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50 YEARS OF EARTH OBSERVATION FROM SPACE AND SPACE LAW

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"There is still time to address this dramatic disconnect between institutions and reality. Doing so requires leadership, vision and faith that our future is not merely work of destiny but ours to shape."
Inge Kaul, Isabelle Grunberg and Marc A. Stern[1]

Abstract

Over the past five decades, space-faring States and international organizations have developed impressive capabilities for observing Earth from satellite platforms. The way humankind view and live in our home planet has fundamentally transformed for the good and for the bad. These fantastic advances are shown in rich details in the excellent book "Earth Observation from Space – The First 50 Years of Scientific Achievements"[2], prepared by a special committee of the National Research Council of the United States National Academies, and published in 2008.

Their conclusions provide ample and rich information, as well as a strong motivation to assess the relationship existing between the technological development of Earth observation systems and the development of legal instruments regarding these very intense and essential activities. They permit us to accomplish the quite useful task of establishing to what extent the remarkable development of Earth Observation technologies has been internationally regulated, and determine the legal deficiencies and insecurity such activities face today and will be facing tomorrow.

One of the conclusions states that "the full benefits of satellite observation of Earth are realized only when the essential infrastructure, such as models, computing facilities, ground networks, and trained personnel, is in place."

The clear awareness of this situation raises some legal issues: at which level are these necessities and demands looked after today by the existing instruments of International Space Law? And what kind of effective commitments should be set up in order to accelerate the dissemination of the full benefits of Earth observation satellites all over the world? Earth observations from space demonstrate successful synergy between science and technology. Is there such a synergy between science and technology, on one hand, and their legal implications, on the other hand?

The present paper aims at giving an answer to such questions.

Introduction

The US National Academies carried out a "decadal survey" entitled "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond"[3] (NRC 2007a), considered an "essential study", the first of its kind in the Earth Science. This study recommends the US Administration "a renewal of the national commitment to support on going observations from space in order to face scientific and societal challenges over the next decades and to understand and manage natural resources".

To complement this decadal survey, the US National Aeronautics and Space Administration (NASA) asked the National Academies to draft a report on the value of the first 50 years of Earth observations from space. This led to preparation of the document entitled "Earth Observation From Space – The First 50 Years of Scientific Achievements", issued by the US National Academy of Sciences in 2008.

The report highlighted important contributions of Earth observation from space to the current understanding of our planet. It points out: "The global view obtained routinely by observations from space is unmatched in its ability to resolve the dynamics and variability of Earth processes. Ship-based observations, for example, cannot provide the spatial and temporal information to detect the dynamic nature of the ocean. Similarly, aircraft and weather balloon measurements alone cannot resolve the details required to understand the complex dynamics of ozone depletion. Space observations provide detailed quantitative information on many atmospheric, oceanic, hydrologic, cryospheric, and biospheric processes. Because satellite information is gathered at regular intervals, it provides, like a movie, a view of changes over time. For the first time, satellites make it possible to track a tropical cyclone from its gestation over the ocean to landfall and to observe the ever-fluctuating intensity of the storm."

One of the central objectives of the National Academies report is to convince the American authorities and public opinion that the United States must continue to support the national programs of satellite observations, which has "revolutionized the Earth Science".

It is amazing that the National Academies consider it necessary to convince the authorities of the country that made such remarkable advances in these essential activities during last half century of the usefulness of these observations.

Earth observation from space is really an international issue. Since its inception, it has been an activity of great interest to the community of States because of its national security impact, and also as an indispensable tool for the improvement of everyday life, the development of all nations and people, the protection of the environment, and the management of natural disasters.

Earth observation from space takes place by remote sensing satellites, and is – or should be – governed by international space law.

Conclusions of the National Academies Report

First of all, the report's seven conclusions are presented, as they are the main topics of reference for the reflexions developed in this paper:

"1. The daily synoptic global view of Earth, uniquely available from satellite observations, has revolutionized Earth studies and ushered in a new era of multidisciplinary Earth sciences, with an emphasis on dynamics at all accessible spatial and temporal scales, even in remote areas. This new capability plays a critically important role in helping society manage planetary-scale resources and environmental challenges.

2. To assess global change quantitatively, synoptic data sets with long time series are required. The value of the data increases significantly with seamless and inter-calibrated time series, which highlight the benefits of follow-on missions. Further, as these time series lengthen, historical data sets often increase in scientific and societal value.

3. The scientific advances resulting from Earth observations from space illustrate the successful synergy between science and technology. The scientific and commercial value of satellite observations from space and their potential to benefit society often increase dramatically as instruments become more accurate.

4. Satellite observations often reveal known phenomena and processes to be more complex than previously understood. This brings to the fore the indisputable benefits of multiple synergistic observations, including orbital, suborbital, and *in situ* measurements, linked with the best models available.

5. The full benefits of satellite observations of Earth are realized only when the essential infrastructure, such as models, computing facilities, ground networks, and

trained personnel, is in place.

6. Providing full and open access to global data to an international audience more fully capitalizes on the investment in satellite technology and creates a more interdisciplinary and integrated Earth science community. International data sharing and collaborations on satellite missions lessen the burden on individual nations to maintain Earth observational capacities.

7. Over the past 50 years, space observations of the Earth have accelerated the cross-disciplinary integration of analysis, interpretation, and, ultimately, our understanding of the dynamic processes that govern the planet. Given this momentum, the next decades will bring more remarkable discoveries and the capability to predict Earth processes, critical to protect human lives and property. However, the nation's commitment to Earth satellite missions must be renewed to realize the potential of this fertile area of science."

To begin with, it is important to note that, indeed, thanks to Earth observation from outer space, Earth sciences have developed as never before, but this accelerated scientific and technological progress, in fact, has helped only part of human society in managing natural resources and environmental challenges. To be truly effective, this new capability needs to reach all human society.

Legal framework

Some of the main provisions of the international legal regime regulating Earth observation activities from outer space are cited, and compared with the technological advances these activities have reached today.

The international legal regime consists basically of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use or Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty)[4], and the 1986 United Nations Resolution on Principles Relating to Remote Sensing of the Earth from Outer Space (UN Remote Sensing Principles), adopted by consensus at the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). This Resolution currently is the only specific international reference in existence on the regulation of remote sensing. It is considered to reflect a customary law.[5]

Carl Q. Christol noted as early as 1988: "The Principles were the product of consensus, but there were numerous compromises along the way. This suggests that the consensus was, if not unsubstantial, at least so thin that some members of COPUOS have viewed the consensus as conditional and subject to review. It cannot be said that the agreement was a temporary one, but the commentary reviewed (...) suggests a grudging acceptance of some provisions, with the view on the part of developing countries in particular, that there is a need to reinforce the Principles beneficial to them in order to buttress existing assurances and commitments."[6]

Part of the problem is that the 1986 Principles have been overtaken by the swift technological advances in the sector that have occurred in the last 22 years. Consequently, remote sensing activities are far from being sufficiently regulated.[7]

If, as the first conclusion of the National Academies report states, "the daily synoptic global view of Earth, uniquely available from satellite observation, has revolutionized Earth studies and ushered in a new era of multidisciplinary Earth sciences, with an emphasis on dynamics at all accessible spatial and temporal scales, even in remote areas", and if "this new capability plays a critically important role in helping society manage planetary-scale resources and environmental challenges", then it cannot be said that the current legal framework of Earth observations activities is equally developed.

The new era of multidisciplinary Earth sciences began just in the middle of the 1980s. And despite the extraordinary remote sensing technological advances registered since that time, the 1986 UN Remote Sensing Principles remain the same, without any updating amendments. Not by chance, it is seen today as an ineffective instrument.

The UN Remote Sensing Principles is an instrument focused on the intent to reconcile the rights and duties of sensing States and those of sensed States. But it would seem that the necessary and fair balance in this relationship was not reached. The technological superiority of sensing States gave them a solid advantageous position in relation to the sensed States. And these have not been able to negotiate the adoption of more guarantees for their legitimate interests.

Principle IV states: "Remote sensing activities shall be conducted in accordance with the principles contained in Article I of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which, in particular provides that the exploration and use of outer space shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and stipulates the principle of freedom of exploration and use of outer space on the basis of equality."

These are the two fundamental pillars of the Outer Space Treaty, usually referred to as the principles of "common benefits" and of "freedom of exploration". The issue is that it is much easier to interpret and implement the second principle than the first one, which is not yet legally defined, despite the great demand for some definition.

Principle IV also states: "These activities shall be conducted on the basis of respect for the principle of full and permanent sovereignty of all States and peoples over their own wealth and natural resources, with due regard to the rights and interests, in accordance with international law, of other States and entities under their jurisdiction. Such activities shall not be conducted in a manner detrimental to the legitimate rights and interests of the sensed State."

Thus, the Remote Sensing Principles formally incorporate both the principle of "freedom of sensing" the territory of any country, at any time, and the principle of full and permanent sovereignty of all States and peoples over their own wealth and natural resources. But they do not specify in which cases and how each of these – in large extent – contradictory principles should be applied.

As Atsuyo Ito noted, the conditions for sensing from space in terms of respecting the rights of sensed States are not explicit: "Hence the data collection policy provides: 1) no restrictions based on geography; objects observed including natural resources and the sea surface; and territories beyond national jurisdiction; 2) no prior consent, consultation, or notification is required before sensing; therefore, no veto right is granted to sensed States with regards to their territories being sensed; 3) no conditions are imposed for sensing capabilities with varying degrees of spatial resolution, or the type of sensor such as radar or optical."[8]

The new Earth Observation from outer space capability effectively plays a critically important role in helping society manage planetary-scale resources and environmental challenges, but it could much wider and better done if a more just and beneficial international legislation on the matter were in place.

It is important to stress that, under Principle VI, remote sensing activities "shall not be conducted in a manner detrimental to the legitimate rights and interests of the sensed State".

This Principle certainly is the strongest provision concerning the protection of the rights and interests of sensed States; however, these are still not defined. Bin Cheng made a remarkable comment on that issue: "Those who are apprehensive that data gathered from outer space by others might work to their detriment or that the data gathered from outer space might be misused by third parties to their detriment can probably find only scant comfort from United Nations Principles."[9]

As to the issues of access and distribution of remote sensing data, there is only the provision formulated in Principle XII: "As soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed State shall have access to them on a non-discriminatory basis and on reasonable cost terms. The sensed State shall also have access to the available analyzed information concerning the territory under its jurisdiction in the possession of any State participating in remote sensing activities on the same basis and terms, particular regard being given to the needs and interests of the developing countries."

On the one hand, this Principle affirms the positive right of sensed States to access the data concerning their territory, as well as the obligation of sensing State to provide these data to the sensed States. On the other hand, it does not establish the appropriate conditions under which this right shall be respected. It is stated that access to the data and the obligation to provide them shall be carried out on "a non-discriminatory basis and on reasonable cost terms". Both seeming requirements may be questionable, as they are not clearly defined, and thus, do not offer any certainty of being fulfilled.

The concept of "non-discriminatory basis" means that the sensing States should provide the data to the sensed States under the same conditions as other States wanting to have access to the data. Sensed States have no preference or priority in relation to other States when they wish to access the data on their own territory. Even in this situation there is no clear regulation or mechanism guaranteeing them this simple access.

The concept of "reasonable cost terms", in turn, is vague, ambiguous, not defined and can be interpreted in different ways. "It could mean marginal costs or market price insofar as it is reasonable for the particular data in question. It does not serve as a general guideline for setting different prices, as could be expected for different types of products or uses by the divergent data generators", as Atsuyo Ito rightly observes.[10]

The new capability of Earth Observation from outer space effectively plays a critically important role in helping society manage planetary-scale resources and environmental challenges, but it could be widely and better done if there were a more just and beneficial international legislation on the matter.

In view of such an uncertain legal framework, it is worth citing the sixth conclusion of the National Academies report. It states: "Providing full and open access to global data to an international audience more fully capitalizes on the investment in satellite technology and creates a more interdisciplinary and integrated Earth science community. International data sharing and collaborations on satellite missions lessen the burden on individual nations to maintain Earth observational capacities."

As can be seen, there currently is an increasing awareness of the crucial issue of access to data produced by Earth observation from space. This awareness provides strong reasons to reflect this positive vision in a new, updated instrument governing remote sensing activities. This instrument must be based on the most important concepts contained in the UN Remote Sensing Principles, such as free and responsible remote sensing from outer space all over the world.

Space co-operation

The fifth conclusion of the National Academies' report cautions: "The full benefits of satellite observation of Earth are realized only when the essential infrastructure, such as models, computing facilities, ground networks, and trained personnel, is in place".

If the existence of such an essential infrastructure in all countries is absolutely necessary, it is indispensable to have great international cooperative action, so that all countries may have access to models, computing facilities, ground networks and to training personnel. Of course, this is a complex undertaking, requiring the active participation of many countries, organizations and institutions. That is why in 2006, the Brazilian delegation to COPUOS presented to the Plenary a three-year plan to study the need for an ample international cooperation program to enable the establishment of a geospatial data infrastructure in all countries, or at least in the majority of them. The plan was approved by COPUOS.

Principle V recommends: "States carrying out remote sensing activities shall promote international co-operation in these activities. To this end, they shall make available to other States opportunities for participation therein. Such participation shall be based in each case on equitable and mutually acceptable terms."

This is certainly a laudable premise, but in reality, it is not sufficient. More than bilateral efforts, multilateral ones are required. What is needed is an international program, supported by a great number of nations, intergovernmental and non-intergovernmental organizations, as well as involvement by all interested enterprises. An emblematic example of this kind of international undertaking is the purpose and the work of the Group of Earth Observation (GEO) and its ten-year program, the Global Earth Observation System of Systems (GEOSS).[11]

According to Principle VI, "in order to maximize the availability of benefits from remote sensing activities, States are encouraged, through agreements or other arrangements, to provide for the establishment and operation of data collecting and storage stations and processing and interpretation facilities, in particular within the framework of regional agreements or arrangements wherever feasible". And according to Principle VII, "States participating in remote sensing activities shall make available technical assistance to other interested States on mutually agreed terms".

Encouraging States to provide for the establishment and operation of data collecting, storage stations, processing and interpretation facilities, without doubt, is a good intention. Yet, today the community of States has to go much further.

Collecting and storage stations, as well as processing and interpretation facilities become a crucial necessity for all States in any program directed towards national and regional development, as well as in any efforts to cope with natural disasters. Technical assistance is just a first and modest step; the majority of States need much more. True progress in this area requires technology transfer as well as capacity building.

International cooperation should aim, *inter alia*, at "fostering the development of relevant and appropriate space capabilities in interested States", as is recommended in point 5 (b) of the 1996 Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of all States, Taking into Particular Account the Needs of Developing Countries.[12]

Earth observation as a global common good

It is clear that all seven conclusions of the National Academies' report strongly support the idea of Earth observation as a global common good.

The concept of public good has its roots in 18th century scholarship[13]. The Scottish philosopher David Hume[14] (1711-1776) and the British economist Adam Smith[15] (1723-1790) wrote about this subject. Since then, a vast and varied literature has been published on the topic in many countries. In recent years, the concept of global public goods has become an increasingly important part of international policy making. The concept appears in the agendas of United Nations agencies, the IMF/ World Bank, and many non-governmental organizations. Everyone depends on public goods; they are indispensable for all peoples and their activities. A clean environment, health, knowledge, property rights, peace and security, are among the examples of public goods that could be made global[16].

According to Inge Kaul, Isabelle Grunberg and Marc A. Stern, "the ideal public good has two main qualities: its benefits are non-rivalrous in consumption and non-excludable". Non-rivalrous means that there is no additional cost incurred in providing the good to an additional person (its marginal cost is zero). Non-excludable means that one cannot exclude others from deriving benefit from the good once it has been produced.

Kaul, Grunberg and Stern stress that the global public goods are public goods whose benefits reach across borders, generations and population groups. They form part of the broader group of international public goods, which include as other sub-group, regional public goods. "Their benefits are quasi universal in terms of countries (covering more than one group of countries); people (accruing to several, preferably all, population groups); and generations (extending to both current and future generations, or at least meeting the needs of current generations without foreclosing development options for future generations). This property makes humanity as a whole the *publicum*, or beneficiary, of global public goods."[17]

Based on the concept of satellite imagery as a public good, in 2004 Brazil adopted a policy of free distribution of data obtained from the China-Brazil Earth Resources Satellites – CBERS.

In 2004-2008, through the Brazilian National Institute of space Research (INPE) more than half a million satellite images had been distributed free of charge through the Internet (www.dgi.inpe.br/CDSR/).

In this way, Brazil became a worldwide example in the Earth Observation field, making remote sensing activities an easy and accessible tool. From these half million images distributed in the last 4 years, 435 thousand came from CBERS.

This free distribution has increased the availability of CBERS-2B satellite images launched in September 2007, and from LANDSAT-5. Since January 2008 Brazil has been distributing about 800 images per day, according to Luiz Geraldo Ferreira, from INPE's Image Generation Division (DGI), where the Remote Sensing Data Center (CDSR) is allocated.

Free distribution through the Internet started with CBERS-2 satellite images and LANDSAT-1, 2, and 3. Since its inception, this initiative has represented important progress in the use of Remote Sensing resources in all the country.

Later, the benefit was extended to South America and now it is extending to Africa. In additon to data from CBERS satellites, the user can access images from the LANDAT 1, 2, 3, 5 and 7 satellites.

The CBERS turned Brazil into the biggest distributor of satellite images from all over the world.

In Brazil alone around 430 thousand CBERS images were distributed to about 15 thousand users from several public and private institutions, which proves the economic and social benefit of offering data free of charge. In China, after adopting a policy similar to Brazil's more than 200 thousand images were distributed, with the Earth and Natural Resources Ministry being its main user.

At the end of 2007, Brazil and China decided to offer the CBERS images free of charge to all the African Continent. The free distribution policy will allow institutions and authorities in Africa to monitor natural disasters, deforestation, and threats to agricultural production and public health risks.[18]

Hence the commentary of the Brazilian researchers Hilceia Santos and Gilberto Camara: "The trend towards openness and free access to remote sensing data worldwide is gaining momentum. The next decade will likely see the emergence of a global land-imaging consortium, which would provide data access from a constellation of satellites. The land imaging satellite constellations will provide free 10-30 meter global land cover multispectral images available worldwide at least once a week, and if possible, every two days. This timely data will meet the needs for fast-response applications, which are critical in all areas. Thirty years of experience using land-imaging satellites shows that timely, free and high-quality geospatial data provide significant societal benefits. There is a high likelihood that this policy will become widespread."[19]

At the COPUOS Plenary Meeting, held in June 19, 2008, in Vienna, Austria, Brazil explained its policy of free access to geospatial data. On this occasion, the COPUOS was considering the item "International cooperation in promoting the use of space-derived geospatial data for sustainable development", a Brazilian proposal adopted in 2006. During this 2008 session, Brazil presented its experience in setting up proper national infrastructure for space-derived geospatial, data collection, processing and application.

It stated that space-derived data can make a large contribution to the national spatial infrastructures of the developing nations, given some conditions. First, they should have access to spatial data as public goods. Secondly, there should a strong investment in capacity building. Thirdly, developing countries should have access to open source software, scientific literature and suitable hardware. However, concerted action is necessary to achieve these goals.

The most important parts of the

Brazilian statement at COPUOS meeting,[20] formulated several relevant proposals:

"Developing nations present both a challenge and an opportunity for spatial data infrastructures (SDI). These countries have significant challenges in handling their natural resources and SDI can play an important role in their management. Most decision-making in developing nations requires spatial data. For example, planning a new hydroelectric power plant needs an assessment of its potential impact on communities and the environment. This leads to a need for building different scenarios based on acceptable data and analysis techniques.

"The first problem for setting up an SDI in a developing nation is to create the data sets, since in most countries they are outdated or nonexistent. Much important information for a spatial data infrastructure can be obtained from satellite imagery. Land imaging data provided by remote sensing satellites provides significant societal benefits associated with applications in areas such as agriculture, deforestation assessment, disaster monitoring, drought relief, and land management. Land use and land cover maps, hydrologic features, the road network, and the urban structures can be extracted from remote sensing data.

"There are grounds for moderate optimism on this matter. Brazil and China have agreed that their CBERS satellite imagery is available as open access in China, Latin America and Africa. The United States has announced that all its LANDSAT archive will be openly accessible. Japan has committed to provide a digital terrain model of the Earth at 30-meter resolution, based on its ASTER sensor. Together, the initiatives of Brazil, China, the United States and Japan show that much can be done to provide developing nations with much-needed data.

"Given that the Earth is a finite place, an ideal configuration of land imaging satellites is possible, covering different ends of the spectrum (optical, infrared, thermal and microwave) and with complementary spatial and temporal resolutions. Many countries, some with existing space program and some with emerging space activities, can contribute to this global, concerted effort. By combining compatible satellite specifications, open data access, open source software, and extensive capacity building, there will be optimal global benefits of land imaging data.

"Satellite data is useful to build spatial data infrastructures in developing countries, but other data sources and technologies are needed. Developing nations need a land survey and registry, where each parcel of land is registered. Fortunately, the costs of building a land registry have decreased enormously in recent years, due to the use of global navigation satellite systems (GNSS). The GNSS technology allows countries to produce road network maps and cadastral maps at a fraction of the previous cost.

"Finally, the technologies for organizing and sharing spatial data obtained from satellites and GNSS-based surveys are also available as open source. There are open source spatial databases that handle large sets of geographical data. These open source solutions are extremely efficient and cost-effective.

"All of these promising technologies need trained personnel to make use of them. How can we make good use of such diverse data for sustainable development? Open access to land imaging data has to be combined with capacity-building on the use of space-based geospatial data. For developing nations, multi-tiered solutions are needed. Short term approaches include training programs through international institutions such as the United Nations Regional Centres for Space Science and Technology. Longer term knowledge building requires international support for undergraduate and graduate education, complemented by open source and low-cost software for processing remote sensing data, which are becoming widely available.

"The global potential benefits of spatial data infrastructures in developing nations should motivate developed nations to contribute significantly to efforts in capacity building. The world needs trained technicians, engineers, and researchers who know how to build and make use of spatial data infrastructures. This requires continual commitment of resources for at least 10 years.

We need sustained investment in education in this area.

"To achieve the goal of free and open distribution and use of land imaging data, a global governance structure is needed. Fortunately, such governance structure exists today. The Group on Earth Observations (GEO) and its associated space-branch, the Committee on Earth Observation Satellites (CEOS) have established plans for a Land Surface Imaging (LSI) Constellation. GEO has a membership of 73 countries, plus the European Commission. Most land imaging satellite operators are members of CEOS. As soon as the member countries of GEO decide to adopt an open data policy and actively commit resources to the proposed LSI constellation of CEOS, the governance structures of GEO and CEOS can organize an effective action.

"Combining open data access and open source software is the best way to combine the efforts of developed and developing nations to promote the use of space-derived geospatial data for sustainable development. Brazil is working hard with its partners worldwide to support and achieve these goals."

Future of Earth observation from space, and some conclusions

"Over the past 50 years, space observation of the Earth has accelerated the cross-disciplinary integration of analysis, interpretation, and, ultimately, our understanding of the dynamic processes that govern the planet", as the seventh conclusion of the National Academies report states. Its expectation is that "the next decades will bring more remarkable discoveries and the capability to predict Earth processes, critical to protect human lives and property".

However, for a bright future to Earth observations from outer space we need to reach agreement on some measures as *conditia sine qua non*:

1) To establish a solid universal commitment to peaceful and constructive exploration and use of outer space, in order to guarantee sustainability for all space activities.

2) To adopt an ample, updated and contemporary legal international regulation of Earth observation from outer space.

3) To promote an international cooperation program to construct in all countries a national infrastructure for space-derived geospatial, data collection, processing and application as essential tools for national sustainable development, disaster management and environment protection.

4) To discuss the creation of a global governance structure to deal with the goal of free and open distribution and use of land imaging data (or at least at a minimum, symbolic cost).

5) To commit all countries to realize the potential of Earth satellite missions science.

The National Academies' report provides an extensive sampling of important accomplishments enabled by Earth satellite data. However, many scientific questions and societal challenges remain unresolved, including improving 10-day weather forecasts, more accurately forecasting hurricane intensity, increasing resolution of earthquake fault systems and volcanoes to detect precursors of events, mitigating climate change impacts, and protecting natural resources.

It is extremely important to sustain the rate of scientific discovery and progress, committing to the maintenance of long-term observing capabilities and to innovation in observation technology. The Earth is a highly dynamic system and not as predictable as initially thought. Thus, long-term observations are required if we wish to understand and predict future changes. Future advances must be associated with fundamental societal benefits, given the current challenges presented, for example, by climate change and loss of biodiversity. We can envision the availability of regional annual climate predictions to assist in water resource management, in control of infectious diseases, early warning systems, operational use of air pollution maps, and improved ability to foresee volcanic eruptions or earthquakes, according to the National Research Council (NRC) Reports 2001a and 2007a.

If we can fulfill these conditions, a report in 50 years will be able to highlight many more valuable scientific achievements and discoveries, assuring prosperity and health for all countries and peoples.

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