TOWARDS AN INTEGRATED EARTH OBSERVATION SCIENCE IN A BIG EARTH DATA ERA

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ABSTRACT:

Earth observation (EO) data – including satellite-borne, airborne or drone-based imagery – have become indispensable for the monitoring of the environment. EO supports tackling the 'grand challenges' at global spatial scales, such as global change and climate variability technology but also retail or insurance. Like a macroscope, it opens research avenues to observe processes occurring over a wide range of spatial and temporal scales, from abrupt changes such as earthquakes, to decadal shifts such as growth and shrinkage of ice sheets. Particularly satellite data became a success story and empowered individuals, businesses and society. Until a few years ago, the term remote sensing mainly stood for a digital raster world view while the GIS community was inclined to the vector world. "Earth Observation" seems to be integrative and to accommodate various means of data acquisition from satellites, aircrafts, drones, to in situ measurements. Today the rapid growth of data science, the consumerization of GIS and remote sensing, and the continued spread of online cartographic tools are prompting a more holistic Earth Observation Science and interdisciplinary educational programmes.

1. INTRODUCTION

Earth Observation has become indispensable for a range of operational applications. A 1990s science textbook may have started with a similar spirit but we currently enter a new era of Earth observation in which this kind of information is democratized and is starting to play a critical role in observing and understanding our environment and, ultimately, our lives. Particularly satellite data became a success story – years after industry formulated similar claims – and empowered various kinds of users:

- **Individuals**. Access to EO information has empowered individuals with a wide variety of vital information about neighbourhoods and foreign destinations to improve individual decisions. Examples range from almost instant weather information to images that allow to explore and to navigate our hometowns or travel destinations.

- **Businesses**. Scientific discoveries and the resulting applications have helped businesses, such as making agriculture more productive, or energy use and transportation more efficient. Companies have leveraged EO technology to provide valuable services, ranging from outdoor and activities recreation to weather-based shipping optimization.

- **Society**. By extending and building on scientific findings in agriculture, forestry, coastal protection or snow and ice applications, individuals, groups or the society at large may redefine various roles under changing conditions and may better understand the risks and benefits of actions and inactions with the environment. This extended perspective positions society to benefit from economic opportunities and may increase society's resilience to the environment's risks.

2. WHY IS EARTH OBSERVATION (EO) IMPORTANT?

Earth Observation industry and agency have been claiming for decades that remotely sensed information are essential for understanding, modelling, and predicting natural and man-made processes. If adequately exploited, regularly collected remote sensing and in-situ measurements are indeed crucial sources for up-to-date knowledge about physical and human-related processes and have been important for at least the last two decades. Why should EO be called important at this time (in 2019)?
I may diagnose four important factors that only cumulated over the last years:

1. An unobtrusive and gradual transition from a narrowly focused understanding of security or 'human security' to a widespread, yet vague use of the concept of 'environmental security' that has been stimulated by several international commission and high-level expert panels (see Blaschke et al. 2008).

2. This has enhanced and partially enabled overarching and organizing international and supranational systems such as the Global Earth Observation System of Systems (GEOSS). Building on earlier and on ongoing work on standards, such systems build the necessary frameworks to implement standards and to harvest their advances while enabling access to information to mass users.

3. Subsequently, several legally binding international frameworks build on EO information as proxies for models monitoring and assessing goals and targets of major international frameworks, such as the United Nations Sustainable Development Goals (SDGs) (United Nations 2015a), the Sendai Framework for Disaster Risk Reduction (United Nations 2015b), the Paris Agreement on Climate Change (United Nations 2015c), or the New

Urban agenda (Corbane et al. 2017; United Nations 2017).

4. Overcoming the classic 'raster-vector dichotomy' a full integration of EO information, remote sensing and image processing methods and GIS concepts now allow for an integrated monitoring and modelling of phenomena which are not or only partially directly visible. Indirect cues derived from remotely sensed data can provide evidence that serves a multitude of domains, including the domains of public health, human settlement observation and the entire human-environment nexus as addressed by the SDGs and GEO/CEOS 'Earth Observations in Service of the 2030 Agenda'.

3. WHY NOW? THE BEGINNING OF A BIG EARTH (OBSERVATION) ERA?

As stated before, EO has provide critical information for climate change research, disaster response, agriculture, forestry or urban applications, such to name a few domains. And it continues to do so on vast areas of the Earth's surface – with increasing amounts of data, increasing ranges of resolutions, decreasing revisiting times and with almost instant access for users via web interfaces.
Daily, terabytes of data are acquired from space- and air-borne platforms, resulting in massive archives with incredible information potential; however, it is only recently that we have begun to mine more than the tip of the iceberg of the spatial wealth of these archives. Not too long ago, I personally claimed that "in essence, we are data rich, but geospatial information poor" (Hay and Blaschke, 2010). I have changed my mind and I will briefly explain why.

In twenty years from now, scientists may look back to the beginnings of the big Earth Observation (EO) data era wondering about the naïveté of the first approaches to Big EO data. They may glorify the optimism when developing first solutions of Big EO data like the European DIAS systems that paved the road towards a 'reversed workflow paradigm': "bring the user to the data instead the data to the user" (see Sudmanns et al. in press). The fascination of new trends and technologies may bear a danger of overemphasizing recent trends, which are just snapshots in history.

This may also hold true for the terms "Space 4.0", mainly used in Europe, and "New Space", used more in North America. Both terms can be understood to characterize a time when space is being opened from the preserve of the governments of a few spacefaring nations to a situation in which there is an increased number of diverse space actors including private companies, academia and citizens in a more interactive way. Doesn't this development come surprisingly late compared to other fields? If so, what are the reasons for this lateness, what will consequences of such a development likely be and who would benefit? And what about the terminology?

Until a few years ago, the *term remote* sensing mainly stood for a digital raster world view while the GIS community was inclined to the vector world. "*Earth Observation*" seems to be integrative and to accommodate various means of data acquisition from satellites, aircrafts, drones, to in situ measurements. The term is currently more used in Europe and is promoted by the European commission and the European Space Agency while particularly North America seems to favour the term *remote sensing*.

In any case, it is claimed, that there are big changes going on which either initiate or require paradigm shifts. Figure 1 aims to simplify and condense major opportunities and challenges of an 'Big EO data era'.

Earth Observation in the era of Big Earth Data

Opportunities	Challenges
Unprecedented amount of data	Majority of data never analysed
Variety and amount of sensors	Non-repeatability of observations
Increased temporal resolutions	cross-sensor data analysis problems
Multi-dimensionality	Computational complexity
large-scale environmental monitoring	New workflows required

Recent innovation elements with a potential to exploit these opportunities

- Cloud computing & Big Data enabled science discoveries and applications
- Easily accessible interactive interfaces to data archives
- Reversing workflows: analysis in the cloud instead of downloading
- Standards and standardized spatiotemporal concepts;
- Harmonized GIScience principles for operational solutions;
- Easy access and availability of Big Data and processing capability
- Active promotion and incubation of innovative research and Start-ups

Figure 1. Opportunities and challenges in the era of Big Earth Data and some recent innovation elements.

4. THE „DIGITAL EARTH" CONCEPT AS A GUIDING FRAMEWORK

In a remarkable speech in January 1998, the then US vice-president Al Gore described the vision of digital Earth as a digital future where even schoolchildren could interact with a computer-generated three-dimensional spinning virtual globe:

"Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a "magic carpet ride" through a 3-D visualization of the terrain. Of course, terrain is only one of the many kinds of data with which she can interact. Using the systems' voice recognition capabilities, she is able to request information on land cover, distribution of plant and animal species, real-time weather, roads, political boundaries, and population. [...]. This information can be seamlessly fused with the digital map or terrain data."

This vision stimulated the foundation of the Society of Digital Earth and the 2009 Beijing Declaration on Digital Earth, renewed by the recent Florence Declaration (27 September 2019).

5. GEOSS AS AN IMPLEMENTATION FRAMEWORK

Technically, in 2019, Al Gore's vision is not a vision anymore. EO-based methods, satellite communication and satellite-based navigation have been proven to significantly contribute to human and environmental security monitoring in a widest sense. Hundreds of applications exist which have found their way into mass deployment. This reaches from assisting rescue teams by determining their position and navigating within difficult and unfamiliar terrain to operational solutions in agriculture, forestry or urban climate monitoring. The remaining challenge is to implement this vision into a framework and into actions.

Although there will never be the one and only implementation framework, the GEOSS (Group of Earth Observation Systems of Systems) https://www.earthobservations.org/geoss.php is currently the most accepted framework for this to happen. Instead of duplicating data, this 'system of systems' platform links together observing systems around the world and support the need for the development of new systems. It promotes common technical standards so that data from the thousands of different instruments can be combined into coherent data sets.

6. TOWARDS IN INTEGRATED EARTH OBSERVATION SCIENCE OR "DIGITAL EARTH SCIENCE"

Interdisciplinary and coordinated research is of critical importance to generate both the technologies and the understanding that societies in the 21st century need to strengthen their monitoring capabilities to safeguard their economies and environments. As stated briefly, supranational organisation such as GEO shall harmonize an understanding of the various definitions and perceptions of threats, challenges, vulnerabilities and risks to the environmental and socio-political systems.
Information derived from remote sensors can contribute to an early recognition and warning of threats and can enable policy makers to prevent the emergence of conflicts or to reduce their impact. Such information can only be interpreted within the context of existing information stored in GIS Systems and Spatial Data Infrastructures (SDIs) which again requires a full integration of the 'raster world' and the 'vector world'.

Despite undoubted strengths in environmental data acquisition from Earth Observation, from in situ monitoring and from field surveillance, there is both scope and need for investment in improved monitoring and surveying. The use of EO for environmental monitoring has reached operational status in meteorology, climatology and climate change research, sea surface monitoring as well as vegetation and land cover mapping. Until recently, the use of EO however remained elsewhere limited because it was unable to deliver useful information at a required accuracy or with sufficient resolution, timeliness and continuity. I may again use the example of Europe and its enormous investments and efforts in the Copernicus programme: this programme has now reached the 'user uptake' as it had aimed for a long time. It started under the abbreviation GMES (Global Monitoring for Environment and Security) and reached already operational status in some fields around 2006/07 (see Blaschke et al. 2007). After years and billions of Euros spent, it has now reached mass markets, Start-ups and mass markets.

While being successful we are increasingly facing another problem: some EO programmes and their products are so complex and complicated to understand that it is not only difficult for the end user. It is also increasingly difficult for the experts to keep track with the hundreds of EO satellites and their thousands of sensors, resulting information products and regional, national and supranational data sets and data regulations.

7. THE NEED FOR INTERDISCIPLINARY EDUCATIONAL PROGRAMMES

Earth Observation (EO) in a big data era still needs to be organized about the aim to acquire and nourish the autonomous knowledge and expertise base or planet needs in order to develop and maintain an effective capacity for global monitoring.

The science involved may be divided into four broad classes:

- **Science-technical domain**: generic technologies that are common to nearly all applications of Earth observation such as feature recognition and wall-to-wall classifications;
- **Application domain**: specific applications which typically require multiple sources including in situ data or GIS data such as population monitoring, disaster monitoring or many urban applications;
- **Socio-political domain**: Studies that aim to assess the status quo, the politically agreed pathways and their spatial footprints as well as potentials and threats that need to be monitored;
- **Citizen- or stakeholder domain**: identify the stakeholders needs' for information and engage stakeholders and citizens.

Given the range and complexity of the sum of the information domains involved one may ask what is the common denominator of the underlying theories, concepts, methodologies and methods. One possible answer is that space and the spatial view are the key or lynchpin to successfully organize such a view.

Here, Blaschke (2005) argues that spatial pattern matters fundamentally because context can have a fundamental influence of meaning and value. Moreover, landscape or urban structures are important in their own right, because different structures have different implications for processes. By implication, therefore, EO programmes which should support sustainability and the sustainability goals (SDG) must not only take account of the outputs of goods and services in a statistical sense, e.g. per country, but also the nature of landscape and urban patterns as an issue in their own right.

Interdisciplinary educational programmes should therefore start with some fundamental education in spatial principles as Geography offers. They must find a balance between efforts for a general understanding of the Earth and capabilities to analyse, interpret, monitor and model various processes.

For a best practice example, I may refer to a kind of blueprint programme: the European Master in Copernicus Digital Earth (http://master-cde.eu), a two-year full-time integrated programme that aims at qualifying individuals to lead initiatives, projects and institutions translating Copernicus data into information for management decisions within a broader "Digital Earth vision".

8. CONCLUSIONS AND OUTLOOK

This short article discusses the needs for an integrated Earth Observation science and very briefly lists some major scientific foundations for this proposed science. The underlying vision is a 'spatially enabled framework' to help monitoring, analysing and steering our planet for a sustainable development.

I briefly outlined the integrating potential of such a spatial framework and used the European Copernicus programme as a proof of concept. This European focus is only chosen for the sake of simplicity, there are many other programmes around the world that need to be assessed in detail before drawing final conclusions. As a first step towards this foresight, numerous issues relating to the timely provision of comprehensive, consistent and readily accessible information services have to be discussed in the full text version of this article and technical developments need to be juxtaposed to methodological challenges and recent achievements in the arising trans-disciplinary field of an integrated Earth Observation science.

I may conclude that today the rapid growth of data science, the consumerization of GIS and remote sensing, and the continued spread of online cartographic tools are prompting a debate about a more holistic Earth Observation Science. The full lengths version of this short article will be published in a journal in 2020 together with serval colleagues and will sketch of the form that such an interdisciplinary science might take.

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