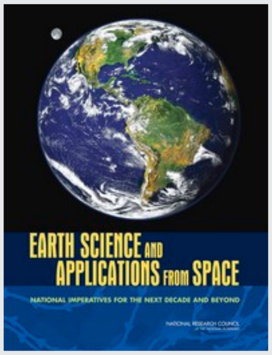

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

DETAILS

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Part III

Reports from the Decadal Survey Panels

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Earth Science Applications and Societal Benefits

Increasing the societal benefits of Earth science research is high on the priority list of federal science agencies and policy makers, who have long believed that the role of scientific research is not only to expand knowledge but also to improve people's lives. Although promoting societal benefits and applications from basic research has been emphasized in national science policy discussions for decades, policy and decision makers at federal, state, and local levels also increasingly recognize the value of evidence-based policy making, which draws on scientific findings and understandings.

The theme of this chapter is the urgency of developing useful applications and enhancing benefits to society from the nation's investment in Earth science research. Accomplishing this objective requires an understanding of the entire research-to-applications chain, which includes generating scientific observations, conducting research, transforming the results into useful information, and distributing the information in a form that meets the requirements of both public and private sector managers, decision makers, policy makers, and the public at large (NRC, 2001, 2003). There are a number of remarkable successes in reaping the benefits of Earth science research. For example, Chapter 11 documents that many nations of the developed world have created sophisticated flood forecast systems that use precipitation gauges and radars, river stage monitoring, and weather prediction models to create warnings of floods from hours to several days in advance. However, there is no global capacity to do this, and developing nations are largely without this capability.

In many cases these successes have evolved largely through serendipitous opportunities for research applications rather than through a systematic, coordinated process. As a response to this concern, the Panel on Earth Science Applications and Societal Benefits offers observations on how to move from discovery to design, balance mission portfolios to benefit both research and applications, and establish mechanisms for including the priorities of the applications community in space-based measurements.

HOW DO WE PROGRESS FROM SERENDIPITY TO DESIGN?

Several factors limit how we can advance the application of Earth science research and observations in the public and private sectors, including (1) inexperience in identifying the requirements of applied users of the data and information, (2) limited knowledge of how managers, policy and decision makers, and the public obtain and use data and information, and (3) the capacity of institutions and organizations to apply new types of data and information to traditional and ongoing processes and ways of doing business.

Earth science can contribute to societal benefits and more effective decision making in multiple ways. It provides information that can be used to identify emerging problems, trends, and changes. In addition, research and observations permit managers, analysts, and decision makers to monitor ongoing phenomena. These resources can also be used to forecast and project future trends, and by so doing, permit managers, policy makers, and decision makers to anticipate problems so that they can be addressed at an early stage. Scientific data and observations also permit those who inform decision makers to test and evaluate scenarios of possible future outcomes. The challenge is to make the scientific information relevant, available, adaptable, and easy to use so that informed and knowledgeable choices can be made.

If Earth scientists are to foster applications and extend the societal benefits of their work, they must understand the research-to-applications chain, which includes understanding societal information needs, conducting research on the uses of information, generating relevant scientific observations, transforming the results into useful information, and distributing that information in a form that is understandable and meets the needs of both public- and private-sector managers, decision makers, and policy makers (NRC, 2001, 2003).

Identifying Users' Requirements

Earth science information can confer tangible and measurable benefits in myriad applications in addition to those identified in Chapters 1 and 2. For instance, some highly detailed studies of the value of Earth science information seek to characterize how it is used and then quantify its benefits in various industrial sectors of the economy. These studies typically (although not exclusively) conduct empirical estimations in which benefits are defined and measured in terms of increases in output or productivity in the relevant economic sector (a detailed review of these studies is in Macauley, 2006). Examples include studies of the value of Earth science information for forecasting crop size and health (Bradford and Kelejian, 1977), geomagnetic storms and their impact on the electric power industry (Teisberg and Weiher, 2000), the markets for agricultural commodities (Roll, 1984) and raisins (Lave, 1963), the economic damage from deforestation (Pfaff, 1999), and means of reducing the social risks and costs of natural disasters (Williamson et al., 2002).

At a more fundamental level, in the application of Earth science information, it is essential to know more about patterns of information seeking and information use both inside and outside the scientific community. This will involve research on where the primary information consumers in an organization are located and how they relate to those who have the power to set agendas and make policy decisions. It will also involve identifying both routine management information needs and policy-making information needs. Finally, it will require that scientists understand the functions and patterns of agenda setting in both organizations and society. A multidisciplinary research approach, linking natural and social scientists in studies of organizations and of the interactions among scientists, data, and decision makers, will provide needed insights. Both NOAA and NASA have periodically supported research of this type, focused on communication and the utility of scientific information for nontraditional users of Earth science observations.

The successful involvement of scientific and operational agencies in this process can be examined through research that focuses on how applications have been developed most usefully in the past and transmitted into operational domains. As earlier chapters in this report emphasize, weather and climate prediction offers several examples of success in transitioning from research to operations. The satellite era began in the late 1950s with the launch of Sputnik and recognition of the potential for observation of Earth.

In the early 1960s, the major challenge was to learn to use scientific research and observations to improve weather forecasting and extend the valid period to a few days.

The Global Atmospheric Research Program was launched in 1974 as an initial step toward a global weather experiment, using a mix of geostationary and polar-orbiting satellites, ground- and ocean-based measurements, and computer processing in combination to yield input for scientific analysis. The experiment was conducted in 1979-1980 as a global initiative, and global weather forecasting has since continued to improve markedly. The transition from science and related technologies to operational benefits took place because a clear objective was envisioned, and societal value and benefits were recognized in advance. The scientific program went forward with the full participation of the operational agencies, which were integral parts of the scientific team.

Another example of a successful transition from research to operations can be seen in the measuring of the interannual variability of the tropical ocean-atmosphere system. The El Niño events of the 1970s and early 1980s led to the design and implementation of the Tropical Ocean-Global Atmosphere Program in 1985 as a 10-year focused research program. The observing system of ocean arrays and satellites was transitioned to operational support in the 1990s. The benefits of being able to predict the occurrence of El Niño and its impacts and to develop effective response strategies that reduced the impacts had become evident. There was strong national and international pressure to maintain that capability.

Evident in both examples are an identified public benefit and the involvement from the beginning of clear operational partners, mainly the national weather services, that also had well-established links with the user community. National and international support and leadership were strong. Those examples demonstrate that recognition of the need for an operational organization that has a close relationship with the user community is essential to developing applications that can deliver lasting benefits.

An example of the difficulty of achieving that linkage can be seen in efforts to develop the capacity for forecasting the physical state of the open oceans. Although weather forecasting and the need for global information to make it effective for national interests are both well established, the case for open-ocean prediction is not as clear. Progress is being made, but the transition of the research results from, for example, the World Ocean Circulation Experiment to an operational ocean-prediction system, delivering information to a broad base of public users, has been slower.

The lesson is that without sustained institutional support for interactions between the producers and the users of scientific information, there is a risk that even successful examples of the applications of Earth science will become one-of-a-kind experiments that are not repeated. Of the examples discussed, only those involving meeting weather-forecasting needs had institutional mechanisms designed specifically to foster two-way interactions. In the other cases, the two-way interactions occurred early in program development through the activities of principal investigators, but there was no clear institutional mechanism to ensure that improvements in observations and methods or changes in applications needs would receive appropriate attention.

In sum, success in using Earth science data for applications of benefit to society will require research as well as data. Such research will improve understanding of successful transitions from research data to societal applications, processes of information adoption and use outside the scientific community, and decision making under uncertainty. Success in applying the results of Earth science will also require sustained communications with potential users of scientific information.

Ensuring Access to Data

Given the breadth of responsibilities of public and private managers and decision makers, potential application of Earth science information will depend on having easy access to data that are accurate and affordable (NRC, 2003).[1] Many of the decision makers and other interested parties who need access to Earth science observations and information to address important environmental issues are unlikely to be highly trained Earth science researchers. Nonscientists must have a convenient and intuitive means of access to Earth science data and observations that are relevant to the problems they are addressing.

Improving data availability and accessibility should include establishing and adopting standardized data-management practices that foster use and can be understood by nonscientific users. Elements of data access and management that need to be addressed include the following:

- The management of Earth observations for operational applications and societal benefit begins with credible, professionally managed data records. The high rate of innovation in both information-management technologies and observational technologies means that data management must be given high priority by scientists and funding agencies to avoid loss of the data in the future. This involves the use of community-accepted metadata standards, repeated integrity checks of the data, and regular upgrades of data-management hardware and software. For a discussion of this issue, see a 2004 report by the International Council for Science (ICSU, 2004).
- Potential application developers will need some combination of baseline, status, and trend information. In general, applied users of Earth science data will find repeated observations of the same phenomena to be more useful than data for a single point in time. Baseline data, however, can play a role in diagnostic analyses.
- Permanent data archiving and dissemination centers will be needed. Such centers will provide access to the data and be a critical source of people who have experience in the use of the data and can provide advice and counsel for new applications. It will be necessary to provide continuing institutional support for data management and archiving. Moreover, because the value of the data increases over time, the cost of providing these facilities needs to be guaranteed over long periods.
- Finally, there will be a continuing need for education or training of new users of the data on how to obtain data, what they mean, and how to use them. New generations of applications will be created by people who need instruction in how to use Earth science data. And new generations of decision makers will need to be educated about the societal benefits of Earth science data. Providing information about the data and training in their use will be a continuing educational process that cannot be neglected.

The panel emphasizes that a commitment to effective data management that meets the requirements of both scientific and nonscientific users of Earth observation data and information is critical for advancing the development of applications that benefit society.

Enhancing Applications Capability

The opportunities and challenges of using Earth observation data for practical applications were addressed in a set of three NRC reports issued during 2001-2003. One, *Transforming Remote Sensing Data into Information and Applications*, emphasized the failure to fund development of applications and the lack of recognition accorded by researchers and the journals in which they publish to the development of applications (NRC, 2001). The lack of financial and professional incentives to pursue and develop applications will limit the involvement of many scientists and could make it very difficult to realize societal

[1]An early example of providing public access to scientific data for policy and decision making was an effort initiated by President Herbert Hoover that eventually was published as a 1,700-page volume, *Recent Social Trends in the United States* (President's Research Committee on Social Trends, 1933), during the Roosevelt administration. Unfortunately, the effort was not repeated, and its impact was limited.

benefits from the Earth sciences. It is therefore important that there be an appropriate level of funding for applications, including public-sector applications at all levels of government, private-sector applications, and not-for-profit or nongovernment applications. It is also essential that professional recognition of the value of advancing societal benefits be part of the decadal vision and its implementation.

The ability to take advantage of new sources of Earth science data for societal benefits depends on cultivating broad institutional and organizational capacity among potential application users. *Using Remote Sensing in State and Local Government: Information for Management and Decision Making* (NRC, 2003) pointed out that the use of remote-sensing data to address problems faced by state and local governments depends on the often ignored factors of institutional leadership and budgetary, procedural, and even personnel issues.

Supporting an Informed Citizenry

A continuing benefit of the nation's investment in the Earth sciences is the potential for improving the communication of Earth science results and teaching of these fields in the formal educational curriculum. The Earth and space sciences have a central role to play in creating an informed and scientifically literate citizenry, particularly with regard to natural hazards, resource use, and environmental change. Satellite imagery and visualization technology and tools have revolutionized how we view Earth, its systems and processes, and the relationships between people and the natural environment. In addition, the synoptic view of Earth available through remote sensing images transcends political boundaries and enhances students' understanding of the planet. Used as teaching tools, satellite information and visualization can help learners of all ages to develop more effective skills in critical thinking and problem solving and can contribute to a better-educated workforce.

Fully realizing societal benefits of Earth observation data and information requires enhancing understanding among applications users and cultivating appropriate institutional and educational capabilities in organizations that are potential users of applications, and among the agencies that produce the underlying data and supporting science. There is also a need to devise professional rewards for those who develop and sustain applications and societal benefits.

BALANCING THE MISSION PORTFOLIO TO BENEFIT BOTH RESEARCH AND APPLICATIONS

As this report emphasizes, benefits of the Earth sciences accrue both from gains in scientific research and from the application of scientific information in decision making. However, the measurement needs for particular research topics and related applications have the potential to differ significantly. For example, consider the state of measurements in land remote sensing, as summarized in Chapter 7. The importance of the Landsat-class measurements in establishing a long-term baseline of land-cover measurements cannot be overstated. The sequence of instruments from the Multispectral Scanner (MSS) to the Thematic Mapper (TM) to the Enhanced Thematic Mapper + (ETM+) has provided the longest, best-calibrated time series of any biophysical time series of Earth—observations that are clearly essential for research, applications, and operational uses. However, newer measurements of Earth's land cover typically fall into one of three different dimensions—higher-spectral-resolution measurements of surface reflectance with high temporal resolution (MODIS and VIIRS), hyperspectral-resolution imaging (as proposed in Chapter 7), or the very high spatial resolution imagery of the private sector's missions, such as QuickBird, familiar around the world now to users of Microsoft Virtual Earth or Google Earth. Although each category of mission measures fundamental properties of Earth's land cover, each optimizes its measurements differently according to the needs of the dominant user communities. As a result, they cannot, for the most part, be substituted for each other, but instead complement each other.

An overall Earth science strategy that merges scientific research and societal application must acknowledge that different research and operational applications will require different approaches to measurement, and provide a means of optimizing potential benefits against available resources for the total observing system. The desired means would involve defining the specific research and application goals of a potential measurement, evaluating the degree to which existing or proposed measurements support those goals, and developing an optimal implementation strategy that balances overall cost with fulfillment of the requirements.

The design of space-based measurements that are tailored for particular applications is an important first step in achieving societal benefits. Developing the requirements for a given application involves better understanding of the scientific issues and the decision-making context within which the targeted measurements play a role. The panel recommends that development of future Earth science mission strategy include social science research into the key drivers of measurement needs for societal decision making.

Extracting societal benefit from space-based measurements requires, as an equally important second step, the development of a strong linkage between the measurements and the decision makers who will use them. This linkage must be created and sustained throughout the life cycle of the space mission. In implementing future missions, scientists engaged in research intended to make both scientific and societal contributions must operate differently than they did when the advancement of science was the primary or only goal of research. Applications development places new responsibilities on agencies to balance applications demands with scientific priorities. The character of missions may change in significant ways if societal needs are given equal priority with scientific needs. For example, scientists interested in measurements of the solid Earth that are relevant to issues associated with protection from or early warning of geological hazards, as emphasized in Chapter 8, should work directly with the natural hazards community to ensure that the measurements and data management systems that they propose are indeed useful for protecting property and lives, as well as for scientific discovery. Box 5.1 lists guidelines that, if routinely incorporated into mission planning, would foster such a balance between research and applications. Box 5.2 lists a series of questions that should be considered as part of any mission planning activity. They emphasize the end-to-end nature of applying Earth science observations to important societal issues.

The potential societal benefit of a measurement will depend in large part on how well these issues have been understood and addressed in a mission proposal, its evaluation, and the implementation of the mission.

BOX 5.1 GUIDELINES FOR MISSION PLANNING TO BALANCE SCIENCE AND APPLICATIONS

- Processes to move from observations to information should be identified in the initial planning of new missions.
- Mission planning should consider performance requirements for applications, such as timeliness of and capacity for data integration.
- Planning should consider the need for ancillary data and should ensure that ancillary data are available when needed.
- Planning and implementation priorities should include the need to link the data to models and decision-support tools and processes.
- Planning should provide effective lines of communication between decision makers and data gatherers.

BOX 5.2 QUESTIONS FOR PLANNERS TO USE IN INCORPORATING APPLICATIONS WHEN SETTING PRIORITIES FOR MISSION SELECTION

- What is the immediate need? What is the projected need?
- Has an analysis of benefits been done? Who are the beneficiaries? How does information from measurements reach them?
- What alternative sources of information exist for the application? In situ sources? Foreign sources? Is the proposed measurement or mission a demonstrable improvement?
- To what degree does the measurement need to be operational or continuous? Can it be a periodic or a one-time measurement?
- What are the requirements for timeliness in delivery of products?
- What are the means for funneling data to decision makers, either directly or indirectly through data brokers (for example, the Weather channel) or interpreters (such as nongovernmental organizations)? What is the commitment on their part to use the data?
- What are the necessary ancillary data? How are they to be made available?
- Are necessary simulation, analytic, or visualization tools in place?
- What is the weakest link in the chain from measurement to use?
- What are the risks if the measurement is not made?

ESTABLISHING MECHANISMS FOR INCLUDING PRIORITIES OF THE APPLICATIONS COMMUNITY IN SPACE-BASED MEASUREMENTS

All the examples in the sections above demonstrate that societal benefits can be achieved by the use of satellite observations, even if the benefits are not well quantified. But only in a very few cases is there a process for ensuring that user communities can introduce their requirements into federal agency planning cycles as agencies decide how to improve or plan their observational capabilities. A formal feedback loop is often missing. In particular, applications communities that are newly developing or that lack institutional structure of the kind in place, for example, in the weather-forecasting community are left with ad hoc processes for influencing agencies' plans for new or improved observations. For example, new measurements for applications in weather forecasting can be evaluated within the existing structures of NASA and NOAA because those agencies have for the most part worked out the processes by which the importance of such measurements can be evaluated, notwithstanding the known difficulties of transitioning new measurements to operations. However, new measurements for land cover, geological hazards, or water resources, to mention just a few applications areas, do not have the benefit of existing relationships between client agencies and the space agencies that would lead naturally to evaluation of their potential for applications. New measurements that would be relevant to such critical issues as deforestation and the loss of biological diversity or interruption of ecosystem services essentially have no client agency, and so individual university researchers or staff in nongovernmental organizations must be relied on to lobby the space agencies, without benefit of strong institutional ties to those agencies.

The space agencies must also incorporate new private partners in their efforts to strengthen the science and applications of Earth observations. The rise of the private sector in using imagery or other remotely sensed data of all kinds in a variety of marketed applications is a relatively recent phenomenon, compared with the history of the U.S. space program. But the commercial success and popularity of such endeavors as Google Earth and Microsoft Virtual Earth point to the fact that there are large and essentially untapped markets of private users for Earth observations, as well as users among the scientific and public institutions. The remote-sensing community is now seeing, for the first time, the private sector performing both essential data acquisition (e.g., hyperspatial-resolution imagery) and essential data applications (e.g., Google Earth and other mapping and geospatial information services) tasks, essentially without governmental intervention. Yet even these endeavors cannot hope to maintain the levels of investment in R&D necessary to sustain progress in overall understanding of the evolving dynamics of the Earth system.

SUMMARY

The panel is certainly aware that it is raising new challenges for research and operations in the Earth sciences, and that existing models for how these might be implemented are scarce. The processes that would lead to a successful research program that emphasizes both scientific discovery and benefits to society need to be strengthened. In addition, agencies implementing missions will require a research and development system that can enable the large capital investment in space hardware and data management needed to fulfill stated intentions for applications with social benefit. Agencies will also have to ensure that the missions they sponsor and the associated research have the longevity to enable learning by their user communities; likewise, it is important that they learn to listen to the needs and desires of new user communities and ensure that both stakeholder and advisory processes are in place to enable sufficient feedback for the benefit of both users and data providers.

Because no one space agency or its partners can hope to encompass the full range of the measurements-to-applications chain, interagency coordination will certainly be required to enable a larger effort that can exceed the sum of its parts in fully realizing benefits. Interactions that are difficult to foresee now among staff with different backgrounds and training will demand new interdisciplinary relationships. Agencies will have to build new evaluation processes and incentives into their research programs to ensure that sufficient attention is paid to the importance of societal benefits (see Box 5.1). These issues are consistent with issues identified in many earlier NRC reports that emphasize the interdisciplinary challenges of developing Earth system science.

Systems of program review and evaluation will also need to be revamped to realize the vision of concurrently delivering societal benefits and scientific discovery. Numbers of published papers, entries in scientific citation indexes, or even the professional acclamation of scientific peers will not suffice to evaluate the success of the missions proposed for the decade ahead. The degree to which human welfare has been improved, the enhancement of public understanding of and appreciation for human interaction with and impacts on Earth processes, and the effectiveness of protecting property and saving lives will also become important criteria for a successful Earth science and observation program.

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