE GHSL.

Digital Earth allows different actors at different levels–individuals, families, organisations or authorities–to elaborate models and strategies concerning safety of living, travelling or working. At another scale DE allows the planning of collective rescue or mitigation measures after natural disasters and improved understanding of the interactions between human artificial spaces and natural environments.

Through information, fusion of GHSL with crowd sourcing and mobile technologies integrated in the DE, it is possible to model the location of people at any point of space and time and consequently take informed decisions about risks or opportunities to cross-specific areas during specific events: to take the best escape route during a flood, or find the best place for communication.

While the knowledge of the physical characteristics of built environments allows more accurate estimations of damage produced by catastrophic events–tsunamis, earthquakes, tornados, floods and eruptions–real-time modelling of the population presence and movements has made a major difference. In the past, we used to take strategic decisions based on static population databases such as the Census, which reflected the resident population count every 10 years, and was therefore always out of date. Now we know the location of people (e.g. commuters, migrants, business people, etc.) at different times of day and night, and their use of space and facilities. We have moved therefore towards a much more dynamic and accurate understanding of the relationships between built environment and society: anywhere, any time, at any scale.

5.2. Individual examples

The year is 2020. About 3 trillion things (including interoperable sensors, Radio Frequency IDentification (RFID), tagged objects and products, livestock and 4 out of the 7 billion humans) are connected to DE, which provides a wide range of cloud-based infrastructures, services and solution-oriented capabilities. The 4 billion members of social networks contribute massively to the development and maintenance of DE with constant feeds of information, alerts of events and news items.

Digital Earth is used at all ages: by children as a learning and play environment, by teenagers socialising and trending, by adults in their daily and professional life, and by the senior generation networking in their retirement with friends and family, and checking their health online maybe more often than necessary.

The multiplicity of social networks and the sharing of information globally have improved the accountability of governments and of multinationals, after a series of well-publicised citizens mobilisations and consumer boycotts. The Hacker Challenge has replaced the World Football Cup as the most watched event, and helps to keep in check novel ways to disrupt DE.

As most objects have become web-enabled, from domestic appliances to buses, it is now possible to programme and undertake activities in more interactive ways at home, the office, and on holiday. Energy efficiency, resource optimisation and waste reduction are key greening principles enabled by this massive deployment of sensors. Smart paints, for example, have been made compulsory on all new building and self-regulate to absorb or reflect sunlight and thus optimise temperature control indoors.

The accelerated pace of technological development is a challenge for policy-makers to ensure that the legislative framework (especially in the interest of the privacy), and the institutional/organisational response is adequate in protecting individuals and avoiding threats to society. Protocols on how to subscribe or unsubscribe to services need constant updating, for example, to ensure that a guaranteed level of privacy is maintained, if one wishes.

What has changed most since 2011 is that speech has become the main method of interaction with DE, replacing text on tiny keyboards. Smell is also gaining popularity particularly for some applications like cookery programmes, and as a way to convey data quality (bad data smells!). Visualisation is now routinely based on augmented reality. Looking at a building we can see and hear about its contents, past history and other useful information like opening hours of commercial concerns, key items for sale and prices instantly compared with similar products purchasable in the neighbourhood or online across the world.

Our comments and feedback about places, experiences or transactions go instantly online (unless we unsubscribe to the service) and contribute to the collective knowledge. Entering an area we are therefore immersed in a virtual space where others before us have left digital postings that are available to us if we so wish.

Traceability has also become a key feature. What was common practice in logistic supply chains has become also the norm for food quality security and control, and has been extended recently to humans who are routinely tagged with different levels of accessibility of their signals. Convicted criminals were the first to be tagged with under skin RFIDs, followed by the military entering operations zones. The debate on tagging children 0–6 years was lively, and exposed the tensions between the comfort of digital parental control with the potential slippery slope of tagging everybody at all times. Some argued that we are traceable anyway via our mobile devices, so what is the difference? Others warned about the dangers of a Big Brother society. It is not surprising therefore that the faculties of Digital Ethics have seen a major increase in the numbers of students who are eager to ensure that DE remains an open and free space for all peoples across the globe.

6. How to get there

The empowerment of individuals, organisations, governments and society through the growing ubiquity of DE in all its forms suggests that there is a real value in establishing a suite of guiding principles and a code of ethics to regulate behaviour.

Implementing the DE vision will be most effective through a global public–private partnership involving four key sectors of society–Research, Government, Commerce and Communities/Citizens (Civil Society).

During 2010 and 2011, the United Nations Framework Convention on Climate Change (UN FCCC) began developing the Technology Mechanism that it promised in the 2009 Copenhagen Accord and 2010 Cancun Agreements. This is intended to include a Climate Technology Centre based in Europe, a 'network', and a Technology Experts Council to thought-lead both the network and the UN FCCC's Conference of the Parties.

For the United Nations, the DE vision represents an important new step forward from 'doom and gloom' scenarios about climate change. These are heavily reliant on counting emissions, developing reduction targets that member nations are reluctant to agree to be legally binding, and trading credits from 'good' ventures to allow 'bad' ventures to continue operating with minimal concern about polluting and damaging the Earth and its atmosphere.

The UN FCCC recently agreed to establish its Technology Mechanism to 'accelerate climate change solutions'. The approach being taken for DE is to exploit advanced aero- and geo-spatial technologies (especially remote sensing and imaging) to rapidly improve the modelling, mapping and simulation of complex environmental and human systems around the entire planet, as advocated by ICSU. A shared understanding of the problem and possible solutions is a necessary condition to increase the opportunity to find acceptable political compromises. In this respect, DE has a very important role to play as negotiations framework.

United Nations agencies and more than 80 international key organisations have members that can contribute to implementing the DE vision; but so far mainly in disparate, disconnected ways. A major effort is therefore required to develop synergies across the potential stakeholders of DE. In addition to the ISDE, examples of DE-relevant organisations include:

- The World Council for Science, which is the most active body supporting the professional development of multi-disciplinary scientists and the promotion of science to sustain and progress humanity.
- The Group for Earth Observations (GEO), which is already collaborating with the ISDE, United Nations agencies, and natural environmental systems organisations (e.g. the World Meteorological Organisation) to advance the GEOSS. GEOSS is an important component to implement the DE vision.
- The UN Programme on Global Geospatial Information Management (GGIM) aims at playing a leading role in setting the agenda for the development of global geospatial information and to promote its use to address key global challenges. It provides a forum to liaise and coordinate among Member States, and between Member States and international organisations. A United Nations Committee of Experts on GGIM has been established by the Economic and Social Council on 27 July 2011 as the official UN consultative mechanism on GGIM (http://ggim.un.org/).

Other relevant organisations, from the potential user side, are, for example, the International Society of City and Regional Planners, the World Business Council for Sustainable Development, the World Federation of Engineering Organisations and

the Institute of Electrical and Electronics Engineers. An important role in the future may also come to be played by the network of networks special initiative to be launched at the Eye on Earth Summit taking place in December 2011 under the sponsorship of the Abu Dhabi government, and the UN Environmental Program (http://www.eyeonearthsummit.org/).

The research needed to underpin the development of DE should be addressed in partnerships among the large research funding organisations like the National Science Foundation in the USA, the Chinese Academy of Science and the European Commission. The key technological innovations are however likely to come from the private sector, particularly through large industrial companies like Microsoft and Google, the telecommunications industry and through the collective effort of the open source community. Not-for-profit organisations like the Gates Foundation and NGOs are also required to ensure accessibility to DE in the developing countries, and support capacity building.

The key challenge is in communicating the DE vision, and building the strategic partnerships among the many stakeholder organisations. To build the momentum and overcome the 'not invented here' syndrome a collective effort is necessary in which every partner can see a benefit. The ISDE has the leading role in building the alliances needed and coordinating the effort, while a network of communications companies is needed to promote the DE key advances and achievements and sustain the momentum.

7. Conclusions

In this article, we argued that the many advances that have taken place in the 13 years since the original vision of DE require a reappraisal and the articulation of a revised vision. Key technological developments have been in the evolution of Internet bandwidth, and in improved visualisation techniques. Equally important have been the social developments, with the widespread adoption of social networks as a key way to communicate and turn citizens into major providers of information. The implications of these combined developments for politics and society have been dramatically shown during the Arab Spring in 2011, in which social media have been central to the mobilisation of millions of people demanding change.

The opportunities for science to exploit these new developments are also very significant: not only to have access to many more dynamic observations about the environment from sensors and citizens, but also to involve citizens in the construction of scientific evidence and to close the gap between science and society.

With this in mind, we have identified some of the key features that DE should have by 2020, when most people and things will be on line at all times. This is potentially creating a paradigmatic shift in the way we relate to each other and with our surroundings. Hence, we have argued that DE should be a dynamic framework to share information globally and improve our collective understanding of the complex relationships between society and the environment we live in. DE should make it possible to navigate across space and time, connecting the global issues to local ones. It should include scientific models to project into the future and help us all understand how the Earth system works and what are the likely consequences of our actions or inactions. It should therefore become the framework for negotiating international accords on the environment but also on acceptable ethical conducts, as

the potential dangers from the development of DE are possibly as big as the opportunities.

Implementing this vision of DE requires a major effort in international collaboration as well as further advances in science and technology. The latter, as we have seen in the last 13 years, continue apace. The key challenge is therefore in developing the framework of governance across multiple stakeholders and the public to harness these new developments, and direct change so that DE emerges as an open framework accessible to all to shape the future of our planet. We have the vision, now let us turn it into reality.

Notes

1. http://www.icsu-visioning.org/wp-content/uploads/GrandChallenges_Pre-publication.pdf
2. Disasters, Health, Energy, Climate, Agriculture, Ecosystems, Biodiversity, Water and Weather.
3. http://www.ngdc.noaa.gov/dmsp (accessed 4 December 2010).

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