The Value of Open Data Sharing

Living Document, Version 1

November, 2015

EDITORIAL NOTE

The report on the Value of Open Data Sharing was first prepared for the GEO-XII Plenary by the GEO Participating Organization CODATA (the ICSU Committee on Data for Science and Technology). Through showcasing diverse benefits of open Earth observations data, the report is designed to facilitate the process of transitioning from restricted data policies to more open policies for government data.

At the GEO-XII Plenary the report received positive feedback from GEO Member countries and Participating Organizations, who also expressed willingness to contribute supplementary case studies. Therefore, it was decided to maintain this report as a living document, with this version for the record as version 1. The GEO community will provide periodic updates, examples and case studies.

To help us on more examples and case studies, please contact:
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Preface and Acknowledgements

The Members and Participating Organizations of the Group on Earth Observation (GEO) make their Earth observation and environmental data available through the GEO Global Earth Observing System of Systems (GEOSS) portal. The preferred approach of the organization is to provide open access and unrestricted use to those data through the GEOSS Data-CORE (Collection of Open Resources for Everyone). This approach has not been adopted by all the GEO participants, despite the call for even greater openness that is promoted by the revised GEO Data Sharing Principles for next decade.

The Committee on Data for Science and Technology (CODATA), a non-governmental Participating Organization of GEO, analyzed and synthesized the existing work on the various benefits and value of open data, with particular reference to Earth observation data made available through GEOSS. The mission of CODATA is "to strengthen international science for the benefit of society by improving scientific and technical data management and use." CODATA is an interdisciplinary committee of the non-governmental International Council for Science (ICSU) in Paris, France. Both CODATA and ICSU are Participating Organizations of GEO. Simon Hodson is the Executive Director of CODATA and the manager of this project. Additional information about CODATA may be found on its website at: www.codata.org.

The report was produced by CODATA specifically at the request of the GEO Secretariat in order to summarise arguments in favour of broad and open data sharing, and to present these to the 2015 GEO Plenary in Mexico. The short timescale for its production meant that it was not possible for the report to go through a formal review process with DSWG. However, DSWG colleagues were consulted and commented on the draft at a number of stages. DSWG acknowledges the merits of the report as an articulation of the value of data sharing and therefore is in favour of the report being presented to the Plenary for information.

The lead author for CODATA was Paul F. Uhlir, J.D. CODATA submitted the draft of this report for formal review by many other individuals who were chosen for their expertise and their geographical representation. These experts included the following:

Enrique Alonso Garcia, State Council of Spain; Bonnie Carroll, Information International Associates; Tim Foresman, Queensland University of Technology; Huadong Guo, RADI, Chinese Academy of Sciences; Simon Hodson, CODATA; John Houghton, Victoria University; Wim Hugo, South African Environmental Observation Network; Jose-Miguel Rubio Iglesias, European Commission; Shuichi Iwata, University of Tokyo; Raed Sharif, Canada's International Development Research Centre; Frazier Taylor, Carleton University; and members of the GEO Secretariat.

CODATA wishes to thank these experts for their contributions to the results of this report, and the GEO community for its constant advocacy for broad, open data.

For CODATA, Simon Hodson, Executive Director.

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EXECUTIVE SUMMARY

OBJECTIVE

As the Group on Earth Observations (GEO) transitions to its second decade of operations, it is important to take stock of what the abiding vision of GEO is: "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information." There are ***several major trends that have made the open and unrestricted uses of public data available through the GEOSS portal essential*** to implementing this vision, including especially the rise of digital networks, *e*-infrastructures and technologies, and the uses of big data. Massive—and increasingly urgent—global public-interest challenges face humanity in the form of climate change, environmental degradation, management of common resources, food security, and health concerns. Open data support and are supported by these larger trends.

BENEFITS

Indeed, ***there are many diverse opportunities and benefits*** to be derived from providing open data through GEO for unrestricted use worldwide. The main reasons are compiled in this Executive Summary and they are substantiated in greater detail in the body of the report.

<u>Economic</u>
Perhaps the most important reasons are the broad economic benefits and growth, both public and private. Public data openly served through GEOSS have been shown to be economic force enhancers, creating value many times over and providing much greater returns on the public investment than have restrictive, proprietary approaches. The generative effects from open data on digital networks are key in this regard.

<u>Societal</u>
Social welfare is enhanced for both individuals and society at large. Open data meet society's expectations of appropriate management of public digital resources, provide diverse reputational benefits, and incorporate ethical principles for accessing and using public data.

<u>Research and Innovation</u>
Public research and private innovation opportunities expand with a policy of openness for upstream data resources. Such data can substantially reduce unproductive barriers to interdisciplinary, inter-institutional, and international research. They enable data mining for automated knowledge discovery in a growing sea of big data. Open data are essential for the verification of research results and in generating broad trust in them. They avoid many inefficiencies, such as the unnecessary duplication of research and the identification of erroneous results. They promote more research and new types of research. They permit the legal interoperability of data when multiple sources of data are combined for new knowledge. Citizen scientists and "crowdsourcing" approaches, which are promoted by GEO, are facilitated.

Moreover, open public upstream data are inputs to and stimulate downstream commercial research and applications that benefit Member economies and the larger society.

Education

Closely related to the public research opportunities is that ***the education of new generations is significantly facilitated***. Open GEO data promote the education of new students and the public, whether at school, in higher education, or increasingly at home. They also support important studies of data collection methods and management. This is why nonprofit research and education were given special status in GEO's first Data Sharing Principles.

Governance

Finally, ***there are key advantages for improved governance.*** Public data made openly available through the GEOSS portal support improved decision-making and transparency in government and society. Such data demonstrate leadership at home and abroad, thereby enhancing influence and legitimacy. For less economically developed countries, open data policies promote capacity building and help to implement "repatriation" objectives. Not least, open public data generally build freedom in society, and trust in governance and its many functions.

CONCLUDING OBSERVATIONS

In sum, the Members and Participating Organizations of GEO stand to gain much more than they lose from making their public Earth observation data available on a full and open basis, freely and without reuse restrictions, as promoted by the GEOSS Data-CORE. They also will avoid all the negative effects that come with attempts at narrow cost recovery and policing leakage in the restricted uses of such data. ***It is thus imperative for GEO to seize the many benefits from publicly generated Earth observation data now, as the new Data Sharing Principles are being implemented for the coming decade.*** It is the primary organizational raison d'être of GEO to make those benefits a reality.

I. INTRODUCTION

A. The Data Sharing Principles of the Group on Earth Observations

The Group on Earth Observations (GEO) is a consortium of the largest amount of publicly funded environmental data in the world. By some estimates, the data controlled by GEO's Members and Participating Organizations exceeds many petabytes in the aggregate, and is rapidly growing to the exabyte level (Mazzetti, Nativi, Santoro, and Boldrini 2014). Many of those datasets are expected to be made available through GEO's Global Earth Observing System of Systems (GEOSS) portal.

Established in 2005, GEO is a voluntary partnership of governments and organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information" (GEO 2005).
The rationale for the organization is thus even truer today than when it was created a decade ago.

It is worthwhile reviewing at the outset GEO's original Data Sharing Principles and those proposed for adoption at the 2015 Ministerial Plenary. The Principles in 2005 for data made available through the Global Earth Observation System of System's (GEOSS) portal were as follows (GEO 2005):

> 1. There will be full and open exchange of data, metadata and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation;
> 2. All shared data, metadata and products will be made available with minimum time delay and at minimum cost;
> 3. All shared data, metadata and products being free of charge or no more than cost of reproduction will be encouraged for research and education.

The draft of the new Data Sharing Principles advocates a more open position for data, consistent with the GEOSS Data-CORE (see Appendix A), made available by GEO through GEOSS (GEO 2014a):

> 1. Data, metadata and products will be shared through GEOSS as Open Data by default, by making them available as part of the GEOSS Data-CORE without charge, without restrictions on reuse, subject to the conditions of registration and attribution when the data are reused.
> 2. Where international instruments, national policies or legislation preclude the sharing of data as Open Data they should be made available through GEOSS with minimal restrictions on use and at no more than the cost of reproduction and distribution.

3. All shared data, products and metadata will be made available through GEOSS with minimum time delay.

As a reader of this short report, you are most likely a funder, manager, steward, or user of an environmental data system that is affiliated in some capacity with the Group on Earth Observations. You know the importance that the organization has; if it did not exist, there would be compelling reasons to create it.

This report provides the rationale for why it is important for GEO to make the data that are available through its GEOSS portal as low-cost to access as possible (free online) and especially unrestricted in use. Put another way, it marshals the evidence for the participants in GEO to adopt the proposed new Data Sharing Principles. If you are already of the view that this is the right approach to take, then the arguments presented here will only help to solidify your opinion and provide a more diverse rationale for that point of view. However, the report is written specifically for those who believe that broad restrictions on access to and use of data are appropriate and good public policy, or who need more reasons to justify greater openness.

B. Underlying Trends

There are several major developments or trends over the past two decades that have made the provision of EO data through GEO on a free and unrestricted basis essential as a default rule. One is the rise of the internet and digital networks. Table 1 summarizes the data characteristics in the pre- and post-internet eras.

Table 1: Comparison of Some Print and Digitally Networked Paradigm Characteristics[a]

Print Paradigm *[Industrial Age]*	Global Digital Networks *[Post-industrial Information Age]*
▪ Fixed, static	▪ Transformative, interactive
▪ Rigid	▪ Flexible, extensible
▪ Physical	▪ Virtual
▪ Digital tools cannot be used to manipulate the content	▪ Many tools available (e.g., visualization)
▪ Local	▪ Global
▪ Limited content types	▪ Unlimited contents and multimedia
▪ Distribution difficult, slow	▪ Easy and immediate dissemination
▪ Copying cumbersome, not perfect	▪ Copying simple and identical

▪ Significant marginal distribution cost	▪ Zero marginal distribution cost
▪ Single user (or small group)	▪ Multiple, concurrent users/producers
▪ Centralized production	▪ Distributed and integrated production
▪ Slow-knowledge diffusion	▪ Accelerated knowledge diffusion
▪ Quasi-private good	▪ Quasi-public good

[a] This table is adapted from Uhlir, Paul F., "The Emerging Role of Open Repositories as a Fundamental Component of the Public Research Infrastructure," in *Open Access: Open Problems,* G. Sica, ed., Polimetrica, p. 62 (2006), *available at* http://eprints.rclis.org/9656/1/OpenAccess.pdf.

As Table 1 demonstrates, there are many features of digitally networked data—from both quantitative and qualitative perspectives—that have radically changed in just the past two decades how we perceive and need to approach data and information resources. From a purely quantitative standpoint, Earth observation systems are a major source of the data deluge and have the concomitant potential to change in many positive ways how we manage the planetary environment. The EO data capabilities that are made available through GEO are the quintessential manifestation of "big data" and one of its most familiar forms.

While the amount of EO data available is significant in its own right, it is the qualitative nature of digitally networked data and information that makes the free and unrestricted provision of those publicly financed resources essential. This report documents that conclusion from many different perspectives.

While these digital developments provide essential rationales for making public data as open and unrestricted as possible, there are many common—and increasingly urgent—global problems that can only be observed and then analyzed with EO data. The development of full understanding of these problems and working toward comprehensive solutions are highly data-driven. Certainly climate change and the well-documented warming of the atmosphere, constitute one such trend. The many manifestations of large-scale environmental degradation, and the response to and mitigation of disasters, are all problems that know no political boundaries and that require a common approach to lessen their effects.

In fact, all of these regional and global problems are reflected in the nine GEO Societal Benefit Areas (SBAs) and are the principal focus of the organization. The current thematic SBAs (in alphabetical order) are: agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water, and weather (see the GEO website for more details at: http://www.earthobservations.org). GEO reflects these broader trends, both digital and environmental, and has the resulting power to effect positive changes to the global commons and to promote the benefits to humanity. The data made available through GEOSS are thus vital for addressing social needs comprehensively. As the first GEOSS 10-Year Implementation

Plan stated: "The societal benefits of Earth observations cannot be achieved without data sharing" (GEO 2005).

C. Scope of the Discussion

This report consequently focuses mainly on the benefits that can be derived from the provision of open GEO data to the public and not on the rationales for restricting them. There are, of course, many well-known reasons for keeping some data more proprietary or secret than others, although they need to be balanced against the benefits of openness discussed here. Such countervailing reasons include restrictions based on the protection of national security, law enforcement, personal privacy, and commercial proprietary concerns. Less well-known and narrower motivations include protections of indigenous peoples' rights, the exact location of cultural artifacts or endangered species, and access and benefit sharing of genetic resources. Many governments or individual ministries favor some immediate or even prospective cost recovery (but see the summary discussion under Part III. CONCLUDING OBSERVATIONS, below, as to why such a position may be "penny wise, but pound-foolish").

The extent of restrictions on the data may vary according to their spectral and spatial resolution, the subject matter being observed, whether the operator is in the public or private sector, and the possibility of serious negative effects. Moreover, each government or organization must determine what data fit those categories, so a wholesale policy of open access is inappropriate. Because the potential negative aspects that might be inherent in any given data-collection system vary greatly, this report does not focus on them further and leaves the reasons for imposing restrictions as a policy judgment to be made by each GEO Member and Participating Organization. Any restrictions, however, such as those noted above, should be based on legitimate factors and need to be balanced against the many benefits that could be realized through a more open data policy.

In particular, there are some unifying features and important arguments that support the open and unrestricted availability of data through GEOSS as a default rule. There are intrinsic benefits that can be realized from the open provision of data on global digital networks. These advantages are the topic of this report and are amply demonstrated.

This report also focuses almost exclusively on public-sector operators of environmental data collection systems, the most voluminous of which are EO satellites. Because of the overview nature of the discussion that follows, the many different sources or levels of processing of observational environmental data, including related *e*-infrastructures and software such as geographic information systems (GIS), are not considered in a nuanced manner or discussed separately. And although a case can be made for some data in some specific circumstances to be made freely available by private-sector operators, we do not dwell on it here either because it is the exception to the rule, rather than the default obligation.

The report also only considers digital data. While analog data may be very useful and in many cases are the only source of historical facts, the rise of networked digital data and information has made analog data of only tangential significance in the present context.

Finally, while the rationale for open and unrestricted availability of data and information can be made very broadly for all types of public data, the focus here as much as possible is on Earth observation and geospatial data made available through the GEOSS portal, with examples given in the SBAs. All of these limitations in scope are necessary to keep the arguments cohesive and tractable, and to limit this overview to a reasonable length.

D. Organization of this Report

The rest of this report focuses on the many benefits that can accrue from the free and unrestricted uses of data served through GEO. Most people look at the economic returns, in part because it is perhaps the easiest to quantify and also because such evidence is very important to make the case. Although there already are many studies that have documented the large increase in monetary benefits from the free and unrestricted dissemination of data, including especially EO or geospatial data, there are numerous other substantial advantages that can be realized as well. The benefits of open data that are reviewed here also include those that are enjoyed by society, both collectively and individually; the inherent ethical dimensions; the enhancement of innovation and not-for-profit research activities; broad educational pursuits; and the improvement of various public policy and governance functions and concerns in both developed and developing countries.

The report concludes with some observations about the importance of the GEO initiative in the coming decade and beyond. In particular, the many barriers posed by restrictions on access and use, and lost opportunity costs and the foregone value from such barriers, are summarized.

Finally, Appendix A provides some definitions of key terms used in this report. Many publications, but by no means all, are included in the bibliography at the end. The references are limited by time, space and language, but together form an extensive set of evidence in favor of an open approach to public data and to EO data made available through the GEOSS portal, specifically.

II. THE MANY DIVERSE OPPORTUNITIES FROM OPEN DATA

A. Supporting Broad Economic Benefits and Growth

Among the main reasons and the greatest amount of evidence in favor of the open and unrestricted availability of public EO (and other) data on digital networks are those in the economic sphere. Many studies and reports have documented the positive value of openness for EO data, specifically, and for various other types of data and information, more generally. This section draws on that past work in describing the issues important for a robust knowledge economy.

Economic studies initially attempted to quantify the overall economic stimulus of open and unrestricted government data in relation to more closed governmental information policies. Although economic effects are difficult to quantify, they are more amenable to measurement, at least as a direct value, than other effects, such as social or political. There have been numerous studies that have looked at the economic value of an open data policy or that have compared the relative economic costs and benefits of open vs. restricted data access policies.

One early study tried to broadly quantify the relative economic advantages of the relatively free and unrestricted information policies with cost-recovery and proprietary approaches (PIRA 2000). Other comparative reports followed, leading to similar conclusions. These included ones by Houghton and Gruen 2014; Beagrie and Houghton 2013; Ubaldi 2013; Deloitte 2012; and Dekkers et al 2006.

Some analyses have been done specifically in the context of Earth observation data, as well as for other types of data, including all types of research data or government data more broadly. Within the Earth observation data community itself, the studies and examples over the past 15 years or so similarly have shown the superiority of free and open dissemination of government EO data. A 2008 workshop held by the U.S. CODATA in collaboration with the OECD compiled a set of reports done on Earth observations and other government data (Uhlir and Sharif, in NRC 2009).

Several examples help to demonstrate both the direct and indirect benefits of an open government Earth observation data policy. In the United States, NOAA collects both geostationary and polar-orbiting meteorological satellite observations, which it either down-streams free to anyone who has a receiving station or makes all the data available for the marginal cost of fulfilling a user request (free online). As a result, a very robust value-added private industry has developed in the United States for both general and specialized weather forecasting products and services.

A 2002 report looked in greater detail at the commercial meteorological sector in the United States (Weiss 2002). According to that report, in the early 2000s the amount of economic activity in the U.S. from the open data policy in the weather satellite sector produced $400-700 million in gross receipts, helped stimulate the formation of 400 commercial businesses for this purpose, and employed about 4,000 people in the private sector. This direct economic growth was further compounded indirectly by the taxes paid back to the U.S. Treasury by the firms and their employees, as well as in social benefits to the general population many times over (see, in particular, Section II.B).

In the European Union, another report analyzed the economic benefits of free and open access to the Sentinel satellite data, now called the Copernicus Programme (Sawyer and de Vries 2012). It found the "business model paradigm" was shifting, particularly for public-sector information (PSI). The report provided sector-specific evidence and analyzed the value of open EO data—especially in the economic re-use of such data.

Similar positive economic effects of open public geospatial Earth observation data were recently found internationally (WMO 2015). At the national level, numerous studies have corroborated such findings as well. These include, for example, the United States (NASA 2012; Kite-Powell 2005), Canada (Roche 2007; Sears 2002), Australia (Houghton 2011; ACIL Tasman 2010), the United Kingdom (Deloitte 2012), and several continental European countries (Ubaldi 2013; Vickery 2011; Garcia et al 2007, Dekkers et al 2006). These reports, and many others, not only documented specific economic benefits of open data in the EO sector, but provided evidence of other, harder to measure, network effects and spillover aspects.

Finally, it should be acknowledged that giving away data from a spacecraft or a sensor system cuts off any direct opportunities for cost-recovery by the operator in the public sector. The studies reviewed above, however, demonstrate that the economic benefits to society and the return on public investments as a whole from an open policy greatly outweigh the benefits that might accrue directly to the public-sector operator.

The Australian Bureau of Statistics (ABS) provides one specific example from a data-intensive government institution, which is one of the few to compare the effects of an open access policy before and after it took effect. It clearly shows that the ABS saved money by giving its data away, including no sales transactions or staffing, far fewer license inquiries with a CC-BY common-use license, and broad social uptake, saving just that one government agency about AU$3.5 million and the users AU$5 million per year, among other cited benefits (Houghton 2011).

B. Enhancing Social Welfare

Although most of the documentation of the value of open public data has focused on the economic effects, primarily because such metrics are easier to quantify, there have been some studies that have tried to demonstrate the benefits to society from such a policy. It is no coincidence that GEO calls the substantive focal points of its work "Societal Benefit Areas."

This section reviews the individual and collective benefits of open data for non-monetary, social applications, including fulfilling the expectations of the "born digital" generation, promoting broad reputational benefits, and implementing ethical principles.

1. Evidence of societal benefits, both individual and collective

A policy of making public data available freely and with no restrictions on reuse, can help citizens make decisions about their lives. Data products and information derived from GEO data can be useful for individuals to better understand the environment in which they live and work, in protecting the health of their family, in better educating themselves, and through the positive results of many other generative and even serendipitous applications (Zittrain 2006; Benkler 2006; NRC 2009; Mayo and Steinberg 2007). Such possibilities are greatly enhanced when they are able to easily locate and use data made available through GEOSS and accessed on computer terminals at their local library, or on their laptops or smartphones virtually anywhere.

Although individuals may not always be personally enterprising, EO organizations in government, in the not-for-profit sector, and various commercial enterprises are more likely to be. Some public organizations that make environmental data openly available have begun to document the social applications and benefits of their data (see, e.g., http://www.ncdc.noaa.gov/societal-impacts/).

2. Meeting society's expectations for access to and use of digital information

An important, but fairly narrow, point is that there is a growing expectation by the younger, "born digital" generations that most data and information online, especially data that are publicly collected, should be able to be freely accessed and shared. Such normative values are entrenched by the capabilities of the technology itself and are therefore growing. If the data are unavailable, costly, or restrictive in their re-dissemination, the users will most likely either opt to use other open sources—if they can—or do something else. In that event, the restrictive public data steward will lose multiple opportunities for enhancing its reputation and whatever collateral benefits that may bring. Conversely, restrictions on public EO data, may breed distrust and disdain by the (potential) users in the national institution, and stymie creativity at the local level.

3. Promoting reputational benefits

Reputational benefits have been associated primarily with the substantial not-for-profit research and educational communities that are an important part of each nation's constituency. More about that aspect is discussed in several sections below.

However, the issue here is the reputational effects from data disseminated to the public, especially if they are freely available and used by many. Salutary effects can accrue to both the provider of the data as well as the many users. Assuming that the data are accurate and useable, as is the case with the vast majority of data made available through GEOSS, the providers of the data that are used will gain in reputation and garner the praises of the users and their circles. The data providers are thus able to avoid the distrust and disdain from the public that were discussed in the previous section. Users of GEO data outside the relatively narrow research and educational communities can similarly gain in recognition—whether professional or merely social—through their varied applications of those data at work or in their personal pursuits. The actual effects or perceptions of such benefits will vary, however, depending on the country or community in which such data access and uses are made.

4. Implementing ethical principles

There are important ethical considerations in determining whether to make data collected by the public sector and with public money freely available, as well as what the users of those data may do with them. Access to information is a fundamental human right, as first posited by Article 19 of the United Nations Universal Declaration of Human Rights some half century ago (UN 1948).

More specifically, if the data made available through the GEOSS portal were collected using public funds, the taxpayer has already paid for that function. The entire activity therefore should be presumed in the public interest and open to the public, in the absence of some legitimate countervailing and overriding purpose (Uhlir 2004).[1] The outputs may be considered as belonging to the public that paid for it, with the GEO data collector and disseminator acting only as an agent on behalf of the public.

Moreover, for government employees, at least, there is no need to apply intellectual property laws to incentivize and protect those public outputs. Excluding the public can be considered unethical and inequitable. Furthermore, those economically or socially marginalized in any society are especially disadvantaged by high prices for data, with the effects of cost recovery policies for public data being especially great in developing countries, where the large majority of people and institutions are poor (see further the discussion in Sections II.E.3 and 4, below).

[1] This assumes that no new investments for *e*-infrastructures and related equipment are needed. There may well be additional public investments of this kind and, like all infrastructures, their costs and benefits should be assessed and validated. The analysis of such other related investments is important, but is outside the scope of this overview.

The users of GEO data also have ethical obligations. They must use the data in accordance with the terms and conditions imposed by the data provider and they must not act contrary to the law of the country in which they live or the norms of the community within which they work. The freer the data policy of the provider regarding the use of its data, the more creative the users can be with the data and the greater the opportunities for generative and serendipitous results. Also, the fewer restrictions there are on the users, the fewer chances there are for the users to contravene them.

It is important to emphasize as well that most GEO data applications have ethical considerations, with some expressly recognized in national and international law. All SBAs have an ethical dimension to them in embodying global public interest problems, and the data supporting public knowledge for their solution may be viewed as global public goods (Stiglitz 1999). There are also strong ethical considerations—now codified in many public policies mandated by Constitutions, treaties, or national laws--that require open data, either expressly or implicitly. Examples of such dimensions include the protection of biodiversity and endangered species from extinction, the maintenance of water and food security in forestalling famines, the protection of populations from pandemics, and the avoidance of deleterious international effects from various forms of environmental degradation—all topics directly relevant to the GEO SBAs (GEO 2015) and open data availability.

Improved responses to disasters are especially prominent in this regard, with the sharing of relevant data—even from private-sector data sources—enshrined in the International Charter on Space and Major Disasters (UN 2000). However, the ethical dimensions of mandatory or encouraged data sharing have already been codified in other major non-sovereign environmental areas that are also topics of GEO SBAs, including the 1949 Antarctic Treaty System (http://www.ats.aq/e/ats.htm), the 1984 Law of the Sea (http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm), the 1985 Vienna Convention for the Protection of the Ozone Layer (https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2&chapter=27&lang=en), the 1992 Convention of Biological Diversity (https://www.cbd.int/), the 1998 Aarhus Convention (https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-13&chapter=27&lang=en) and many other international environmental executive agreements and national laws (Uhlir, Chen, Gabrynowicz, and Janssen 2009).

C. Growing Research and Innovation Opportunities

All of GEO's SBAs have very strong research and education applications. To the extent that research and education is performed in the public sector or with government funds, and is fundamentally not-for-profit, it may be presumed to be carried out in the public interest and have public-good characteristics. Public data from GEO sources used for such public research and educational purposes thus have particularly strong rationales for free and unrestricted uses. As noted earlier in this report, the special status of not-for-profit research and education was explicitly called out for more favored treatment in the third Principle of the original GEO Data Sharing Principles (GEO 2005). This is especially true for data collected from non-sovereign areas, such as the Antarctic, the high seas, the atmosphere and outer space, as discussed above.

1. Enhancing interdisciplinary and international research

The GEO SBAs have numerous discipline and sub-discipline characteristics, with many different participating institutions often in multiple countries. Supporting data that provide the factual basis for most areas of research has always been absolutely essential, but is becoming even more so as research is ever more data intensive. Many are now calling such data-intensive research or data science as the "fourth paradigm" of the research process (Hey, Tansley, and Tolle 2009).

The rise of digital networks and technologies has also enabled opportunities inherent in working across boundaries. Indeed, this is one of the defining features of GEO itself, and the Internet generally (WSIS 2003), and can result in great advances in knowledge and applications as new generative and serendipitous connections are constantly made and old boundaries erased.

There are several types of boundaries that have caused major barriers to the progress of science and to human development, all of which can be ameliorated by the availability of free and unrestricted data. Two of them are considered here.

The first is disciplinary. Prior to the Internet, most researchers collaborated, if at all, with other researchers in the same discipline. The broad availability of digital networks changed that and made hybrid, cross-disciplinary investigations much more common. "Small science" became "big science" and new interdisciplinary fields emerged, such as geoinformatics and sustainability science (NRC 1997; NRC 1999). More recently, we have seen the formation of data-intensive science, as noted at the outset of this section. The GEO SBAs and the rise of open access policies for research data in many science-funding organizations reflect that trend. It is thus not enough for a funding agency or a research facility to enable only a small circle of principal investigators (PIs) from the same discipline to have privileged access to some data. The PIs need access to many kinds of data and to the data produced by other scientists, while many others--whether researchers from other disciplines or even citizen scientists--need access to the data produced by many projects or facilities.

The other boundary is a political one, across nation-states. Many research collaborations are increasingly international in scope, yet each nation has its own laws, culture, and norms that can make cooperation difficult. Such projects reflect not only the global reach of the Internet and the resulting “global village” syndrome, but also the need to address recognized problems that bridge nations in a multi-national way and are independent of political boundaries. More to the point, EO satellite systems and the data they produce are inherently international and can provide the information resources that are needed to research those problems and find solutions. To the extent that those data collection platforms are publicly owned and operated, they are able to support such inquiries broadly and with reduced legal friction and transaction costs if the data are free and unrestricted.

GEO’s SBAs and its organizational principle is to transcend those boundaries with an open data approach and thereby enhance the potential for synergistic discoveries and an increase in human knowledge as a global public good.

2. Enabling data mining

One of the key attributes of the deluge of digital bits today from EO sensors and many other sources is the requirement to perform automated knowledge discovery; that is, to have machines find, extract, combine, and disseminate the data with minimal or no human intervention (NRC 2012b). The accumulated databases, even when properly documented, curated, and stored are simply too large for humans to do the initial interface (NRC 2015). New software and algorithmic methods are continually being developed for extracting knowledge from big data.

Even 15 years ago, there already were some examples of significant discoveries being made through the mining of large archived databases on an open basis. For example, new galaxies, quasars, and other astrophysical objects and phenomena were automatically discovered when using data mining techniques (NRC 2001). More recently, the Landsat program has been supporting new generations of researchers with new technologies and funding for data mining discoveries (Serbina and Miller 2014). The problems of sifting through vast amounts of digital resources to find patterns, correlations, and outliers worthy of further study in large databases has only become more urgent.

These applications, of course, require other technological improvements to succeed, and a discussion of this ancillary infrastructure or data processing techniques is beyond the scope of this report, as previously noted. There are nonetheless many legal obstacles that make the intelligent sifting of massive databases by others than just the rights-holder difficult or impossible. Unnecessary intellectual property protections of government databases create a big hurdle that can easily be modulated to allow beneficial user exploitations. Publicly funded big data—especially in collections of information—thus increasingly require open access and uses to allow the applications capable of extracting value from them (Hague Declaration 2014).

Some governments have begun to expressly consider the link between open data and the need for such automated intermediation (Obama 2013). As the preeminent international organization devoted to disseminating open environmental data, GEO also can and should be a world leader in stimulating automated knowledge discovery and generation as a public good for human benefit worldwide.

3. Permitting interoperability in the creation of new data sets (when data from multiple sources are combined)

A major focus of GEO has been to promote the interoperability of its Members' data (GEO 2015). Because scientists—and others—often use multiple sources of data, many of which may not be their own, they need to be able to integrate those data in a successful manner to generate new knowledge, products, and services.

Interoperability may be defined as "the ability of a computer system or software to work with other systems or products without special effort on the part of the user" (Belmont Forum 2015). The interoperability of data has technical, semantic, and legal dimensions. From a technical standpoint, the data need to have compatible formats and well-known qualities that make those diverse data possible to integrate to form new data products. For most geographically referenced environmental data made available through the GEOSS portal, geographic information software (GIS) has been used already for several decades to accomplish such applications. GIS-enabled applications are thus especially valuable for almost all GEO data, although they are not discussed separately here.

Interoperability of diverse data is also dependent on semantic compatibilities, which have two main aspects. The first, more obvious one, is that the metadata used to describe any given dataset may well be in a different language from that of the user, and therefore difficult to understand, even with automated translation software. The other semantic aspect relates to the nomenclature of the discipline or sub-discipline that generated and described the dataset. Different disciplines have very different ways of naming and describing different (or even the same) phenomena that are important to their understanding, but that may be incomprehensible or even contrary to the usage of that term in another discipline. If a researcher wishes to integrate data from multiple languages, disciplines, and other sources, such problems may proliferate and pose insurmountable barriers.

Finally, there is the problem of legal interoperability that is the most germane here. In 2014, the GEO Data Sharing Working Group (DSWG) published a white paper, *Mechanisms to Share Data as Part of the GEOSS Data-CORE*, which defined legal interoperability this way (GEO 2014b):

“Legal interoperability among multiple datasets from different sources occurs when:
- use conditions are clearly and readily determinable for each of the datasets,
- the legal use conditions imposed on each dataset allow creation and use of combined or derivative products, and
- users may legally access and use each dataset without seeking authorization from data creators on a case-by-case basis, assuming that the accumulated conditions of use for each and all of the datasets are met” (GEO 2014b).

That white paper went on to say that:

> Public domain status is the best legal option for promoting the various social benefits and goals intended by GEO through making available data as the GEOSS Data-CORE by enabling and securing unrestricted re-use, re-dissemination, and legal interoperability. Public domain may be created formally by public laws through national legislation that excludes certain categories of data and information from copyright protection or prohibits impositions of restrictions on their use. The public domain may also be created through regulation or policies that place publicly-funded data in the public domain, as well as through national funding mechanisms, such as grants or contracts (GEO 2014b).

Until relevant government measures are broadly adopted and enforced in the jurisdictions of GEO Members, however, that white paper recommended that they use waivers of intellectual property laws and common-use licenses on a voluntary basis for the data, metadata, and products that they control. The white paper concluded that GEO Members and Participating Organizations should “consider adopting one of the following existing voluntary waivers or standard common-use licenses compatible with the GEOSS Data-CORE mechanism:
a. Creative Commons Public Domain Mark.
b. Statutory waiver of copyright.
c. Creative Commons Public Domain Waiver (CC0).
d. Open Data Commons Public Domain Dedication and License (PDDL).
e. Creative Commons Attribution License (CC BY 4.0).” (GEO 2014b)

These legal interoperability mechanisms all allow the researcher and anyone else who wishes to combine data from different sources, re-use or re-disseminate them on an open basis. Such mechanisms provide the user with certainty that such actions are lawful, at least in the context of infringement of intellectual property rights.

4. Reducing inefficiencies, including duplication of research

Many inefficiencies can be avoided with the open availability of data. Public research, in particular, needs to access large amounts and diverse sources of factual data and information to conduct studies, communicate findings, and share results with the world. Factual data, such as the GEO data sources, are the currency of science. Barriers to access and re-use makes the research process more difficult, incomplete, or inefficient. By making access to data restricted or too expensive for researchers, the chances of duplicating efforts and wasting resources are greatly increased.

For example, a country may fund multiple ground stations with public money to download data that are freely broadcast from an orbiting remote sensing satellite. Despite the free access provided by the operator of the satellite to its data and the payment by a government ministry of the public ground-station equipment, the ground station managers may not share the data that they archive with others. In that case, not only has the government ministry funded multiple ground stations at substantial public expense, but the country's researchers did not get the benefit of broad use of the free data that were downloaded by those stations.

5. Promoting new research and new types of research

Of course, more research can be conducted and new types of research can be promoted if the data are openly available since many more scientists, their machines, and their institutions can access and use the data. Open data reinforce scientific inquiry and encourage diversity of analysis and opinion. They can add increasingly to the reputation and subsequent reward of the researcher. They also encourage the testing of new or alternative hypotheses and methods of analysis. Finally, the open availability of data can lead to serendipitous results, enabling the exploration of topics not envisioned by the initial investigator(s) and the primary research community (Beagrie and Houghton 2014; Arzberger et al 2004).

6. Facilitating citizen scientists and crowdsourcing approaches

Digital networks allow new forms of research to be undertaken, but only if the data and information are openly available for people to access and use. The Internet enables entirely new forms of collaborative knowledge production on a broadly distributed, interactive, and even anonymous basis, changing the hierarchical and centralized organizational models through which information was produced and knowledge diffused previously (Benkler 2006; Uhlir 2006). One of the prominent GEO initiatives for the next decade along these lines is to promote cooperation with citizen scientists and either obtain data using crowdsourcing techniques or add value to existing data in that highly distributed way (GEO 2015).

There are many examples already of the involvement of the general public in voluntary *ad hoc* associations to accomplish specific research tasks. One such application is the provision of a database online in segmented scenes on which the public can work voluntarily. One of the earliest examples of this approach was a project called NASA Clickworkers, in which the public was asked to mark the boundaries of craters on the moon (see: http://www.nasa.gov/open/plan/peo.html). The results showed that such crowdsourcing was more accurate (and cheaper) than having a Ph.D. geologist doing the same work.

Another crowdsourcing application is through distributed computing and processing. The first such instance was launched by the Search for Extra Terrestrial Intelligence in SETI@home. In that project, tens of thousands of volunteers have downloaded distributed processing software onto their computers, which processes the data received by the SETI project while the computers are not in use by the owners (see http://www.setilive.org). For a list of results by SETI, see http://www.crowdsourcing.org/navigate-search?q=Seti.

Other such projects soon followed, including in the EO and remote sensing area. For example, the collection and analysis of satellite imaging is not detailed enough to obtain a comprehensive understanding of vegetation cover. Besides various formal ground sensor systems, such data can be crowdsourced through the participation of citizen scientists using personal cell phones (See and McCallum 2014).

One type of crowdsourcing that has been very successful has been through citizen scientists contributing data to a project, which then puts the entries in a database. Examples include the submission of oceanographic data (Lauro et al. 2014) or bird sightings (Robbins 2013), but many such projects have been undertaken.

A variation of this has been implemented with the more professional and organized contributions of data by researchers. For instance, in the United States, the National Oceanic and Atmospheric Administration (NOAA) uses crowdsourcing techniques for obtaining some magnetic data at its National Geophysical Data Center. NOAA uses the CrowdMag App, in which users can enable background recording with a digital magnetometer installed on their phones so that NOAA can anonymously collect magnetic field data to help keep track of Earth's ever-changing magnetic fields (see http://www.ngdc.noaa.gov/geomag/crowdmag.shtml). For NOAA´s crowdsourcing initiatives, in general, including the NOAA Integrated Ocean and Coastal Mapping, see Glang 2013.

Even private-sector entities have advanced crowdsourcing techniques. For instance, Digital Globe Corporation, has organized huge numbers of volunteers to conduct image interpretation services to identify and locate flotsam from the lost MH370 aircraft (Barrington 2014). This project helped upgrade the scale and complexity of crowdsourcing using remote sensing data in the Earth and environmental sciences.

The incentives for the people who participate in these and many other projects are not monetary; they are reputational in nature and are also driven by the personal satisfaction of contributing to a topic or project that they support. At the same time, they would not participate if their data and those of the other contributors led to results kept on a proprietary basis. Thus, open access to the resulting crowdsourced database is a key feature.

7. Stimulating downstream applications and commercial innovation

The non-commercial, public-sector systems used for collecting EO data that are then made available through GEOSS may be considered "upstream data." That designation refers to data that are meant to be a community resource, and that are non-commercial, non-proprietary, and should not be restricted from broad use, including by value-added firms. The U.S. government has followed this policy, which does not distinguish between commercial and non-commercial users in its access and re-use terms and conditions (OMB 2000). This has led to the very large differences that have been documented and analyzed in various studies reviewed above (see Section II.A.1).

Scientists have always cooperated in the public sphere, with fewer barriers among government and academic scientists than between researchers in the private sector. Whereas the sharing of data was (and can be) relatively less problematic in a purely public setting, researchers funded by public money have increasingly been encouraged to form public-private partnerships (PPPs) to commercialize the fruits of their research that may have economic potential or at least to find new revenue sources. At the same time, with increased competition and smaller profits endemic in the private sector, research-intensive firms have looked to public-sector scientists for joint collaborations at a lower overhead. This has led to a restructuring of the research process, with most data directly produced by the private sector or in PPPs being highly proprietary or secret, whereas those same entities have relied increasingly on access to open data for their work.

Open data from public sources thus helps to fuel downstream applications and the creation of wealth, more broadly. Moreover, there have been high-level recommendations for a "global network of data innovation networks" to bring organizations and experts together for the common good and use open data to innovate collaboratively (Data Revolution Group 2014). For a discussion of further issues and references to many reports, see the OECD website on "Data driven innovation for growth and well-being" (http://www.oecd.org/sti/ieconomy/data-driven-innovation.htm).

8. Encouraging the verification of previous results

Science is mostly a process of small, incremental advances, with an occasional leap forward though a major discovery. The analogy of "Standing on the Shoulders of Giants" is as apt now as it was a few hundred years ago, when it was etched into the sarcophagus of Sir Isaac Newton. However, this process is crucially dependent on the independent verification of the published results, not only through what has come to be known as "peer review," but also afterward.

Thus one of the most important benefits for the scientific community and for the integrity of the scientific process itself has been to provide access at least to the data underlying published research results (e.g., National Research Council 2009a; 2004; 2003; 1999; and 1997). Although the amounts of data needed to be accessed to verify the findings in any one article may be relatively small, the volume becomes quite large when one adds up the many thousands of research results that are made with the data provided (or could be provided) through GEOSS. It is inefficient and likely to be quite costly to obtain permission many times over to share the data underlying each finding, which a blanket policy of openness would eradicate all at once.

D. Facilitating the Education of New Generations

Educational uses and users are another favored category, closely coupled with not-for-profit research. Many of the rationales used above for providing data to the academic research community are also applicable to promoting better education, particularly at the higher education levels. What everyone knows is that a well-educated population is an asset to every nation. Data that are easy to obtain and use through GEO can help foster such benefits.

Open data support the education of people at many levels, and across all ages and disciplines. As we have already seen, researchers have much to gain from the unfettered access to and use of data.

As big data and data science grow in prominence, there will be an increasing demand for university graduates to be capable of using, integrating, and generally managing large volumes of data, not only within their own disciplines, but across many others. Data curation and data management generally is an expanding field of work, with many jobs already available at data centers and repositories, digital libraries, archives, and all types of businesses, as two studies recently reported about the U.S. job market (NRC 2015; Manyika et al. 2011). Restrictive and costly data policies are significant barriers to the education and training of new generations of such students, driving up costs of education and taking away time from study and research.

Just as more open data can benefit students, both disadvantaged and not, it can also benefit in educating more established researchers in providing examples of the latest data techniques and big data management. Although many researchers have some limited access to data and databases for this purpose, they do not necessarily have a broad range of examples to use, nor are they able in many cases to access and use the data on their own or on different platforms and venues. They also cannot use those opportunities to show or teach others informally in different settings. The point is that a very restrictive data policy limits the educational opportunities of students, experts, and many others who may not be part of some formal educational program. With the greater use of digital networks for distributed or distance education, this is a major barrier to education, training, and self-help instruction.

Although there are clear opportunities for better jobs in the digital economy that require higher education degrees, younger students in the secondary and even primary levels can learn a lot from environmental observations and data that are openly available. For example, in the United States, NOAA has had a program for younger students to learn from and use meteorological data in their schools' regular curricula (see http://www.goes-r.gov/education/students.html#NOAA). Similarly, the open EO data from other government organizations have supported the education of students in schools (see, e.g., the Globe Program at https://www.globe.gov/).

The general public too can learn a lot, whether at work or at home. Some of these educational pursuits involve formal mid-career retraining to become data curators and digital stewards (NRC 2015). Many others are simply informal personal learning and the ubiquitous fact-checking. The phenomenal success of Google Earth, using government remote sensing data that are in the public domain and even commercial remote-sensing data on an open basis (though partially restricted in use), demonstrates the power and demand for such information, and has been used for geography lessons in the classroom (Ganzel 2010).

Open data made available through the GEOSS portal therefore can significantly enable and enhance all these educational and training endeavors.

E. Benefits for Effective Governance and Policy Making

Finally, there are the issues of better public policy making (including better regulation) and more effective governance in general. This report has already demonstrated how businesses, researchers, educators, and individuals of all kinds can benefit from the open access to networked data made available through the GEOSS portal. But does this apply to government policy makers and managers themselves?

All the GEO Members are representatives of governments, leaders of various Ministries and public organizations, and/or public-sector information managers and policymakers. They have a strong interest in improving the decisions they have to make on behalf of their constituents, to demonstrate leadership, and to build freedom and trust of the public they represent. Developing countries, in particular, can be the beneficiaries of open GEO data, even if they do not have their own data-collection systems. These topics are explored in greater detail below.

1. Improving decision making

As one might expect, there are numerous significant opportunities for improved decision making in the public sector, from the local to global levels. For purposes of keeping this review simple, we divide the discussion according to the national level (e.g., local, state or province, and country), and at the international level (e.g., bilateral, regional, and global). There are many telling examples from all these perspectives.

From a national point of view, for instance, the Earth Resources Observation and Science (EROS) Data Center, which is managed by the United States Geological Survey (USGS) in Sioux Falls, South Dakota, archives many kinds of remote sensing data and provides most of them freely. That data center documents numerous uses of various state agencies in the United States (Nelson 2011). Similarly, at the international level, open GEO data can be used more extensively in decisions by governmental entities in all the Societal Benefit Areas. For example, the Global Infrastructures for Supporting Biodiversity research (GLOBIS-B) project, supported by the European Commission, fosters global cooperation of biodiversity research infrastructures and biodiversity scientists to promote the implementation and calculation of Essential Biodiversity Variables (EBVs). The concept of EBVs was introduced by the Group on Earth Observations Biodiversity Observation Network (GEO BON), one of the SBAs. For more information, see the GLOBIS-B website (http://www.globis-b.eu/).

These examples—and many more like them—are difficult, if not impossible, to demonstrate if government ministries have to buy the data from other ministries, even in their own countries, or overcome other time-consuming bureaucratic burdens.

2. Demonstrating leadership and broadening influence

It is no coincidence that EO data made freely open and unrestricted in use by the Members of GEO are by far the most ubiquitous and are also found in the most applications worldwide. Data providers that disseminate GEO data openly are consequently well-known in other countries, their websites are broadly visited and used, and the users are appreciative of the opportunities. For example, the EROS Data Center, cited above, keeps (anonymized) statistics on international users (Nelson 2011).

The broad use of such data can have many economic and other spillover effects, as noted earlier, including political ones that accrue to the government data center, organization, and/or country providing the data. Such effects are difficult to quantify, but are sure to exist (Uhlir and Schröder 2007). Open data providers in government do not primarily provide their data for those reasons, but they enjoy such collateral benefits nonetheless.

3. Promoting capacity building in developing countries

One of the most important advantages from the open data principles practiced by GEO and its Members and Participating Organizations are for economically developing countries. The World Bank categorizes countries by level of economic development (http://data.worldbank.org/about/country-and-lending-groups#High_income). The groups of low-income and lower-middle-income economies and countries do not have many of their own EO systems or data centers, but they particularly can benefit from the applications of those data. The same is true for economically disadvantaged individuals or institutions within even more wealthy nations.

The open provision of data through GEO makes such data available for use by those least able to afford any access fees. Open data policies provide a level playing field and opportunities for a leapfrogging effect. Such policies enable the supply of data to data-poor areas, where such information can be most needed (Data Revolution Group 2014; NRC 2012a; NRC 2002).

Thus, for example, a geospatial data training and policy workshop in 2014 in Beijing, China and Nairobi, Kenya organized and conducted by CODATA used free Landsat data for the hands-on data management sessions and then developed the Nairobi Principles on Data Sharing for

Science and Development in Developing Countries (CODATA 2014). Open EO data made available through the GEOSS portal can be a very valuable tool for capacity building in the environmental and information sciences and related applications (GEO 2015).

4. Helping to implement "data repatriation" objectives of developing countries

Among the pernicious effects of colonization of poor countries by the richer ones over the centuries has been the transfer of valuable heritage materials (also called "patrimony" in Hispanic countries), consisting of both human-made and natural artifacts. The human-made ones consisted of archeological treasures, artistic works, and other valuable creations. Natural ones were comprised mostly of specimens of flora and fauna, many unique and sometimes endangered or even now extinct.

Many of these artifacts ended up in the hands of private dealers and personal collections. However, a substantial fraction of both the artificial and natural ones were—and still are—displayed in museums, primarily in the OECD countries. The GEO SBAs, especially the one focused on biodiversity, but also in the other environmental areas, have much to gain by free and unrestricted access to the virtual representations and the data about these holdings, some of which are the only way for many users to get any access at all if the species has become extinct. Importantly, it is also a way for the originating country to obtain unfettered access to at least the digital representations of the specimens—assuming that the language and literacy barriers can be bridged.

Data "repatriation" has been championed by the Global Biodiversity Information Facility (GBIF). In 2008, the GBIF Governing Board passed two resolutions in this regard. First, it recommended that "natural history institutions housing biodiversity materials from other countries ensure that species and specimen-level data and associated metadata be digitised and made openly and publicly available through mechanisms cooperating with GBIF." It also recommended that funding agencies and private foundations around the world "provide funding for research, capacity building, training and other relevant activities that include the digitisation and open dissemination of species and specimen-level data collected beyond their national territories, in accordance with GBIF-mediated standards and protocols" (GBIF 2008).

The key concept here is for the data to be "made openly and publicly available" through other organizations that cooperate with GBIF. Without the open data policy of GBIF, which only requires a default rule that data be properly attributed, most data users in the developing world countries of origin could not afford to access them.

5. Building freedom and trust

We have seen ample evidence of the individual and collective freedom of action that open data bring in myriad opportunities for applications. Digital networks multiply those opportunities exponentially. It is thus no coincidence that the countries that have the most closed and tightly regulated access to information in the public sector are also the most dictatorial and oppressive, with the lowest rankings in the personal freedoms of their citizens (Uhlir 2004).

According to article 19 of the Universal Declaration of Human Rights, the right to freedom of opinion and expression "includes the freedom to seek, receive and impart information and ideas through any media and regardless of frontiers" (UN 1948). Article 27(1) of the same Declaration provides for the "right freely to participate in the cultural life of the community ... and to share in scientific advancement and its benefits" (UN 1948). Thus, one of the ultimate goals of any society striving for human development is the empowerment of all its citizens through access to and use of information and knowledge.

The many laws and policies for open data referenced in this report have built on this fundamental concept and promoted that freedom of information—particularly in the public sphere. The GEO Data Sharing Principles are consistent with numerous other Earth observation and geospatial data laws and principles that promote access to and use of such public data, thereby empowering individuals in society to freely pursue their own decisions in an informed way.

Together with such enhanced freedom is the building of trust in the governance of any nation. Open data are strongly indicative of confidence of the governing institutions in their positions, as well as a maturity of the political system and of concomitant transparency in governance. The citizens of each country recognize that and support it. These are the aspirational ideals that the Member governments of GEO implicitly adhere to when endorsing and implementing GEO's Data Sharing Principles.

III. CONCLUDING OBSERVATIONS

The preceding discussion illustrated the impressive extent, the existing value, and the unrealized potential that truly open public EO data can have worldwide. Open data are thus of fundamental importance to GEO and all public geospatial applications.

What is not always so obvious is what is lost when such public data are not free to access and use. Of course, many of the benefits from an open data approach outlined above would either not be realized or would be substantially attenuated. Nonetheless, there are additional negative effects that perhaps are not as apparent (Uhlir and Schröder 2007).

From a purely economic or financial standpoint, a policy of cost recovery for public EO data has many embedded hidden costs that can make the monetary returns illusory (NRC 2009). Although not expressly addressed in this report, a substantial fraction of the functions associated with producing, maintaining, and disseminating the data are already subsidized by the public. Because the public data provider is frequently a monopoly and has no private-sector competitor, the operation is inherently inefficient from an economic theory perspective, with unnecessary transaction costs and onerous restrictions on public goods (Weiss 2002). Even if there are competitors in the private sector, they operate at a disadvantage to the subsidized public entity (NRC 2009).

Even less obvious are the lost opportunity costs, since many potential users who would use the data if they were free and unrestricted, will opt for alternate and perhaps less effective solutions instead, assuming that any alternates are even available (NRC 1999). There is thus not only a failure to capture many of the benefits from the public investments, but a strong disincentive for the stimulation of an economically rewarding (and taxpaying) value-added industry and the applications or development of other social goods. Charging other government entities for access and restricting their uses only shifts public monies around in a counter-productive circle (Weiss 2002).

Research and education would suffer as well (NRC 1997; NRC 1999; NRC 2003). Many of the individuals and even the institutions in these areas are in the public sector and cannot afford even small costs for obtaining data. Moreover, they are inherently re-users of data, not end-users, so restrictions on the uses are especially limiting. They are also much more cooperative, so such restrictions would particularly hurt interdisciplinary and international research projects. Finally, automated extraction and knowledge creation would essentially be stopped, at a time when such approaches are even more essential.

Last but not least, the opportunities for improved governance would suffer. Because individuals and institutions in developing countries are least able to afford any costs of obtaining GEO data, they would be the most disenfranchised. The gap between the OECD nations and the least developed countries would continue to widen.

In sum, the Members of GEO stand to gain much more than they might lose from making their public EO data available on a full and open basis, freely and without reuse restrictions, as promoted by the GEOSS Data-CORE. They also would avoid many of the negative effects that come with attempts at cost recovery and policing leakage in the various potential uses of their data. For all these reasons, openness for such data should be the default rule. It is therefore imperative for GEO to seize these many benefits from publicly generated environmental data now, as the new Data Sharing Principles are being implemented for the coming decade. And it is the primary organizational raison d'être of GEO to make those benefits a reality.

APPENDIX A

Definition of Key Terms

There are some concepts used throughout this report that may not be obvious or that may mean different things to different people. It is therefore useful to provide a few definitions.

A key distinction needs to be made between a pure public and private good, and how to characterize goods that are somewhere in-between. A ***public good*** is both not exhausted in its use (non-depletable) and cannot be kept from others (non-excludable) (Wikipedia 2015 at https://en.wikipedia.org/wiki/Public_good). The warnings from a lighthouse are often cited as being a pure public good, but there are few goods or services that have both aspects in their entirety.

A ***private good*** can be both depleted and excluded. Most tangible objects have private good characteristics.

Data and information, whether from a public or a private source, have ***quasi-public good*** characteristics. That is, they can be used without diminution, since an exact copy can be made and shared while the original remains intact, but they can be excluded, since it is possible to keep them restricted or even secret. The exclusion of data from a public entity is inherently inefficient, however.

EO satellites and sensor systems—whether public or private—that collect data also have *quasi-public good* attributes. If the source is fully governmental, however, there is the further dimension of a public interest in the collection of the data, whether to support research, improve the economic and social welfare of the country's citizens, or enhance various governance objectives, all of which have strong public-interest dimensions themselves.

Not-for-profit academics and educators also have many public-interest goals, but have increasingly been encouraged to commercialize their outputs and to form public-private partnerships. Although their products and services may not have fully public-interest objectives, they frequently have the creation and transfer of knowledge to the public as their principal purpose and therefore practice public openness as a default rule. It is for these reasons that not-for-profit researchers and educators were given preferential status as users of GEO data in the 2005 Data Sharing Principles (GEO 2005).

Global public goods are important to consider in the context of public EO satellites and the uses of the resulting data for ameliorating global problems for broad human benefit. Human knowledge, the fruit of such data and information, has global public good qualities (Stiglitz 1999).

Externalities are another important economic concept that is most relevant here. An "externality is the cost or benefit that affects a party who did not choose to incur that cost or benefit" (Wikipedia 2015 at https://en.wikipedia.org/wiki/Externality). The externality may have a positive or negative effect. Economists developed this information theory to describe the effects of a telephone or fax system. Simply put, there is no value in producing and using only one telephone or fax machine, but with every device added to the system, the value from its use--usually positive—increases exponentially. The same can be said for the Internet, particularly for online information in the public domain that can be accessed and reused by anyone with access to a networked computer—a ***network effect***. This is true of EO data that are freely available and have no use restrictions, including through the GEOSS Data-CORE.

Data**, **data products**,* and ***metadata are all subject matter at the heart of the GEOSS Data Sharing Principles, and therefore of this report. ***Data*** may be defined as "a set of values of qualitative or quantitative variables" or as "individual pieces of information" (Wikipedia 2015 at https://en.wikipedia.org/wiki/Data). Whereas data can run the gamut of unprocessed or "raw" facts from observation or experiments to highly processed products, they typically need to be organized and stored in a collection of information, commonly referred to as a ***database*** or ***dataset***.

Data products are data that have undergone correction and higher levels of processing from their original, raw state. Data products are usually standalone datasets, often in an image form or some other graphical representation that makes them easier to use. ***Value-added data*** is a term closely related to data products and can be used interchangeably with that term.

Finally, ***metadata*** "describes other data. It provides information about a certain item's content," such as a database (http://www.techterms.com).

Turning now to data policy, the concept of ***full and open*** access to data is a term used for some 25 years and was the formulation used in the 2005 GEO Data Sharing Principles. "Full and open exchange" means that "data, metadata and products made available through the GEOSS are made accessible with minimal time delay and with as few restrictions as possible, on a nondiscriminatory basis, at minimum cost for no more than the cost of reproduction and distribution" (GEO 2009).

Open data is a relatively new term that is very relevant here as well. The history of satellite remote sensing and other forms of digital data collection is still quite short—less than 60 years for the United States and the former USSR, and even less for other countries and regions. Because comprehensive laws and policies always lag the progress of technology, their implementation has been shorter still and in many ways are not yet fully formed. Such laws and policies are usually accompanied by analyses of the benefits and drawbacks of different courses of action. Those analyses are undertaken by governments and academia, often at the request of public-sector entities, and it is those reports and articles that form not only the evidentiary base for each nation's course of action, but for this report.

Even more recent are the various declarations, statements, and policies that promote openness for public and publicly funded data. Some are governmental or inter-governmental (e.g., Bromley 1991; WMO 1995; OMB 2000; Chinese Ministry of Science and Technology 2003; Strong and Leach 2005; OECD 2007 and 2008; European Union 2010; G8 2013; National Science and Technology Council 2013; Holdren 2013; and Sunlight Foundation 2015), while others are academic (e.g., Berlin Declaration 2003; The Royal Society 2012; Hague Declaration 2014; CODATA 2014; and RECODE Project 2015), or discipline-based (e.g., Bermuda Principles 1996 for human genome data; Bouchout Declaration 2014 for biodiversity data). However, together they show a rising recognition about the value of openness on digital networks and an emerging consensus for implementing laws and policies that affirmatively recognize such an approach.

Open data have been defined more succinctly as "data that can be freely used, re-used and redistributed by anyone - subject only, at most, to the requirement to attribute and sharealike" (Open Knowledge 2015). The Royal Society of the United Kingdom goes on to say that data must be "Intelligently open:" meaning that to be fully open, data need to be discoverable, accessible, intelligible, assessable, and usable (Royal Society 2012).

Common-use licenses, ***waivers of rights***, and ***information commons*** are also new terms that should be defined in this context. ***Common-use licenses*** were first introduced in 2002 by Creative Commons, a not-for-profit organization of lawyers and scholars in the United States (http://www.creativecommons.org). Creative Commons and some other groups like it are dedicated to developing and improving licenses "with some rights reserved." Unlike copyright law and database protection statutes under which the data rights holder has "all rights reserved," a common-use license derogates from those rights in favor of the users and then relies on copyright and database protection laws to enforce those reduced rights. A ***waiver of rights*** is the legal means employed by data providers to eliminate all intellectual property protections and allow users unfettered use of the data set.

The most appropriate and frequently applied licenses for promoting broad, unrestricted uses of data include the Creative Commons "attribution only" (CC-BY 4.0 license), which allows the recipients of the data to use them in any lawful way, subject only to the requirement that the data source be duly attributed. The Creative Commons waiver of rights (CC0) eliminates even that legal attribution requirement, and relies instead on the norms of the community for giving credit to the data sources. For both instruments, see http://www.creativecommons.org.

By applying such common-use licenses or waivers of rights to GEO data sets and other works protected by intellectual property laws, the rights holder can voluntarily promote the unrestricted uses of the data. Together with others using the same or similar legal instruments, the rights holders can collectively form an ***information commons*** that can benefit not only all users, worldwide, through the private law construction of a vast public domain (Reichman and Uhlir 2003), but the original rights holders or providers of the data as well. Some GEO data providers now use these legal instruments for making their data available through the GEOSS Data-CORE and the specific benefits of such openness are detailed in the body of this report.

Finally, there is the ***GEOSS Data-CORE***, which is a distributed pool of documented datasets, contributed by the GEO community under the following principles, as set forth in the 2010 GEOSS Data Sharing Action Plan (see also GEO 2013):

1. The data are free of restrictions on re-use;

2. User registration or login to access or use the data is permitted;

3. Attribution of the data provider is permitted as a condition of use; and

4. Marginal cost recovery charges (i.e., not greater than the cost of reproduction and distribution) are permitted.

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