

CHAPTER 13

THE SOCIAL AND ECONOMIC IMPACT OF EARTH OBSERVING SATELLITES

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Research, development, and operational investments of the U.S. government and NASA for Earth observations have had a large impact on the economy of the U.S. and on the world. With the participation of other federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA), and the Department of Interior, United States Geological Survey (USGS), new industries have been created. New technologies have been advanced from the laboratory to the marketplace more quickly than if there had been no space program. Not only have jobs and income been created, but new ways of viewing the world now exist and other innovations that can be traced to U.S. government requirements and investments have improved the quality of life. Describing these technological advances is relatively easy; measuring their economic and social benefits is difficult. This paper reviews economic and other measures that have been applied to the benefits that Earth observation satellites have brought. The process of measuring benefits faces two major difficulties: 1) economists do not agree on the best approach to measurement because each issue and problem as well as each application focuses on a menu of different approaches and 2) no single measure exists that provides a comprehensive indicator of Earth observations impacts and benefits.

This essay will review developments in two areas: 1) a summary and evaluation of selected studies that have attempted to quantify and describe the various observable and measurable impacts of using Earth observation satellites and 2) a focus on the value of information used in the economy that can be attributed to satellite observations. This is different from just trying to measure historical impacts because it looks to the marginal value of additional information that can be derived from improved forecasts of many variables, which include weather and climate, river flow, soil moisture, snow cover, and land use. In general, information about these variables is derived from ground, aerial, and satellite sources and is combined in models that predict near- and long-term conditions. Since much is already known and published about these variables and the predictions are currently in use by many economic sectors, with each sector making large contributions to the gross

domestic product (GDP), improved forecasts—though constituting only small-percentage gains—can add up to equal a large impact.

Over the past 30 years since the launching of the first civilian Earth observation satellite, ERTS-1 (later renamed Landsat-1), much has been written about the potential impacts of the data on various economic sectors. This paper will only briefly summarize these studies as a background for a more comprehensive analysis of the impacts of the value of improved forecasts in three areas of growing importance: natural hazards (mainly from weather and climate), electric energy production, and the management of freshwater resources.

Following the discussion of results, this paper also summarizes the assumptions, methodology, and analytical problems in developing consistent, accurate, and reliable results with the tools currently available.

THE SOCIOECONOMIC BENEFITS OF EARTH OBSERVATION SATELLITE SYSTEMS

Beginning with the polar-orbiting Television Infrared Observing Satellite (TIROS)-1 in 1960, NASA's first Earth observation satellites focused on providing a view from space of Earth's cloud patterns. These were extremely useful in both civilian weather forecasting and in planning military maneuvers. Later versions of these satellites added microwave instruments that could probe layers of the atmosphere to provide estimates of temperature, pressure, and humidity—measurements that are required as inputs to weather forecast models. Because many terrestrial weather measurements were available in North America, early TIROS satellite data made only modest contributions to forecasting accuracy within this continent. However, they made a sharp improvement in weather forecasting in other parts of the world, where weather data were only sparsely available. Steady improvements in the TIROS series (now called POES, the Polar-orbiting Operational Environmental Satellites, and operated by NOAA) have made these polar orbiting satellite measurements indispensable around the world. The U.S. allows all nations, indeed any entity with the appropriate receiver, to download data from these satellites without cost.

In the late 1960s NASA's geostationary Applications Technology Satellites (ATSs) demonstrated the utility of making frequent observations of weather conditions over North America for tracking severe storms, such as hurricanes and tornadoes. In the 1970s, NASA and NOAA agreed to build an upgraded version of ATS called GOES—Geostationary Operational Environmental Satellite. Built and launched by NASA and operated by NOAA, the POES and GOES systems now provide some 95 percent of the data that NOAA's National Weather Service (NWS) uses in its weather forecast models. Information provided by the data from these satellites is credited with saving many lives and reducing property damage from severe storms.¹ Every day, weather forecasts provide information used by

1. The National Climatic Data Center, <http://www.ncdc.noaa.gov/oa/climate/research.html> (accessed 30 November 2006).

industry, government, and the average citizen to lower the risks they face from adverse weather conditions. Many of these uses can be quantified; others can only be described qualitatively. Later sections discuss some of these results.

In the early 1970s NASA created the Landsat program to gather multispectral data about Earth's surface features.² The first of this series of satellites was launched in July 1972. The satellite proved a technical success, returning images of large areas of Earth's surface in four different color bands that could be probed for information about geology, biology, snow and ice cover, and human settlement patterns. Even before the launch, NASA had started an effort to involve other agencies in experimenting with the data for assisting in their applications. It also encouraged countries around the world to establish data receiving stations to collect data over their territories. Although the data showed immediate potential utility for use in resource management, mineral prospecting, and agriculture, NASA found it difficult move the system into operational status. The software and computer hardware were cumbersome to use and, at first, analysis was largely carried out using paper imagery.

Even today, with the benefit of extremely powerful Geographic Information System (GIS) and sophisticated imaging processing software, as well as the Global Positioning System (GPS) to place landscape details into a geographic reference system, incorporating Earth observations into routine agency resource management operations continues to be difficult for several reasons. First, potential users do not feel confident that research sensors will be made operational and data from them will be available in the future. Second, government budgets often do not include enough funds for processing and operations once the hardware has been built, flown, and tested. Third, there are cultural and communications barriers between space researchers and data users that are often difficult to overcome.

Nevertheless, Landsat data have been used widely for such scientific studies as the examination of the state of the world's forests and estimates of the amount of carbon sequestered by them. They have also contributed to a better understanding of the rates of deforestation and reforestation around the world. For agencies that have incorporated Landsat data into their routine operations, the data provide a broad, synoptic view of the landscape and an enhanced ability to manage the natural and cultural resources of the lands they manage.

NASA's Landsat effort was sufficiently successful for it to obtain the financial backing from Congress to build three satellites that carried similar, 80-meter-resolution MultiSpectral Scanners (MSSs) and to extend the Landsat mission to Landsats 4 and 5, which carried an enhanced 30-meter sensor called the Thematic Mapper (TM). These were launched in 1982 and 1984, respectively; the 25-year-old Landsat 5 still returns imagery from orbit, though at a reduced capability. The

2. Pamela E. Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System* (Cambridge, MA: MIT Press, 1990).

TM sensor carries seven spectral bands, six of which operate between the blue and near-infrared parts of the spectrum. As detailed below, Landsat 6 failed and Landsat 7 is now in orbit and supplying data.

LACIE and NASA's Applications Program

The 1974 to 1978 Large Area Crop Inventory Experiment (LACIE) and its 1978 to 1983 successor program, Agriculture and Resources Inventory Surveys Through Remote Sensing (AgRISTARS) were designed to develop uses for the Landsat data to measure crop production, first in the U.S. and then in other parts of the world. They were a joint program of NASA, NOAA, and the USDA. (AgRISTARS was primarily a USDA program to make operational the results of LACIE, but budget pressures and changing priorities of the Reagan administration greatly reduced the spending for AgRISTARS.)³

In one interesting experiment in the LACIE program, Landsat and other data were used to estimate the Soviet Union's wheat crop. Crops yields are heavily dependent on weather conditions. The lack of knowledge and good forecasts of the Soviet crop led to significant increases in the price of wheat in 1972. As described by Dr. Forrest Hall, senior research scientist at NASA's Goddard Space Flight Center,

In 1972, the Soviet Union experienced a major wheat crop failure. The U.S. had sold large quantities of wheat to the Soviet Union at low prices before the crop failure was announced. The failure drove up wheat prices, and the U.S. ended up buying wheat back from the Soviets at a loss When we started selling it, we were selling it for \$1.92 a bushel, and we ended up buying some of it back at \$4 or so a bushel That really made us realize that our conventional (crop-estimation) systems at that point were not very accurate.

In order to add an element of stability to the world's agricultural markets, NASA and the USDA began a program to see if Landsat data could be used to estimate global crop production.⁴ The resulting improvements in wheat crop forecasting from LACIE were documented to be within 6 percent of the final Soviet figures, which were released more than six months later than the LACIE estimates.⁵

3. "United States Civilian Space Programs, Volume II, Applications Satellites," Report Prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives, 98th Congress, May 1983, pp. 231-237.

4. http://science.nasa.gov/headlines/y2000/ast04dec_1.htm (accessed 24 August 2007).

5. R. B. MacDonald and F. G. Hall, "Global Crop Forecasting, *Science* (New Series) 208, no. 4445 (16 May 1980): p. 670. In spite of the overall accuracy, it is noted by others that the value of the accuracy was somewhat diminished by offsetting errors in area and yield estimates (U.S. General Accounting Office, "Crop Forecasting by Satellite: Progress and Problems," PSAD-78-52, 7 April 1978, as quoted in "United States Civilian Space Programs, Volume II, Applications Satellites," p. 233.

An economic methodology was constructed to measure the value of these information improvements in forecasting, which was based on the premise that more accurate observations affect the commodity-price distribution. By reducing the variation in prices of highly volatile commodities, consumers receive direct economic benefits (a Marshallian surplus) in the form of more stable prices.⁶ Over time and with improved satellite resolution and additional data, the same type of analyses have more than adequately demonstrated the value of better information in forecasting in many other areas, as described in other sections of this paper. Although the Landsat satellites proved technically successful, NASA did not want to operate Landsat indefinitely and the Office of Management and Budget was not keen to approve continued funding for the system.

In the late 1970s, influential members of the Carter administration also felt that the private sector should assume operation of the Landsat system and provide the data commercially. In order to move the Landsat system to a private operator, the administration crafted a plan that would first transfer operational control over Landsats 4 and 5 to NOAA and then later to the private sector. Several years later, the Reagan administration pushed hard to move the system into private hands as soon as possible. Congress supported this decision by passing the Land-Remote Sensing Commercialization Act of 1984 (P.L. 98-365), which also included important provisions allowing the commercial development and operations of land remote sensing satellites.

As soon as NOAA took over Landsat operation, it raised the price of data from near zero to several thousand dollars per scene, which caused the volume of data sales to plummet. RCA, Inc. and Lockheed Martin Corp. formed EOSAT, Inc. to operate the Landsat system and to increase the small market for the data. However, EOSAT was unable to build a commercial market to a size that would support fully private development of the Landsat satellites. For one thing, the federal government remained by far the largest user of Landsat data. In addition, the price of data continued to be prohibitive for many users. Further, Landsat 6 incurred a complete launch failure and did not achieve orbit.

Congress in 1992 decided that Landsat did indeed provide sufficient benefit to the country to be continued, and drafted legislation to ease the restrictions on private operation of land remote sensing that were in the 1984 law and to bring future Landsat satellites back under government operation.⁷ NASA was instructed to build and launch Landsat 7, which is still orbiting⁸ and supplying data to users

6. David F Bradford and Harry H. Kelejian, "The Value of Information for Crop Forecasting with Bayesian Speculators: Theory and Empirical Results," *The Bell Journal of Economics* 9 (Spring 1978): pp. 123-144.

7. The Land Remote-Sensing Policy Act of 1992 (P.L. 102-555).

8. Landsat 7, however, suffers from a failure in its Land-scan corrector that makes part of the data in each scene unusable.

around the world. USGS now operates Landsats 5 and 7. NASA will build a successor to this satellite, which will be operated by the USGS. Long-term continuity of this capability is still in doubt, however.⁹

This abbreviated summary of the trials and tribulations of the Landsat system illustrates that even though a satellite system may prove technically successful for the economy, finding the will to move it into operational use can be fraught with difficulties. This state of affairs has come about because Earth observation data have both public and private uses. Governments have invested in expensive space systems because the information obtained fulfills various mission purposes, ranging from national security to planning and monitoring natural resources. At the same time, commercial and private for-profit uses of the very same data provide opportunities for economic growth and benefits.

These dual capabilities have fueled many policy debates over the years that have led to some very odd compromises. In the U.S., for example, Congress has declared that satellite (and other) weather information is a public good,¹⁰ while at the same time leaving all other remote sensing data products undefined and therefore sometimes treated as public goods and sometimes as private goods.¹¹ To further confuse the policy debate, civil space activities fall under two other legislative mandates: 1) they are “for the benefit of mankind”¹² and 2) the information obtained from space should be openly and widely disseminated.¹³ In addition, government policy also calls for government-collected information to be disseminated with user charges set no higher than the costs of dissemination.¹⁴ Also, unlike many other nations, the U.S. government also prohibits the copyright of government publications.

Therefore, all remote sensing data are mixed public-private goods, making market pricing and measuring benefits on an economic basis extremely difficult. Clearly, private sector value-added firms (those taking and/or purchasing government information from satellites and processing the images for commercial

9. A forthcoming report by the Office of Science and Technology Policy will reportedly recommend the development by the government of long-term operation of a Landsat-type system to ensure moderate resolution data continuity for the long term.

10. A public good is one that is non-excludable (nobody can be denied the use of the good) and non-rival (one person's consumption of it does not affect another's). Public goods often reflect the intervention of governments into the marketplace where market systems have failed to provide either competition and/or service to everyone for necessary services at an equitable price. Public goods are also collective goods where a profit-motivated firm would not provide the service (e.g., national defense).

11. We need a citation for the mid-1980's legislation.

12. “National Aeronautics and Space Act of 1958,” Public Law 85-568, 72 Stat., 426. Signed by the President on 29 July 1958, §102(a).

13. *Ibid.*

14. Executive Office of the President, Office of Management and Budget, Circular No. A-130, Revised, Management of Federal Information Resources, Washington, DC: 28 November 2000, §8(a)7(c).

purposes) can provide useful, measurable benefits. However, the prices do not reflect the total costs to society of producing the information since the space component is often heavily subsidized by government programs. As policy has evolved over time, the private sector is now developing its own satellites, with data products sold both to governments and to the private sector. However, the legislative mandates still allow for a significant amount of competition between government-subsidized information and for-profit systems, which makes a true economic and benefit analysis of Earth observation data very complex.

Although some of the technology in the U.S. commercial satellites derives from systems developed for classified satellites, much of the hardware and the associated supporting image processing software sprang from NASA's efforts to make Landsat data useful for operational applications. Further, government investments in GPS and GIS software have made Landsat data truly useful for a wide variety of scientific and applied purposes. These ancillary government inputs can also be considered as benefits, though extremely difficult to quantify.

Scientific research on climate has also proved highly beneficial. By the early 1980s, NASA began to focus on developing a view of Earth as an integrated, interdependent system. NASA scientists reasoned that global satellite observations would be essential in developing global climate models. In 1987, at a time when NASA was reappraising its role in space research and development following the loss of Space Shuttle *Challenger*, NASA published a report entitled *Leadership and America's Future in Space*.¹⁵ Among other things, this report included a proposal for a "Mission to Planet Earth" that would study and characterize Earth on a global scale. This report was rescoped, rebaselined, and reshaped (NASA's terminology) in steps over several years to fit a much smaller \$7-billion budget profile in which the original large, polar-orbiting platforms were replaced by several smaller, less capable versions, but which have been highly successful in producing excellent scientific data.

Some of the instruments from the Earth Observing System (EOS) satellites could provide the basis for operational instruments operated by another federal agency. Nevertheless, NASA and these agencies will still face the difficulty of making the transition from research to operations unless the relevant agencies (NOAA and USGS) are able to take over the development and operation of their own satellites or find ways to involve the private sector in supplying such information commercially.

The issue becomes clear in an examination of the longevity of the Tropical Rainfall Measuring Mission (TRMM), launched in 1997. TRMM is a joint Japanese-U.S. mission to study the effects of tropical rainfall, which orbits in an inclined orbit between +/- 35 degrees latitude. Data from the TRMM Microwave Imager (TMI)

15. Ride, Sally K., "NASA LEADERSHIP and America's Future in Space," A Report to the Administrator, August 1987.

and the Precipitation Radar (PR) instruments on this satellite have not only led to enhanced understanding of the role of tropical rainfall in Earth's system but have also proven extremely capable of providing improved estimates of rainfall amounts in tropical cyclones. Data from the PR have also led to much-improved estimates of tropical cyclone path and intensity.¹⁶

However, by 2004, although the satellite was still in excellent operating condition (well beyond its planned scientific mission), for budget reasons NASA decided to stop collecting data from the satellite and to deorbit it. That move would have saved the agency about \$4 million per year (though much of that savings would be consumed by deorbit maneuvers over several years). The outcries of dismay from scientists and from weather forecasters in Japan and in the U.S., and a National Research Council Report on TRMM, caused NASA to rethink its approach. Some weather forecasters, especially in Japan and Europe, were already using the data for operational purposes in measuring rainfall and in tropical cyclone warnings.

Therefore, in May 2005 NASA reversed its earlier decision and extended the operation of TRMM either until it fails or its fuel runs out sometime in 2010 or 2011. TRMM is still operating and in 2005 contributed to improved observations of Hurricanes Katrina and Rita as well as other tropical cyclones. Although its benefits to society have not been quantified, the National Research Council report enumerated many of its contributions to weather and climate prediction models.¹⁷ These successes make it clear that a satellite system, if extended to the globe, would provide continuing and improved data which would result in benefits to all nations.

The following sections summarize results of several studies carried out by the Space Policy Institute on the benefits of EOS systems.

NATURAL HAZARDS, MITIGATION, AND RESPONSE

Some of the most familiar and recognizable Earth observation images in the U.S. popular mind are the dramatic pictures of major hurricanes headed for the U.S. coast. The pictures, captured by the NOAA GOES satellites, serve to illustrate the danger these enormous storms pose for the affected coastline and assist in urging citizens reluctant to evacuate the area that they should leave. To the extent that the satellite systems that produce images of these and other weather-related natural disasters save lives and allow affected communities to prepare their homes and businesses to withstand the storms' onslaughts, they bring a clear benefit to the U.S.

In general, more accurate prediction of severe weather can help to reduce substantially the economic and social costs of weather-related disasters. Better

16. National Research Council, *The Future of the Tropical Rainfall Measuring Mission: Interim Report* (Washington, DC: National Academies Press, 2005).

17. 4.3.1.2 Operational Assimilation of TMI and PR Data for Weather and Climate 21 Prediction Models, p. 61.

information induces governments, businesses, and individuals to invest in loss-reduction activities; it can also reduce economic costs from unnecessary loss-reduction activities that derive from uncertainty about adverse weather (e.g., evacuations during hurricanes). This section summarizes what is known about these types of benefits as applied to weather-related natural hazards such as hurricanes.

A few economists have attempted to quantify the economic impacts of severe storms in specific industries. For example, research by Timothy Considine et al. on the costs of evacuating energy production platforms in the Gulf of Mexico estimated that achieving a 50 percent reduction in hurricane and tropical storm forecast error would save producers about \$18 million annually. According to his analysis, a perfect forecast could lead to savings between \$225 million and \$275 million, illustrating the nonlinear nature of forecast value in this case. However, for energy producers in the Gulf, averting the risk of losing lives is generally far more important than saving short-run operations costs. The costs of evacuation from a platform are much lower than the perceived costs of loss of life. If “losses are perceived to be very substantial, producers will always take preventive action regardless of evacuation costs.”¹⁸

Preparing for and Responding to Hurricanes

Satellite data from several instruments can contribute to the delivery of more accurate, timely hurricane forecasts (table 13.1). Satellite data also have a role in mitigating the damaging effects of hurricanes and in responding to and recovering from hurricane damage (table 13.2). For example, digital elevation models, coupled with land cover information and estimates of storm force, allow modelers to estimate the force and extent of storm surge along the coast.¹⁹

TABLE 13.1—SATELLITE CONTRIBUTIONS TO MORE ACCURATE, TIMELY HURRICANE FORECASTS

Satellite Instrument	Measurement	Utility
TMI-TRMM Microwave Instrument	Precipitation rate and distribution	Rain estimates, flood warnings
Precipitation Radar	Storm track, rain rate in storm	Increased accuracy of evacuation warnings
QuikSCAT	Surface winds speed and direction	Storm force, track predictions
GOES, POES	Imagery, atmospheric soundings	Storm track, rain estimates, force

18. T.J. Considine, C. Jablonowski, B. Posner, and C. H. Bishop, “The Value of Hurricane Forecasts to Oil and Gas Producers in the Gulf of Mexico,” *Journal of Applied Meteorology* 43 (2003): pp.1270–1281.

19. LIDAR-derived digital elevation models (from aircraft instruments) of Broward County, FL, have allowed the county to avoid significant evacuation costs during severe hurricanes by reducing the required evacuation area. Ray A. Williamson, Henry R. Hertzfeld, Joseph Cordes, and John M. Logsdon, “The Socioeconomic Benefits of Earth Science and Applications Research: Reducing the Risks and Costs of Natural Disasters in the USA,” *Space Policy* 18 (2002): pp. 57–65.

TABLE 13.2—SATELLITE CONTRIBUTIONS TO MITIGATION, RESPONSE, AND RECOVERY OF HURRICANE DAMAGE

Satellite Instrument	Measurement	Utility
Landsat Thematic Mapper, SPOT	Land cover, flooding extent	Flood modeling, recovery planning
QuickBird Ikonos Orbview	Damage type, extent; detailed digital elevation model	Insurance estimates, detailed cleanup planning
Shuttle Radar Topographic Mapper	Digital elevation model	Storm, flood modeling
Radarsat	Flooding	Flood extent, disaster designation

The most destructive tropical cyclone in recent years to strike the U.S. was Hurricane Katrina, which made landfall southeast of New Orleans in late August 2005 and quickly moved northeast, spreading death and destruction across southern Louisiana and western Mississippi. Much of the storm damage was directly related to the massive amount of rain. The heavy rainfall and storm surge destroyed parts of New Orleans levees, flooding the city and displacing much of the city's population. Less than a month later, this storm was followed by Hurricane Rita, which made landfall near the Texas-Louisiana border. The storm surge it caused led to extensive damage along the Louisiana and southeastern Texas coasts. Both storms were among the most well-forecast storms in U.S. history because of the early concern they raised among forecasters and the public. Despite highly accurate forecasts for both storms, they caused at least 2,000 deaths directly or indirectly, massive short- and long-term population displacement, and thousands of destroyed homes and businesses.

Earth observation satellites had a major role in tracking the storms and in response, recovery, and rebuilding efforts immediately afterwards. Information derived from NOAA's GOES and POES satellites was used to estimate storm intensity with considerable accuracy. NASA contributed data from the TRMM satellite, which had led to improved hurricane path and rainfall predictions. However, even though the information was highly accurate, response at all levels of government was slow and halting, which led to a much higher death rate—demonstrating that better information does not always lead to better decision making in times of crisis.

During response and recovery after the storm, NOAA, NASA, and private companies contributed time and considerable effort to acquiring both aerial and satellite imagery of the damaged areas. This helped citizens, some of whom were several hundreds of miles from their homes, view the damage to their neighborhoods and houses and decide how to respond appropriately. In addition, the International Disaster Charter was activated to assist.²⁰ The Charter is an international consortium

20. The formal name is Charter on Cooperation To Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters; see http://www.disasterscharter.org/main_e.html (accessed 1 November 2006).

of space-capable nations, including the U.S., that have pledged to provide imagery to countries afflicted by major disasters.

Potential International Benefits of Improved Weather and Climate Information

The international benefits of improved weather and climate information involve virtually the same list that we would put together for the U.S., with the important difference that for developing countries, especially, these improvements could have even greater primary economic and social benefits. As one example, table 13.3 summarizes the immediate economic damage and recorded deaths for the 1998 Hurricane Mitch, which swept across Central America in November 1998. However, these figures do not reveal the costs associated with damaged agricultural production or the long-term displacement of residents.

Country	Deaths	Damage Costs
Honduras	6,500	\$4 billion
Nicaragua	3,800	\$1 billion
El Salvador	239	Not available
Guatemala	256	Not available
Mexico	9	Not available
Other	14	Not available

Source: <http://wlf.ncdc.noaa.gov/oa/climate/severeweather/extremes.html> (accessed 24 August 2007).

El Niño and the Southern Oscillation (ENSO)

Recent development of forecast models of the short-term climate variation of the El Niño and La Niña cycle has proved a significant success. These models could not have been developed without the data from global satellite observations. The temperature and precipitation changes caused by the ENSO phenomenon have led both to significant losses and benefits, depending on which region of the world is studied. Among other things, this interannual climate swing is responsible for a significant level of uncertainty in the prediction of long-term weather patterns. Hence, U.S. and global climate research has focused considerable attention on not only a deeper understanding of the biophysical mechanisms behind ENSO, but also on the ability to predict ENSO effects. Scientists have also focused on the economic and social effects of ENSO in order to reduce the level of uncertainty and risk faced by agriculture, fisheries, and the general public throughout the world.

The climate research community has made significant progress in the past decade in understanding the physical relationships between the warming or cooling of the ocean along the western coast of South America and changes in weather

patterns elsewhere in the world. This understanding, coupled with data from several satellites, has led to an improved ability to predict the return of El Niño, which can then be used to alert weather-sensitive industries around the world that they may face increased risk of experiencing abnormal weather phenomena in their regions.²¹

Learning to predict the onset of El Niño and its sister phenomenon La Niña with sufficient accuracy, can have a major impact on the U.S. economy. Table 13.4 summarizes one analyst's estimates²² of the socioeconomic gains and losses from the El Niño of 1997–1998. Note that, contrary to popular belief, in this case the gains vastly outweigh the losses for North America. Similar charts for other regions for the same incident would probably show a different picture, with greater losses than gains. Whether gains or losses are at stake, however, better knowledge of the timing and strength of the ENSO cycle would assist governmental policy makers and private sector investors to capitalize on the benefits of this climate cycle and reduce the risk of loss.

Source	Losses
Property losses	\$2.8 billion (insured losses were \$1.7 billion)
Federal government relief costs	\$410 million
State costs	\$125 million
Agricultural losses	\$650–\$700 million
Lost sales in housing and snow-related equipment	\$60–\$80 million
Losses in the tourist industry	\$180–\$200 million
Source	Savings/Benefits
Reduced heating costs	\$6.7 billion
Increased sales of merchandise, homes, and other goods	\$5.6 billion
Reduction in costs for snow/ice removal from roads	\$350–\$400 million
Reduction in normal losses because of the lack of snowmelt flood and Atlantic hurricanes	\$6.9 billion
Income from increased construction and related employment	\$450–\$500 million
Reduced costs to airline and trucking industry	\$160–\$175 million
Cost/Benefit Summary	
Costs	Benefits
Human lives lost: 189	Human lives not lost: 850
Economic loss: \$4.2 to \$4.5 billion	Economic benefit: \$19.6 to \$19.9 billion

21. Richard A. Kerr, "Signs of Success in Forecasting El Niño," *Science*, 297 (26 July 2002): pp. 497–498.

22. Stanley A. Changnon, *El Niño 1997–1998: The Climate Event of the Century* (New York: Oxford University Press, 2000), pp. 144, 149, 152

THE BENEFITS OF WEATHER AND CLIMATE INFORMATION FOR THE ELECTRIC ENERGY INDUSTRY

Weather is an important component in the analysis and operational components of both the demand and supply of electricity. It strongly affects electricity demand via heating and cooling needs in businesses and residences. Accurate weather forecasts are extremely valuable for accurate electricity demand forecasts, which are used to determine the load carried by the electric infrastructure, conduct transactions on the electricity market, and manage electricity flows across the power grid. On the supply side of the electric power industry, weather data have applications in both electricity transport and generation. High temperatures and severe weather events (such as hurricanes, lightning, and ice storms) can damage transmission and distribution systems and interrupt electricity supply. Weather also affects the capacity to generate electricity from fossil fuels and renewable sources; the latter, which represents an ever-growing portion of the electricity supply, is particularly sensitive to weather conditions. NOAA's operational environmental satellites, augmented by land- and sea-based systems, gather meteorological data that lead to valuable information inputs on both the demand and supply sides of electricity production. Innovation in space meteorological technology, as well as more extensive understanding and utilization of current capabilities, will provide the electric power industry with more sophisticated weather information of even greater economic value than that available today.

Accurate weather forecasts are crucial in maintaining the reliability of the supply of electricity to users through management of the power grid (especially, close monitoring of overload conditions) and the prediction of severe weather. Partly as the result of the increasing deregulation of the electricity industry, electric utilities have installed more efficient transmission technologies to compete effectively. Yet these measures have often also introduced new vulnerabilities to the grid from weather by making it more sensitive. In the U.S. the aging of the hardware and equipment in the electric power grid has also led to reduced reliability. These changes have increased the need for the industry to make more efficient use of weather and climate data than ever before.

Temperature is the most important weather factor influencing electricity demand. People use more energy on hot days to cool indoor environments and on cold days to warm them. Heating degree days (HDDs) and cooling degree days (CDDs) are commonly used measures of energy demand. They indicate the variation of daily temperatures from a temperature that would require no external energy inputs for heating or cooling.²³ Differences in temperature above or below 65°F determine the need for heating and cooling, the largest component of electricity use.

23. Daily temperature is calculated as the average between the daily minimum and maximum, and the HDD/CDD is the absolute value of the difference between this and 65°F. Energy Information Administration, "Short-Term Energy Outlook," July 2007, <http://www.eia.doe.gov/emeu/stco/pub/a2tab.html> (accessed 24 August 2007).

Decreasing forecast errors can reduce the costs of unnecessarily buying and selling electricity on the open market. Error grows more costly as the time between purchase and consumption diminishes, which becomes apparent in high spot-market prices. Commercial weather information vendors such as Itron, Inc., Weather Bank, Inc., and Weather Services International specialize in providing load forecasts and forecasting software to energy utilities and independent system operators (ISOs). They obtain raw data from the National Weather Service and other data providers and then turn this information into forecasts tailored to the specific needs of each customer in the electric power industry. The most common electric power applications are for the very-short-term (minutes to hours ahead) to the short-term (1 to 10 days ahead).²⁴

The costs to utilities of an inaccurate forecast can be very high, especially for day-ahead or hour-ahead forecasts. Hourly changes in weather can result in over- and underestimating demand and costly decisions regarding the operation of electricity generation units. Improved forecasts from the use of satellite weather information have resulted in direct economic payoffs to the electric utility industry. Electric load forecasts are valuable to utilities and ISOs for allocating power over different parts of the electric grid and for optimizing purchases on the spot and day-ahead markets.

Electric utilities derive the greatest economic benefit from weather forecasts that are accurate over the 2- to 4-day time frame. Improved 7- to 10-day weather forecasts would also provide some economic benefit for utilities. The companies use monthly and seasonal weather forecasts for scheduling maintenance and for meeting U.S. Environmental Protection Agency (EPA)-set yearly emission allotments. Long-term forecasts assist in planning for new power generation facilities.

The many studies of the value of better terrestrial weather forecasts all indicate that benefits to the electric utility industry are significant, often reaching millions of dollars. However, the studies have been made in an uncoordinated way—each one measuring the benefits at one point in time for one region and often for one particular application. As enumerated below, economic benefits from better weather information are measured in many ways with a variety of methodologies. Each methodology may be particularly relevant to specific case studies and situations. Yet measures derived from different methodologies cannot easily be added together, making it impossible at present to calculate a single, aggregate measure of the economic value of improving weather forecasts and other information. However, more accurate forecasts coupled with intelligent and timely use of those forecasts by the industry is already yielding benefits in the tens of millions of dollars annually. As weather forecasts improve with new satellite-based information, and improved data assimilation into forecast models, these benefits will increase.

24. Frank A. Monforte, vice president of forecasting, Itron, Inc., personal communication. See Henry C. Hertzfeld and Ray A. Williamson, "Weather, Climate Satellite Data and Socioeconomic Value in the Electric Utility Industry," A Report to NOAA (Washington, DC: Space Policy Institute, George Washington University, December 2004), p.13.

The social benefits of supplying better weather forecasts to the public and government agencies are equally robust but even more difficult to measure accurately. Nevertheless, because the entire modern infrastructure depends in some way on the availability of electrical power, it is clear that when the U.S. electrical power grid operates reliably, the general public and public services benefit substantially from reduced uncertainty in the supply of electricity.

Satellite information can also provide significant benefits in planning, locating, and operating electric production dependent on renewable sources of energy such as wind, sunlight, and water. As of 2007, at least 17 states have mandated the use of renewable energy sources in generating electrical power; other states are rapidly adding similar regulatory requirements. Some have followed the federal example and instituted tax incentives to assist the development of this component of the industry. Satellite-based remote sensing can aid in realizing the potential of exploiting renewable energy resources by aiding in the optimal siting of generating facilities as well as in the operational decisions of generating facilities and electric power grid management. State and federal governments may wish to consider increased investment in the research and development of environmental satellites to support sound and sustainable economic and environmental policies, both in the energy and space industries. The increasing global demand for energy resources makes this particular use of satellites very significant and immediately practical. There are clear economic and social benefits to the use of satellite data for locating sites and for routine operations of renewable-source generating stations, yet the magnitude of the economic benefits that satellite data can provide have not yet been quantified.

SATELLITE INFORMATION IN QUANTIFYING AND MANAGING WATER RESOURCES

Clean, fresh water, so crucial in supporting life and national economies, is becoming increasingly difficult to obtain, especially in arid and semi-arid climates. Freshwater, with less than 0.5 parts per thousand dissolved salts, may be found in lakes, rivers, and bodies of groundwater. Only 3 percent of water on Earth is freshwater, and more than two-thirds of this is frozen in glaciers and ice caps.

In the near future, ensuring adequate supplies of freshwater to support all the competitive water needs of the world will likely become one of the most contentious issues facing global society. Improving water resource management (supply and distribution) has clearly become one of the most important challenges of modern life. As noted in a recent report, "Earth's water resources can no longer be taken for granted. Water is an issue that cannot be ignored, if we want the world to sail safely through the century ahead."²⁵

25. ITT Industries, *ITT Guidebook to Global Water Issues*, <http://www.itt.com/waterbook> (accessed September 2006).

Information derived from Earth observation satellites could improve knowledge of the supply of freshwater and assist in managing its distribution to water users. However, so far, few researchers have attempted to assess the value of space systems in addressing the challenges of improved water management.

As noted in the preceding section, electricity generation and transmission derives significant benefits from satellite data. Socioeconomic analysis of this industry is aided by the fact that electricity is a commodity and the prices and markets that exist are very important in the allocation of electric power among users, despite the distortions created by the significant amount of government regulation that is also involved.

Electricity and water are both treated as public utilities in the U.S., but that is where the direct comparisons end. Electricity is a uniform commodity, being transmitted to users by wires from power plants. Water stems from many sources, is transferred to users by different means, and cannot efficiently be transported over long distances. Table 13.5 summarizes some of these differences.

TABLE 13.5—ELECTRICITY AND WATER COMPARED		
	Electricity	Water Resources
Sensitivity to price changes	Yes	No
Distribution system	National/regional	Regional/local
Sources	Coal, hydroelectric, nuclear, oil, alternatives	Water cycle
Originates (distribution)	Power plants	Rivers; ground
Reusability/recovery	None	In some applications
Social/cultural approaches	Commodity, becoming a necessity	Basic need, but some uses are "commodities"
Markets	Sophisticated trading: spot, day-ahead, long-term markets	No large-scale, organized economic markets
Legal impediments	Regulatory, but relatively consistent across the nation	Many different local systems; different treatment of ground and river water
Measures of value	Sales, usage, cost savings, hedging on prices	Gross usage (not \$), cost savings, scarcity
Direct benefits	Industry (profit incentive) Consumers (price effects)	Agriculture, hydroelectric, nuclear plant cooling
Indirect benefits	Quality of life	Recreation
Age of industry	Approximately 100 years	Ancient

Additional theoretical problems create even more uncertainties and issues in trying to grasp the aggregate value of satellite information for uses of water resources. Overall, valuing information is quite difficult because information only has value if it is used or expected to be used. Thus, measuring the benefits of access to information depends on the ability to be able to measure the expected use of the information rather than the information itself. When the uses are diffused among different users and markets, the measurement problem is greater. Further, when no true price-responsive markets exist for the commodity, the problem is many times harder to evaluate. Finally, when the supply of water and the raw information are not precise or even affect the user in a direct buyer/seller market, yet another difficult variable is introduced

Therefore, we face a multipart problem: valuing weather and moisture information from proxy measures created by satellites; valuing a commodity that is not a market commodity; and valuing a commodity that, for many high-value uses, is not consumed but is replaced after its use. Figure 13.1 illustrates these issues and problems.

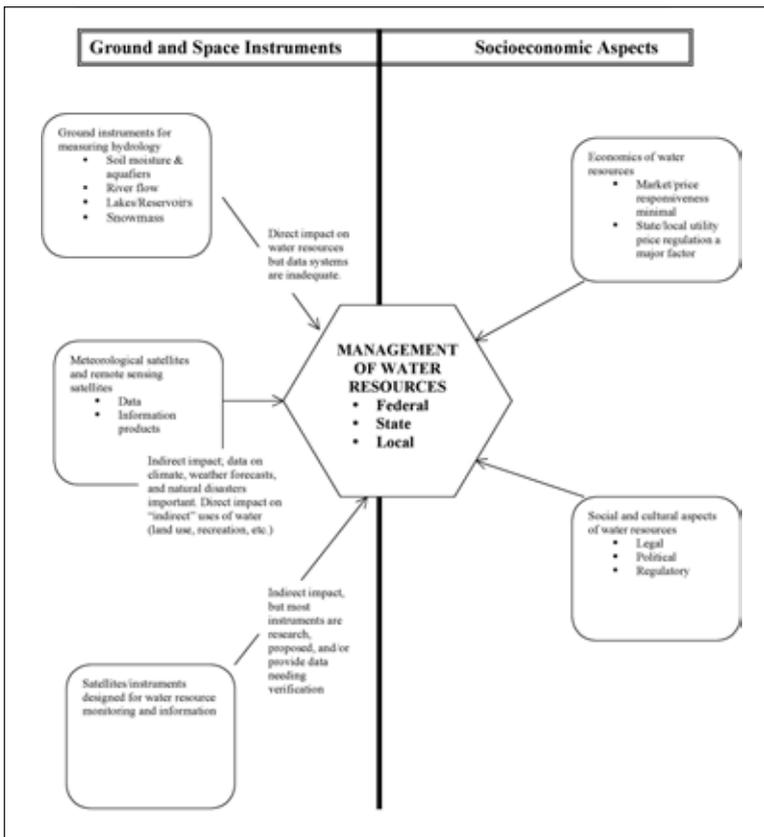


Figure 13.1—Data sources for water resource management and the use of economic models to measure the impact of weather resource data.

Despite the difficulties of actually measuring the socioeconomic benefits of satellite data for water resource management, satellite data can contribute numerous benefits for specific economic sectors of the economy. For example, table 13.6 illustrates the potential use of satellite data for irrigated agriculture.

TABLE 13.6—REMOTE SENSING IN IRRIGATED AGRICULTURE

Agricultural use of water for irrigation is commonly one of the highest-volume usage categories for freshwater; in the United States nearly 40 percent of freshwater withdrawals in 2002 were used for irrigation purposes.²⁶ Worldwide, on average 70 percent of water use is in the agriculture sector.²⁷ However, agriculture is not typically the highest-value use of water; municipal and industrial usages generally have greater social and economic value. As development occurs and populations grow, more pressure is felt to provide greater amounts of water to the higher-valued usages. Therefore, increasing efficiency and productivity in agricultural usage of water may provide benefit in allowing increased availability of water for higher-valued usages. Remote sensing applications are able to measure several indicators of performance related to irrigated agriculture. Applying remote sensing techniques in measuring these indicators may provide avenues to increased productivity and efficiency. A selection of these indicators is presented in the following chart.

Indicator	Remote Sensing Principle	Potential Satellites/Instruments
Crop water stress index	Surface energy balance	Landsat (Thematic Mapper)
Evaporative fraction	Surface energy balance	Landsat (Thematic Mapper)
Water deficit index	Surface energy balance	Landsat (Thematic Mapper)
Evapo-transpiration	Surface energy balance	ASTER, AVHRR
Spatial geometry of crop yield	Vegetation index	Landsat, IRS-LISS (Indian Space Research Organization—Linear Imaging Self-Scanner)
Irrigation intensity	Multispectral classification	Landsat, IRS-LISS
Crop intensity	Multispectral classification	Landsat, IRS-LISS
Irrigated area	Multispectral classification	Landsat, IRS-LISS
Soil salinity	Microwave	SMOS (planned)
Soil moisture	Microwave	SMOS (planned)

Some of these measurements are relatively robust, and some require additional research and/or the development of new sensors and new, sophisticated algorithms and modeling to make operational use of the data they provide.

The preceding sections have illustrated some of the measurable and nonmeasurable benefits from the use of Earth observations satellite data. They also pointed out some of the practical problems in measuring these benefits. The following sections elaborate these issues from a methodological standpoint.

26. S. S. Hutson, N. L. Barber, J. F. Kenny, K. S. Linsey, D. S. Lumia, and M. A. Maupin, *Estimated Use of Water in the United States in 2000* (Reston, VA: U.S. Geological Survey Circular 1268, 2004).

27. Chris Perry, "Irrigation Reliability and the Productivity of Water: A Proposed Methodology Using Evapotranspiration Mapping," *Irrigation and Drainage Systems* 19 (2005): pp. 211–221.

MEASURING SOCIOECONOMIC BENEFITS

Economic Measures

There are several approaches to measuring economic benefits:

- A macroeconomic approach that attempts to gauge the impact on the entire economy through measuring changes in GDP, employment, income, or other economy-wide parameters.
- A microeconomic approach that focuses on the impact of consumer welfare through the price mechanism; that is, with new technology and new products, the relative price of a particular good or service will decrease, which, in turn, makes consumers better off.
- An approach that focuses on reducing uncertainty in decision making, which can be evaluated in a number of ways, including assessing consumer preferences through surveys, hedonic measures (parameters associated with the attributes or use of a good or service), avoidance of a particular externality (e.g., costs of cleanup from pollution), or the value-added by using one method over alternatives (e.g., irrigated vs. non-irrigated land for agriculture).
- Other indirect or proxy measures such as counting the number of patentable inventions, number of users of a good or service, or other measures where the actual value or affect on the market is indeterminate.

The following two tables illustrate some of the many economic sectors and applications in which the impact of Earth observation data is very important. Table 13.7 summarizes some of the uses of weather and climate data in the public sector and table 13.8 in the private sector and by individuals. Often, the economic and social values of these uses are very difficult to estimate because they are spread throughout the economy and through a wide variety of entities, including local communities, families, and diverse businesses.

Major Industry	Examples of Specific Applications
Agriculture	Crop management Irrigation decisions Prevention of weather-related diseases
Energy	Planning purchases of gas and electric power Managing responses in emergency situations Managing capacity and resources
Aviation/Transportation	Optimizing flight patterns Reducing wait times on runways Avoidance of sudden volcanic plumes
Tourism/Recreation	Improving ski slope demand/production of artificial snow Marine forecasts/warnings

TABLE 13.8—USES OF WEATHER AND CLIMATE DATA IN THE PUBLIC SECTOR AND BY INDIVIDUALS	
Entity	Examples
Federal, state, local government	Managing public resources
	Managing assistance programs
	Managing disasters, emergencies
	More efficient emergency evacuation
	Reducing operational costs
	Improving operational capacity and safety of U.S. military forces
Citizens	Improving safety
	Managing daily choice of activities
	Improving quality of life
	Reducing lives lost

MACROECONOMIC MEASURES OF SOCIOECONOMIC IMPACTS/ BENEFITS OF SPACE PROGRAMS

A macroeconomic production function model can be used to estimate impacts of technological change attributed to R&D spending on the GDP and derivative measures such as employment and earnings. The results of using this type of model are expressed as a rate of return to a given investment or as a total value.

This economic formulation is best used to develop estimates of a very large program or agency because it focuses on the totality of the economic impact on the entire national economy. Even for an agency such as NASA, the \$16 billion annual budget (not all of which is either space- or R&D-related) is comparatively small in relation to the more than \$10 trillion GDP for the United States. Trying to ferret out the technology improvements attributable to a specific program such as Earth observations, attribute these improvements to a particular budget line, and then estimate their impact on the economy is extremely speculative on a macroeconomic level.

Another approach to a consolidated measure of benefits is to add up the measured benefits in particular industrial sectors from microeconomic studies to a U.S. or national total. This also yields inappropriate and unreliable estimates. The reason for this is not the logic of the addition, but simply that different point estimates for different products and sectors, coupled with somewhat different econometric methodologies and different time periods, amount to adding up apples and oranges and fails virtually all tests of validity and reliability.

Microeconomic Measures of Space Applications

As appealing as a single number to aggregate all of the benefits from space R&D (or even just from the R&D spent on Earth observations) may be, economists have turned to using more focused examples to measure impacts and benefits through the tools of microeconomics. Analyses at the industry, firm, and product or service levels have been able to provide a useful window on the benefits derived from Earth observations. Several different tools are used for these analyses.

The first is based on the benefits consumers realize from lower prices and greater capability from innovations. If the results of R&D can be translated into goods and services that are less expensive, then the benefits can be measured by the amount “saved” from not having to pay as much as without the new products or services. Conversely, producers can also benefit from being able to offer more products and services at lower prices. The distribution of benefits between consumers and producers depends on the market structure of the industry and products. For Earth observations, these types of benefits can be analyzed by comparing the costs of obtaining weather and land use data from nonspace sources (airplanes, ground measures, etc.) with the costs of buying satellite imagery. Clearly, the greater the area that needs to be observed in detail, the larger the benefits from using space imagery. In many cases, space imagery provides new services that were not available through more traditional methods.

Although cost/benefit analyses are derived from this general framework, the results of those analyses are inherently inaccurate. The costs involved are largely from government expenditures for mission-oriented, dual-use, public goods and are very difficult to isolate program-by-program and mission-to-mission. One should note that cost/benefit analysis was developed to analyze the impacts of regulatory measures (a true before-after situation) rather than on the impacts of new technologies, many of which have no comparable “before” market uses.

Another microeconomic method is the examination of data that provide evidence of the direct transfer of technology from federal space R&D programs to the private sector. The results of these analyses are reported as actual numbers measured (number of patents or inventions, value of royalties, value of sales, etc.). They are rarely compared to associated government expenditures, again because of the difficulty of linking general government funding to specific products or patents.

Qualitative analyses of the benefits of Earth observations, which range from monitoring vegetation and tracking hurricanes, to national security operations, focus on descriptive case studies. Although these activities may have a clear positive effect on human life, valuing the information in a market/price format does not fully describe their impacts.

In summary, there are numerous methods for valuing the impacts of new and better goods and services from Earth observations. Each is useful for particular purposes and in particular situations. No measure can capture the entire impact. The best that can be done is to take particular uses of Earth observation data that have been studied in detail and report on the benefits from those uses.

Reducing Uncertainty

The creation and distribution of accurate weather forecasts involves several elements, beginning with scientific research and continuing through to the delivery of information to government agencies, businesses, and consumers. The process can be viewed both over time (i.e., research results may precede actual use of information by end-users) and at a given point in time (the institutional system structure of information delivery). Measuring the value of information therefore requires evaluating a complex process and has typically only been attempted through studies of specific, isolated examples.

Benefits to society derive from public investment in increasing the amount and the quality of information about natural processes such as weather and climate. Increased scientific knowledge per se generates real benefits. For example, better observations of the geophysical processes that influence weather and climate help advance scientific knowledge directly, or indirectly, by providing better data for calibrating scientific models and/or testing scientific hypotheses. However, despite considerable research on the topic, no accurate metrics exist that enable economists to determine both the quality and the future monetary value of economic benefits that may arise from acquiring new knowledge. Indeed, even the use of peer review and other methods of selecting future scientific missions cannot predict with accuracy the success of such scientific pursuits in operations.

Nevertheless, better information about weather and climate provides tangible socioeconomic payoffs that, at least in principle, lend themselves to quantification. These benefits derive from the fact that weather and climate information can help reduce uncertainty in several ways, as illustrated in the following sections.

IMPROVED CIVIL GOVERNMENT AND MILITARY PLANNING

Weather conditions have a major role in government planning for such tasks as administering forests, grasslands, and other lands under federal management. The 2000 fire in Los Alamos, New Mexico, provides an instructive example. In that case, a fire that was deliberately set by federal officials to reduce the load of dry underbrush raged out of control when the winds turned unfavorable. Better local weather forecasts of wind conditions²⁸ might have prevented the devastating effects of that fire—reducing or eliminating the severe social and economic effects of that experience. Also, weather forecasts at airports can reduce operational costs. A 1995 Australian study found savings of \$6–\$7 million per year from improved fueling decisions.²⁹

28. Keith Easthouse, "Park Service Unfairly Scapegoated for Los Alamos Fire," *Forest Magazine*, April 2001, <http://www.forestmag.com/losalamosfire-update.fjm> (accessed 24 August 2007).

29. Roy J. Leigh, "Economic Benefits of Terminal Aerodrome Forecasts (TAFs) for Sydney Airport, Australia," *Meteorological Applications*, Volume 2, (Royal Meteorological Society, 1995), pp. 239–247.

Military operations, whether in war or peacetime, are affected by weather conditions. The military services need accurate weather information in order to increase personnel safety and to gain an information edge over adversaries. Accurate weather forecasts can reduce operational costs by allowing commanders to make better decisions regarding movements and deployments of troops. For example, accurate information regarding winds, sea state, and ocean currents can enable ships to follow more cost-effective courses than would be possible without such information.

Responding to Natural Hazards

The unexpected and severe flooding of the many major rivers in Europe and China in the summer of 2002 and the 1998 devastation in Central America from Hurricane Mitch serve as reminders of the potentially huge economic costs of natural hazards. Better prediction of weather and climate cannot reduce the likelihood that severe weather events will occur but can help substantially lower the costs to society of such events. These cost savings come in two forms: 1) people are more likely to invest in loss-reduction activities when better information is available and 2) better information can also reduce economic costs that arise when uncertainty about adverse weather causes government authorities, people, and business to “err on the side of caution” and undertake what later turn out to be unnecessary loss-reduction activities.

Improved Industrial Planning

Reducing uncertainty about weather and climate facilitates the process of planning in a variety of industrial sectors. More accurate predictions about future weather and climate enable farmers and agribusinesses to estimate future crop yields, leading to reduced uncertainty about yields and prices. In economic terms, such reduced uncertainty translates directly into better use of scarce productive resources, as well as dampening the fluctuations in prices of agricultural products. Similarly in the energy generation industry, improving the predictive ability of forecasts by an average of only one degree can result in more efficient use of power generating resources and can mean hundreds of thousands of dollars saved each year for electric utilities.³⁰ Many utilities employ their own forecasters at a high annual cost because of these potential large savings. Weather forecasts are also critical for airline operations since better forecasts will reduce operational costs (mainly by saving fuel and improving safety) at airports and in-flight.

30. National Oceanic and Atmospheric Administration (NOAA), Geostationary Operational Environmental Satellite System (GOES), “GOES-R Sounder and Imager Cost/Benefit Analysis (CBA),” prepared for the GOES Users Conference, 1–3 October 2002, Boulder, CO, http://www.osd.noaa.gov/goes_R/goesrconf.htm (accessed October 2002); Del Jones, “Forecast: 1 Degree Is Worth \$1B In Power Savings,” *USA Today*, 19 June 2001. Note that other factors, including political and regulatory actions, can overshadow any savings from forecasts. For example, the wild fluctuations in price and energy availability in California over the past several years resulting from a policy of deregulation would make an economic analysis of separating out the price and efficiency effects of better forecasts very difficult.

Insurance and Hedging against Uncertainty

Finally, providing better information concerning the probabilities of weather-related events also enables the emergence of markets that help mitigate the economic and financial consequences of uncertainty. These markets, which allow the consequences of uncertainties to be “priced” in the form of insurance and hedge contracts, are able to function because information about weather and climate makes it possible to attach probabilities to uncertain events.

In each of these instances, however, new information has value only to the extent that more scientific information reduces uncertainty in ways that are economically valuable. In the case of planning for and responding to natural hazards, information about weather and climate will be valuable to the extent that 1) having more information provides a measurable or significant reduction in uncertainty and 2) reducing uncertainty “matters” in the sense that having more reliable information has the potential to affect choices made by individuals, businesses, and government. Similarly, increased scientific knowledge about weather and climate, by itself, does not facilitate pricing in insurance and/or hedge markets if this information cannot be translated into the probability distribution of future weather events and then efficiently distributed to users.

The value of information has particularly interesting qualities. Before information is released to potential buyers (*ex ante*), the value to a potential user of the information is not known. Information has economic value only when it is actually used. The transmission of information gained from analysis of data from the environmental satellites to end-users is complex and much information is ignored, lost, or not used. Even if information is disseminated in a timely fashion, sometimes the interpretation may not be clear and potential benefits will disappear. Who will ultimately pay for the information, how much they will pay for it, and what is the actual value of the information are all difficult to evaluate until after the information is obtained and actually used.

Derivatives

Virtually all companies face financial risks from unexpected variations in temperature, precipitation, and other weather-related events. In order to reduce the financial risk that unexpected weather variations might cause, companies whose income depends significantly on the weather are likely to make use of use financial instruments such as weather derivatives to hedge against major losses from unpredicted weather. Whether it is a ski resort protecting itself from a warm winter or an electric utility hedging against price increases in fuels from a cold winter, actual market transactions can provide a window on the value of these natural events to businesses.

Weather derivatives are financial instruments that act very much like puts and calls in the stock and futures markets, and are specific to each company, location, and type of weather condition (temperature, precipitation, wind speed, snowfall, etc.). They tend to cover short periods of time (typically, two weeks to one season in

length) and the contracts are usually written to limit the seller's financial exposure. Since they are traded on markets developed for this purpose, the makers of the markets charge a fee (premium) for this service. Since derivatives are especially relevant to business market transactions and are not well understood outside of the industry, they are useful in providing a view of an often-overlooked indicator of the value of weather forecasts.

Purchasing derivatives reveals one facet of the economic value of information on weather and business activity. In March 2003 an analysis of the weather derivative market reported a total of 7,239 contracts (from both a survey of the industry and the contracts reported from the Chicago Mercantile Exchange) with a notional value of nearly \$4.2 billion. More than 98 percent of these weather derivative contracts have been based on temperature (the rest were based on precipitation).³¹

Although satellites play a long-term role in improving the accuracy of forecasts and of historical data, the information from satellites tends not to affect the short-term assessment of risks for weather derivatives since these risk assessments are based on history, not on predictions. Nevertheless, future improvements in predictive capabilities (particularly from improvements in satellite instrumentation and data distribution) may well influence the derivative market.

Clearly, as weather prediction capabilities improve, the *potential* for directly using satellite data for derivatives (along with other weather information) will become economically and financially more feasible. As real-time data become more accurate, the historical time series in future years will improve. Satellite weather data will have a great influence on the market and price volatility of weather derivatives.

SUMMARY AND CONCLUSIONS

The preceding short descriptions of socioeconomic benefits from satellite Earth observations data illustrate some of the existing and potential contributions that these systems make to the economy and to societal well-being. It is clear in examining such cases in more detail that numerous impediments in U.S. institutions and in organizational culture prevent government agencies and private companies from taking full advantage of the benefits these data supply. Impediments include the mixed record of NASA and NOAA in moving research findings to operational use; lack of knowledge within companies and local communities about the benefits satellite data can bring to them; institutional inertia and reluctance to make investments in new ways of conducting operations; and the necessary costs of training and equipment to upgrade operations.

31. PricewaterhouseCoopers, "The Weather Risk Management Industry: Survey Findings for November 1997 to March 2001," prepared for The Weather Risk Management Association, Washington, DC, June 2001 (updated in 2003).

Further, it is apparent that we cannot develop a reliable overall estimate of what we know intuitively must be true—that the benefits from Earth observations from space have had a huge and significant impact on the economy. The quality of life, the ability to protect our nation, and the ability to manage environmental and natural resources are very much improved by the use of space-based instruments.

The considerations in this paper suggest that increases in *scientific* information about weather and climate do not automatically or immediately create information that is of *economic* value. A direct implication is that the mix of government-funded projects could change over time depending on how policy makers take into consideration the balance between the economic and commercial value of Earth observations and the research, scientific, and qualitative (social) value of Earth-sensing activities.³²

The value of weather and climate information itself has been shown to be relatively small as a percentage of the economy.³³ However, when dealing with weather and climate where each year billions of dollars of property is damaged and many lives are lost as a result of severe weather events, even a small improvement in predictive capability can add up to major savings.³⁴

Despite these concerns and the methodological measurement difficulties we have enumerated, government agencies and private companies derive sufficient benefit from many of the systems to justify continued and expanded government investment in them, especially when their utility for nonquantifiable international and national security operations is taken into account. Nevertheless, especially in an era of substantial pressure on the discretionary portion of the federal budget, decision makers will continue to press for hard evidence that the investments are worth the cost. Part of this presents a dilemma. Increases in technological capabilities will advance the potential of benefits; however, without a corresponding increase in providing incentives to users and in moving the research results to operational capabilities, it will be very difficult to achieve greater economic benefits, particularly those that can be measured quantitatively.

32. It should be clearly recognized that these two goals are not mutually exclusive, due to the dual-use nature of most Earth observation data. In other words, providing data that has social value also contributes to economic and commercial uses.

33. A good review of some of the economic issues in measuring the value of weather information can be found in Molly K. Macauley, "Some Dimensions of the Value of Weather Information: General Principles and a Taxonomy of Empirical Approaches," <http://sciencepolicy.Colorado.edu/socasp/weather1/macauley.html> (accessed March 2002).

34. For a review of the magnitude of losses from extreme weather, see Tom Ross and Neal Lott, The National Climatic Data Center, <http://www.ncdc.noaa.gov/oa/climate/research.html> (accessed 30 November 2006); "Extreme Weather Sourcebook 2001," <http://sciencepolicy.Colorado.edu/sourcebook/data.html> (accessed 28 July 2007). Other compilations can be found in "Natural Disasters 2000, Annual Review," (Munich, Germany: Munich Re; also available as a CD-ROM); A. Arguez and J. Elsner, "Trends in U.S. Tropical Cyclone Mortality During the Past Century," (Florida State University: Tallahassee, FL, 11 April 2001).

Hence, additional research on socioeconomic benefits will be essential, quantifying where possible the economic benefits satellite systems provide to the U.S. economy. Our research so far demonstrates, among other things, that too little effort has been put into this important task. The recent National Research Council study, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, underscores this need in its Chapter 5: Earth Science Applications and Societal Benefits.³⁵

35. National Research Council, Committee on Earth Science and Applications from Space, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (Washington, DC: National Academies Press, 2007).

