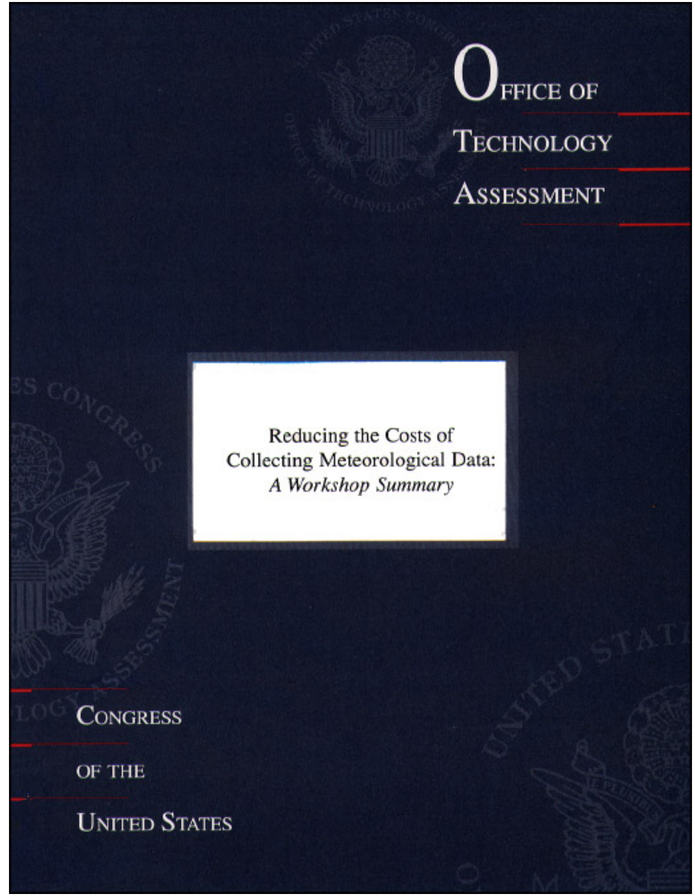
Reducing the Costs of Collecting Meteorological Data: A Workshop Summary

June 1995



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Reducing the Costs of Collecting Meteorological Data

Information about the Earth obtained from satellite systems assists the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) in conducting its legislatively mandated programs to provide weather and flood forecasts and warnings for the American public, improve public safety, and provide weather information for commerce and science. NOAA's National Environmental Data and Information Service (NESDIS) operates two meteorological satellite systems—the geostationary operational environmental satellite (GOES) system and the low Earth orbit (LEO) polar-orbiting operational environmental satellite (POES) system in support of the meteorological data needs of the NWS. The Department of Defense's (DOD's) Defense Meteorological Satellite Program (DMSP) provides similar meteorological data to support the surveillance, war-fighting, and peacekeeping operations of U.S. military forces. Under normal operating conditions, each system consists of two satellites in orbit and the associated satellite control and data receiving stations, data archives, and data distribution networks. Appendix A summarizes the technical characteristics of these systems and outlines their planned development and launch schedules.

Satellite systems are inherently expensive because spacecraft cannot be readily and cheaply reached for servicing and must be designed to operate autonomously for years. In addition, launching satellites to orbit is expensive.[1] Because space systems' costs

[1] See U.S. Congress, Office of Technology Assessment, *The National Space Transportation Policy: Issues for Congress*, OTA-ISS-620 (Washington, DC: U.S. Government Printing Office, May 1995) for a discussion of current efforts to reduce the costs of reaching space.

are high, policymakers are exploring a variety of means to reduce costs. The two U.S. polar-orbiting meteorological satellite systems serve different users, yet they provide similar data. For example, both satellites collect images of Earth's cloud cover and surface.[2] Hence, in order to reduce the costs of collecting meteorological data from satellites, the Administration, with the encouragement of Congress, has undertaken the consolidation of DOD's DMSP system and NOAA's POES system, an effort that fell short in the past.[3] This convergence, which has just gotten under way this fiscal year, is expected to achieve its major cost savings in the next century as the number of U.S. polar-orbiting spacecraft declines from four to two (Appendix A). Yet Congress is facing the task of drastically reducing federal spending over the next few years, as well as over the longterm. Hence, the Subcommittee on Energy of the House Committee on Science asked the Office of Technology Assessment (OTA) for assistance in exploring options for reducing the costs of collecting meteorological data, focusing especially on NOAA's satellite programs.

In connection with its assessment of Earth observations from space,[4] OTA convened a one-day workshop on "Reducing the Costs of Collecting Meteorological Data." The workshop was designed to explore in preliminary fashion the range of technological and programmatic options for reducing costs as Congress considers the content and costs of federal efforts to gather and distribute meteorological data. The workshop gave officials from NESDIS, NWS, DOD, NASA, industry representatives, private data users, and the university community an opportunity to explore these options as a group (appendix B).[5]

These options fall into two general categories: 1) actions that NOAA might take with sufficient support of Congress and the Administration; and 2) efficiencies and other advantages that might be gained by encouraging greater interagency cooperation, international coordination, and reliance on the private sector. Factors behind these options include NASA's past and current role in developing space systems of meteorological relevance, current plans to consolidate DOD and NOAA polar-orbiting systems, the increasing sophistication of foreign meteorological data collection systems, and the expanding role of private companies in space. Most of the options explored for possible future savings entail significant technological and programmatic risks. The workshop discussion underscored the circumstance that operational systems on which the nation depends have a relatively low tolerance for risk, resulting in a need for conservatism in making system changes.

In general, **although workshop participants expressed varied opinions about the issues raised in this short background paper, they all agreed that satellite observations remain critical to the collection and use of meteorological data**. Satellite data provide a perspective on glob-

[2] However, the imagers on the two satellites emphasize different measurements. The Optical Linescan System (OLS) aboard the DMSP satellite monitors cloud cover, while the Advanced Very High Resolution Radiometer (AVHRR) aboard the POES satellites additionally gathers multispectral data on the Earth's land and ocean surface.

[3] DOD and NOAA have collaborated in eight previous convergence studies, most of which contributed to operational improvements and closer cooperation between DOD and NOAA. However, attempts to meld the systems into a single one always failed on grounds that such a move would weaken U.S. national security without appreciably lowering overall system costs, and agency concerns over whether a single system would serve both civilian and military user communities adequately.

[4] Carried out for the House Committee on Science; the Senate Committee on Commerce, Science, and Transportation; the House and Senate Appropriations Subcommittees on Veterans Affairs, Housing and Urban Development, and Independent Agencies; and the House Permanent Select Committee on Intelligence.

[5] The workshop did not address questions of NOAA's (or any other agency's) ability to estimate and control programmatic costs or to manage its programs.

al weather and climate that neither surface-based nor in-situ measurements can provide. GOES sensors, for example, provide synoptic[6] data for regions between 60º N and 60º S latitudes, allowing forecasters to follow both large- and small-scale storms affecting the United States. The polar-orbiting satellites provide data in areas of the globe, such as the poles and the oceans, not covered by other measurement systems. These data are needed to support the forecasting models of the NWS and the needs of the military in planning a variety of operations, including classified programs.

Workshop participants also agreed that satellite observations, which average data over wide geographic areas, need to be supplemented by surface-based and in-situ meteorological measurements, especially over the conterminous United States. Radar, radiosondes, and other observations provide detailed profiles of temperature and pressure through the lower atmosphere and direct measurements of storm structure and intensity. Data from these systems, operated by the NWS, can be used to calibrate satellite measurements. **Surface-based, in-situ, and space-based measurements are all necessary to continue to provide the quality of weather forecast information now available, and to support future improvements in service**.

The following discussion, which summarizes the principal points of the workshop, centers around answers to several primary questions directly related to reducing the costs of providing meteorological data:

- *Are there ways to realize economies in the NOAA satellite budget, while providing the functional equivalent of the existing NOAA satellite systems in collecting the meteorological data required by the National Weather Service and for other public uses*?
- *Can the 10-year development cycle for new satellite systems be shortened without incurring unacceptable cost and schedule risk*?
- *How can the process of inserting new technology into an operational system be improved?*
- *What potential is there for improving the use of existing satellite and other data sources in weather forecasting and warning?*
- *How do NOAA's programs fit with other national and international Earth observations programs?*

Detailed investigation of these questions and the development of specific options for congressional action would require a much more extensive effort than reflected in this short background paper.

Alternative Means for Collecting Meteorological Data

Are there ways to realize economies in the NOAA satellite budget, while providing the functional equivalent of the existing NOAA satellite systems in collecting the meteorological data required by the National Weather Service and for other public uses?

Workshop participants answered this question with a qualified "yes." The workshop devoted extensive discussion to alternative means of collecting meteorological data. However, most participants also agreed that NOAA has worked diligently to develop cost-effective systems capable of meeting the data requirements of its NWS and other federal data users. Because of the need to maintain continuity of data delivery, NOAA has developed a conservative approach to replacing failed satellites and to developing new satellite systems.[7] Several workshop participants cautioned that changing the existing goal of maintaining two fully operational GOES and POES satellites in orbit or stretching out the replacement schedule by counting on achieving longer average satellite lifetimes might lead to unacceptable breaks in service that could harm the U.S. economy and threaten public safety. **As an operational**

[6] I.e., images of large portions of the Earth from the same point of view at one time.

[7] In pursuing the GOES-Next development, NOAA and NASA deviated from this conservative approach which led to higher costs.

agency upon which many thousands of data users depend, NOAA's approach to the development of new satellite systems is necessarily much more conservative than NASA's. Should a NASA research and development satellite fail or be delayed, the consequences are much less than if one of NOAA's satellites were to fail or be delayed.

Nevertheless, most participants agreed that the potential of using smallsats[8] or commercial satellite systems as possible substitutes or adjuncts for the proposed GOES and POES systems warrants further investigation by NOAA and experts external to NOAA. The workshop also discussed the use of ground systems and in-situ measurements to supplement satellite data and to provide data backup. The following paragraphs summarize the workshop discussion regarding alternative means of data collection.

- ***Smallsats.*** The existing multiple-sensor platforms (GOES, POES, and DMSP) co-locate sensors aboard a single spacecraft, making possible simultaneous measurements of related weather characteristics. Scientists have transformed the resulting data into a plethora of useful information. Yet system operators and data users might benefit from the greater flexibility allowed from using smaller satellites. Recent experience in developing smallsats for communications and remote sensing services suggests that smallsats carrying a few instruments might provide a wide range of benefits, including the ability to insert new technology into an operational system and the advantage of replacing failed sensors more flexibly than possible today.

For example, the current satellites can be deemed "non-operational" after suffering the loss of only one critical sensor, such as the advanced very high resolution radiometer (AVHRR) aboard the POES satellites.[9] Replacing a failed sensor with an identical one flown on a smallsat might prove cheaper than orbiting an entire multi-sensor replacement satellite.[10] Smallsats might also be used to remove some sensors from the larger satellites (e.g., Search and Rescue, ionospheric sensors, ARGOS), thereby reducing large satellite cost and complexity while perhaps providing a market for the smallsat interests. The current experiment to obtain temperature and humidity soundings by occultations of global positioning satellite (GPS) signals uses a GPS receiver on a smallsat. Initial results appear promising.[11]

Smallsat providers, who are building smallsats for Earth remote sensing and communications, seem eager to develop such services. However, these programs are in the very early stages of development and flight, so their utility, especially for operational purposes, is not yet tested.[12] In addition, some current instruments on NOAA satellites are too heavy to be accommodated on small spacecraft. Determining whether smallsats could perform a cost-effective role in collecting meteorological data would require the analysis of many technical, management, and legal issues. These issues include: whether smallsats could fly in formation and provide the necessary data quality and operational capability at lower costs; smallsat platform stability; the budgetary effects of changes in procurement rules; the acceptance

[8] I.e., satellites of 500 kilograms or less.

[9] NOAA will continue to operate other instruments aboard a satellite on which one instrument has failed.

[10] However, the size of the existing sensors aboard POES and GOES satellites do not lend themselves to smallsats. Hence, new sensors would have to be developed.

[11] C. Rocken, T. Van Hove, J. Johnson, F. Solheim, R. Ware, M. Bevis, S. Chiswell, and S. Businger, "GPS/STORM-GPS Sensing of Atmospheric Water Vapor for Meteorology," *Journal of Atmospheric and Ocean Technology*, June 1995 (in press).

[12] For example, Orbital Sciences Corporation has had difficulties bringing two of its Orbcomm data communications smallsats on line to support the Orbcomm system. See Warren Ferster, "OSC Recovers Orbcomm 2, Orbcomm 1 Remains Down," *Space News*, May 22, p. 1, 21.

of smallsat data by the data users; and the cost and feasibility of developing new ground controlling and data processing architectures.

- ***Commercial options***. Leasing space on commercial satellites for sensors or purchasing data and information services from commercial providers could also be explored. Some GEO communications satellites fly in orbits that would allow continuous observation of Alaska, Hawaii, and portions of the coterminous United States. The developing low Earth orbit (LEO) smallsat communications constellations also might be used to fly small meteorological sensors. Participants warned that the option of leasing sensor space on commercial satellites might be much more expensive than providing the sensors on government-owned satellites. For example, on GEO communications satellites, for a given launch vehicle capacity, a pound of satellite given up to carrying an Earth sensor means less station keeping fuel for the satellite, therefore reducing the substantial income possible from providing communications services.[13] For LEO satellites, where stationkeeping is less of an issue, volume and weight constraints on additional instruments may inhibit use of such resources. Nevertheless, several participants suggested that such an option should be explored, and the cost estimates examined in detail.

In earlier reports, the Office of Technology Assessment has suggested as an option that the government might achieve economies by making data purchase agreements with private firms, in which the government determines the data parameters and the private sector provides the required data.[14] NASA, for example, will be receiving ocean color data from Orbital Science Corporation's (OSC) SeaSat satellite when it becomes operational in late 1995. This particular arrangement is possible because 1) NASA provided much of the funding for building the satellite up front in return for five years of data; 2) OSC plans to sell data commercially, which should make it possible for OSC to earn a profit on the arrangement; 3) the data have commercial value only for a day or two, which allows NASA to distribute the data widely to scientists after a short delay without disrupting the data marketplace. Delays on the launch of SeaSat have made government officials extremely skeptical about such arrangements with the private sector for the delivery of operational data.[15] They will likely remain so until private firms demonstrate their ability to deliver data of high quality on an agreed schedule.

Data purchase agreements would have to be structured in such a way that the firms with which the government contracts would be able to earn a profit within acceptable risk to the firm and the government. This may be difficult unless the data also have commercial value. Yet, under current arrangements, most unprocessed meteorological data have only small commercial value, if any. Currently, NESDIS and NWS develop a variety of data products that private

[13] One participant from a commercial satellite firm, for example, estimated that maintaining a GEO communications satellite on orbit uses about 30 pounds of fuel. A year's revenue from a 24-transponder satellite amounts to about $12 million. Hence, placing a 30-pound sensor on a communications satellite would cost about $12 million, just for space on the satellite. Developing and integrating the sensor on the spacecraft would cost more.

[14] U.S. Congress, Office of Technology Assessment, *Civilian Satellite Remote Sensing: A Strategic Approach*, OTA-ISS-607 (Washington, DC: U.S. Government Printing Office, September 1994), pp. 15-17;

U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, OTA-ISS-604 (Washington, DC: U.S. Government Printing Office, September 1994), ch. 4.

[15] This project has experienced a variety of delays as a result of difficulties in developing the spacecraft and the Pegasus XL launcher that will launch the satellite. This has led to a loss of scheduled data delivery to scientists and other users. However, should the satellite prove operationally successful, it could contribute to changing the way the government provides for its remotely sensed data needs. See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., ch. 4.

weather forecasters use as a basis for their targeted weather forecasts markets.

The commercial value of meteorological data might increase in the future if policy changes allowed the privatization of some NWS and NESDIS functions.[16] European countries, for example, have privatized some of their weather forecasting functions and now charge private firms for providing and processing meteorological data. The United States has heretofore maintained a policy of open access to all Earth observations data (generally free or at the cost of reproduction)[17] in order to support U.S. foreign policy objectives and the use of data in science and for weather forecasting. Hence, major policy changes would require considerable study to determine their short- and long-term effects on private industry as well as on the government.

- ***Surface-based and in-situ data collection systems***. Satellite systems are vitally important to the meteorological processing communities since they provide predictable, repetitive meteorological coverage over a relatively wide range of space and time scales. As noted earlier, radiosondes and radar also provide essential meteorological data, especially over the continental United States. Ocean buoys have been used extensively to provide ocean surface data. Additionally, aircraft-mounted sensors yield data on weather conditions in a narrow range of altitudes along common air routes over the United States and international routes served by U.S. carriers. Other sources of data include the radars on board the Aegis-class Navy ships. Surface-based data are also critical to calibrating satellite sensors and validating information derived from the satellite systems.

Several workshop participants believed that the coordination of satellite observations coincident with other collection methods could be improved. Early user participation in the system development process and all through the development period would assist greatly in coordinating the data from ground systems with satellite data, and might uncover additional opportunities for cooperative, cost-saving efforts.

Workshop participants also discussed whether modest improvements in radar and other non satellite systems would provide sufficient backup for the satellite systems in the event of a satellite loss. For example, they briefly discussed the utility of over-the-horizon (OTH) radars for gathering data on surface winds over the oceans on either coast, and the use of NEXRAD radars for offshore storm measurements. OTH systems can provide long-range data on surface winds and storm movements.[18] However, they are relatively expensive to operate. Line-of-sight NEXRAD radars are limited in utility to about 150 miles beyond the facility because of the curvature of the Earth. The workshop also briefly discussed the potential for using unpiloted air vehicles (UAVs), which are under development for surveillance and atmospheric research,[19] and the potential use of GPS occultations, mentioned above, to provide soundings of temperature and humidity. Although the workshop reached no

[16] Several reviewers, however, expressed considerable skepticism regarding the likelihood that the commercial value of meteorological data would increase substantially.

[17] The exception has been the data from the Landsat satellites, which are sold by EOSAT, a private corporation that manages the Landsat satellites for the federal government. See U.S. Congress, Office of Technology Assessment, *Remote Sensing and the Private Sector: Issues for Discussion*, OTA-TM-ISC-20 (Washington, DC: U.S. Government Printing Office, March 1984), ch. 4, for a discussion of public and private goods as they relate to remote sensing.

[18] OTH radar uses the reflective properties of the ionosphere at HF frequencies to "bounce" the radar beam long distances.

[19] See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, OTA-ISC-558 (Washington, DC: U.S. Government Printing Office, July 1993) pp. 124-125. See also U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, OTA-BP-ISS-122 (Washington, DC: U.S. Government Printing Office, November 1993), p. 3; ch. 3.

conclusion on these issues, several participants suggested that detailed exploration of the current relationship between surface-based collection systems and satellite systems was warranted. The NWS through its North American Atmospheric Observing System (NAOS) Program is in fact seeking to assess the performance of various mixes of satellite and ground-based observation systems, using quantitative tools such as Observing System Simulation Experiments (OSSEs). However, this plan will not be fully implemented before calendar year 1997.

Shortening the Development Time for New Satellite Systems

Can the 10-year development cycle for new satellite systems be shortened without incurring unacceptable cost and schedule risk?

NOAA and NASA, which is NOAA's agent for spacecraft procurement, arrived at a 10-year development cycle for new satellite systems over many years of developing systems. The planned cycle includes about one year for concept studies (Phase A), a three-year period of risk reduction (Phase B-engineering review) during which scientists and satellite engineers demonstrate the feasibility of the chosen design, and six years for production (Phase C&D). Workshop participants generally agreed that NOAA might be able to cut a year or two from this cycle if NOAA, helped by the Office of Management and Budget and Congress, were able to streamline the procurement steps during the phases, reduce documentation requirements, and work with contractors to shorten their development schedules.[20]

However, several participants warned that attempting to shorten the time for detailed system studies and testing might lead to increased probability of failure and higher costs. For example, during development of the GOES-Next series of satellites (GOES I through GOES-M) during the early 1980s, NOAA decided to bypass the Phase B engineering review, during which spacecraft designers and users evaluate the new satellite design and scrutinize any major design changes from the previous satellite designs. That and other factors regarding the GOES procurement led to serious delays with the GOES-Next development and substantial additional cost to the program.[21]

NASA could help by focusing some of its R&D efforts on developing new instruments and spacecraft for NOAA. NASA's experience with its smallsat program may lead to new insights and new practices that can substantially shorten development time. Once NASA proves the viability of using smallsats for research and development purposes, NOAA may learn enough to be able to incorporate smallsats in its operational program.

The workshop examined the issue of whether to proceed now with detailed planning of the NPOESS and follow-on GOES systems (GOES-R and beyond) or to examine new ways of doing business. Based on historical experience, program officials fear that waiting to start an approved program may result in permanent budget cuts and program realignments. Yet, the programs discussed in the workshop have enjoyed long and successful histories and there is no reason to assume they will achieve anything less in the future. Additionally, all these programs have considerable documentation to facilitate the future successful development of systems. Ultimately, the

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[20] NASA is experimenting with procedures to shorten its development and procurement procedures. Although the necessity to provide continuity of data from an operational system may mean that some of NASA's procedures would not work effectively for NOAA, early experience suggests that NOAA could benefit by studying NASA's experience closely.

[21] See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., pp. 38-39.

driver for development of a new system is the estimated date a replacement system would be needed.

Technology Insertion

How can the process of inserting new technology into an operational system be improved?

Operational information systems require an unbroken supply of data from the satellite systems. They therefore require backup capability in space and on the ground and a guaranteed supply of replacement hardware. In turn, these requirements translate into maintaining a proven production capability when new versions of operational satellites are introduced. They also require a parallel effort to improve system capability continuously without jeopardizing ongoing operations. Finally, new technology must be introduced without placing an undue financial burden on the operational system. **Workshop participants agreed that the transition from research instrumentation to operational instrumentation can be successful when managed with a disciplined, conservative approach toward the introduction of new technology.** In addition to minimizing technical risk, minimizing cost has been an important factor in the success of operational programs, especially for NOAA.

During the 1960s and 1970s, the successful development of NOAA's operational weather satellites was assisted by both a vigorous R&D program within the agency and by strong ties to several NASA programs, especially OSIP (Operational Satellite Improvement Program) and NIMBUS.

- ***Operational Satellite Improvement Program***. Throughout the 1960s and 1970s, NASA assisted with the development of NOAA operational satellites through OSIP. For example, NASA built and paid for the launch of the first two geostationary operational satellites that NOAA operated. TIROS-N, the prototype for the modern NOAA POES satellite, also started out at NASA. OSIP ended in 1981 as NASA withdrew from its interagency agreement with NOAA.[22] NASA's support for NOAA operational programs continued but was carried out with NOAA's reimbursement of NASA. The end of the NASA-NOAA partnership may have contributed to the subsequent difficulties NOAA experienced in the development of GOES-Next. It also marked a lessening of support within NASA for the development of operational meteorological instruments. Instead, NASA became more focused on experimental research instruments designed to support basic scientific investigations.
- ***NIMBUS***. The NIMBUS program began in the early 1960s. Initially, NASA conceived of NIMBUS as an Earth observation program that would provide global data about atmospheric structure. In addition, NASA intended to replace its TIROS satellite with NIMBUS and to use it to develop an operational series of weather satellites for NOAA. Instead, NOAA chose to focus on TIROS as its operational system, in part to minimize technical risk. NASA used the NIMBUS program as a research test bed for observational payloads. Eventually, NASA launched a total of seven NIMBUS satellites with payloads that have matured into advanced research and operational instruments for current and planned spacecraft including POES, DMSP, UARS (Upper Atmosphere Research Satellite), and EOS.[23]

Workshop participants underscored the perception that the existing process for inserting new technology into the NOAA satellite systems was inadequate. Officials from NOAA and NASA have been discussing ways in which

[22] NASA was faced with a tightly constrained budget, the result, in part, of Shuttle cost overruns.

[23] See H.F. Eden, B.P. Elero, and J.N. Perkins, "Nimbus Satellites: Setting the Stage for Mission to Planet Earth," *EOS, Transactions, American Geophysical Union* 74(26):281-285, 1993.

the two agencies might once again collaborate more closely to provide NOAA with a new means to insert advanced technology into the NOAA program. Smallsats, such as the "Lewis and Clark" satellites[24] NASA is developing for surface remote sensing, or NASA's New Millennium Spacecraft Program, might offer a means to accomplish this goal. However, the two agencies must overcome institutional barriers within the Administration and Congress in order to make this successful. Currently, NOAA does not have sufficient funding to manage the development of new technology.

Following the paradigm of the series of GOES User Conferences[25] might provide the scientific groundwork to enable the systems to be more flexible in inserting new technologies and might set the terms for serving a broader marketplace for meteorological data and data products. A series of focused workshop/conferences of several days' duration could also provide innovative ideas to improve technology insertion. These efforts would also provide a basis for industry to plan technology developments in concert with operational needs.

Improving the Use of Existing Data Sources

What potential is there for improving the use of existing satellite and other data sources in weather forecasting and warning?

The data user/information provider community present at the workshop appeared to be skeptical of the need for proceeding immediately with planning for the development of new sensors and spacecraft. The lead times for complex hardware systems are long but so are the lead times for algorithm and model development (e.g., the European Remote Sensing Satellite (ERS)-2 has been launched and ERS-1 data are still not used operationally at the European Center for Medium Range Weather Forecasts (ECMWF) and the U.S. National Meteorological Center (NMC)). Several thought that by adopting the paradigm of a user conference focused on data requirements and the development of new forecasting models, some of these development tracks could be properly phased to ensure optimal weather prediction models when data/information become available from new or improved sensors and/or spacecraft.

Although NASA's Pathfinder activities of its EOS Program were undertaken to develop long-term trend data sets for global change research, these data sets are also useful to determine the parameters of future hardware systems, making new hardware more effective than otherwise possible. Unfortunately, system developers often consider the process of developing new information products to be secondary to hardware development. An evaluation of how the hardware development process should mesh with the development of information products would be time well spent. Quantitative methods could be used to assess the tradeoff between cost and operational effectiveness for new measurements and products.

A Strategic Plan for Earth Observations

How do NOAA's programs fit with other national and international Earth observations programs?

In its series of reports on Earth observations from space, OTA noted that the United States does not have a consistent, overall plan for Earth observations. This is the natural outgrowth of the way the United States divides responsibilities within the federal government and an authorization and appropriations process that has encouraged agencies to develop and acquire space-based remote sens-

[24] These are smallsats devoted to testing new ways of developing relatively inexpensive spacecraft and new spacecraft technology .NASA's contract with TRW calls for development of a sensor and spacecraft capable of collecting data of 30 meters resolution in nearly 400 spectral bands (Lewis) .The spacecraft under development by CTA (Clark) will be capable of sensing Earth's surface at 3 meters resolution in black and white and 15 meters in three color bands .Compared to larger satellites, however, both have relatively narrow fields of view .

[25] These were a series of regional conferences for data users.

ing systems uniquely suited to their particular needs. This has led to some redundancy and overlap of satellite systems, nationally[26] and internationally.[27] To maximize the nation's return on its investment in remote sensing technologies, to meet the needs of data users more effectively, and to take full advantage of the capabilities of other nations, Congress may wish to encourage the Administration to initiate the development of a long-term, comprehensive strategic plan for civilian satellite remote sensing.

A national strategy for the development and operation of future remote sensing systems could help guide near-term decisions to ensure that future data needs will be satisfied. By harmonizing agency priorities with overall national priorities, a strategic plan would help ensure that agencies carry out programs that serve national data needs, not just the narrower interests of individual agencies.

OTA's report, *Civilian Satellite Remote Sensing: A Strategic Approach*, discusses the possible elements of a strategic plan in some detail. A strategic plan for satellite remote sensing would provide a general framework for meeting U.S. data needs for a diverse set of data users in the public and private sectors. The plan should also remain flexible enough to respond effectively to changes in remote sensing technologies and institutional structures, and to improvements in scientific knowledge. However, developing such a plan carries certain risks. Without careful attention to the hazards that have jeopardized previous efforts to coordinate programs affecting many participants, a comprehensive plan could result in a cumbersome management structure that is overly bureaucratic, rigid, and vulnerable to failure. It could also undermine existing operational programs that have successfully met the needs of individual agencies.

Convergence of the POES and DMSP systems, and the further examination of different alternatives for the NOAA satellite program and for NASA's EOS program could provide elements of an overall strategic plan. A strategic plan would also have to incorporate the needs for non-satellite data. Additionally, it would consider in some detail how future plans of NASA and non-U.S. satellite agencies meet overall needs as well as provide possible alternatives.

[26] For example, the POES and DMSP systems, which are now being consolidated into a single polar-orbiting system.

[27] For example, the multispectral and radar surface remote sensing systems under development in several countries.

Appendix A: Existing U.S. Operational Meteorological Satellite Programs

Geostationary Operational Environmental Satellite Program

NOAA has been operating GOES satellites since 1974. GOES satellites maintain orbital positions over the same Earth location along the equator at about 36,000 km (22,300 miles) above Earth, giving them the ability to make continuous observations of weather patterns over and near the United States. Continuous measurements are necessary to monitor the formation of severe storms, which can develop in less than 30 minutes. GOES satellites provide both visible-light and infrared images of cloud patterns, as well as "soundings," or indirect profile measurements, of the temperature and humidity throughout the atmosphere. NOAA has been operating GOES satellites since 1974. Data from these spacecraft provide input to meet the forecasting responsibilities of the National Weather Service. Among other applications, the GOES data assist in monitoring storms and provide advance warning of emerging severe weather. The vantage point of GOES satellites allows for the observation of large-scale weather events, which is required for forecasting small-scale events. They have a crucial role in monitoring hurricanes. Images from GOES provide a visual summary of weather conditions across the United States and are used routinely by television weather forecasters to inform the public about impending weather conditions.

To supply complete coverage of the continental United States, Alaska, and Hawaii, the GOES program requires two satellites, one nominally placed at 75º west longitude and one at 135º west longitude. GOES-7, which was launched in 1987, and has already exceeded its five-year design life, is currently located at 135º west longitude. GOES-8, the first in the GOES-Next series of satellites, became operational in October 1994 and is located at 75º west longitude. GOES-J (now GOES-9) was launched on May 23, 1995, and will take the place of GOES-7, which will be retired. GOES satellites are designed to last about five years. NOAA plans to launch replacements as needed (table 1).

Polar-orbiting Operational Environmental Satellite Program

The POES satellites follow orbits that pass close to the north and south poles. They orbit at about 840-km altitude, providing continuous, global coverage of the state of Earth's atmosphere. Data gathered by POES includes data essential for assimilation into weather prediction models. Specific data collected include atmospheric temperature, humidity, cloud cover, ozone concentration, and Earth's energy budget, as well as important surface data such as sea-ice and sea-surface temperature and snow and ice coverage. In order to maintain continuity of data delivery, NOAA will replace POES satellites as needed, nominally on a three-year schedule (table 2).

POES satellites carry several instruments:

1. The *Advanced Very High Resolution Radiometer (AVHRR)*, which determines cloud cover and

Earth's surface temperature, including sea surface temperature and vegetation cover.

2. The *High Resolution Infrared Radiation Sounder (HIRS)*, which measures energy emitted by the atmosphere in 19 spectral bands in the infrared region of the spectrum, and one spectral band at the far-red end of the visible spectrum to infer the temperature structure of the atmosphere in cloud-free regions.
3. The *Microwave Sounding Unit (MSU)*, which detects energy in the troposphere in four areas of the microwave region of the spectrum to infer the temperature structure of the atmosphere in cloudy regions.
4. The *Stratospheric Sounding Unit (SSU)*, a three-channel instrument that has flown on all NOAA POES satellites except NOAA-12. It measures the intensity of electromagnetic radiation emitted from carbon dioxide at the top of the atmosphere, providing scientists with the necessary data to estimate temperatures through the stratosphere.
5. The *Space Environment Monitor (SEM)*, a multi-channel charged-particle spectrometer that measures the flux density, energy spectrum, and total energy deposition of solar protons, alpha particles, and electrons.
6. The *ARGOS Data Collection System (DCS)*, which consists of approximately 2,000 platforms (buoys, free-floating balloons, remote weather stations, and even animal collars) that transmit temperature, pressure, and altitude data to the POES satellite.
7. The *Solar Backscatter Ultraviolet Radiometer/2 (SBUV/2)*, which measures concentrations of ozone at various levels in the atmosphere and total ozone concentration. This instrument is flown on all POES satellites that cross the equator in the afternoon.
8. The *Search and Rescue Satellite Aided Tracking System (SARSAT, or S&R)*, which locates signals from emergency-location transponders on board ships and aircraft in distress and relays these data to ground receiving stations.
9. The *Earth Radiation Budget Experiment (ERBE)*, which was flown only on NOAA-9 and NOAA-10. ERBE measures the monthly average radiation budget on regional to global scales and determines the average daily variations in the radiation budget.

Beginning with NOAA-K, the MSU and SSU will be replaced with the Advanced Microwae Soundings Unit (AMSU)-A and AMSU-B. The AMSU-A is a 15-channel microwave temperature sounder that will greatly increase the ability to infer the temperature structure of the atmosphere in cloudy regions. The AMSU-B is a five-channel microwave humidity sounder that will allow data users to infer the water vapor structure of the atmosphere.

Defense Meteorological Satellite Program

The DMSP program collects and disseminates global environmental information for the U.S. Department of Defense. Sensors on DMSP view most of Earth twice per day. The primary sensor aboard DMSP satellites is a visible and infrared imager. Data from this sensor are also supplemented with atmospheric and oceanographic data. The current Block 5D-2 satellites are being replaced with upgraded 5D-3 satellites.

Each DMSP satellite contains the following sensors:

1. The *Operational Linescan System (OLS)*, a visible and infrared imager that monitors cloud cover. The OLS also uses photomultipliers to enable observations at very low light levels.
2. The *Special Sensor Microwave/Imager (SSM/I)*, a radiometer used for determining soil moisture, precipitation, and ice cover, has four channels and a spatial resolution of 25 to 50 km. It also provides data used to determine sea-surface wind speed, but not direction.
3. The *Special Sensor Microwave/Temperature Sounder (SSM/T1)*, used for vertical temperature sensing, has seven frequency ranges.
4. The *Special Sensor Microwave/Water Vapor Sounder (SSM/T2)*, used for determining humidity through the atmosphere, has five channels and spatial resolution of 40 to 120 km.
5. *Space Environment Sensors*: SSB/X-2, a gamma- and X-ray spectrometer; SSM, a magnetometer; SSJ/4, a precipitating charged particle spectrometer; and SSI/ES-2, a plasma and ion/electron scintillation monitor. Information from these sensors is used to predict and plan for the impact of the space environment on space systems.

The Integrated Program Office

In order to support the transition from the existing DOD DMSP and NOAA POES satellite systems to the single, converged system of the 21st century, DOD, NOAA, and NASA have set up an Integrated Program Office (IPO), composed of representatives from each agency. The IPO is funded by NOAA, DOD, and NASA.[1] Each agency has the lead on one function of the operational system—acquisition (DOD), operations (NOAA), and technology transition (NASA)—but each functional office includes representatives of all agencies. This arrangement is designed to institutionalize each agency's incentive to support the overall system.

The IPO has begun planning for replacing the existing DOD and NOAA operational polar-orbiting systems of four satellites and associated support systems with a three-satellite U.S.-European system beginning around the year 2005. The United States will fly one satellite with an early morning equator crossing to support DOD's need for cloud observations and other early morning data, and one satellite with an afternoon equator crossing. The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) plans to contribute a similar satellite to the converged system, which would cross the equator in mid-morning.

[1] NASA provides personnel only.

Appendix B: Workshop Participants

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