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Earth Science Remote Sensing Data

Contributions to Natural Resources Policymaking

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Abstract

This paper traces the evolution of space-derived remote sensing data and data products from their initial dissemination to their impact on public policy related to climate change. We focus on the examples of renewable energy, public health, and ecosystem assessment. Our approach differs from previous studies that have characterized the value of data in terms of the fundamental scientific phenomena they describe. In our research we have sought to identify contributions of space-derived earth science in “making a difference” beyond scientific understanding, thereby providing at least a partial answer to questions about the utility of research posed by Congress, the Office of Management and Budget, managers at the National Aeronautics and Space Administration, and other decisionmakers.

Key Words: Natural resources, climate change, space, data

JEL Classification Numbers: Q2, O38

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Introduction and Background

Earth science data collected from the unique vantage point of space range from measurements of the earth's water cycle and radiation budget to observations about air quality, land elevation, and vegetation. Some 73 earth science satellites currently operate under national and regional government auspices or under commercial ownership. In 2005, the U.S. National Aeronautics and Space Administration (NASA) alone was flying some 80 instruments on 18 spacecraft. These instruments use remote sensing technologies that include scatterometers, multispectral and hyperspectral imagers, polarimetric and sounding radiometers, radar and laser altimeters, sounding lidar and radar, and synthetic aperture radar (NASA 2003). The instruments provide more than 1,800 science data products for study of physical, geophysical, biochemical, and other parameters.

The value of these data traditionally has been assessed in terms of their contribution to theoretical and observational scientific understanding and measurement of earth processes, the relationships among those processes, and how they may be changing over time. The processes include, for example, the workings of physical parameters of the atmosphere, biosphere, land, oceans, and solid earth; global temperature gravity fields; and the extent and nature of anthropogenic and natural changes in climate. In addition to these research themes, some earth-observation data products have long been used for more directly applied purposes. Notable examples are routine use of remote sensing data for geologic exploration, crop monitoring, weather monitoring and prediction, and ship routing.

Impelled in part by the National Performance Review of 1993 and the Government Performance and Results Act of the same year, and continuing to the present under the 2002 President's Management Agenda, NASA has been exploring the role of earth science data in serving society—specifically, in providing information useful in making public policy. To be fully responsive to these mandates, NASA's focus on public policy was intentionally distinguished from exclusively scientific study and from using data products for routine or operational management of natural resources. It was also distinguished from a small number of

previous studies that sought to monetize the value of earth science by estimating, for example, the savings to various industries (electric utilities, commercial aviation) enabled by earth science.

In initiating its study of the link between data and policy, NASA set forth a conceptual framework in the form of a flow chart (Figure 1). The flow from the collection of earth observations to their use as a source of information for policy begins when data are put into technical models about land, the atmosphere, and the oceans. These models lead in turn to predictions and observations to inform “decision support tools”—typically computer-based models used to assess phenomena such as resource supply, the status of real-time events (such as forest fires and flooding), and relationships between environmental conditions and other scientific metrics (such as water-borne disease vectors and epidemiological data). Most decision tools are operated by other agencies at the national, state, or local level or in international institutions. Examples include the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy, and offices that support the United Nations. These tools, or models, are part of larger decision-support systems that include not just computer tools but the institutional, managerial, and financial decisions involved in managing resources. The ultimate outcomes of the flow of information are policy decisions affecting local, state, regional, national, and even international affairs. Of course, not all—or, as some critical observers might argue, few—policy decisions are based on data and models. But among decisions that are influenced by such information, the flow chart in Figure 1 characterizes a systematic approach for connecting science to policy.

Since its initial formulation at NASA, this framework for describing the relationship between science data and public policy decisions has been widely adopted. One example of adoption in the United States is in the Climate Change Science and Climate Change Technology program strategies, both established in 2002 as part of a cabinet-level structure to oversee public investment in science and technology related to climate change. Another example is adoption in the Framework Document for the Earth Observation Summit, an international plan for coordination of the world’s earth observation networks requested by the G-8 Heads of State meeting in Evian, France, in 2003. In both of these examples, the architecture of Figure 1 well illustrates the path between the collection of earth-observation data and decisionmaking (Subcommittee on Global Change Research 2003; Group on Earth Observation 2004; Birk 2005; Macauley 2005).

In late 2002, using this framework, NASA began an evaluation of the contribution of earth science data to policy decisions about climate change. NASA asked experts outside the

agency to identify examples of decision-support tools that are using or could use NASA's earth science and technology research results to enhance national decisionmaking processes with national or international significance. The specific focus in the project reported in this paper was to identify policy decision support tools related to climate change.¹ Several characteristics of the policy process for climate change initiatives significantly complicate the analysis. One is that at present, no national climate change policy yet exists, beyond a significant research effort to further scientific understanding.² At the same time, a collection of other policy decisions about energy, water, land use, environmental regulation, and human and ecosystem health influence climate and its effects. NASA itself affirms that it is not a policymaking agency but has, as one of its objectives, that its earth science data products should be developed to serve research to improve understanding, monitor change, and forecast earth processes in static and dynamic contexts.

Another challenge in connecting science and policy is the complexity introduced by interactions and feedback among climate-related physical and economic microsystems. For instance, in the case of energy, the economics of renewable energy resources—as well as the implications of those economics for fossil fuel use and greenhouse gas emissions, oil independence and national security, power supply and reliability, changes in heating and cooling demand, and patterns of transportation demand and supply—come into play. In the case of human health, heat stress, cold-weather afflictions, changes in fertility due to stress, and the spatial and temporal ranges of infectious diseases all play roles. Among the interactions in the case of water are quality, quantity, and distribution; the development of coastal wetlands; sea-level changes; and many other factors, including aquatic ecosystems, habitat loss, habitat migration, invasion of new species, changes in drought and floods, changes in heating and cooling demand, changes in hydropower output, changes in crop yields, and water-borne disease vectors.

With these complexities, tracing the contribution of earth science data and modeling to climate change policy is demanding indeed. Nevertheless, some significant contributions can be

¹ Separately, NASA has also studied uses of the data for managing resources—another of the “outcomes” identified in Figure 1. For detailed information about these uses, see NASA 2003.

² This highly focused research effort is described at <http://www.climatescience.gov/> (accessed May 2005).

found. The next section illustrates several initiatives addressed in the larger research project from which these case studies are drawn.

Some Contributions of Earth Science Data to Climate-Related Public Policy

Earth science data have been used in the making of climate-related policy in many areas. The examples we discuss below are:

- renewable energy (wind, solar) assessment in the Energy Information Administration's National Energy Modeling System and Annual Energy Outlook;
- ecosystem science in the United Nation's Millennium Ecosystem Assessment Synthesis Report (United Nations 2005), the National Health Assessment Group's report (2000) on the potential consequences for human health of climate variability and change, and the World Health Organization's report (2003) on climate change and human health (including water-borne disease);
- and carbon sequestration under provisions of the 1992 Energy Policy Act.

In carrying out our project, we held several workshops involving experts in each of these areas. For each topic—energy, water, and carbon sequestration—the experts represented the modeling (decision support tool) community and the public policymaking arena. Detailed information and extensive web links to these case studies are at a website developed as part of our project (<http://appl-policy.saic.com/>).

Renewable Energy

The Energy Information Agency's (EIA) National Energy Modeling System (NEMS) predicts the energy, economic, environmental, and security impacts on the United States of alternative energy policies, including those related to controlling carbon and other greenhouse gas emissions. NEMS is a computer-based model offering 25-year projections of energy markets and energy-related developments. Each year, the EIA uses results from NEMS to produce *The Annual Energy Outlook*, a major reference tool that serves as a basis for policy evaluation and research.

NEMS draws from several modules, among them one describing the supply of renewable energy. This module assesses wind, geothermal, solar, biomass, and other renewable supplies. Measurements of the sun's energy, for example, acquired from instruments on several NASA

spacecraft under the agency's Surface Meteorology and Solar Energy (SSE) project, are provided to the National Renewable Energy Laboratory (NREL), which maintains the National Solar Radiation Database (NSRDB). The EIA uses the NSRDB in NEMS to provide information on the solar resource. The renewable energy portion of NEMS is critical, given the current policy attention to renewable energy as an alternative to fossil fuels, the new national policy in the Energy Policy Act of 2005 extending tax credits for producing some renewables, and state initiatives to mandate a certain share of renewables in the state's energy mix.

Water-Borne Disease

Climate change can alter the environmental background for pathogens, directly affecting human and ecosystem health. Modeling efforts to detect the effect of climatic conditions on chronic and infectious diseases make use of remote sensing data to identify the antecedents (leading environmental indicators observed months to years in advance) of health and ecosystem risks; long-term trends in vector populations; and correlations between climate variability and water-borne disease problems. Research using the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (NOAA/AVHRR) and NASA's land remote sensing instrument LANDSAT led directly to several scientific findings and policy recommendations included in the *Millennium Ecosystem Assessment* of the United Nations (2005). Launched in June 2001, the assessment was completed in March 2005. It is intended to help to meet assessment needs of key international agreements, including the Convention on Biological Diversity, the Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species, as well as needs of other users in the private sector and governments around the world. If the assessment proves useful to its stakeholders, such integrated assessments are likely to be repeated every 5–10 years. National and subnational ecosystem assessments will be conducted at regular intervals.

Other research using earth science data has influenced policy recommendations published in *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, a report produced in 2000 by the National Assessment Synthesis Team, under the auspices of the federal government's Global Change Research Program. The Global Change Research Act of 1990 established the mandate for the group. The project involves coordinated use, through co-registration and other techniques, of off-the-shelf computer models for statistical, epidemiological, remote sensing, and geographic information system analyses that,

taken together, shed light on environmental conditions that increase the risk of water-borne pathogens and their implications for human health and ecosystems.

The National Assessment Synthesis Team's report was widely cited in *Climate Change and Human Health: Risks and Responses*, a report issued in 2003 by the World Health Organization (WHO) in collaboration with the World Meteorological Organization and the United Nations Environment Program. The WHO report details the linkages between environmental data, pathways by which climate affects health, and health effects across all regions of the world. It also recommends how government should respond.

Carbon Sequestration

The 1992 Energy Policy Act contains a provision enabling businesses and other entities to register greenhouse gas emissions and reductions. Section 1605(b) of the Act allows (see www.eia.doe.gov/oiaf/1605/policy.html):

any company, organization or individual to establish a public record of emissions, reductions, or sequestration achievements in a national database. Reporters can gain recognition for environmental stewardship, demonstrate support for voluntary approaches to achieving environmental policy goals, support information exchange, and inform the public debate over greenhouse gas emissions.

NASA's Carbon Query and Evaluation Support Tools (CQUEST) project was developed to support U.S. federal guidelines (issued by agencies including the Department of Agriculture, the Department of Energy and the EPA) for a voluntary program for sequestration of carbon in biomass and soils under Section 1605(b). An online program based on the tools of geographic information systems, CQUEST uses the output from the Carnegie-Ames-Stanford Approach (CASA) ecosystem model that simulates the fluxes of all major biogenic greenhouse gases and biogenic reactive tropospheric gases. The output of the model can serve as an independent evaluation of sequestration reports by industrial emitters who have reforested land to mitigate CO₂ emissions from their plants. Reforestation can enhance carbon sequestration and, in some cases, result in a net carbon loss. Planners and regulators in the United States and elsewhere are developing systems of carbon credit trading in which, for instance, industrial emitters of CO₂ pay other entities, such as the owners of reforested land, for enhancements that result in net carbon sequestration. Accurate estimates of how much carbon various types of ecosystems can absorb or have absorbed, and annual variations in large-scale carbon sink or source fluxes, underpin a successful system of carbon credit trading. Land areas that consistently sequester carbon through

growth in net ecosystem production may provide sinks for industrial CO₂ emissions. Conversely, land areas that do not consistently sequester carbon over time may be adding to already increasing atmospheric CO₂ from fossil-fuel-burning sources. Land-surface data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) are central to the C-QUEST/CASA project.

Additional Notes

In all three of these examples, the experts with whom we spoke indicated that they are considering the use of other NASA data now being made available from NASA sensors.

In the case of energy policy, modelers are engaged in discussions to understand how NASA earth science data from the most recently launched instruments might be more fully used. For example, NREL is in the process of updating its wind-energy resource information. Most of the updated information is being developed through regional and micro-scale modeling efforts. NASA's MODIS data on land-surface temperature, sea-surface temperature, land cover, land-surface emissivity, snow cover, ice cover, vegetation, and leaf area have the potential to satisfy some of the input needs of regional and micro-scale modelers.

In the case of water-borne disease, potential data applications include use of NASA's MODIS to identify conditions such as harmful algal blooms, suspended solids, and organic matter concentration that may provide indicators of water-borne diseases. Many researchers believe that soil moisture has a close correlation with water-borne pathogens, in which case accurate and timely soil-moisture data with reasonable spatial resolution would be useful as a tracer or predictor of water-borne diseases. NASA's Advance Microwave Scanning Radiometer (AMSR) can provide soil moisture data at a spatial resolution of 25 kilometers (km). In the future, NASA's Hydrosphere State Mission will provide global maps of the primary land-surface controls of processes that link the water, energy, and biogeochemical cycles.

In the case of CQUEST, considerably more NASA data may be used in the future, including surface solar radiation data from the SSE project, rainfall accumulation data from the AMSR, and carbon cycle measurements at 1 x 1.5 km spatial resolution from the planned Orbiting Carbon Observatory (OCO) to evaluate the carbon flux estimates produced by CASA.

Another tool to which space-derived earth science data may soon contribute is the Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP is a computer model that analyzes health benefits as a function of changes in air quality. The model estimates

changes in the incidence of adverse health effects, as well as the estimated economic value of the change in those effects, and reports air quality and population exposure results. BenMAP has been used to:

- generate population- and community-level ambient pollution exposure maps;
- compare benefits associated with regulatory programs;
- estimate health impacts and costs of existing air pollution concentrations;
- estimate health benefits of alternative ambient air quality standards; and
- perform sensitivity analyses of health or valuation functions, or of other inputs.

BenMAP requires ozone and aerosol data. BenMAP's predicted air quality data presently are obtained from the Community Multiscale Air Quality (CMAQ) model, the primary air quality model used by the EPA. CMAQ predicts ozone and particulate matter distribution on a horizontal grid that can include all or part of the United States, with a spatial resolution as large as 108 km and as small as 4 km. NASA's Tropospheric Emission Spectrometer (TES), which has now been placed into orbit aboard the AURA satellite and whose data have now been made available can provide ozone observations in the lower troposphere at 0.5 x 5 km for a nadir scan and 0.5 x 23 km for a limb scan. CMAQ can benefit from NASA data by using the ozone data from TES and the aerosol data from MODIS and the Multiangle Imaging SpectroRadiometer (MISR) to evaluate predictions, initial and boundary conditions, and data assimilation procedures. In the future, aerosol vertical profile data will be available from NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission, which will provide initial and boundary conditions and data for assimilation procedures for CMAQ, as well as an immediate evaluation of CMAQ's particulate-matter predictions.

Issues Associated with NASA Earth Science Data

The modeling experts with whom we spoke raised questions about the availability and applicability of NASA's earth science remote sensing data. This section highlights some of the more outstanding issues.

There was considerable frustration among some experts regarding the format of data. Science data products are typically provided through a government Distributed Active Archive Center (DAAC) in an HDF format, although some DAACs can also provide data in a GeoTIFF format.³ The modeling and geographic-information-system community, on the other hand, commonly uses different formats (such as binary, ASCII, NetCDF, and shape files). Format conversion—typically tedious and time consuming—is always necessary.⁴

Other issues can impede full use of data products, such as the map projection used by some DAACs. Researchers have found map projections for some data products to be awkward, leading to the need to reproject the data on more conventional projections. These researchers would prefer that the DAACs use a common latitude/longitude projection for data sets and make available continental subsets of the data.

Another concern focuses on data quality. To use data with confidence, modelers must understand NASA's quality control and validation procedures. It is routine procedure for NASA to apply stringent quality controls on data before they are made available. These procedures include, for example, validation and verification of accuracy and geographic and temporal rectification. But such information is not always available from the DAACs, requiring the user to track it down.⁵

³ Eight NASA DAACs located around the United States process, archive, document, and distribute data from NASA's Earth Observing System (EOS) satellites and other measurement programs. NASA acknowledges the challenge of different formats and plans sessions at meetings of researchers in the coming year to address this problem (email correspondence with Ronald J. Birk, program director, Applied Sciences Program, Science Mission Directorate, National Aeronautics and Space Administration, 22 June 2005).

⁴ Many users of the data products note that even if their preferred formats are not available, they would like a format that enhances interoperability with their other information products and their software.

⁵ Two examples are the quality of the AMSR and NOAA-NASA Pathfinder Special Sensor Microwave/Imager (SSM/I) soil moisture data and MODIS and MISR aerosol optical depth data sets. Mesoscale and synoptic scale modelers have been investigating the potential for using AMSR and SSM/I soil moisture data as initial conditions in their model or as a validation data set for their predictions. However, these modelers have raised questions as to the quality/validity of the soil moisture measurements. Users of the MODIS and MISR aerosol optical depth data for radiative transfer calculations have found the data to be very "noisy" at times, that there are many MODIS grid-squares for which no monthly average data exist, and that persistent, relatively high levels of aerosol optical depth are found in certain geographical regions and in certain seasons for no obvious reason. MODIS monthly averages are not calculated when MODIS is acquiring data over high reflectivity regions such as the Arizona and Nevada deserts because MODIS aerosol optical depth data cannot be determined accurately in high reflectivity areas. Users have indicated that the MISR aerosol product appeared to be more reliable than the MODIS aerosol product because the MISR data appear to be less noisy and do not have as many "no data zones" as the MODIS product.

These concerns limit use of other NASA remote sensing products because modelers believe that “noise” permeates these data sets. Modelers reported to us that they do not have the time or resources to examine each data set to determine its usefulness for their research; moreover, modelers argue that data quality verification is “not their job.”⁶ NASA’s Application Program has indicated that they will provide the resources to improve data quality where that improvement is required for user applications.

Another issue is delivery of data from a DAAC. A data delivery process known as the Earth Observation System Data and Information System (EOSDIS) Core System (ECS) allows only passive transfer of data files to the user—that is, the DAAC “pushes” the data to the user. The firewall for most federal, state, and commercial users, on the other hand, allows only *active* file transfer (where the user pulls the data from the source). Because the file transfer protocols are incompatible, a DAAC cannot, under normal circumstances, deliver data directly to the user through a regular subscription service. To circumvent this problem, some DAACs have developed anonymous file transfer sites outside their firewall. In such cases, the DAAC sends the data required by users to a location from which they can pull them to their computer system. In other cases, the DAAC has sent the data to a site set up by the user from which the user then extracts the data. In some situations, users have taken other steps to acquire needed data. For example, the DAAC sometimes pushes data to a user’s home computer, which usually means that the data must be broken up into subsets because of memory limitations; in these cases, data delivery may take several days. In still other cases, federal users have had data mailed to them on a CD, or a number of CDs, which can take three weeks or more to arrive.

Most users believe that the solution to this problem is to have the DAACs set up anonymous file transfer sites outside their firewall and to have all DAACs establish a common approach. NASA’s Research, Education, and Application Solutions Network (REASoN) project is developing standardized procedures for delivering NASA data to models and the modeling community in specific cases. Universal procedures to systemize delivery of NASA data will not be possible until the next generation of EOSDIS is available.

⁶ From limited investigation of products such as the Global Ozone Chemistry Aerosol Radiation Transport (GOCART) data set, users have concluded that an aerosol data set that is an integral of observed data (as are the Aerosol Robotic Network, or AERONET, data) and satellite products would provide the best representation of the aerosol optical depth over some geographic region and period, preferably a 10- to 15-year period. They added that the data set would have to undergo significant quality assessment.

Another instance of delivery problems concerned a government user who had ordered four months' of data for the continental United States, only to discover that the data set was a global data set with more than 30 days of missing data. The user emailed the DAAC contact about the missing data but received no reply. The user eventually obtained the missing data from a member of NASA's science team for the instrument in question. The science team member acquired that data from the same DAAC from which the user had ordered in the first place. In this case, NASA's Applications Program intervened to ensure that any further data orders from this user would be complete and expedited.

The spatial resolution of NASA data versus the grid spacing used by modelers is another concern of the community. This issue arises because NASA data were originally acquired for scientific purposes, not to help solve applied problems.⁷ Where the spatial resolution of the satellite data is smaller than the grid resolution of the models and tools, the technique of spatial averaging can produce a spatial resolution for the remote sensing data that is compatible with the grid resolution of the models and tools. In the opposite case, however, where the spatial resolution of the satellite data is much larger than the grid resolution of the models and tools, compromises have to be made. In some cases, the lower-resolution remote sensing data are applied directly in a model or tool that has higher grid resolution, without prior investigation of the consequences of the action. This practice can lower the spatial accuracy of the parameter provided by the remote sensing data or affect the subsequent information generated by the model or tool. Yet NASA data are used in such cases because, more often than not, they are the best available.

There also appear to be instances where the expertise required to make use of NASA data is too high for some end users. For instance, an agency that was evaluating information from its decision tools found that the decisionmakers who were the audience for the information sometimes did not fully understand either the NASA data or the data products created from them. The decision support tool in this case was an extremely technical model that required

⁷ The earth science instruments of NASA satellites have spatial resolutions that vary from about 250 square meters to over 100 square kilometers. However, in the development of some products (typically, "Level-3" or highly processed products), the spatial resolution is often degraded to minimize the noise existing in the data or to acquire a sufficient amount of data to produce a gridded data set. For example, a 0.5-km² Level-2 product may end up as an 8-km² Level-3 product; a 40-km² Level-2 product may become a Level-3 product with a grid of 5 degrees latitude by 5 degrees longitude. On the other hand, models and tools applied by users of NASA data have grid resolutions that vary from 1 square kilometer to 2–3 degrees latitude by 2–3 degrees longitude.

considerable expertise to generate and apply results. To solve this problem, a step could be added to the assessment of applicability of NASA earth science data and research results to specify the level of expertise that end users must have to apply model results in their decisionmaking process. If the level of required expertise is too high, or the education process too long or too rigorous, then it may be useful for NASA to work closely with the agency using the data.

Concluding Observations

We conclude with a metaphor. Just as the modesty of salt belies its salience in food, space-derived earth science is essential but probably underappreciated in its contribution to the making of laws, regulations, and other policies governing natural resources and the environment. Even though policymakers may be unaware of the role of earth science, the cogency of their debates on various public policies depends on the extent to which scientific results have been appropriately translated and communicated throughout the process from data collection to policy information.

When earth science data are used for policymaking, a *team* of experts typically forges the link between data and policy. Similarly, the most effective applications of data come about when the modelers work hand-in-hand with policy analysts, who in turn communicate policy implications and options to decisionmakers. Teaming was present in all of the applications investigated in this paper. Science and policy can also be linked when policy questions impel researchers, but such links are more difficult to bring about. At present, NASA earth science research grants do not require researchers to generate data products designed to answer policy questions. It is an interesting question whether incentives to do so are desirable. There is significant merit in using data for research *per se* rather than focusing their use on policy issues, but perhaps both objectives could be incorporated in research grants. Another gap—having nothing to do with NASA's contribution—can open when analysis does not precede policymaking or when it is not used to assess policy effectiveness. Notwithstanding these challenges, earth science data have made and are likely to continue to make critical contributions to policy.

In future research, we will be examining policy and regulatory issues anticipated to drive the management of natural resources during 2010–2020. That decade is a period when operational satellites (as distinguished from research satellites testing innovations in instruments) will provide most of the observations presently provided by NASA. It is also a period for which planning is now underway for the next generation of NASA research satellites. Our objective is

to identify for NASA some of the key future policy issues in these resource areas, and to use that information to help NASA ensure the usefulness of tomorrow's data for tomorrow's policy concerns.

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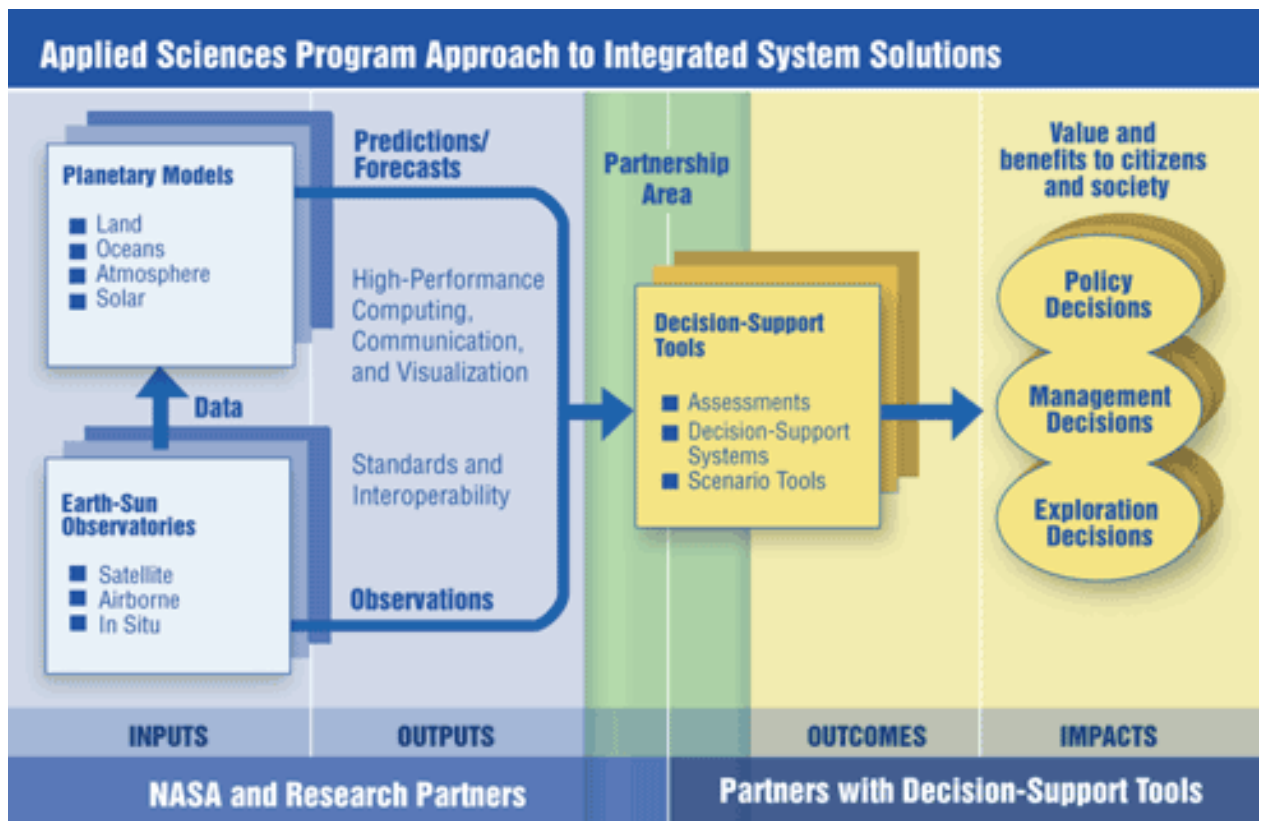


Figure 1. Framework for the Use of Earth Science Data in Policymaking

Source: NASA, *The View from Space: NASA Earth Observations Serving Society* NP-2003-11--589-GSFC, 2003, p. 3