# Earth Observations, Science, and Services for the 21st Century

**American Meteorological Society**
**Policy Workshop Report**
**May 2012**

AMS Policy Workshop Report

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American Meteorological Society

Policy Program

The American Meteorological Society's Policy Program is supported in part through a public—private partnership, which brings together corporate patrons and underwriters, and Federal agencies. Sponsoring agencies include the National Oceanic and Atmospheric Administration (NOAA), The National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). Corporate partners include Ball Aerospace & Technologies, ITT Exelis, and Lockheed Martin.

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## **Foreword**:

Almost a century ago, when the American Meteorological Society was founded—well *before* satellites, *before* weather radar, *before* computerized models and *before* today's pervasive information technology (IT)—AMS members looked beyond their rudimentary observations and science to *services* that would provide human benefit. Before they could reliably predict the weather, they predicted they could provide for public health and safety even in the face of natural hazards. Before they could dependably forecast drought or flood or heat or cold they envisioned supporting farmers and all aspects of commerce and industry. When planes were still made of wood and canvas, ships were only just transitioning to diesel power, and horses outnumbered cars 3-to-1, meteorologists foresaw that they would be indispensable to air- and surface-based transportation.

It's all in the AMS logo created in 1919 on the cover of this report.

*Nearly one hundred years later, this forecast—in retrospect, one of the most remarkable ever made—has verified.* Today **Earth observations, science, and services** (Earth OSS) comprise one of this country's critical infrastructures, taking a place alongside electrical grids, communication networks, financial systems, transportation, waterworks, etc., as one of the essentials for developed nations around the world. Today agribusiness, the energy sector, water-resource managers, public-health officials, the financial markets, emergency managers, military commands, diplomats, and leaders of the world's nations all rely on **Earth OSS**. Business and government leaders shape decisions and actions based on detailed knowledge of meteorological, oceanographic, geophysical, and ecological conditions. In today's globalized society, decision makers need to know the conditions prevailing *now*—locally and regionally, everywhere worldwide. And they want to know how these conditions are *changing*—on time horizons from minutes and hours extending out to years, decades, and centuries. **Earth OSS** provides needed answers.

In part, the extraordinary success of **Earth OSS** is the result of sustained community effort, spanning public, private, and academic sectors. It builds on scientific and technical breakthroughs in other areas, such as physics and chemistry, and in IT and other technologies. But it's also the fruit of a century of uninterrupted funding and supportive policies on the part of federal agencies and the U. S. Congress. The reality? Every American has made a contribution.

But every American also has a stake in where things go from here. And much remains to be done.

That is where this workshop and this report come in. The more than one hundred experts who gathered in November 2011 represent only a small fraction of the stakeholder community. And the three days of the workshop were too brief for definitive conclusions. But they did allow participants to delineate the policy issues that must be addressed if **Earth OSS** are to continue to develop and maintain the capabilities the nation will require going forward. And participants were able to develop rudiments of a prospectus for the future policy discussion and formulation needed, with respect to: priority setting; redefining public—private partnerships; communicating across sectors more effectively; sustaining levels of investment; and developing and maintaining an adaptive, nimble culture able to respond to rapid societal change.

As this report suggests, we can make a forecast for coming decades. We can predict that **Earth observations, science, and services** will keep pace over the coming century with rapidly evolving demands for knowledge and understanding with respect to how the system and all its components work—and what the Earth system and its working parts will do next. But the outlook is conditional. We'll succeed only if we keep investing and innovating—not just in the science and technology but also in the governing policies.

The AMS and its Policy Program are committed to helping all parties work toward this goal—in the national interest and for the benefit of humankind.

**Key Findings and Recommendations:**

Earth observations, science, and services (Earth OSS) inform and guide the activities of virtually all economic sectors and innumerable institutions underlying modern civilization. Increasingly, Earth OSS are a fundamental component of efforts to meet basic human needs such as providing food, shelter, energy, health, and safety. At the same time, the opportunities for societal benefit from Earth OSS are ever increasing.

Taken together, Earth OSS in the United States comprise a national asset that, if lost or degraded, will not meet future societal needs that span the whole of the national agenda. This infrastructure is not concentrated but widely distributed across Federal agencies and all levels of government, throughout an extensive and growing private sector, and in university research laboratories.

Earth OSS face considerable challenges. Most notably, economic downturns and Federal budget deficits put efforts to build and maintain our Earth OSS capabilities at serious risk. Furthermore, the increasing cost of satellites creates challenges for NOAA, NASA, and the military. NASA's Earth observing satellite fleet is aging, making the potential for failures and gaps in data continuity considerable. For NOAA, satellite operations are a large fraction of the agency's overall budget. As a result, small expansion of satellite budgets (proportionally) can consume the resources needed for other critical Earth OSS programs.

Unfortunately, few policy makers or members of the public recognize the importance of Earth OSS and most take the necessary infrastructure for granted. This creates a challenge because the demand and support for Earth OSS is weaker than justified by the scale and scope of the societal benefits that result.

Opportunities to improve the provision and use of Earth OSS also abound. Most notably, improvements in Earth OSS are possible through 1) increased investment designed to shore up and expand U.S. Earth OSS capability, 2) more effective use of limited resources through improved prioritization, 3) better communication among Earth OSS providers, users, decision makers at all levels (federal, state, and local), and the public, 4) improved collaboration, 5) more effective Federal policy, 6) better linking of observations and science to services, and 7) creative problem solving to address multiple unrelated societal needs simultaneously.

Key findings of this report:

1. Earth observations, science, and services (OSS), taken together, constitute a key national infrastructure, critical to ongoing efforts in the United States to:

    A. Use Earth's natural resources (including, but not limited to, energy, food, and water) most effectively,

    B. Protect and maintain environmental quality, essential biological resources, and planetary life-support services, and

C. Promote public safety, health, and uninterrupted economic activity in the face of natural hazards.

2. There is a common Earth OSS infrastructure that simultaneously supports and enhances multiple sectors of the U.S. economy including: agriculture, energy, transportation, water resource management, public health, and national security.

3. The continued viability of Earth OSS infrastructure is at risk because of inadequate and intermittent rates of investment in its development, function, and maintenance.

4. Improvements to the existing policy framework have considerable potential to enhance Earth OSS capabilities and use in critical economic sectors.

In order to ensure the adequacy and continuity of Earth OSS over the short, intermediate, and longer term, this report recommends national policies for Earth OSS that:

1. Identify current and future needs and priorities;

2. Articulate a range of options for supporting existing and emerging public—private partnerships;

3. Foster the necessary communication and collaboration among natural and social scientists, scientists and service providers, service providers and communication experts, service providers and users, Federal agencies, and domestic and international providers;

4. Provide the national investments needed to support and further enhance this critical infrastructure.

5. Adapt readily and naturally to changing challenges and new opportunities.

In addition to these five recommendations, a sustained effort to conduct policy analysis and promote a high-level national discussion will be necessary to ensure the adequacy and continuity of Earth OSS over the short, intermediate, and longer term. Therefore, the American Meteorological Society (AMS) plans to make that sustained effort through a series of follow-on activities to conduct policy analyses and foster discussions that advance Earth OSS capacity.

## Introduction

**Earth observations** reveal a wide range of characteristics and functions of our planet. This observing system consists of ground, oceanic, aerial, and satellite-based resources. Never before in human history have we had the capability to observe the planet in the way we now do.[1]

With this vast capability, we observe physical systems (e.g., weather events, the land surface, and coastal areas), biological resources (e.g., terrestrial and aquatic ecosystems), and social institutions (e.g., agriculture, the built environment, and urban areas) that underpin U.S. social and economic well-being.

Furthermore, the reach of current observations and the potential for future improvements has increased dramatically over the last several decades.[2] Throughout most of our history we knew only about the places where we lived. Now, in addition to locations inhabited by humans, satellites allow us to see ice-covered areas, remote tropical regions, high mountains, and other hard-to-reach areas.

Instruments located at, or near, the Earth surface collect measurements from fixed sources, including weather stations, ocean buoys, radar arrays and lidars, and mobile units, such as ships, trucks, planes, and other vehicles. They include a wide range of measurements that provide information about weather systems and atmospheric conditions (e.g., temperature, precipitation, humidity, cloud amount and characteristics, wind speed and direction, solar radiation, pressure), physical conditions of the Earth surface (e.g., timing of lake and river freezing and thawing), and biological characteristics (onset of spring and winter through bud burst, flowering, and migration). Notably, lidars and radars enable observations in three dimensions, which helps reveal differences in conditions throughout the atmosphere.

From this combination of observations, humankind has learned an enormous amount about how the Earth behaves, including how severe weather events develop and progress, how sea ice has changed over time, and how the Greenland and Antarctic ice masses are responding to external changes, among other key insights. Our knowledge extends from developed to developing countries, and from habited to uninhabited regions.

*Satellite Types*. Two types of satellite orbit have been particularly important for weather and climate information: geosynchronous and near polar.

Geosynchronous satellites orbit the Earth at the same speed that the Earth rotates. As a result, their location remains fixed with respect to the Earth. This allows almost continuous observation of the same region, which allows us to keep watch over weather systems as they develop and evolve. However, such “geostationary” satellites provide limited coverage of high latitudes and are far from the Earth’s surface, which limits the type of data and spatial resolution of the observations.

Polar orbiting satellites circle the Earth from pole to pole (or nearly so) as the Earth rotates. This provides frequent observations of polar regions and captures information throughout almost the entire world. However, current polar orbiters observe low- and mid-latitude regions no more frequently than twice a day. Nevertheless, the availability of observations throughout the world provides critical data for computer models that forecast weather events more than two or three hours out (for which data from more distant regions is necessary).

Federal agencies, particularly NASA, NOAA, and the Department of Defense (DoD) provide much of the leadership and funding for the nation's Earth observing satellites

**Earth sciences** consist of basic and applied analysis and experiments (in the lab, in the field, or in physical models) that increase our knowledge and understanding of the characteristics and functioning of the Earth system. This knowledge and understanding, appropriately applied, can alert us to societal risks, inform risk management decisions, and create new opportunities for societal advances. Earth science is conducted primarily in academic institutions and Federal agencies but the private sector (including for-profit and not-for-profit organizations) also participates in scientific research on the Earth system. Critically, Earth science enables understanding of Earth observations, while observations can validate, falsify, and help guide scientific research.

Federal agencies such as NASA, NOAA, the Department of Energy (DoE), DoD, the Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Geological Survey (USGS) conduct Earth science research internally and fund external research through competitive research grants. The National Science Foundation (NSF) also supports Earth science research through external grants.

**Earth system services** attempt to synthesize our knowledge and understanding of the Earth system (based on observations and science) and apply that knowledge to improve social and economic well-being. Services include weather forecasts and warnings, assessment of fire risk, flood and drought monitoring and prediction, tsunami propagation modeling and forecasting, natural hazard preparedness and response, public health warnings, disease prevention and control, and decision support for policy makers in water resources, agriculture, transportation, and other key economic sectors. Increasingly, these services account for specific user needs with respect to timing of service delivery, format of services, method of dissemination, and level of expertise of the audience.

Government agencies at all levels (state, federal, and local) provide Earth system services. For example, the National Weather Service provides data, forecasts, and warnings, which improve routine activities for people and businesses, and protect life and property in the face of severe weather events. Within the private sector, both for-profit companies and humanitarian institutions provide Earth system services. For example, for-profit companies create detailed forecasts to meet the needs of specific entities. Humanitarian organizations assist with disaster response and recovery.

## The Importance of Earth OSS to Society at Large

*Earth observations* enable a wide range of routine activities and alert us to dangers from severe weather and other natural hazards. Furthermore, observations provide a long-term record that enables us to assess climate variability and change, and a rigorous basis for making predictions through model development, testing, and validation. These predictions enable informed risk-management decisions, identify new opportunities for advancement, and help us better understand the workings of our Earth system. *Scientific research* enriches our present and future prospects by helping us understand and characterize weather- and climate-related risk. Research also identifies and expands opportunities for commerce. It guides our efforts to preserve the biological systems on which we depend. It enables us to assess economic impacts of weather and climate events and communicate more effectively with the user community and the public. *Earth services* help society use Earth-system knowledge and understanding to greatest effect—for public health and safety, economic growth, environmental protection, and national security.

Indeed, Earth OSS inform and guide the activities of virtually all economic sectors (Table 1) and innumerable institutions underlying modern civilization. Earth OSS are a fundamental component of efforts to meet basic human needs such as the provision of food, shelter, energy, health, and safety. Increasingly, advances in Earth OSS create new opportunities for social and economic benefits throughout the United States, as captured by the six focus areas of this report: agriculture, energy, water resources, public health, disaster preparedness and response, and national security. Numerous other economic sectors (e.g., tourism, transportation, insurance, and finance) also depend heavily on Earth OSS.

For example, *the agricultural sector* relies on Earth observations to monitor and protect against crop losses due to flood, drought, frost, and pest infestations. Numerous weather dependent management decisions in the agricultural sector rely on Earth OSS, such as what crops to plant, which varieties to use, when to plant, and when to apply fertilizers, pesticides, and water. Furthermore, because temperature and moisture stress reduce crop yields, weather and climate forecasts are critical for food production itself and for recognizing when social challenges or unrest may arise because of reduced yields.

*The energy sector* is also highly dependent on Earth OSS, particularly for weather and climate information. Accurate predictions of summer heat and winter cold help utilities predict consumer demands for energy and avoid blackouts and heating fuel shortages. Renewable energy sources (e.g., onshore/offshore wind, solar, hydro, marine and hydrokinetic, and biomass) are particularly dependent on Earth OSS because of their direct reliance on atmospheric conditions such as cloud cover, wind speed, and water availability. Furthermore, Earth OSS help decision makers identify and mitigate harmful unintended consequences of energy production and use, such as the public health consequences associated with air pollution and climate change.

*Water resource management* relies on a range of Earth OSS products to determine water availability, quality, and need. Observations of temperature, precipitation, stream

Table 1: Economic Sectors and Earth OSS

| Sector | Role | Observations | Science | Services | Needs |
|---|---|---|---|---|---|
| Agriculture | Provide food and material | Inform management decisions: crop choice, timing of planting and harvest, when to apply fertilizer, pesticides, and water | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |
| Energy | Provide electricity, transportation, and heating that drive economic activity and societal well-being | Allow demand predictions based on weather, which helps avoid blackouts and shortages<br>Identify weather related risks to infrastructure (power production facilities, energy grid) and informs mitigation efforts<br>Provide information on availability of renewable energy sources (wind, solar, hydro)<br>Identify harmful and unintended consequences of energy production and use | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |
| Water Resource Management | Ensure water quality and availability. Reduce flood risk | Enable projections of water quality and availability along with management decisions (e.g., temperature, precipitation, soil moisture, and stream flow) | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |
| Public Health | Surveillance, preparedness, response, and recovery | Enable public health officials to recognize when weather conditions could lead to public health impacts (e.g., floods, heat waves, and extreme events) or when conditions are favorable for disease outbreaks | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |
| Disaster Preparedness and Response | Issue warnings, implement protective measures, assist in recovery efforts | Provide advance warning for impending extreme events (e.g., hurricanes, tornados, floods, winter storms, and heat waves).<br>Enable immediate protection of life, property, environmental resources, and economic activity | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |
| National Security | Defense and security | Inform strategic and tactical decisions (e.g., timing of military operations, resource needs for troops).<br>Identify regions at risk of conflict and helps contain the risk of spreading<br>Enables strategic and effective use of military for humanitarian missions | | | Weather forecasts and climate projections over days, weeks, seasonally, annually, and perhaps longer time scales |

flow, humidity, and soil moisture are critical for determining flood and drought severity. These data provide a basis for flood warnings, operation of water management systems, water quality protection, floodplain mapping, and the design of critical infrastructure (e.g., bridges, levees, and dams). For example, observations improve the models that enable planners to design and deploy infrastructure.

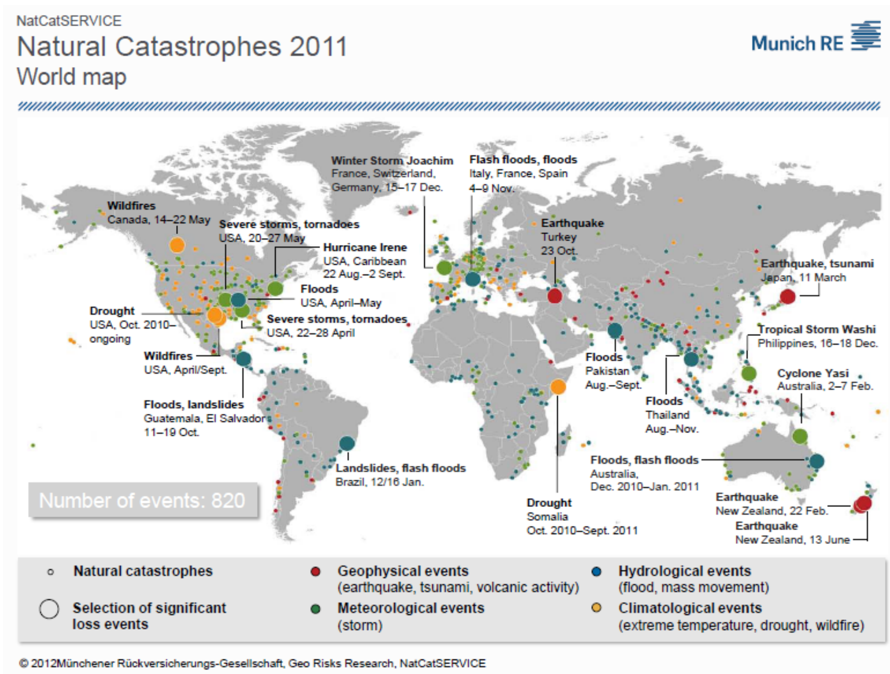


Figure 1: Natural Catastrophes in 2011. Munich Reinsurance Company concludes that there were 820 events throughout the world that caused significant financial losses last year, including roughly US$ 46B in the United States. (The statistics/analyses provided here are the property of Munich Reinsurance Company).

Severe weather events and natural catastrophes occur frequently in the United States and throughout the world (Fig.1). *Disaster preparedness and response* efforts rely on Earth OSS for advance warning of impending extreme events (e.g., winter storms, droughts, hurricanes, tornados, floods, and heat waves) along with information needed to anticipate the extent and duration of natural disasters. In addition, Earth observations provide critical information for geophysical hazards such as volcanic eruptions, tsunamis, and earthquakes. As a result, Earth OSS enable the immediate protection of life, property, environmental resources, and economic activity.

*Public health* uses Earth OSS in support of four critical functions: surveillance, preparedness, response, and recovery. For example, observations enable health officials to recognize when conditions create potential weather-related public health impacts (e.g., due to floods, heat waves, and extreme events) and to recognize when environmental conditions are suitable for disease outbreaks. This provides advance warning to enable preventative measures and the strategic deployment of limited resources.

*National security* depends heavily on Earth OSS for strategic and tactical decisions (e.g., the timing of military operations and the resource needs for troops), which often depend upon assessments and forecasts of weather events and on the ground conditions. Furthermore, national security issues arise in parts of the world where weakened or failing states experience acute weather events, natural disasters, and climate variability and change. Our Earth OSS system helps spot these troubled regions and allows targeted efforts to provide humanitarian aid or otherwise avert or manage local and regional conflicts that have potential to spread.

Earth OSS also help members of the military identify a range of looming national security issues such as potential new military missions as Arctic sea ice melts and northern countries jockey for shipping routes and access to natural resources in the Arctic region.

Finally, Earth OSS infrastructure is widely recognized as a key component of U.S. international statesmanship because it contributes critical resources for global security and humanitarian assistance to people in communities throughout the world. This contribution helps reduce surprises and adverse impacts associated with storms, droughts, wildfires, and other natural hazards throughout the world, which helps build good will and promotes collaboration.

In sum, Earth OSS comprise a national asset that, if lost or degraded, will not meet future societal needs that span the whole of the national agenda. This infrastructure is not concentrated, but is widely distributed across federal agencies and all levels of government, throughout an extensive and growing private sector, and in university research laboratories.

## Challenges facing Earth OSS

Budget concerns. The discrepancy between U.S. Federal spending and revenues is a major driver of current budget discussions. Typically, Federal spending is roughly 20% of GDP, while taxes raise about 18% of GDP in revenue. However, spending is currently about 25% of GDP while revenues have fallen to about 15%. Part of this discrepancy is a result of the current economic slowdown. Spending is up because more people depend on the social safety net during an economic downturn, while revenues are down because of weakened economic activity. Other factors also contribute, including: increases in spending (primarily spending associated with military operations and the prescription drug benefit enacted in 2003) and decreases in revenue as a result of the tax cuts enacted in 2001 and 2003 and extended in 2010.

Proposed budget cuts generally focus on discretionary spending, which includes Earth OSS. Therefore, funding to maintain or improve Earth OSS faces a challenging budget and political environment. When budget allocations to Earth OSS decline, the quality of the overall infrastructure is at risk and the potential for gaps in data collection, reductions in scientific capacity, and disruption of critical services become more likely.

Total annual U.S. Federal investments in Earth OSS are difficult to estimate, but are on the order of $10-20 billion or less.[3] Though considerable, this constitutes considerably less than 0.25% of GDP and less than 1% of the total Federal budget. Therefore, the U.S. system for understanding and dealing with Earth system challenges and opportunities is relatively inexpensive, particularly with respect to its importance for U.S. social and economic well-being (described above).

Nevertheless, the cost of satellite observations constitutes a major fraction of the spending on Earth OSS and the current approach for deploying satellites in the U.S. creates considerable challenges for the Federal budget process, for ensuring data continuity, and for all components of our Earth OSS infrastructure.

*High expectations.* The Earth OSS community's past successes have created somewhat unrealistic expectations. There are increasing requests for the Earth OSS community to 1) deliver ever higher spatial and temporal resolution, 2) predict future changes in both averages and extremes, 3) provide detailed forecasts for temperature, precipitation, cloudiness, wind speeds, and a range of meteorological variables over longer and longer timescales, 4) provide results that will be useful to ever growing communities, 5) forecast actual impacts and consequences on people (i.e., societal consequences) rather than the more straightforward details of weather or climate events, and 6) enable thoughtful choices about climate change risk management.

These expectations put additional pressure on limited budgets because the resources required to achieve potential advances must often come at the expense of other components of our Earth OSS capability.

*Reliable and cost-effective access to space*. Satellite costs have been increasing. Satellite observations require technologically advanced instruments with sensitive tolerances that must withstand the space environment. Furthermore, we build satellites one (possibly two) at a time and wait long periods of time (often 10 years or longer) before building the next comparable one. This eliminates the potential for per satellite cost savings associated with economies of scale (i.e., the cheaper per satellite cost of producing additional units). As a result, satellite observations account for a substantial fraction of Federal expenditures on Earth OSS. For example, NASA's recently launched Earth-observing satellite, Suomi National Polar Orbiting Partnership (Suomi NPP), cost $1.5 billion.

The relatively high cost of satellite missions creates challenges for NOAA, in particular, because the big satellite operations are a large fraction of NOAA's overall budget. As a result, even small proportional increases in satellite cost create risk of cannibalizing other NOAA programs.

Even the Department of Defense (DoD), with its relatively large and robust budgets relative to other Federal agencies, is currently contemplating eliminating its polar satellite programs as a consequence of resource constraints.

The vast majority of NASA's Earth observing satellites now in orbit are past the end of their design lifetimes.[4] Despite being well engineered and vigorously maintained, aging satellites are at increased risk of experiencing problems and failures. A notable disconnect exists between the aging satellite fleet and the Federal funds needed to maintain and replace it (Fig. 2). This indicates a need to expand Federal funding overall, to increase the priority of Earth OSS among competing Federal projects, to set Earth OSS priorities in the face of constrained satellite budgets, or, perhaps most likely, a combination of all three approaches.

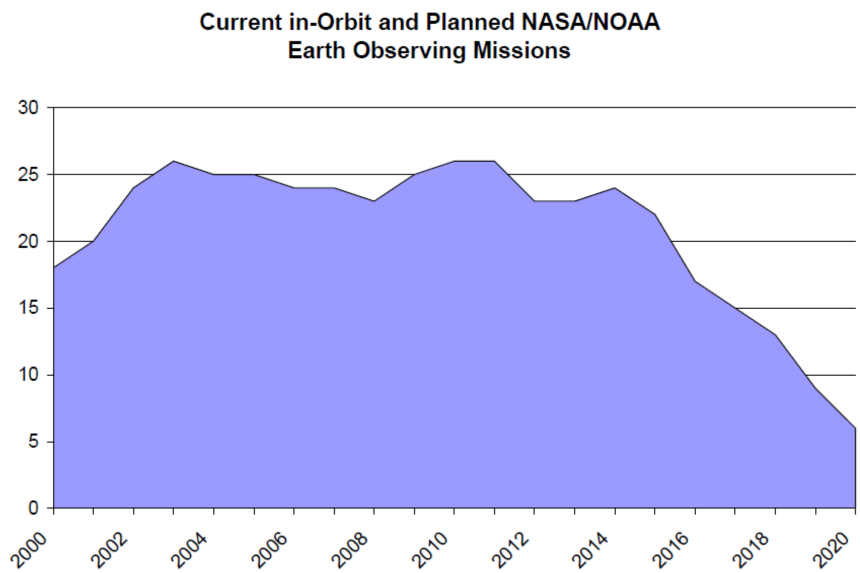


Figure 2: Number of operating (2000-2011) and planned (2012-2020) NASA and NOAA Earth observing missions.[4] The estimated lifetimes for missions already in orbit are taken from data supplied by NASA and NOAA. Note: Planned missions are included only when the missions are funded and have a specified launch date in NASA or NOAA budget submissions. Thus, the graph does not show missions that have been proposed or planned, but not yet funded or selected. NASA plans to select Venture stand-alone missions every 4 years and instruments every 15-18 months, but selections have not yet been made and launch dates have not yet been identified. These missions, once solidified, would play a role in mitigating the decline; however, even the most optimistic projected launch cadence remains significantly below what would be required to prevent a major decline in NASA and NOAA's orbiting space.

*Cooperation*. The Earth OSS community has been particularly effective at collaboration and cooperation across agencies and internationally. In many instances, the Earth OSS community has been a model for how such cooperation can work effectively and for the benefits that result. Nevertheless, issues arise because of the need for intra-agency and multi-agency collaboration and cooperation. A particular challenge is transitioning from science missions, which are typically led by NASA, to long-term service-oriented satellites, which are the purview of NOAA, DoD, and the Department of the Interior. These transitions often represent an expansion of duties for the service agencies, which requires either new resources or the reprogramming of existing resources.

Setting priorities, even within the Earth OSS community, is difficult because numerous agencies, people, disciplines, and objectives are involved. There is no overarching inter-agency decision body that can prioritize choices and optimize decisions. For example, roughly 12 appropriations bills, 4 committees of Congress and 6 examiners in the

Office of Management and Budget (OMB), and at least 10 Federal agencies are engaged in Earth observations. This illustrates both the importance of Earth OSS throughout society and the challenges in achieving broad consensus about priorities.

*Communication.* There is great need for the community to better quantify and communicate the value of Earth OSS to the nation. Policymakers and members of the public often do not fully recognize the importance of Earth OSS to society. For instance, few realize that NOAA and NASA satellites provide the data that underpin weather forecasts or fully understand how the nation benefits from these forecasts. Similarly, leaders in major economic sectors that benefit from Earth OSS do not fully realize how much their efforts rely on Earth OSS, the nature of the risks to existing Earth OSS capabilities, or the potential of new advances in Earth OSS. As a result, they do not push for Earth OSS in proportion to their reliance upon it. This creates a political challenge for Earth OSS because it can be easier to sacrifice high value but under appreciated resources (i.e., Earth OSS) rather than less valuable but more popular budget items.

Finally, decisions made today won't impact Earth OSS immediately. For example, satellites take considerable time to scope, build, test, launch, and make operational. This creates a serious risk during the budget process because sacrificing long-term Earth OSS capabilities can become a politically expedient, yet socially counter productive, choice.

## Opportunities for Earth OSS

Opportunities to improve the provision and use of Earth OSS abound. Most notably, improvements in Earth OSS are possible through 1) increased investment designed to shore up and expand our Earth OSS capability), 2) more effective use of limited resources through prioritization, 3) better communication among Earth OSS providers, users, decision makers at all levels (federal, state, and local), and the public, 4) improved collaboration, 5) more effective Federal policy, 6) better linking of observations and science to services, and 7) creative problem solving to address multiple societal needs simultaneously.

Given the foundational importance of Earth OSS to the nation's economic and social well-being, efforts are needed to ensure the strength and effectiveness of Earth OSS in the years ahead. This will depend on the adoption of national policies to promote Earth OSS, the effective collaboration of the public, private, and academic sectors, and the availability of adequate funding for Earth OSS resources.

To help ensure the adequacy and continuity of Earth observations, science, and services (OSS) over the short, intermediate, and longer term, this report identifies five key recommendations, described below.

## Recommendation 1: Identify current and future needs and priorities

Priority setting activities at the Federal level and within the Earth OSS community could identify investments most likely to bring large returns, consolidate or eliminate less valuable initiatives, and thereby improve the allocation of limited funding.

Efforts to set priorities will depend on two key advances: 1) ensuring that we have the knowledge base needed to set priorities, and 2) development of a national Earth observation strategy with a decadal timescale to identify key Earth observation goals. Within the executive branch, priority setting across agencies has the potential to improve the use of resources and inter-agency collaboration by improving the alignment of initiatives with budget allocations.

## Recommendation 2: Articulate a range of options for supporting existing and emerging public—private partnerships

The nation's Earth OSS infrastructure and resources depend heavily on relationships between the public and private sectors that involve government institutions at the federal, state, and local levels, as well as for-profit companies, non-governmental organizations (NGOs), and the academic community.

Currently, most Earth observation projects, particularly those conducted in space, follow a contracting model in which the government buys satellites and related services from aerospace companies. This approach allows the government to provide public goods and services to society.

Some alternative public—private partnership (PPP) approaches could potentially allow the government to provide comparable levels of public service at lower cost. For example, a corporation could directly invest in building infrastructure to harvest observation data and sell it back to Federal agencies. DoD gets 80% of its communications data from commercial satellites, and has extended this "anchor tenant" model to Earth observations through the EnhancedView program. These types of arrangements make it possible for the government to pay a lower price because the corporations also sell the data to other customers. However, such ventures require that data access must be at least partially closed, which challenges the current open data policy in the United States and has the potential to reduce the overall societal benefit of public expenditures.

Increasingly, it may be possible to boost the breadth of observation data collection while easing the burden on the Federal budget by engaging the public. For example, mobile devices (such as smart phones and vehicles) have the capacity to serve as widely distributed sensors that can automatically collect and transmit observation data with minimal financial investment to OSS providers.

**Recommendation 3: Foster the necessary communication and collaboration among natural and social scientists; scientists and service providers; service providers and communication experts; service providers and users; Federal agencies; and domestic and international providers**

*Communication.* The Earth OSS community needs better communication with policy makers and the public, particularly with respect to Earth OSS's role in preserving life, protecting property, and enhancing economic prosperity. This should be straightforward given the frequency of severe events and natural disasters (both avoided and not) and yet gaps in communication remain.

Critically, improvements in communication among providers and users are also needed to ensure that Earth OSS are as effective as possible. Too often, providers of Earth OSS fail to fully understand and account for the needs of the user community. Better understanding of user needs has the potential to greatly improve the delivery of science and services that will be widely used and most valuable. At the same time, the user community is not always fully aware of the potential applications of Earth OSS.

*Links to Services.* Service providers, in particular, could increase their effectiveness by carefully refining messages to be most effectively understood and incorporated into the decision-making process (e.g., whether and how to deploy maintenance crews in advance of severe events, when to evacuate, how to most effectively respond to warnings).

*Collaboration.* International collaboration makes it possible to improve Earth OSS by expanding data availability, sharing resources, and reducing redundancy. The United States remains a leader in international collaboration, most notably through policies that promote data openness and sharing. This provides considerable leverage for U.S. investments in Earth OSS and creates a powerful incentive for other countries to contribute to the global observation network.

Note also that the U.S. Earth observation infrastructure is extremely helpful to both U.S. international statesmanship and global security. NASA, NOAA, and DoD weather and environmental satellites, sensors, processing, and services provide people in communities around the world with information that reduces suffering and impacts associated with storms, droughts, wildfires, and other Earth system events.

**Recommendation 4: Provide the national investments needed to support and further enhance this critical infrastructure**

Given our estimate that the entirety of U.S. Federal spending on Earth OSS is at most $30 billion, which is less than 0.25% of GDP, our nation's system for understanding and dealing with Earth system challenges and opportunities is relatively inexpensive. At this level of Federal investment, even a doubling of Earth OSS expenditures would have minimal impacts on the overall budget. However, such a doubling would both shore up our aging Earth OSS infrastructure and enable advances needed to ensure further protect lives, property, the environment, and economic activity.

### Recommendation 5: Adapt readily and naturally to changing challenges and new opportunities

The potential exists to leverage investments in Earth OSS with additional societal objectives or co-benefits. Federal responses to economic weakness provide a clear example. When consumer and business spending is weak, as is currently the case, basic economic principles suggest that increased spending by the government on things like infrastructure can improve the economy and job creation by increasing demand. Although Earth OSS is a small fraction of Federal spending and the nation's overall economy, investments in Earth OSS infrastructure can be expected to contribute a boost to a weak economy. At the same time, investments in Earth OSS infrastructure would contribute to longer-term social and economic well-being by improving knowledge and understanding of the Earth system in the future.

### Next Steps and Remaining Needs for Earth OSS

This report's key findings and five recommendations constitute a step toward ensuring the adequacy and continuity of Earth OSS over the short-, intermediate-, and longer term. However, this will not be sufficient given the complexity and persistence of the challenges and opportunities facing Earth OSS. Rather, a sustained effort to conduct policy analysis and promote a high-level national discussion will be necessary.

Toward this end, the American Meteorological Society (AMS) plans a sustained effort to conduct policy analyses and foster discussions that advance Earth OSS capacity. The workshop underpinning this study was a beginning of this effort at AMS. We intend to conduct a series of follow-on workshops and activities that look more narrowly at the roll of Earth OSS in each of the economic sectors explored preliminarily here. This combination of an initial overarching exploration of the role of Earth OSS in society and more specific and narrowly focused series will help us better understand the Earth OSS needs of each sector and will help expand communication and collaboration between the Earth OSS community and those economic sectors.

Four key questions remain and will likely constitute the basis of this ongoing work: 1) Is the level of effort enough to keep pace with what the United States will need over the next decade and in the decades ahead? 2) How can the nation most effectively decide on the best balance among observations, basic and applied research, and operational services? 3) What are the most appropriate and effective roles for the government, business, NGO, and academic communities? 4) How do we maximize the return on Federal investments?

This last question likely rests on priority-setting at a range of scales including what aspects of Earth OSS are the highest priorities, and how best to resolve choices between accuracy and cost. Fortunately, Federal investments in Earth OSS are relatively small and can be maintained and expanded at minimal risk of exacerbating the current Federal budget deficit. Indeed, given the nation's growing reliance on weather and climate information, efforts to expand our Earth OSS capability are virtually certain to broadly benefit the U.S. economy.

## Conclusions

The Department of Homeland Security defines critical infrastructure as the assets, systems, and networks so vital to the United States that their incapacitation, due to terrorist attack, natural disaster, or other emergency, would have a debilitating effect on security, national economic security, public health, or safety. By this definition there can be little doubt that Earth OSS constitutes a key element of the country's critical infrastructure.

Indeed, Earth observations, science, and services (Earth OSS) inform and guide the activities of virtually all economic sectors and innumerable institutions underlying modern civilization. Earth OSS are a fundamental component of efforts to meet basic human needs such as the provision of food, shelter, health and safety. Increasingly, advances in Earth OSS create new opportunities for social and economic benefits throughout the United States.

Critically, improvements in communication among providers and users can help ensure that Earth OSS are as effective as possible and create the potential for co-benefits (e.g., ancillary societal improvements through investments in Earth OSS).

Key findings of this report:

1. Earth observations, science and services (OSS), taken together, constitute a key national infrastructure, critical to ongoing efforts in the United States to:

    A. Use Earth's natural resources most effectively (including, but not limited to, energy, food, and water),

    B. Protect and maintain environmental quality, essential biological resources, and planetary life-support services, and

    C. Promote public safety, health, and uninterrupted economic activity in the face of natural hazards.

2. There is a common Earth OSS infrastructure that simultaneously supports and enhances multiple sectors of the U.S. economy including agriculture, energy,

transportation, water resource management, public health, and national security.

3. The continued viability of Earth OSS infrastructure is at risk, due to inadequate and intermittent rates of investment in its development, function, and maintenance.

4. Improvements to the existing policy framework have considerable potential to enhance Earth OSS capabilities and use in critical economic sectors.

In order to ensure the adequacy and continuity of Earth OSS over the short, intermediate, and longer term, this report recommends national policies for Earth OSS that:

1. Identify current and future needs and priorities;

2. Articulate a range of options for supporting existing and emerging public—private partnerships;

3. Foster the necessary communication and collaboration among natural and social scientists, scientists and service providers, service providers and communication experts, service providers and users, Federal agencies, and domestic and international providers; and

4. Provide the national investments needed to support and further enhance this critical infrastructure;

5. Adapt readily and naturally to changing challenges and new opportunities.

These five recommendations constitute a step toward ensuring the adequacy and continuity of Earth OSS over the short, intermediate, and longer term. However, one report and a set of recommendations issued one time and without further refinement will not be sufficient given the complexity and persistence of the challenges and opportunities facing Earth OSS. Rather, a sustained effort to conduct policy analysis and promote a high-level national discussion will be necessary.

Fortunately, Federal investments in Earth OSS are relatively small and can be maintained and expanded at minimal risk of exacerbating the current Federal budget deficit. Indeed, given the nation's growing reliance on weather and climate information, efforts to expand our Earth OSS capability are virtually certain to broadly benefit the U.S. economy.

## Acknowledgments

The speakers and participants at the AMS Policy Workshop *Earth Observations, Science, and Services for the 21st Century* provided critical insights through their presentations and discussion. This work was supported in part by funding from our corporate patrons (ITT-Exceles and Lockheed Martin), corporate underwriters (Ball Aerospace), NOAA (grant NA09NWS4670020) and NASA (grant NNX07AH21G). The findings, conclusions, opinions, and recommendations expressed in this report do not necessarily reflect the views of AMS, its underwriters, or the workshop sponsors.

## References and Notes

1.“Taking Predictions to the Next Level: Expanding Beyond Today's Weather, Water, and Climate Forecasts and Projections.” Background to the theme for the AMS 2013 Annual Meeting by President Louis Uccellini: “*The meteorological community can take enormous pride in 1) making prediction a fundamental part of its scientific and operational/service heritage, 2) developing and applying complex numerical models that now rely on a real-time, satellite-dominated global observing systems, involve the atmosphere, ocean, land and cryosphere components of the Earth System and are run on the World's largest computers, and 3) forecasting extreme events, in some cases over a week in advance. The advancements over the past 60 years in the Meteorological and related Earth System sciences, global observing systems and computer capabilities, combined with the ability to provide decision support services through the public and private sectors, have been a crowning achievement for the entire enterprise related to weather, climate, and ocean predictions.”*

2. Committee on Earth Science and Applications from Space. 2007. Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. Space Studies Board, Division on Engineering and Physical Sciences. National Research Council of the National Academies. The National Academies Press. Washington, D.C.

3. Based on the aggregation of the budgets for NOAA's relevant line-offices, NASA Earth Sciences, NSF's GEO directorate, DoE's Office of Science, and USGS, along with the assumption of roughly similar levels of investment in Earth OSS at DoD, and in combination for the remaining Federal agencies.

4. Committee on the Assessment of NASA's Earth Science Program. 2012. Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey. Space Studies Board of the National Research Council. The National Academies Press. Washington, DC.

Appendix A: Forum Agenda

## Earth Observations, Science, and Services for the 21st Century

NOVEMBER 1—3

An American Meteorological Society Workshop
at
University of California in Washington
1608 Rhode Island Avenue, NW
Washington, DC 20005

## Tuesday, November 1

7:30 Registration and Continental Breakfast

8:00 Welcome and Opening Remarks
Jon Malay, President, American Meteorological Society
William Hooke and Ellen Klicka, AMS Policy Program

8:10 **Part 1: Overview of Existing Resources**
Jack Kaye, NASA
Bob Marshall, EarthNetworks
Mary Glackin, NOAA

9:40 Break

10:00 **Part 2: Budget and Business Model**
Eric Webster, ITT
Scott Gudes, Lockheed Martin
Peter Colohan, White House OSTP
Grace Hu, OMB
Gene Whitney, Congressional Research Service
Ann Zulkosky, U.S. Senate Staff

12:00 Lunch

**Part 3: Sectors That Depend on Earth Observations, Science and Services**
1:00 **Agriculture** Sector Panel
Steve Shafer, USDA
James Jones, University of Florida
David Letson, University of Miami

2:45 Break

3:15 **Energy** Sector Panel
Bryan Hannegan, Electric Power Research Institute
Randall Luthi, National Ocean Industries Association
Gary Geernaert, U.S. Department of Energy

5:00 Forum ends for the day

## Wednesday, November 2

7:30 Continental Breakfast

7:50 Logistics

8:00 **Water** Sector Panel
Lewis E. (Ed) Link, University of Maryland
Eugene Stakhiv, U.S. Army Corps of Engineers
Tim Cohn, U.S. Geological Survey

9:45 Break

10:00 **Disaster Preparedness/Safety** Sector Panel
Matt Cowles, National Emergency ManagementAssociation
Gregory Shaw, George Washington University
Mary Ellen Hynes, DHS

11:45 Lunch

1:00 **Public Health** Sector Panel
Mark Keim, CDC
Gregory Glass, Johns Hopkins
George Luber, CDC

2:45 Break

3:15 **National Security** Sector Panel
Cmdr. Tony Miller, U.S. Navy
Robert W. Corell, Global Environment and Technology Fund

5:00 Forum ends for the day

## Thursday, November 3

7:30 Continental Breakfast

7:50 Logistics

8:00 **Part 4: Future Needs and Opportunities for U.S. Federal Policy**
Molly Macauley, Resources for the Future
Lea Shanley, Woodrow Wilson International Center
Vladimir Tsirkunov, World Bank
Jean Fruci, Former Congressional Staff

10:00 Break

10:15 **Part 4 continued**

11:30 **Closing Keynote**
Gov. Jim Geringer, ESRI

12:00 Closing Remarks

12:15 Adjourn

Appendix B: Forum Participants

Sharon Abbas
Margaret Arnold
Ken Ashworth
Randy Bass
Zack Bastian
Steve Bieber
Thomas Blazek
Andrea Bleistein
Jennifer Boehme
Matthew Borgia
Mariel Borowitz
Mark Brender
Caitlin Buzzas
John Campbell
Louis Cantrell
Chris Carter
Kaitlin Chell
Kendall Childers
Tim Cohn
Peter Colohan
Robert W. Corell
John Cortinas
Matt Cowles
Amy Daniels
Michael Darzi
Darien Davis
Laura Delgado Lopez
James Devine
Elizabeth Doerr
Rob Doornbos
Sue Estes
Allan Eustis
Thomas Fahy
Genene Fisher
Kathleen Fontaine
Jean Fruci
Arti Garg
Gary Geernaert
Gov. Jim Geringer
Mary Glackin
Gregory Glass
David Green
Scott Gudes
Erik Hankin
Bryan J. Hannegan
John Haynes
Dan Hendrickson
Paul Higgins
Douglas Hilderbrand
Leonard Hirsch
Paul Hirschberg
William Hooke
Patrick Horan
Grace Hu
Mary Ellen Hynes
Kellee James
James Jones
Jack Kaye
Mark Keim
Jonathan Kelsey
Ellen Klicka
Mary Ann Kutny
Fabien Laurier
Arron Layns
P. Patrick Leahy
Renee Leduc Clarke
David Letson
Lewis E. (Ed) Link
Sarah Lipscy
George Luber
Randall Luthi
Molly Macauley
Jonathan Malay
Robert Marshall
Gary Matlock
Tim McClung
Cmdr. Tony Miller
Shali Mohleji
Amanda Parker
Richard Pentimonti
James Peronto
John Petheram
Maria Pirone
Marty Ralph
Katie Ray
Scott Rayder
Scott Rayder
David Reidmiller
Gregory Robinson
Linda Rowan
Chris Scheve
Cindy Schmidt
Kevin Schrab
David Schurr
Samantha Segall Anderson
Keith Seitter
Steven Shafer
Lea Shanley
Gregory Shaw
Cory Springer
Eugene Stakhiv
James Stalker
Sheila Steffenson
Matt Taylor
Mackenzie Tepel
Wendy Marie Thomas
Steve Tracton
Vladimir Tsirkunov
Ana Unruh Cohen
Carolyn Vadnais
Mark Vincent
Eric Webster
Gene Whitney
Derrick Williams
Don Winter
Joe Witte
Neil Wyse
Martin Yapur