Earth Observation for Climate Change

A Report of the CSIS Technology and Public Policy Program

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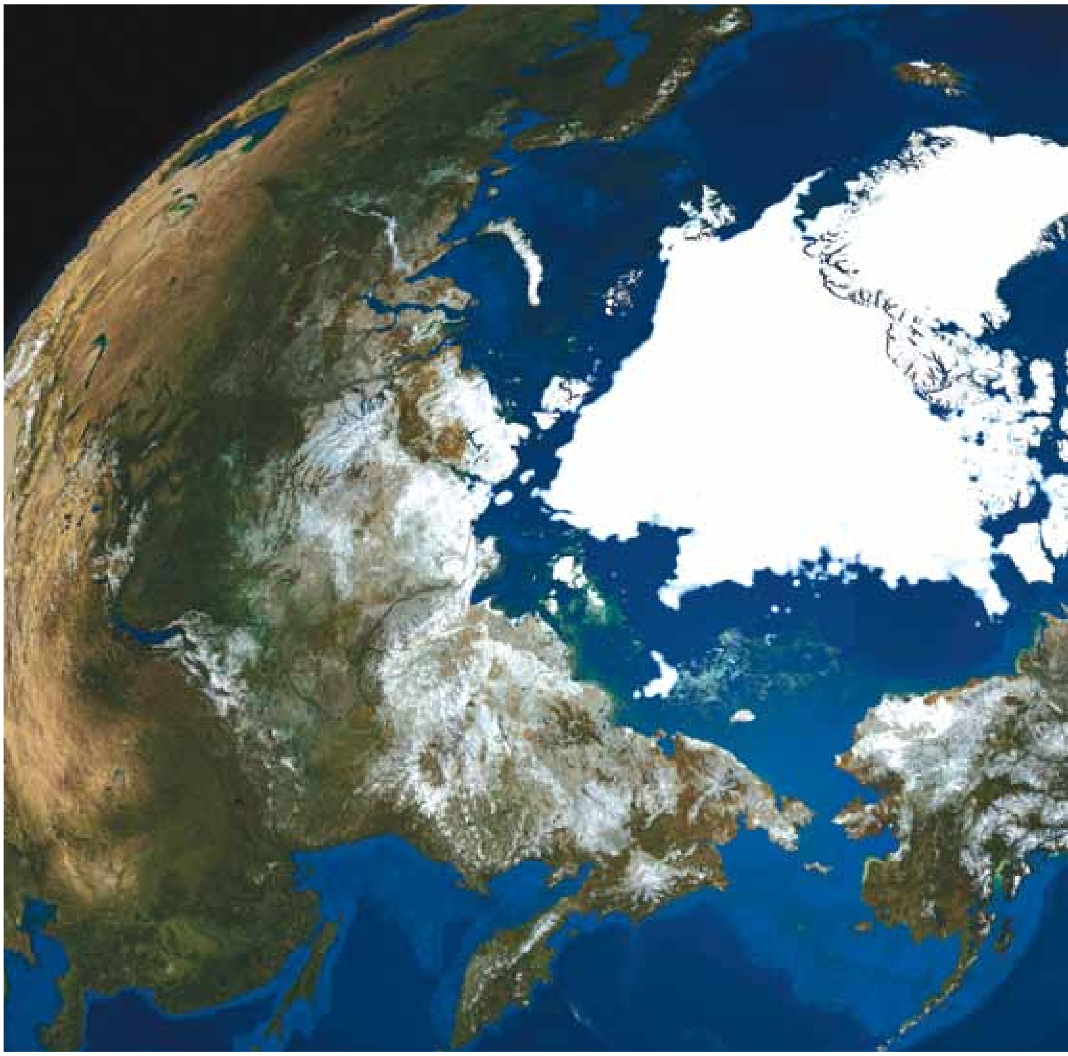

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Cover photo: Reuters/NASA. The Advanced Microwave Scanning Radiometer (AMSR-E), a high-resolution passive microwave instrument on NASA's Aqua satellite, shows the state of Arctic sea ice on September 10 in this file image released September 16, 2008.

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FOREWORD

Slowly, painfully, we are developing a new policy framework that we hope will enable our society to cope with a changing climate. But currently we do not have in place the necessary "knowledge infrastructure" to make this new system work.

As we develop new policies, we are confronted with critical questions of capacity and responsibility for this endeavor. The scientific community has done a great deal to study the nature and pace of global climate change and increase our understanding of these global phenomena—both in terms of what we know and what we do not know. Now, as policymakers, businesses, the international community, and households consider ways to reduce emissions in the hope of avoiding the most severe effects of a changing climate, build more resilient infrastructure and systems to withstand the unavoidable impacts of climate change, and plan for dealing with climate-related disasters, our ability to provide decisionmakers with the information that they need must grow and improve.

Among many complex issues, we need to understand climate-related trends as they apply to state and local communities; we must decide how to monitor emissions and check results against agreed-upon reductions and expected outcomes; we must address how to better model the economic effects of emissions reductions plans and a changing natural environment in ways that will help us understand the impact of new climate policies. We need to establish methods of assessing the relative costs and benefits of more aggressive action that will allow us to prioritize actions to take for climate change, and, of course, we need to continuously improve on understanding how and why the Earth's climate is changing so as to build greater certainty into policy efforts.

This is a daunting task for government, which must manage information on an unprecedented scale. Federal agencies will have to translate vast quantities of scientific data into knowledge that can guide policymakers and administrators. Currently, the federal government is generating enormous amounts of data and analysis on the Earth's climate, on ocean temperatures and currents, on jet streams and Arctic ice melt. Over time, our ability to monitor emissions and understand important feedbacks, including societal adjustments to the policies in place as well as a changing climate, will need to improve and expand.

The government does have an excellent starting point with the work of the U.S. Global Change Research Program and the Earth observation functions supported by the National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA). NOAA has made tremendous efforts, working with foreign partners to create the Global Earth Observing System of Systems (GEOSS). This network seeks to provide global, real-time data in an open, collaborative, and transparent way. But the implementation of GEOSS has not progressed much beyond developing a blueprint for the system.[1]

1. Group on Earth Observations (GEO), *2007–2009 Work Plan Progress Report,* http://www.earthobservations.org/documents/geo_v/08_2007-2009%20Work%20Plan%20Progress%20Report.pdf, p. 3.

To establish a new policy framework for addressing these challenges, the federal government must ask and answer the question: Where do we attain knowledge, process it, and make policy on such an enormous scale? The United States has the opportunity to build the knowledge platform we will need to help inform the hard decisions that lie ahead.

The 2008 CSIS report, *CSIS Commission on Smart Power: A Smarter, More Secure America,* called for the United States to find ways for "investing in the global good." The report highlighted five critical areas for engagement, including technology and innovation. It singled out climate change as an issue that required American leadership to help establish global consensus and develop innovative solutions to manage a new and complex global challenge. Climate change is a global challenge, but it is also an opportunity for the United States to build its global leadership.

Now is the time for the current administration to build up the knowledge infrastructure for climate change. It will clearly take a team effort to coordinate resources, streamline decisionmaking, and disseminate information, perhaps as part of a new National Climate Service, to start now to build this critical knowledge infrastructure. Without the knowledge this infrastructure would establish and a realistic process to manage it, we will be sailing in uncharted waters with rumored and uncertain landmarks.

John Hamre
President and CEO
Center for Strategic & International Studies

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EXECUTIVE SUMMARY

Until this year, America's civil space policies—and the budgets that derive from it—were shaped to a considerable degree by the political imperatives of the past and by the romantic fiction of spaceflight. We believe there is a new imperative—climate change—that should take precedence in our national plans for space and that the goal for space spending in the next decade should be to create a robust and adequate Earth observation architecture.

There is unequivocal evidence, despite careless mistakes and noisy protests, that Earth's climate is warming. While the effects and implications of this are subject to speculation, there should be no doubt that the world faces a major challenge. There are important shortfalls in data and analysis needed to manage this challenge. Inadequate data mean that we cannot determine the scope or nature of change in some key areas, such as the melting of Antarctic sea ice. Long-term changes in daily temperature are not adequately understood, in part because of limited observations of atmospheric changes. Our understanding of how some anthropogenic (man-made) influences affect climate change is still incomplete.[1] These shortfalls must be remedied, if only to overcome skepticism and doubt.

Climate change now occupies a central place on the global political agenda, and the United States should adjust its space policies to reflect this. Assessing and managing climate change will require taking what has largely been a scientific enterprise and "operationalizing" it. Operationalization means creating processes to provide the data and analysis that governments will need if they are to implement policies and regulations to soften the effects of climate change. Operationalization requires the right kind of data and adequate tools for collecting, analyzing, and disseminating that data in ways that inform decisionmaking at many levels of society.

Satellites play a central role in assessing climate change because they can provide a consistent global view, important data, and an understanding of change in important but remote areas. Yet there are relatively few climate satellites—a total of 19, many of which are well past their expected service life. Accidents or failures would expose the fragility of the Earth observation system.[2] We lack the required sensors and instruments for the kinds of measurement that would make predictions more accurate and solutions more acceptable. Weather satellites, which take low-resolution pictures of clouds, forests, and ice caps, are not adequate to the task. NASA builds impressive Earth observation satellites for climate change, but these have been experimental rather than ongoing programs.

Climate change poses a dilemma for space policy. The programs needed to manage climate change have been woefully underfunded for decades. The normal practice is to call uncritically

1. Intergovernment Panel on Climate Change (IPCC), *Climate Change 2007: Synthesis Report*, November 2007, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

2. See table on page 12.

for more money for civil space and its three components—planetary exploration, Earth observation, and manned spaceflight. In fact, civil space has been lavishly funded. Since 1989, NASA has received $385 billion, with $189 billion in the last decade.[3] This is more than the space budgets of most other nations combined. The problem is not a lack of money but how it has been spent. The bulk of this money went to NASA's manned space program. This is a legacy of the Cold War. Manned spaceflight showed that market democracies could surpass scientific socialism. The point has been made. Spaceflight provides prestige, but a long series of miscalculations have left the United States with a fragile and fabulously expensive space transportation system. It will take years to recover, and some goals, such as a voyage to Mars, are simply unachievable absent major breakthroughs in physics and other sciences.

If we accept that climate change poses serious risks to regional stability, national security, and economic health, the United States needs to reconsider its funding priorities for civil space. Earth observation is crucial for national security and the economy; manned spaceflight programs provide prestige. The United States must make climate-monitoring satellites its priority for funding if it is serious about managing climate change. In practical terms, this means a reduction in the spending on human spaceflight in order to fund a sustained program of satellite-building to create a robust climate monitoring space system.This is, of course, not an all-or-nothing issue. The United States can fund a range of space programs, manned and unmanned, for exploration and for Earth sciences. It is a question of priorities. Our recommendation is that the funding given to Earth observation should increase, as it is more important now for the national interest to monitor and manage climate change, even if that means a slower pace for other programs, such as manned spaceflight, until a robust Earth observation system has been put in orbit.

Having the right data is only part of the challenge. The usefulness of that data depends on the strength of climate models and computing capabilities and our ability to make this information available to decisionmakers and user communities in a useful form. In the United States, these functions could be provided by a strengthened and reorganized interagency climate information structure bolstered by the creation of a National Climate Service, which could aggregate and analyze climate data in ways tailored to support management, policymaking, and the information needs of a broad-based user community.There is also an opportunity for the United States to lead an international effort that takes the many existing collaboration structures—such as the Global Earth Observation System of Systems (GEOSS) and the Global Climate Observation System (GCOS)—and operationalizes them. The Global Framework for Climate Services being advocated by the World Meteorological Organization could provide the platform to make climate data more accessible to policymakers.

The United States is the nation that is most active in space and the nation with the greatest need to demonstrate responsible leadership. A willingness to cooperate and share will help build America's global influence. Operationalizing science to manage climate change, building the capacity to acquire the needed information and share it with a wide range of users, and bolstering these capabilities at the international level as a part of a productive engagement strategy in what has so far been a contentious road to international agreement should all be goals for the United States both to address climate change, contribute to solving a global problem, and rebuild U.S. leadership. To this end, our recommendations are as follows:

3. In constant 2008 dollars. A historical of NASA's budget can be found here: http://www.nasa.gov/news/budget/index.html.

- The U.S. approach to climate change policy should be shaped by the need to inform decision-makers and planners in both government and the private sector by providing understandable metrics and analyses of the effectiveness of and compliance with mitigation programs and adaption plans. The customers for this should include federal agencies, state and local governments, private sector users, and other nations.
- To better serve the national interest, the United States should increase its Earth observation capabilities—especially space-based sensors for carbon monitoring—to improve our ability to understand the carbon cycle and to inform any future international agreement. This means that until these capabilities are adequate for monitoring climate change, investment in Earth observation satellites should take precedence over other space programs. Increased spending on Earth observation satellites specifically designed for climate change should be maintained until the current capability shortfall is eliminated.The United States should accelerate the creation of a National Climate Service to improve climate information management and decisionmaking. In a related effort, the United States should support the World Meteorological Organization in its efforts to create a World Climate Service for similar reasons.
- The United States should complement its national effort by supporting and expanding multilateral efforts to coordinate Earth observation for climate change, building on existing international efforts such as the GCOS. This could entail coordinated investment in space and subsidies for ground facilities in developing countries, recognizing that the United States, the European Union, Japan, and Canada will bear the largest share of the cost at this time.

EARTH OBSERVATION FOR CLIMATE CHANGE

There has been speculation for more than a century on how human activity may change the Earth's climate. The era of speculation is over. If there has been any surprise, it has been that the pace and scope of change caused by "anthropogenic influences" have proven to be more rapid than expected. While skeptics remain, most observers now agree that human activities (particularly the burning of carbon fuels and deforestation) contribute to and accelerate climate change.

There is now broad consensus that national interests are threatened by climate change. Concern over the effect of climate change led to a discussion over its implications for national security and international stability.[1] Many studies agreed that climate change creates new risk for national and economic security, as a result of dislocation of populations or a scarcity of resources such as water or food. To the extent climate change is a national security problem, it is a problem that is not amenable to solution by military tools. Instead, progress will depend on diplomacy, science, and technology.

Climate change is a global problem. A global response is necessary, using existing or new vehicles for cooperation. While there is broad consensus that national interests are threatened by climate change, turning this consensus into meaningful action will be difficult. Negotiation takes

1. Influential reports and statements, frequently cited by policymakers, that have been released in support of this view include the following: Sharon Burke et al., *A Strategy for American Power: Energy, Climate and National Security* (Washington, D.C.: Center for New American Security, June 2008), http://www.cnas.org/files/documents/publications/Burke_EnergyClimateNatlSecurity_June08.pdf; Joshua W. Busby, *Climate Change and National Security: An Agenda for Action*, Council on Foreign Relations, November 2007, http://www.cfr.org/content/publications/attachments/ClimateChange_CSR32.pdf; Kurt Campbell et al., *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change* (Washington, D.C.: Center for New American Security and CSIS; November 2007), http://www.cnas.org/files/documents/publications/CSIS-CNAS_AgeofConsequences_November07.pdf; Thomas Fingar, *National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030,* Testimony before the House Permanent Select Committee on Intelligence, House Select Committee on Energy Independence and Global Warming, June 25, 2008, http://www.dni.gov/testimonies/20080625_testimony.pdf; Sherri Goodman et al., *National Security and the Threat of Climate Change,* Center for Naval Analysis Corporation (Alexandria, Va.: CNA Corporation, 2007), http://securityandclimate.cna.org/report/National%20Security%20and%20the%20Threat%20of%20Climate%20Change.pdf; Michael A. Levi et al., *Confronting Climate Change: A Strategy for U.S. Foreign Policy,* Council on Foreign Relations, 2008, http://www.cfr.org/content/publications/attachments/Climate_ChangeTF.pdf; Pew Center on Global Climate Change, "National Security Implications of Global Climate Change," August 2009, http://www.pewclimate.org/federal/memo/national-security-implications; Marc A. Levy et al., *Assessment of Select Climate Change Impacts on U.S. National Security,* Center for International Earth Science Information Network, Columbia University, Working Paper, July 1, 2008, http://www.ciesin.columbia.edu/documents/Climate_Security_CIESIN_July_2008_v1_0.ed070208_000.pdf; R. Schubert et al., *Climate Change as a Security Risk,* German Advisory Council on Global Change, May 2007, http://www.wbgu.de/wbgu_jg2007_engl.pdf.

place in the context of competing national economic interests. The countries most vulnerable to the effects of a changing climate, mostly developing countries, do not have the capacity to cope with these changes and look to developed countries for assistance. Our understanding of how to mitigate and adapt to climate change is still at an early stage. Remedies have been identified, but their effectiveness has yet to be measured. Finally, the data necessary for assessing the effect of these efforts and the mechanisms for sharing that data are partial and incomplete, designed to inform science and not policy.

There is still a great deal we do not know about the local and global effects of climate change. Several recent studies identified gaps and weaknesses in climate science activities. One of the main conclusions of this research is that climate science to date has been geared toward fulfilling needs within the scientific community rather than meeting the needs of decisionmakers who must determine how to adapt and respond to a changing climate.

Managing climate-related risks requires accurate, robust, sustained, and wide-ranging climate information. Sustained and continuous observations are needed for researchers to evaluate and test climate model accuracy and to identify causes of particular elements of climate change. The international community must address four key uncertainties and gaps in climate research if we are to significantly improve our confidence in climate change prediction and understanding: [2]

- Incomplete global data sets for analysis and modeling uncertainties restrict the types of studies that can be performed.
- The lack of observational data restricts the types of climate change that can be analyzed.
- Multi-decadal changes in daily temperature range are not well understood.
- Confidence in attributing some climate change phenomena to anthropogenic (man-made) influences is limited.

These gaps and uncertainties are directly related to the availability of adequate Earth observations. Earth observation provides the evidence necessary for informed decisionmaking. It supports the monitoring and verification of emission reductions. A comprehensive and global perspective in climate monitoring is needed to understand the interconnectivity of Earth's terrestrial, atmospheric, and oceanic systems.

Understanding the climate problem requires accurate, robust, sustained, and wide-ranging climate information. Masses of data are already collected for atmospheric, oceanic, and terrestrial phenomena.[3] These data are shared among the research community through various international

2. See Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report*, November 2007, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

3. These include (1) earth radiation (including solar irradiance), upper-air temperature, upper-atmosphere wind speed and direction, water vapor, cloud properties and composition (such as the presence of long-lived greenhouse gases including carbon dioxide, methane, ozone, and other), and aerosol properties; (2) sea-surface temperature, sea-surface salinity, sea level, current, the presence of sea ice, and ocean color (an indicator of biological activity); (3) terrestrial variables such as river discharge, water use, ground water, snow cover, the extent of glaciers and polar ice caps, permafrost and seasonally frozen ground, albedo (a measurement of the reflection of sunlight or other radiation), land cover (including vegetation type), and biomass. See Sue Barrell, *Global Climate Observing System: COP9, Milan,* http://unfccc.int/cop9/se/present/barrell.pdf. Some observers noted that there has been "significant progress" in collection due to the growing availability and increased use of satellite observation.

data centers, but the informational needs of policymakers are different from those of researchers. The primary requirements for policy are timely and consistent access to data for assessing actions and reducing uncertainty. The data (and improved models to use that data) that policymakers will need fall into several categories:

- **Trend data** that track the shrinking of the polar ice caps or forests, the presence of gases in the upper environment, or changes in ocean temperature or currents. Depending on the adequacy of predictive models, these data would allow assessment of the rate and nature of climate change.
- **Regional data** that enable the identification of specific regional problems to allow for tailored solutions or aid programs. The need for cross border collection complicates the gathering of these regional data.
- **Effects assessment data** that would reduce uncertainty and allow policymakers to determine whether mitigation or adaptation policies implemented to address climate change are having any effect.
- **Compliance data** to monitor progress in support of an agreement. One of the lessons of the recent climate negotiations in Copenhagen is that ensuring compliance with any future agreement to limit emissions will be politically sensitive for some countries and beyond the technical or financial means of many others.
- **Planning data** that provide consistent and timely information that insurance companies, farmers, urban planners, major corporations, and others will need to reduce uncertainty.

These data would allow local planners, governments, businesses, and private sector consumers like the insurance industry to assess the likelihood of certain impacts and conduct cost-benefit analysis of different response options (see appendix A for a more detailed discussion of such options). On the international level, this type of regional information is necessary for determining which areas of the world will be most affected and should receive a higher priority for aid, financing, technology, and capacity building.

Monitoring and verifying of greenhouse gas (GHG) emissions is of particular importance. Reaching an agreement to reduce greenhouse gas emissions is complicated because of the inherent scientific uncertainty and incomplete understanding of the carbon cycle and warming of the Earth. Recent scientific advancements, however, allow us to conclude with a high level of certainty that climate change and global warming are unequivocal and that the primary driver is carbon dioxide produced by burning of fossil fuels and, to a lesser degree, by deforestation;

Currently, identifying trends in GHG emissions relies on weaving together data collected from existing ground-based networks and space-borne instruments, using a process called "trace-transport inversion." As the United States and other nations consider whether to adopt cap-and-trade policies, they will need a coordinated and efficient system for collecting and distributing data to support carbon markets and to promote transparency and accountability through accessible public information.

Better climate information has helped us move beyond the question of whether action to manage climate change is warranted to what types of actions and polices are needed. Information is key to an effective approach to climate change. At a national and international level, many countries are preoccupied with how to ensure that decisionmakers and user communities have access to the types of information that will make the climate efforts successful. This includes coordinated systems for Earth observation, enhanced modeling capabilities, an organizational structure that allows science to be more responsive to relevant policy questions or functions, and places where information can be gathered and made accessible to broad-based user communities.

Meeting the needs of climate policy requires a transformation in how climate research is incorporated into public policymaking.[4] "Operationalizing" information systems—investing in the Earth observation systems necessary for producing the right data over the right time and space horizons, coordinating data collection, interpreting and sharing to maximize the data's benefits, focusing on the human and social science effects of climate change, improving modeling capabilities, and making this information accessible and relevant for a wide range of users—is a necessary step in designing effective U.S. climate policy. It also represents an opportunity for America to demonstrate global leadership and contribute to building global capacity to understand and more effectively respond to the climate.

The climate negotiations in Copenhagen, Denmark, in December 2009, failed because of differences over how to share responsibilities and burdens. The challenges inherent in these negotiations will not be easily overcome. However, the troubled negotiations in Copenhagen present the United States with an opportunity. The 2008 CSIS report, *CSIS Commission on Smart Power: A Smarter, More Secure America,* called for the United States to use its technology and scientific prowess to engage other nations in efforts that serve both U.S. interests and the interests of the global community. This report identifies Earth observation and climate change as one such opportunity and provides recommendations on how the United States can, working with other nations, acquire the technology and build the institutions needed to assess and manage climate change. It suggests three steps that the United States can take:

- expand international cooperation,
- consolidate and strengthen its national effort, and
- launch civil space policy in a new direction.

Expanding International Cooperation

Climate change will require a coordinated global response. An ideal climate policy structure would use research efforts to assess the relative merits of different adaptation and mitigation strategies. It would be supported by collaborative multinational monitoring and assessment efforts. It would include processes for technology transfer and provide financial support for mitigation efforts at a national level. This structure does not now exist, but by building on existing efforts and the strong foundation of scientific collaboration, we could make comparatively rapid progress in building a new framework to support policymaking and provide climate information for decisionmaking.

Many of the building blocks for managing climate change already exist under the aegis of the United Nations (UN). The United Nations Environment Programme (UNEP) and the World

4. National Research Council of the National Academies, *Restructuring Federal Climate Research to Meet the Challenges of Climate Change*, Committee on Strategic Advice on the U.S. Climate Change Science Program, Division on Earth and Life Sciences (Washington, D.C: The National Academies Press, 2009), p. 3.

Meteorological Organization (WMO), along with other international organizations,[5] sponsor the Global Climate Observation System (GCOS). GCOS provides for comprehensive observations for research and for detecting and attributing climate change.

GCOS supports the United Nations Framework Convention on Climate Change (UNFCCC),[6] which is the primary vehicle for international coordination, and the (now somewhat tarnished) Intergovernmental Panel on Climate Change (IPCC). These organizations, along with the World Climate Research Programme (WCRP), provide the international framework for scientific cooperation in studying climate change.[7] GCOS's mission is to harmonize national observation systems to avoid both gaps and redundancies in Earth observation programs. The systems in GCOS, which are owned and operated by the agencies of member countries, include climate data collection centers around the world. GCOS, by ensuring free and unrestricted availability of climate and climate-related data, provides information on the earth system to inform decisions made by governments and businesses.[8]

GCOS is buttressed by two organizations that plan and coordinate Earth observation from space. The Committee on Earth Observation Satellites (CEOS), established by the G-7 in 1984, is the principal body for coordinating Earth observation among national civil space programs. Twenty-eight space agencies along with other national and international organizations participate in CEOS.

CEOS supports the Group on Earth Observation (GEO), an operational body established in 2005 to provide "a single, comprehensive and sustained system for Earth Observation."[9] GEO, with a permanent secretariat in Geneva, is a voluntary partnership of governments and international organizations that provides a framework for coordinated strategies and investments. U.S. leadership was instrumental to the formulation of GEO. GEO's members include 77 governments, the European Commission, and 56 "participating organizations." GEO has met four times since 2005 and has created a ten-year plan to build the Global Earth Observation System of Systems, or GEOSS.[10]

GEO is the body that coordinates and sets up the architecture for the "system of systems" to ensure complete coverage and compatibility of data. It is a high-level (ministerial) forum for all nations and UN/intergovernmental organizations that contribute or use Earth observation data to work out the details involved in ensuring that systems are compatible and data are available across the globe. CEOS is one of many contributors to the GEOSS. GEO works from above to ensure that all contributions to the GEOSS are compatible and encourages and coordinates resourcing and planning for the missing pieces.[11]

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5. The Intergovernmental Oceanographic Commission of UNESCO and the International Council for Science.

6. The UNFCC grows out of a 1992 treaty "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system.

7. Organization of the Intergovernmental Panel on Climate Control, http://www.ipcc.ch/organization/organization.htm.

8. World Meteorological Organization, *Global Climate Observing System: Ensuring the Availability of Global Observations for Climate*, November 2007, http://www.wmo.ch/pages/prog/gcos/documents/GCOS_brochure_GoodQuality.pdf.

9. "Earth and Space Week: Third Earth Observation Summit agrees ten-year GEOSS action plan," *European Space Agency*, February 17, 2005, http://www.esa.int/esaEO/SEMSABYEM4E_index_0.html.

10. The United States has an interagency working group called USGEO to coordinate contributions to GEOSS.

11. Personal communication, Vice Admiral Conrad Lautenbacher, October 7, 2009.

GEOSS provides common standards for architecture and data sharing. Each national system used in GEOSS must be configured so that it can communicate with other participating systems. Contributors subscribe to the GEO data-sharing principles on the full and open exchange of data and products. GEO is developing a "GEOPortal," a single Internet gateway to data. Developing countries can use GEONETCast, four communications satellites that transmit data to low-cost receiving stations. Potential users include decisionmakers in the public and private sectors, resource managers, planners, emergency responders, and scientists.

GCOS, GEO, CEOS, and GEOSS have made valuable contributions to improving our ability to monitor climate change, but they do not add up to a comprehensive approach for responding to climate challenges. In April 2009, the WMO released the Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004–2008.[12] The report concludes that while implementation of observation systems in support of the UNFCCC has progressed significantly over the last five years, "sustaining the funding of many important systems is fragile, there has been only limited progress in filling observing system gaps in developing countries, and there is still a long way to go to achieve a fully implemented global observing system for climate [p. ii]."

The future of the GCOS is important, given the lack of progress in other areas of global cooperation on climate issues. The UN negotiations in Copenhagen did not yield global agreement, and reaching global agreement (especially one that actually has any effect) will be a long, drawn-out process. In the interim, American leadership in creating an expanded multilateral system for sharing, analyzing, and operationalizing climate data will strengthen global understanding of climate issues and help build a collaborative approach and common understandings that will support future negotiation. Even if nations are unable to agree upon a coordinated approach to mitigation, the need to address climate change will still exist, and understanding the effect of inaction on the future course of climate change remains essential.

Operationalization—making the data and knowledge generated by satellites and science useful for policy and planning—is the real challenge for GCOS and its member states. Without a greater effort to operationalize climate data, the global effort on climate change will most likely fail, an outcome that is not in our national interest. Operationalization requires a new approach. The existing vehicles for international data sharing have been mainly aimed at the scientific community. As the provider of climate-related observations to support the activities of the UNFCCC and national governments, GCOS is the best multilateral entity to own these new responsibilities of managing and expanding the international climate knowledge base.

The GCOS mission should be expanded to include helping the international community and national governments to understand, organize, and prepare to respond to climate changes and to provide analytical capability to integrate climate change information to other priorities and initiatives (development, trade, security, etc.). GCOS could be the international provider of data and analysis for climate change, providing detailed assessment to support policymakers, particularly in less-developed countries that may currently lack the resources for aggregation and analysis. Expanding and energizing GEO would also help, as the premise of GEO is to ensure the availability of Earth observation data and knowledge worldwide.

12. Global Climate Observing Secretariat (GCOS), *Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC 2004–2008*, April 2009, http://www.wmo.ch/pages/prog/gcos/Publications/GCOSProgressReport_ReviewDraft_080409.pdf.

At a national and international level, many countries are preoccupied with how to ensure that decisionmakers and user communities have access to the types of information that will make the climate efforts successful. Efforts to improve coordination in Earth observation are paralleled and reinforced by the WMO's work to create a Global Framework for Climate Services (GFCS)—essentially a structure to connect research to policymakers. The September 2009 meeting of the World Climate Conference agreed to establish the GFCS to connect research to policymaking. The framework has four components: observation and monitoring; research and modeling; a climate services information system; and a "user-interface program." In combination, the climate services information system and the user interface program will constitute a "World Climate Service System."[13]

The goal of the new service will be to better inform decisionmakers (particularly in less-developed nations) by supplying data and analyses on climate change. The first organizational meeting was held in January 2010. When it is finally implemented, the World Climate Service System will provide climate and Earth observations, models, and forecasts to provide critical climate data to governments and other users around the world. This cooperative framework, when it is fully functional, will be an important step for "operationalizing" climate change.

Strengthening the National Response

On a national level, the United States is beginning a similar effort to better inform decisionmakers about climate change. U.S. climate change policy is based on three components: slowing the growth of emissions; strengthening science, technology, and institutions; and enhancing international cooperation. Climate change has been a priority for the Obama administration, and it now needs to be reinforced by organizational measures that, like the World Climate Service System, provide essential information to decisionmakers. Effective climate change policy requires the government to provide the user community with information on anticipated climate changes and the potential effect of any policies. Federal government, states, local communities, businesses, and individuals all require information to make decisions about how to respond to climate change.

The U.S. ability to provide this information is complicated by the fact that no single agency has both the mandate and requisite budget for providing ongoing climate observation, prediction, and services. Thirteen U.S. federal agencies are involved in climate change.[14] Coordination of the various climate management components of these agencies is the responsibility of the Office of Science and Technology Policy (OSTP), in partnership with the Office of Management and Budget. This ad hoc structure has grown up over time and is no longer adequate. Climate services are disparate and disconnected. Data collection is inadequate, and computational resources necessary for precise climate prediction are insufficient. A new organization to consolidate, analyze, and disseminate climate data would help overcome this problem. Fragmentation damages the effective use of the information that we currently collect.

Efforts to overcome this fragmentation date back more than two decades. In 1988, the Reagan administration created the Global Change Research Program (USGCRP) to coordinate interagency collaboration in research and observation for climate change. In 1990, the Global Change

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13. World Meteorological Organization, "Global Framework for Climate Services," November 3, 2009, http://www.wmo.int/pages/gfcs/index_en.html.

14. These agencies include USAID, DOA, DOC (NOAA+NIST), DOD, DOE, DOHH (NIH), DOS, DOT, DOI (USGS), EPA, NASA, NSF, and the Smithsonian Institution.

Research Act (GCRA) created the Global Change Research Program to increase understanding and share information on global environmental change. In 2001, the Bush administration created the Climate Change Research Initiative (CCRI) to accelerate research in climate change and reduce gaps in understanding. The USGCRP and CCRI were eventually merged into a single entity under the USGCRP name.

The next step is to create a National Climate Service, which would translate scientific data information to guide policy preparation to manage the effects of a changing climate. In February 2010, the Obama administration announced the creation of a NOAA Climate Service (NCS). NCS would draw on researchers and funding currently within NOAA's Office of Oceanic and Atmospheric Research, the National Weather Service, and NESDIS. This new service will bring together existing modeling, forecasting, and observation science currently spread through various branches of the NOAA and could eventually include regional centers to provide support for local governments and businesses.

NOAA's new National Climate Service is a good first step toward the operationalized approach we need. It begins the essential transition from climate research to operationally focused climate data and services. It could become the focal point for sharing the authoritative climate information Americans will need in a changing climate. But this effort needs congressional support and an accelerated schedule for full implementation.

A New Focus for Space Policy

Climate change poses a dilemma for space policy. If we accept that climate change poses credible and major risks to regional stability, national security, and economic health, the United States needs to reconsider how it spends its money for civil space. Earth observation data are critical to understanding the causes and effects of climate change and quantifying changing conditions in the environment. The shortage of satellites actually designed and in orbit to measure climate change is unacceptable if we are serious about climate change.

Until this year, U.S. space policy was on autopilot. The Bush space policy did not differ markedly from the space policy of Jimmy Carter. The hallmark of this period was heavy investment in the shuttle and space station. The commitment to these 1970s technologies eroded public interest in space. A science reporter for a national newspaper said that when he wrote on the unmanned Mars explorers, thousands of readers would look at the story on the newspaper's Web site, but when he wrote about the shuttle, there would be only a few hundred "hits."

The overlong commitment to the shuttle and the station ended in final years of the Bush administration, but unfortunately it was replaced with an unworkable vision for manned exploration that would have consumed a major portion of the space budget. In fact, a mission to Mars is beyond the technical capabilities of any nation. Leonardo da Vinci could draw helicopters and aircraft, but they were made of wood and cloth. Until breakthroughs in materials, chemistry, and physics, his ideas could not be implemented. The same is now true for manned planetary exploration. Our propulsion and life support systems will not support a manned flight to Mars.

In contrast, a return to the Moon is achievable. The dilemma is that NASA would need another $150 billion to return to the moon more than 40 years after the first visit. There is no doubt that a return to the moon would bring prestige to the United States and that if another nation such as China was to get there beforehand it will be interpreted as another sign of U.S. decline. Years of a static approach to space policy have put us in this uncomfortable situation. From the perspective of the national interest, however, the United States would be better served by building and maintaining a robust space capacity for monitoring climate change.

This is a question of priorities. Manned flight should remain a priority, but not the first priority. Earth observation data is critical to understanding the causes and effects of climate change and quantifying changing conditions in the environment. The paucity of satellites actually designed and in orbit to measure climate change is disturbing. The United States does not have a robust climate-monitoring infrastructure. In fact, the current infrastructure is in decline. Until that decline is reversed and an adequate space infrastructure put in place, building and launching satellites specifically designed for monitoring climate change should be the first priority for civil space spending. Manned spaceflight provides prestige, but Earth observation is crucial for security and economic well-being. The United States should continue to fund as a priority a more robust and adequate space infrastructure to measure climate change, building and orbiting satellites specifically designed to carry advanced sensors for such monitoring.

Satellites provide globally consistent observations and the means to make simultaneous observations of diverse measurements that are essential for climate studies. They supply high-accuracy global observations of the atmosphere, ocean, and land surface that cannot be acquired by any other method. Satellite instruments supply accurate measurements on a near-daily basis for long periods and across broad geographic regions. They can reveal global patterns that ground or air sensors would be unable to detect—as in the case of data from NASA satellites that showed us the amount of pollution arriving in North America from Asia as equal to 15 percent of local emissions of the United States and Canada. This sort of data is crucial to effective management of emissions—the United States, for example, could put in place regulations to decrease emissions and find them neutralized by pollution from other regions.[15] Satellites allow us to monitor the pattern of ice-sheet thickening and thinning. While Arctic ice once increased a few centimeters every year, it now melts at a rate of more than one meter annually. This knowledge would not exist without satellite laser altimetry from NASA's ICESat satellite.[16]

Satellite observations serve an indispensable role—they have provided unprecedented knowledge of inaccessible regions. Of the 44 essential climate variables (ECV) recognized as necessary to support the needs of the parties to the UNFCCC for the purposes of the Convention, 26 depend on satellite observations. But deployments of new and replacement satellites have not kept pace with the termination of older systems. Innovation and investment in Earth observation technology have failed to keep pace with global needs for monitoring and verification. Much of our data comes from satellites put in orbit for other purposes, such as weather prediction and monitoring. The sensors on these weather satellites provide valuable data, but they are not optimized for monitoring climate change or for adequately assessing the effect of mitigation efforts. More precise and specialized data are needed to understand and predict climate change, and getting these data will require new orbital sensors.

Countries have improved many of their climate observation capabilities, but reports suggest little progress in ensuring long-term continuity for several important observing systems. The bulk

15. Gretchen Cook-Anderson, "NASA Satellite Measures Pollution from East Asia to North America," National Aeronautics and Space Administration, March 17, 2008, http://www.nasa.gov/topics/earth/features/pollution_measure.html.

16. Robert Bindschadler, Testimony before the Subcommittee on Commerce, Justice, Science, and Related Agencies, House Committee on Appropriations, March 18, 2009, http://legislative.nasa.gov/hearings/2009%20hearings/3-18-09%20Bindschadler.pdf.

of climate data is collected by the United States, and NASA's investment in the Earth Observing System missions has provided the climate-quality data used to establish trends in sea level, ozone concentrations, ocean color, solar irradiance, Earth's energy balance, and other key variables. While this investment has made an invaluable contribution, it is not an operational system. Many satellites currently in orbit are operating well past their planned lifetimes. In the next eight years, half of the world's Earth observation satellites will be past their useful life. One reason for this is that many of the satellites that provide critical data for monitoring climate change are experimental satellites (such as TRMM—the Tropical Rainfall Measuring Mission). Satellites built as research efforts provide real benefit, but if they are not replaced when their service life ends and if a permanent operational capability for Earth observation is not put in place, we will face insurmountable problems for observing capabilities and our ability to manage climate change.

Many missions and observations for collecting climate data are at risk of interruption. These include measurements of ocean color that are critical for studying phytoplankton bloom and the role of ocean biomass as a carbon source and sink and data on the role of forests in the carbon cycle. Perhaps the most important shortcoming involves the monitoring of carbon dioxide (CO_2) emissions and greenhouse gases. Reduction and regulation of CO_2 emissions are part of every discussion on how to manage climate change, but the crash of NASA's Orbiting Carbon Observatory (OCO) satellite left the world essentially bereft of the ability to make precise measurements to assess emissions reduction efforts. OCO cost approximately $278 million,[17] which was about 2 percent of NASA's annual budget for manned space flight in 2009. Its loss will cripple global carbon monitoring until we have its replacement, finally funded this year and scheduled for launch no later than February 2013.

Existing GHG monitoring networks and programs are predominantly ground-based, but they are not truly adequate to the task. Ground-based networks are limited because they can only provide disjointed pieces of a larger picture. Moreover, these systems are aging, and investment for replacement has declined.

We now rely on Japan's GOSAT, the European Space Agency's SCIAMACHY sensor, and Canada's microsatellite, CanX-2, for observations of atmospheric concentrations of carbon; however, these sensors are not advanced enough to meet data requirements needed to understand critical aspects of the carbon cycle, and they are highly constrained by their range of coverage. For example, the carbon produced from a fossil fuel power plant is too small to measure with GOSAT, and low spatial resolution and high uncertainty of measurements limit the monitoring capabilities of SCIAMACHY.[18]

The implications are serious for measuring the effectiveness of climate policies. If reduction in GHG emissions (the most significant being carbon dioxide) is the centerpiece of mitigation efforts and a goal for both national legislation and international agreement, we are woefully unprepared to assess the effectiveness of these measures. It will be difficult to assess and adjust CO_2-reducing measures without greater investment in orbiting sensors.[19]

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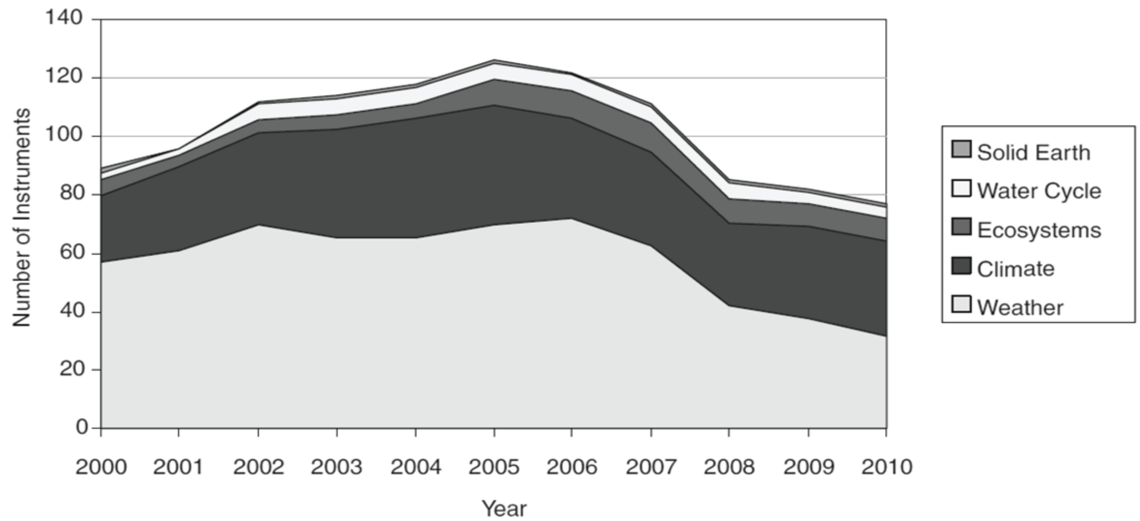
17. Eric Hand, "NASA ponders 'carbon copy' of crashed mission," *Nature* 458 (April 15, 2009): 814–815, http://oco.jpl.nasa.gov/news/index.cfm?FuseAction=ShowNews&NewsID=37.

18. JAXA launched their Greenhouse Gases Observing Satellite (GOSAT) in January 2009. The University of Toronto Institute for Aerospace Studies Space Flight Laboratory launched CanX-2 in April 2008.

19. Board on Atmospheric Sciences and Climate, Committee on Methods for Estimating Greenhouse Gas Emissions, "Letter Report on the Orbiting Carbon Observatory," National Research Council of the National Academies, 2009, http://www.nap.edu/catalog/12723.html, p. 2.

Figure 1. Number of U.S. Space-based Earth Observation Instruments in 2000–2010



Source: National Research Council of the National Academies, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (Washington, D.C.: The National Academies Press, 2007), 2007; http://www.nap.edu/catalog/11820.html.

The need for information has never been greater, but there are significant gaps in global Earth monitoring capabilities.[20] Although more than 50 nations operate or plan to operate Earth observation satellites, most of these are basic electro-optical satellites, essentially orbiting digital cameras that lack the necessary sensors for precise climate monitoring. There are only a handful of dedicated satellites for monitoring climate change, and the time has passed when general-purpose weather satellites can meet our informational needs. Japan, Europe, and the United States operate satellites with some of the sensors needed to monitor climate change, but a recent National Academies study found that of the 26 essential climate variables that can be monitored from space, we have coverage of only 16.[21] Only a coordinated federal policy and investment, including revised priorities for our civil space programs, can change this.

For most of the last decade, NASA was unable to replace its climate-monitoring satellites. Replacing these satellites is crucial to avoid a drastic decline in collecting the most valuable information for monitoring climate change. The Obama administration has proposed a budget for NASA's Earth science programs of $2.4 billion in new funding over the next five years, an increase of more than 60 percent. The new funding, which requires congressional approval, will help replace OCO and allow NASA to replace the twin GRACE satellites that make detailed measurements of Earth's gravity field that can provide important climate data.

The request for NOAA's budget for climate-related activities has been increased as well. NOAA will be spending $2.2 billion to maintain and further develop satellites and to support climate

20. National Research Council of the National Academies, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, Space Studies Board, Division of Engineering and Physical Sciences (Washington, D.C.: The National Academies Press, 2007).

21. Ibid.

Table 1. Existing Climate Satellites (International)

Mission	Type	Agency	Launch	Status
PARASOL	Climate	CNES	2004	Operational
SciSat	Climate	CSA	2004	Operational
Envisat	Climate	ESA	2002	Operational
Oceansat-2	Climate	ISRO	2009	Operational
GOSAT	Climate	JAXA	2009	Operational
ACRIMSAT	Climate	NASA	1999	Operational
Aura	Climate	NASA	2004	Operational
Cloudsat	Climate	NASA	2006	Operational
GRACE	Climate	NASA	2002	Operational
ICESat	Climate	NASA	2003	Operational
Jason-1	Climate	NASA	2001	Operational
Orbview-2/SeaWiFS	Climate	NASA	1997	Operational
QuikSCAT	Climate	NASA	1999	Operational
Terra	Climate	NASA	1999	Operational
TRMM	Climate	NASA	1997	Operational
CALIPSO	Climate	NASA/CNES	2005	Operational
Aqua	Climate	NASA/JAXA	2002	Operational
Jason-2/OSTM	Climate	NOAA/EUMETSAT	2008	Operational
Odin	Climate	SNSB/ESA	2001	Operational

Source: This table was compiled by reviewing the satellite inventories of national space agencies. For a list of the inventories consulted, please see appendix B.

research; $435 million has been requested to support the U.S. Global Change Research Program, with $77 million in new increases for core climate services and observations.

Spending on space has always been a question of priorities. Until recently, those priorities were frozen in time, reflecting political needs that were decades out of date. Our national priorities have changed. A new priority, reflecting the new challenges to our security and national interest, involves monitoring and understanding climate change. Debate over climate change is fierce and there are many skeptics, but the signs of major changes are undeniable. Warnings of catastrophe are likely overblown, but we do not fully understand the implications of climate change or the utility of various measures to mitigate it.

Climate change is occurring, and it creates new risks. In this context, the recent decision to scale back spending on human space flight and increase spending on Earth observation is a better match for national priorities and interests. It updates a space policy that has been badly out of date for years.

Observation of climate change began more than a century ago with simple measurements of the Earth's average temperature. These were interesting, but inadequate. The breakthrough in understanding climate change came with Earth observation satellites. Satellites provide global awareness in ways that other technologies cannot match. The monitoring needed for a serious effort requires observations that can only be done from space.

Recommendations

Climate change will have pervasive and unavoidable effects on economic and national security. Managing these consequences and mitigating them when possible are new and difficult tasks for governments. Progress in mitigating and adapting to climate change will require the world's countries to agree to coordinate their actions. Reaching such agreement will be no easy task. That said, climate change offers a unique opportunity for the United States to engage other nations in pursuing common interests and addressing future challenges. Not only is the United States well positioned to lead on this issue because of its significant space and scientific capacity, it also faces global expectations that it should shoulder the leadership burden for climate change. A commitment to building the space and information infrastructure needed to manage climate change could demonstrate the U.S. leadership, based on competence and advancing the global good, that the world respects and admires.

Operationalization is the next step for dealing with climate change—to make the data and knowledge generation by satellites and science easier to use in policymaking. Operationalization requires a new approach. Climate change has largely been an issue of science. The existing vehicles for international cooperation and data sharing are aimed at the scientific community. Effective global management of climate requires a new approach with three integrated elements—space, networks, and collaboration. Our belief is that a concerted effort to analyze and share data from the many national efforts could significantly advance our understanding of the risks and causes of climate change, better measure the effects of mitigation policies, and guide planning on how to adapt to changes in the environment.

Achieving such a concerted effort will require coordination must occur on several different levels if it is to have a meaningful effect. The first—the collection and measurement of relevant data—depends largely on satellites. Without the proper data, it would be very difficult to develop and aggregate a global picture of climate change and its nature and pace. It would be difficult to measure the effects of mitigation efforts, determine when or whether policies are effective, or predict when and how climate effects will affect local communities.

The second level is to expand the analysis and sharing of information. In some ways, we are only in the early stages of developing a global enterprise for assessing climate change. Much of the research and analysis conducted thus far has been focused on understanding the nature and pace of climate change, forecasting future changes in Earth's natural systems based on changes in different variables, and substantiating theories about how human efforts to reduce the effects of climate change might actually have some effect. More work is needed in each area to improve our understanding and update it as the natural environment continues to change.

Finally, data must move from the scientific community to the policy community—to governments and policymakers—if data are to guide change. While the UN's Intergovernmental Panel on Climate Change tailored analysis to meet policymakers' needs in the hopes of reaching a global consensus for action, the challenge today is to extend and strengthen connections between the science and policy communities.

A coordinated multinational effort to better inform the policy process can change this. Our belief is that a concerted effort to analyze and share data from the many national efforts could significantly advance our understanding of the risks and causes of climate change, better measure the effects of mitigation, and guide planning on adapting to changes in the environment. To this end, our recommendations follow:

The U.S. approach to climate change policy needs to inform decisionmakers and planners in both government and the private sector by providing understandable metrics and analyses of the effectiveness of, and compliance with, mitigation programs and adaption plans. The customers for this should include federal agencies, state and local governments, private sector users, and other nations.

To better serve the national interest, the United States should increase its Earth observation capabilities—especially space-based sensors for carbon monitoring—to improve our ability to understand the carbon cycle and to inform any future international agreement. This means that until these capabilities are adequate for monitoring climate change, investment in Earth observation satellites should take precedence over other space programs. Increased spending on earth observation satellites specifically designed for climate change should be maintained until the current capability shortfall is eliminated.

The United States should accelerate, expand, and reinforce a National Climate Service to improve climate information management and decisionmaking. In a related effort, the United States should support the World Meteorological Organization in its efforts to create a World Climate Service System.

The United States should complement its national effort by supporting and expanding multilateral efforts to coordinate Earth observation for climate change, building on existing international efforts such as GCOS. This could entail coordinated investment in space and, subsidies for ground facilities in developing countries, recognizing that the United States, EU, Japan, and Canada will bear the largest share of the cost at this time.

APPENDIX A
ELEMENTS OF CLIMATE CHANGE

In 2007, the Intergovernmental Panel on Climate Change, or IPCC, a scientific group created by the United Nations in 1988 to evaluate climate change, released its Fourth Assessment Report on climate change. The report reflected scientific consensus that climate change is the result of increased levels of greenhouse gases in Earth's atmosphere and that these increased emissions are primarily the product of the burning of fossil fuels for energy (coal, oil, and natural gas) and practices in agriculture, land use, and forestry. Roughly three quarters of emissions come from burning fossil fuels for energy and the rest from deforestation and land use.

The accumulation of greenhouse gases above normal levels started with the industrial revolution and has already had appreciable effects on Earth's climate. Some of the observed effects of a warming Earth over the last century include more rainfall over land masses as well as increased drought in already arid areas, shorter winters and melting glaciers, stronger storms, particularly in the North Atlantic, and rising sea levels.

Climate change has the potential to weaken already unstable areas. The number of climate-related refugees could increase dramatically. Tensions within and between countries over resources or the perceived cause of emissions and climate change could intensify. Climate-related instability would likely affect the global economy. Poor countries or those with weak governments will have a harder time dealing with these effects. Wealthier countries may be more able to adapt, but will still face strains in dealing with the effects of climate change.

The IPCC suggested that by dramatically reducing greenhouse gas emissions, society can avoid the most dramatic effects of a changing climate. An effective strategy for dealing with climate change involves three pillars: mitigation to avoid the worst projected outcomes of a changing climate, adaptation to cope with the unavoidable effects, and a commitment to science and observation to bolster our ability to understand, mitigate and adapt.

Mitigation includes any purposeful efforts to reduce greenhouse gas emission or enhance greenhouse gas "capture." While no global goal has been agreed upon, the general consensus is to reach agreement on policies that will reduce the overall accumulation of greenhouse gases in the Earth's atmosphere in time to slow the pace and magnitude of changes in the global climate and avoid irreversible changes to the Earth's natural systems.

The most commonly cited goal is to limit global temperature rise to 2 degrees above pre-industrial temperatures. This would require society to reduce emissions approximately 50 percent to 80 percent by the year 2050. Scientists and policymakers believe this target is now less achievable due to a lack of global progress on reducing emissions and improved scientific understanding about the pace of climate change. However, countries still agree that reducing emissions to stabilize the Earth's atmosphere is the ultimate objective. Emission reductions can come from better land-use and forestry practices, increased energy efficiency, energy conservation, sequestration of CO_2, or using low or no carbon sources of energy.

Mitigation activities are widely expected to reduce economic growth, something that no government is eager to embrace. The economics of mitigation only look promising if the estimated costs of a changing climate are taken into account. Global negotiations on climate change were guided by the principle of "common but differentiated" standards for action, a formula that may now be intrinsically unworkable. Developed countries are responsible for the vast majority of emissions currently accumulated in the atmosphere because of industrialization. Developing countries believe it is the responsibility of developed countries to reduce emissions and bear the burden of remedying the situation. The unfortunate reality, however, is that emissions growth going forward comes from rapidly emerging developing economies, most notably China and India. While the largest of these countries have agreed to slow the pace of emissions, the bulk of the developing world still looks to receive support (financing, technology, capacity building) for emissions reduction or adaptation measures, in addition to a show of leadership-by-example through aggressive emissions reductions by developed countries.

Adaptation refers to the social and economic changes taken in response to climate effects. In the broadest terms, adaptation can be planned (purposely set in motion to deal with expected or observed changes) or autonomous (happen in a less coordinated fashion in reaction to climate changes). Adaptation efforts generally reduce vulnerabilities or increase resilience.

Adaptation is often thought of as an alternative to mitigation (i.e., if climate change cannot be slowed or avoided then society must adapt). In reality, adaptation and mitigation are both vitally important elements of a successful climate strategy. Climate models that forecast the potential effects of unabated climate change suggest that human capacity to adjust to a changing natural environment can be overcome by the pace and magnitude of those changes. At the same time, even the most aggressive mitigation strategy cannot shield society from the ongoing and expected climate changes due to historical emissions accumulated in the atmosphere. For many parts of the world, particularly lesser-developed countries, adaptation strategies are crucial for survival and continued stability.

Like mitigation, adaptation requires time, money, and planning. It also requires communities to weigh the benefits and the costs of specific adaptation measures, a difficult task made even more complicated by uncertainty regarding the timing and magnitude of climate change. Communities must balance planning for high impact, low probability events with planning for low impact, high probability trends. In addition, economic, technological, cultural, and information barriers to adaptation often challenge even the most conscientious efforts to improve resiliency and lower vulnerability.

There are significant challenges in going from predictions of how the climate may change to the effects these changes may have on water, resources, or human health. Meeting this challenge requires boosting adaptation research; bolstering capacity to monitor change and its effects; producing the sorts of integrated assessment on the pace, patterns, and regional effects of climate change that will be needed by decisionmakers and providing metrics and goals for both mitigation and adaptation; and making climate data and information accessible to those who need it.

APPENDIX B

INVENTORIES CONSULTED IN A REVIEW OF EXISTING CLIMATE SATELLITES (INTERNATIONAL)

ASI	http://www.asi.it/en/activity/earth_observation
BNSC	http://www.bnsc.gov.uk/
CAST	http://en.cast.cn/CastEn/Show.asp?ArticleID=30801
CAST HJ-1 Series	http://en.cast.cn/CastEn/Show.asp?ArticleID=30801
CBERS	http://www.cbers.inpe.br/?hl=en
CEOS EO Handbook	http://database.eohandbook.com/database/missiontable.aspx
CNES	http://www.cnes.fr/web/CNES-en/461-cnes-programmes-alphabetical-index.php
CONAE	http://www.conae.gov.ar/eng/satelites/satelites.html
CSA	http://www.asc-csa.gc.ca/eng/default.asp
DLR	http://www.dlr.de/en/desktopdefault.aspx/
EO Portal	http://directory.eoportal.org/missions_calendar.php
ESA	http://www.esa.int/esaEO/index.html
GISTDA	http://new.gistda.or.th/en/
ILRS	http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/index.html
INPE	http://www.inpe.br/ingles/index.php
ISRO	http://www.isro.org/satellites/earthobservationsatellites.aspx
ISRO Future Programs	http://www.isro.org/scripts/futureprogramme.aspx
JAXA	http://www.jaxa.jp/projects/sat/index_e.html
JAXA Earth-CARE	http://www.jaxa.jp/article/special/eco/kimura_e.html
JMA	http://www.jma.go.jp/jma/jma-eng/satellite/index.html
Landsat	http://landsat.usgs.gov/about_mission_history.php
NASA	http://eospso.gsfc.nasa.gov/eos_homepage/mission_profiles/mission_search.php
NASA Science	http://nasascience.nasa.gov/earth-science/mission_list
NOAA	http://www.ngdc.noaa.gov/dmsp/index.html
NOAA GEOS	http://www.oso.noaa.gov/goesstatus/
NPOESS	http://www.ipo.noaa.gov/index.php
NRSCC	http://www.nrscc.gov.cn/english/about-mj1.asp

NRSCC Presentation	http://www.geosec.org/documents/cop/ag_gams/200707_01/eo_satellite_systems_initiatives_china.pdf
NSAU	http://www.nkau.gov.ua/nsau/newsnsau.nsf/HronolE/FB2A22693196D325C2257611005C0913?OpenDocument&Lang=E
Orbital	http://www.orbital.com/SatellitesSpace/ImagingDefense/OV2/index.shtml
RADARSAT-2	http://www.radarsat2.info/about/faq/faq_sat.asp
Russian Space Web	http://www.russianspaceweb.com/spacecraft.html
Russian Space Web Future Missions	http://www.russianspaceweb.com/2010.html
Russian Space Web site	http://sputnik1.infospace.ru/
Waterloo University	http://www.ace.uwaterloo.ca/index.html

Note: See table 1 on page 12.

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