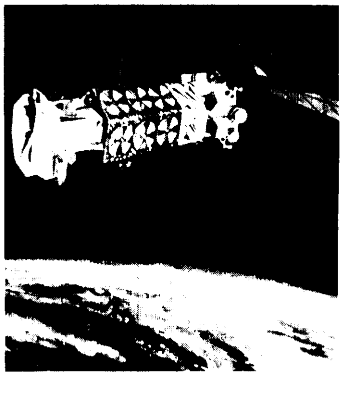
Planning for Future Remote Sensing Systems 3

This chapter provides an overview of institutional and organizational issues surrounding the development of operational environmental satellite remote sensing programs. In particular, the chapter examines issues related to the development of a multiagency weather and environmental monitoring satellite system and its place in a national strategic plan for environmental satellite remote sensing programs.

Three themes emerge from the discussion in this chapter. **First, the United States does not have an institutional mechanism for identifying national environmental remote sensing interests, ordering them by priority, and fashioning a coordinated approach to managing them.** In May 1994, the Clinton Administration announced its proposal to coordinate several existing environmental satellite remote sensing programs by consolidating ("converging") the National Oceanic and Atmospheric Administration's (NOAA's) and the Department of Defense's (DOD's) polar-orbiting operational meteorological programs and capitalizing on the National Aeronautics and Space Administration's (NASA's) experimental remote sensing programs.[2] However, with its focus on just three federal agencies and only weather and



[1] *Operational* programs are distinguished from *experimental* programs by having long-term stability in funding and management, a conservative philosophy toward the introduction of new technology, stable data-reduction algorithms, and, most importantly, an established community of data users who are dependent on a steady flow of data products

[2] The operational programs are NOAA's Polar-orbiting Operational Environmental Satellite Program (POES) and DOD's Defense Meteorological Satellite Program (DMSP). The NASA program most relevant to the convergence effort is the Earth Observing System (EOS).

climate monitoring, this proposal is not intended to serve as a comprehensive approach to satellite-based environmental remote sensing.

Second, the proposed consolidation of NOAA's and DOD's polar-orbiting meteorological programs raises both "cultural" and technical issues. The technical issues center on developing an affordable and reliable spacecraft and sensor suite that will meet the different requirements of the two agencies. This challenge is exacerbated—perhaps even dominated—by problems inherent in combining programs that originate in agencies that serve different user communities. NOAA's and DOD's meteorological programs have different priorities, different perspectives, and different protocols for acquisition and operations. These differences developed in over two decades of independent operation and have manifested themselves in numerous ways—most visibly in the different instruments that currently make up satellite sensor suites.

Third, the principal challenge to NOAA, DOD, **and NASA in implementing a joint-agency satellite system to monitor Earth's weather and climate will be to develop organizational mechanisms that ensure stable, multiyear funding and stable management.** Historically, executive branch agencies and their congressional authorization and appropriation committees have provided long-term stability in the management and funding of operational programs. Joint-agency operational programs would require similar continuity in management and funding. However, the involvement of multiple budget examiners within the Office of Management and Budget (OMB) and the involvement of multiple authorization and appropriation committees within Congress (all operating on an annual budget cycle) create new risks of program disruption.

The Clinton Administration's proposal to consolidate the nation's current and planned weather and climate satellite remote sensing programs had its origins in a desire to reduce costs. However, the Office of Technology Assessment (OTA) found that converging programs could have several benefits even if there were no cost savings. These include the institutionalization of efficient mechanisms to develop research instruments and manage their transition to operational use, the institutionalization of long-term (decadal-time-scale) environmental monitoring programs, and a strengthening of international partnerships that would facilitate new cooperative remote sensing programs.

A NATIONAL STRATEGIC PLAN FOR ENVIRONMENTAL SATELLITE REMOTE SENSING SYSTEMS

In an era of fiscal austerity, designing programs to perform space activities more efficiently and with greater return on investment has emerged as a key element of national space policy. Greater program integration, both domestically and internationally, has the potential to reduce costs and redundancy. However, it can also add such risks as program delays, increased costs, and the possibility that program goals will be compromised. In the past, the development of new or improved sensors and spacecraft has proceeded according to the specific needs of the funding agency. The nation is now engaged in a reexamination of this model as it considers the risks and benefits of multiagency programs and the emerging possibilities of engaging the private sector in providing satellite services.

In an earlier report,[3] OTA observed that the need to maximize the return on investments in remote sensing was spurring calls for the creation of a single, flexible, national strategic plan for remote sensing. The elements of such a plan, OTA suggested, should include mechanisms to:

- guarantee the routine collection of high-quality measurements of weather, climate, and Earth's surface over decades;
- develop a balanced, integrated, long-term program to gather data on global change that in-

3 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-558 (Washington, DC: U.S. Government Printing Office, July 1993).

eludes scientifically critical observations from ground-, aircraft-, and space-based platforms[4]
- develop appropriate mechanisms for archiving, integrating, and distributing data from many different sources for research and other purposes; and
- ensure cost savings by incorporating new technologies in system design developed in either the private or the public sector.

A coherent plan for future environmental remote sensing systems can help guide the near-term decisions that are necessary to ensure that the data needs of users in the early part of the 21st century will be satisfied. A particular challenge in the development of a national strategic plan would be to address the needs of an expanding and diverse "user community." Several attendees of an OTA workshop[5] stressed the importance of the early involvement of frequent users of remotely sensed data for research, operations, and applications to inform the process that would set national policy and establish a strategy for developing national remote sensing capabilities (see chapter 2).

Users of environmental remotely sensed data are not just agencies of the federal government; they also include academic researchers, businesses, and state and local governments. Increasingly, the user community for remotely sensed data also includes foreign governments. The diversity of users reflects the varied applications of environmental remotely sensed data, which range from investigations of the physical and chemical processes responsible for ozone depletion and other "global change" phenomena to resource management and urban planning.

Meeting the data needs of the next century is likely to require new remote sensing spacecraft and sensors in addition to upgraded versions of current systems. The first priority of future environmental satellite remote sensing missions will be to continue the present collection of operational meteorological data for weather prediction and monitoring. However, to support state-of-the-art numerical weather prediction models, as well as other applications, these systems will need expanded capabilities, including sensors with higher spatial, spectral, and radiometric resolution.[6] In addition, the environmental remote sensing systems of the 21st century are likely to have to meet new observational needs for data over the oceans and land surface. These include:

- ***Monitoring of the oceans—for example, ocean productivity, ice cover and motion, sea-surface winds and waves, ocean currents and circulation, and ocean-surface temperature.*** NOAA's and DOD's monitoring systems currently gather data related to several of these variables; however, the data are not sufficient to support such high-priority scientific concerns as understanding the phenomena responsible for the onset of ENSO (El Niño and the Southern Oscillation) events.[7] Improved ocean monitoring data would also have commercial value, especially to the fishing and shipping industries. More generally, an expanded set of observations over the oceans is necessary to

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[4] U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, OTA-BP-ISC-122 (Washington, DC: U.S. Government Printing Office, November 1993).

[5] *A National Strategy for Civilian Space-Based Remote Sensing*, OTA workshop, Office of Technology Assessment. Washington, DC, Feb. 10, 1994.

[6] Designers of remote sensing systems are forced to make compromises and tradeoffs among several parameters that characterize system performance. These parameters include spatial resolution, spectral resolution (the capability of a sensor to categorize electromagnetic signals by their wavelength), radiometric resolution (the accuracy with which intensities of signals can be recorded), and the number of spectral bands (a spectral band is a narrow wavelength interval). (See box 2- 1.)

[7] For example, by monitoring sea-surface levels in the Pacific Ocean, a satellite altimeter can detect the equatorial waves that tend to precede the onset of El Niño. See D.J. Baker, *Planet Earth: The View from Space* (Cambridge, MA: Harvard University Press, 1990), pp. 70-71.

improve understanding of the role of oceans in the global carbon, biogeochemical, and hydrologic cycles, and in regulating and modulating Earth's climate.

- ***Monitoring of the land surface with new operational sensors such as a synthetic aperture radar (SAR)[8] and with follow-ons and additions to the Landsat series.*** Future visible and infrared imaging systems are likely to feature higher spatial resolution, improved radiometric sensitivity, stereo imaging, and a larger number of spectral bands than does the current Landsat. Such systems would support operational needs to manage nonrenewable and renewable resources. The systems would also support applications such as mapping and land-use planning.
- ***Monitoring of key indices of global change, especially changes in climate, through programs designed to measure ozone concentration and distribution, Earth's "radiation budget," and the atmosphere's aerosol content and characteristics.*** Meeting these needs will require the development of affordable spacecraft and finely calibrated instrumentation that can be flown in a continuous series for periods measured in *decades.* Future systems will also have to support detailed "process studies" to improve scientific understanding of the complex physical and chemical ocean-land-atmosphere processes responsible for global change. This will require a mix of both satellite and in situ measurement systems.[9]

By linking different government environmental remote sensing programs, as well as private-sector developments, a national strategic plan for environmental satellite remote sensing might assist in the creation of an integrated remote sensing system that is less susceptible than current systems to single-point failure or changing priorities—a more "robust and resilient" system for Earth observations. For example, NASA has designed the Earth Observing System (EOS) program with the assumption that it will be complemented by Landsat. However, the failure of Landsat 6 and recent budgetary problems have demonstrated that Landsat has not acquired the characteristics of an operational program, which include relatively stable budgets, spacecraft and launcher backups, and a "launch-on-failure" capability to ensure continuity of operation. Similarly, programs such as the Navy Geosat follow-on are vulnerable to budget cuts in a time of rapidly changing security requirements.

A national strategic plan might also assist in the development of new sensors and advanced technologies. In some cases, government and private-sector partnerships are needed to develop specific systems.[10] In others, such as the development of an affordable multifrequency SAR, these partnerships may have to be extended internationally. More generally, there is an urgent need to coordinate efforts among researchers in government laboratories, academia, and the private sector to reduce the size, weight, and resultant cost of satellite remote sensing systems. To lower costs, future systems should accommodate demonstrations of advanced technologies. However, the tension between continuing past observations and in-

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8 A SAR would Provide a unique all-weather, day-and-night capability to make high-spatial-resolution global measurements of Earth's surface. As discussed below, it would complement visible and infrared sensors.

9 U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System,* op. cit., pp. 3, 13.

10 For example, unpiloted air vehicles. Government and private-sector partnerships might also assist in the development Of new technologies for Earth observation, which are described in appendix B of U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications,* op. cit. NASA is pursuing technology demonstration as part of its Landsat 8 program and through its Office of Advanced Concepts and Technology. On June 8, 1994, NASA announced contract awards for two new Smallsat Earth observation satellites that will demonstrate advanced sensor technologies. NASA expects them to cost less than $60 million each and be developed, launched, and delivered on orbit in 24 months or less on a Pegasus launch vehicle.

fusing new technology continues to be among the most challenging aspects of planning future remote sensing programs.

A national strategic plan would recognize explicitly that Earth observations cross agency boundaries. For example, NOAA's operational environmental satellites currently focus primarily on measurements of atmospheric variables. However, the study of Earth as a system will require complete coverage of both Earth's surface and the atmosphere, with instruments tailored in measurement frequency and duration to the particular local, regional, or global phenomena under study. For example. meeting the objectives of the U.S. Global Change Research Program (USGCRP)[11] will require integrating satellite data and in situ data with validated models to derive global data products that may be compared over periods ranging from seasons to centuries.

A comprehensive plan for environmental satellite remote sensing would help ensure that program and instrument choices were driven by truly national needs instead of the sometimes parochial interests of individual federal agencies. Currently, the United States does not have an adequate system for allocating funds to programs that serve data users who are outside the normal program bounds of the operating agency, nor does it have a reliable system for allocating funds to programs that cut across agency boundaries. Under the existing system for appropriating federal program funds, the agency responsible for a program must defend that program to the office of Management and Budget and to congressional committees. Programs compete for funding and attention both within and outside agency boundaries. As a result, programs that cut across agency boundaries or are perceived as peripheral to the agency's central mission are vulnerable regardless of how important they may be to the federal government as a whole (see discussion of Landsat below).

A national strategic plan should also strive to achieve an appropriate balance between "hardware" and "software" development. Sensors collect data, but models and algorithms are necessary to translate these data into useful information. Several participants at an OTA workshop[12] noted the tendency to meet new requirements for environmental remote sensing systems by "pushing the technology" and neglecting (by comparison) less costly software solutions. Meeting new **requirements for environmental remote sensing systems in the most cost-effective manner will require an examination of the "end-to-end" process that turns data into information.**

NOAA has historically been the lead agency in managing civil operational satellite programs. However, NOAA has lacked the budget authority and the in-house capability to develop and flight-test instruments for new operational programs. The majority of NOAA's funding is currently directed at meeting its principal mission, which is to provide reliable short-term weather forecasting and weather warning. Without new budget authority, NOAA might have difficulty funding expenditures for new climate and ocean monitoring instruments and spacecraft, or even for such improvements as upgrading the calibration and number of spectral channels of the Advanced Very High Resolution Radiometer (AVHRR) sensor to make it better suited for land remote sensing

11 For a description of the USGCRP, see U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, op. cit., and references therein.

12 *A National Strategy for Civilian Space-Based Remote Sensing*, op. cit

BOX 3-1: Monitoring Global Vegetation with AVHRR Sensors

The Clinton Administration's proposal to converge NOAA and DOD meteorological satellites has not altered NOAA's plans to design next-generation meteorological satellites with features that improve their utility for land remote sensing. In particular, NOAA plans to improve the calibration and sensitivity of the visible and infrared radiometers of the Polar-orbiting Operational Environmental Satellite System (POES). The improvements would greatly enhance the utility of future Advanced Very High Resolution Radiometer (AVHRR) instruments for monitoring changes in vegetation—a use that was not anticipated during the original design of AVHRR but that is now used operationally in recognizing and forecasting crop production, crop failures, and famines.

AVHRR's visible and infrared detection bands make observations in spectral bands that are similar to those on the Landsat instrument, which is used for vegetation monitoring. However, NOAA satellites provide daily observations of a particular region while Landsat revisits only once every 16 days. This can lead to unacceptably long gaps in coverage, especially in regions that are frequently cloudy. Furthermore, the lower spatial resolution of AVHRR (1.1 km nadir; 4 km at edge of scan) compared with the Multispectral Scanner (MSS) or Thematic Mapper (80- and 30-m ground spatial resolution, respectively) is currently more appropriate for generating global data sets. Using the high-spatial-resolution Landsat data would overburden current data-processing and -handling capabilities.

Even with NOAA's planned improvements, detecting and eliminating the effects of clouds—a problem more difficult over land than ocean—would remain a problem in interpretating the signals from land vegetation. Also complicating the interpretation are the effects of atmospheric absorption and scattering and the dependence of a satellite-sensed reflectance on the sun-ground target geometry.

SOURCE: Office of Technology Assessment, 1994.

(box 3-1) or for being better able to determine cloud type.[13]

Higher stability and better calibration of satellite sensors will also be required by global change researchers attempting to distinguish real changes from instrument-induced effects. In addition, experience has shown that satellite data can be applied to a host of applications for which they were not originally intended; instrument calibration is frequently the factor that limits the extent of these applications. For example, better calibration might allow climate trends to be discerned from an analysis of sea-surface temperatures, which are derived from weather satellite data.[14] A national strategic plan for environmental remote sensing may be useful in reaching a consensus on how best to fund and develop improvements such as better calibration of satellite sensors.

13 Cloud type is determined from analysis of multispectral-image data from instruments on operational meteorological satellites. Currently, the number of spectral channels available and the calibration is insufficient for unambiguous determination of some clouds (for example, polar clouds). Several proposed EOS instruments may help in cloud classification. See *Committee on Earth Observation Satellites (CEOS) 1993 Dossier—Volume C: The Relevance of Satellite Missions to Global Environmental Programs* (September 1993), p. C-34.

14 R.H. Thomas, *Polar Research from Satellites* (Washington, DC: Joint Oceanographic Institute, February 1991).

MONITORING WEATHER AND CLIMATE

B NOAA's Polar-orbiting Operational Environmental Satellite Program[15]

In 1960, the United States launched the world's first weather satellite, TIROS-1 .[16] TIROS provided systematic cloud-cover photography and observations of Earth with broad-band visible and infrared imagery. Images obtained in visible wavelengths gave researchers global views of the structure of weather systems and weather movement. Infrared sensors allowed these views to be extended into hours of darkness. Combining both types of imagery allowed a determination of cloud type and the relative altitudes of the uppermost cloud layers. Although considered experimental, the success of TIROS- 1 led to operational uses of the data, which the U.S. Weather Bureau pursued simultaneously with NASA's research and development satellite-improvement program.

As noted in chapter 2, NOAA operates its current satellite programs primarily to support the data needs of the National Weather Service for weather warning (the geostationary satellites) and global forecasting (the polar satellite program). To support its Polar-orbiting Operational Environmental Satellite Program (POES), NOAA operates two Advanced TIROS-N (ATN) [17] spacecraft in complementary, circular, sun-synchronous polar orbits, with morning and afternoon equator crossings that designate the spacecraft as AM and PM (box 3-2). Since its inception, NOAA has operated its meteorological satellites to serve the public good. This has resulted in continuity of weather observations and public availability of weather warnings (figure 3-1).

The POES system primarily provides daily global observations of weather patterns and environmental conditions in the form of quantitative data that can be used for numerical weather analysis and prediction. As a result, NOAA's principal requirements for POES are high-quality imaging, primarily at optical wavelengths, and high-resolution temperature and humidity "soundings."[18] U.S. weather models are initialized with satellite temperature and humidity measurements immediately to the west of the United States in the eastern Pacific Ocean at times corresponding to the release of weather monitoring balloons (00 Greenwich mean time (GMT) and 12 GMT). Therefore, NOAA has a particular need for afternoon (PM) temperature and humidity measurements over the eastern Pacific. For similar reasons, European weather organizations need morning data acquired over the Atlantic Ocean.

The key instruments and services available from the two operational POES satellites have

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15 For an overview of NOAA and DOD programs, see D.J. Baker, *Planet Earth: The View from Space,* op. cit. A detailed description of sensors and spacecraft design appears in National Oceanic and Atmospheric Administration, *ENVIROSAT-2000 Report: Comparison of Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Opera tional Environmental Satellite (POES) Program* (Washington, DC: U.S. Department of Commerce, October 1985).

16 *TIROS* is the acronym for Television and Infrared Observing Satellite. In this chapter, the term *TIROS satellite* is used interchangeably *with* the term (NOAA) *POES satellite.* T] ROS was the culmination of a project begun under the Department of the Army, which was then transferred to a newly created NASA and completed by NASA's Goddard Space Flight Center.

17 TIROS-N, launched in 1978, was the prototype for the modem NOAA polar-orbiting environmental satellite. The ATN, which dates to 1984, is an enhanced version of TIROS-N. Its increased capacity allowed the addition of the Solar Backscatter Ultraviolet (SBUV) instrument, the Earth Radiation Budget Experiment (ERBE) instruments, and the search and rescue system, SARSAT.

18 Data on the temperature and humidity structure of the atmosphere are necessary to understand the stability of the weather patterns and to forecast short- and long-term changes. Satellite instruments used to remotel y probe the temperature and moisture structure of the atmosphere are generally refereed to as sounding instruments. To determine the temperature of the surface of Earth, infrared or microwave observations are made at wavelengths at which the atmosphere is transparent. To determine the temperature structure of the atmosphere, observations are made at wavelengths where there is absorption and emission by a uniformly mixed gas. Atmospheric moisture distributions may be monitored by sensors that detect emissions from water vapor. See National Oceanic Atmospheric Administration and National Aeronautics and Space Administration, *Space-Based Remote Sensing of the Ear/h: A Report to the Congress* (Washington, DC: U.S. Government Printing Office, September 1987).

BOX 3-2: Sun-Synchronous Orbits

A space-based senor's view of Earth depends on the characteristics of its orbit and the sensor's field of view. A sun-synchronous orbit is a special polar orbit that allows a satellite's sensor to maintain a fixed relation to the sun, a feature especially useful for meteorological satellites. Each day, a satellite in a sun-synchronous orbit passes over a certain area at the same local time. One way to characterize sun-synchronous orbits is by the time the satellites cross the equator. Equator crossings ("nodes") occur at the same local time each day, with the descending crossings occurring 12 hours (local time) from the ascending crossings. "AM" and "PM" polar orbiters denote satellites with morning and afternoon equator crossings, respectively.

A morning platform allows viewing of the land surface with adequate illumination before the daily cloud buildup and provides an illumination angle that highlights geological features. Afternoon crossings are more appropriate for studies such as the role of clouds in Earth's weather and climate. NOAA's nominal 1330 crossing time for its weather satellites allows relevant measurements to be made while the operational need to deliver a daily weather forecast for the continental United States each evening is satisfied.

NOAA and DOD meteorological satellites are placed in sun-synchronous orbits to support such measurements as sea-surface temperature and cloud distribution and characteristics. Other satellites in sun-synchronous orbits include Landsat and the planned SeaStar ocean-color monitoring satellite (via the SeaWiFS instrument). However, some measurements, such as measurements of tides, waves, and ocean currents, do not require synchrony with the sun. The TOPEX/Poseidon satellite, for example, flies in midlatitude orbits. Sun-synchronous orbits are also not necessary for measurements of Earth's radiation budget.

The morning (AM) NOAA satellite orbits at an altitude of 810 km at an inclination of 98.86° and has a period of 101 minutes. Its local equatorial crossing time is approximately 0730. The early afternoon PM (nominally 1330) satellite orbits at an altitude of 850 km at an inclination of 98.70° and has a period of 102 minutes. Each satellite views the same portion of Earth twice each day. Thus, the two satellites give NOAA approximately 6-hour gaps between data collections. In the United States, the afternoon mission is primary, and the morning mission provides supplementary and backup coverage. In Europe, the morning mission provides the primary coverage.

SOURCES: Office of Technology Assessment, 1994; D.J. Baker, *Planet Earth: The View from Space* (Cambridge, MA: Harvard University Press, 1990), pp. 17-22.

changed only slightly since the launch of TIROS-N in October 1978. The principal instruments on recent POES satellites are an optical surface and cloud imager (i.e., AVHRR) and infrared and microwave temperature and humidity sounders (HIRS—High-Resolution Infrared Sounder, SSU—Stratospheric Sounding Unit, and MSU-Microwave Sounding Unit (box 2-4)).[19]

NOAA's current POES satellites are built with a design life of 2 years, which has usually been ex-

19 HIRS measures scene radiance in 20 spectral bands, permitting the calculation of the vertical temperature profile from Earth's surface [o about 40 km altitude. SSU is used to measure the temperature distribution in the upper stratosphere between 25 and 50 km. MSU gives NOAA an all-weather (i.e., cloudy or clear condition) capability for temperature and moisture measurements. NOAA is developing a completely new Advanced Microwave Sounding Unit (AMSU) for POES to improve the quality of temperature and humidity sounding. Ibid., pp. 60-68.

ceeded.[20] To ensure continuous availability of weather data, NOAA attempts to procure these satellites at intervals that would allow launch within 120 days of "call-up." The NOAA-J spacecraft and the enhanced NOAA-K, -L, and -M are in production or test. The launch vehicle for future POES satellites (and for DOD's Defense Meteorological Satellite Program (DMSP)) is the Titan 11,[2] The cost of the K, L, M series is approximately $100 million per satellite.

Before the Clinton Administration's convergence proposal was announced, agreement in principle had been reached between Europe, represented by the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat), and the United States, represented by NOAA, to transfer responsibility for the morning (AM) segment of NOAA's polar-orbiting constellation in approximately the year 2000.[22] The United States entered this arrangement to reduce costs and to gain the benefits of shared data, mutual backup, and some simplification in operations. The Administration's convergence proposal has not altered the U.S. desire to enter into an arrangement with Europe to provide the morning meteorological satellite; however, it has prompted the parties involved to start renegotiating the terms of the agreement. At the time this report was written, several issues relating to implementation of the agreement had not been resolved. In particular, issues regarding U.S. control of real-time data from U.S. instruments on board the European METOP[23] satellite had not been fully settled (see below).

FIGURE 3-1: POES Image of Hurricane Hugo, 1989

The proposed convergence of NOAA and DOD weather satellites has also not altered either agency's plans to implement major upgrades (block changes) in next-generation systems. For example, NOAA had planned to use the extra capacity of satellites O, P, and Q to fly an upgraded complement of its current instruments while testing new instruments that would be candidates for future operational use. At one time, the O, P, Q series had been scheduled for launch starting in

20 For example, NOAA's primary PM and AM mission spacecraft, NOAA-1 1 and NOAA- 12, are still operational after launch in September 1988 and May 1991, respectively. However, the next satellite in this series, NOAA- 13, which was launched into a PM orbit on August 9.1993, failed on August 21, 1993, because of a power system failure.

21 Titan II replaces the Atlas-E.

22 The first launch of an operational European spacecraft, METOP- 1, is scheduled for December 2000. Plans call for METOP to carry a U.S. operational instrument package in addition to European-supplied instruments. Europe has also agreed to supply a high-latitude ground station. This arrangement will eliminate blind orbits—that is, orbits where data transmission is not possible because the satellite is not in the line of sight of a ground station.

23 A term derived from metrological Operational Mission.

2000. However, when the series was delayed until 2005, NOAA developed plans to launch "gap-fillers," designated as NOAA-N and -N', to ensure continuity between K, L, M and the block upgrade. It now appears that satellites N and N' will serve as gap-fillers between J-M and a converged system (table 3-1).

TABLE 3-1: NOAA's POES Program Launch Schedule and Status

NOAA satellite	Projected launch date/status
J (PM)	September 1994/under contract
K (AM)	September 1995/under contract
L (PM)	September 1997/under contract
M (AM)	September 1998/under contract
N (PM)	September 2000/under contract anticipated
N' (PM)	September 2003/under contract anticipated
O (PM)	September 2005/old baseline[a]
P (PM)	September 2008/old baseline
Q (PM)	September 201 l/old baseline

[a] Schedule before the Clinton Administration's convergence proposal was completed, If the convergence plan is executed, NOAA will terminate the planned launch of satellites O, P, and Q and instead incorporate features of this block change into the proposed NOAA-DOD-NASA national polar-orbiting environmental satellites

Source National Oceanic and Atmospheric Administration, 1994

DOD's Operational Meteorological Program

Like NOAA, DOD has an operational requirement for meteorological data. As executive agent for a joint-service program to provide global weather data, the U.S. Air Force operates a series of meteorological satellites under its DMSP. The first satellite in the DMSP series was launched in 1976. The current system includes satellites and sensors; ground command and control (distinct from NOAA's); Air Force, Army, Marine Corps, and Navy fixed and mobile tactical ground terminals; and Navy shipboard terminals .24 Operational users of DMSP products obtain data via a centralized system (AFGWC, for Air Force Global Weather Central); direct links to DMSP are also possible.

DMSP satellites support the needs of classified surveillance programs and the tactical needs of the fighting forces for information about the weather. Data from DMSP are used by the military to:

- detect and forecast the absence or presence of clouds,
- determine wind speed over the open ocean,
- provide precipitation data to determine cross-country mobility of armor forces,
- optimize performance of electro-optical sensors,
- provide data for artillery and missile targeting,
- provide input data for weather forecasts over data-denied or enemy territory, and
- provide space environmental data to support space systems operations.[25]

The DMSP space segment normally consists of two satellites in 833-km, circular, sun-synchronous polar orbits that are similar to the POES satellites, but with different equator crossing times.[26] Unlike NOAA, DOD has designed its satellites to be flexible in orbit crossing times to support changing mission requirements.[27] DMSP carries payloads that are specific to DOD requirements for data encryption, survivability, launch responsiveness, flexibility in orbit selection,

24 Most DMSP terminals can also receive NOAA satellite data directly.

25 G.R. Schneiter, Director, Strategic and Space Systems, Office of the Under Secretary of Defense (Acquisition), U.S. Department of Defense, testimony before the Subcommittee on Space of the Committee on Science, Space, and Technology, House of Representatives, U.S. Congress, Nov. 9, 1993.

26 The most recent DMSP launches had local equator crossing times of 0530 and 0730.

27 NOAA's principal requirement for gathering data for its numerical weather forecasts does not require flexible orbit crossing times (in fact, NOAA weather models are designed to be initialized at the same time of day).

low-light imagery, and constant-resolution cloud imagery for automated data processing (box 2-5).[28]

The primary sensor carried on every DMSP satellite is a visible and infrared imager known as the Operational Linescan System (OLS), which was first flown in 1976 on Block 5D spacecraft. OLS imagery is used to depict cloud types and cloud distribution and to locate cloud-free areas. OLS data are also used to identify the location, extent, and development of significant weather systems; the location of jet streams, troughs, and ridges; and areas of potential turbulence and icing. DMSP satellites also carry an advanced passive millimeter-wavelength microwave imager, the Special Sensor Microwave/Imager (SSM/I), that provides information concerning sea states and ocean winds, polar ice development, precipitation, and soil moisture estimates, data that are of great interest to a wide variety of users (box 3-3). SSM/I is

BOX 3-3: Several Applications of Passive and Active Microwave Sensors

A "passive" microwave radiometer looking down at Earth from space measures the natural emissions from the viewed surface and from the intervening atmosphere. A satellite-borne microwave radiometer can distinguish sea ice from water, even though both may be at the same temperature, because the emissivity[1] of water differs markedly from that of sea ice. In fact, ice can be distinguished depending on whether it is new (a few centimeters thick), first-year (up to 2 m thick and generally snow covered), or old (characterized by having cracks and deformations because it has undergone freeze-thaw cycles; also, it is less saline than new ice). These distinctions are of more than academic interestold ice is harder and thicker than new ice and poses a greater hazard to shipping. Similarly, soil moisture measurements are possible because of the varying emission from dry or wet soil (however, these measurements are more difficult than those that distinguish ice from water).

An "active" microwave instrument, such as the radar altimeter on the Navy's GEOSAT, provides its own source of illumination. By measuring the radar returns, an altimeter can be used to deduce wave height, which is an indirect measure of surface windspeed. When the wavelength of microwaves is in the millimeter region, scattering from objects like raindrops becomes pronounced; thus, microwave sensors can be used to detect rainfall and water vapor in the atmosphere. A synthetic aperture radar (SAR) allows much higher spatial resolution than does ordinary radar. Operating at microwave frequencies, SAR returns, like all radar, are sensitive to the electrical and geometric properties of Earth's surface, its cover, and its near subsurface. The combination of high spatial resolution and surface-sensitive radar returns has applications in uses from mapping to global change research.[2]

[1] All matter at any temperature above absolute zero will emit electromagnetic radiation with an intensity proportional to its temperature. A perfect emitter, known as a *black body*, has an emissivity of unity, which means that it emits radiation at the maximum possible rate. This rate varies only with the temperature of the emitter and is independent of all other characteristics. However, real objects differ from this ideal, and the emissivity, or "brightness," of an object also varies according to its surface characteristics.

[2] For a discussion of SAR technology and applications, see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-558 (Washington, DC: Government Printing Office, July 1993), app. B.

SOURCE: Office of Technology Assessment, 1994.

[28] See Department of Defense comments in U.S. General Accounting Office, *Weather Satellites: Economies Available by Converging Government Meteorological Satellites*, GAO NSIAD-87-107 (Washington, DC: U.S. Government Printing Office, 1987), p. 51.

also used for hurricane and typhoon characterization.[29] DMSP carries two passive microwave sounding instruments—SSM/T-l and SSM/T-2—that provide **data that** allow derivation of vertical temperature and tropospheric water vapor profiles of the atmosphere, respectively.

Historically, to support tactical operations and other missions, one of the two operational DMSP spacecraft has had an equator crossing at dawn and the other has been operated at varying crossing times later in the morning (for example, 0830). These satellites meet DOD's particular needs for imagery at a time when clouds are less likely to obscure the ground. DOD also uses data from the DMSP satellites and from NOAA's PM satellites as inputs to numerical forecast models. Together, DMSP and POES weather satellites meet DOD's requirements for 4-hour refresh rates for cloud-imagery data and DOD-NOAA requirements for 6-hour refresh rates for sounding data.

Four DMSP satellites are in storage and five are under construction: S 11, **S** 13, S14, and S15-S20. S11, S13, and S14 are Block 5D-2 design; S 15-S20 are Block 5D-3.[30] The recurring cost of each 5D-3 satellite is approximately $134 million.[31] DOD expects the DMSP spacecraft to achieve *4 years* of operation on-orbit for the spacecraft in storage and 5 years for the spacecraft being constructed .32 Assuming that the historic reliability of DMSP spacecraft continues, the last DMSP under construction could be launched in 2006 or later.

Comparing NOAA's and DOD's Polar-Orbiting Operational Meteorological Programs

Differences between NOAA's and DOD's meteorological programs in part reflect the comparatively greater importance DOD attaches to cloud imagery (to support tactical operations) than to sounding measurements of atmospheric temperature and moisture. Although NOAA shares DOD's requirement for cloud imagery, it has a particular need for high-accuracy temperature and moisture profiles of the atmosphere. These data initialize NOAA's twice-daily global numerical weather forecasts.

The differences between NOAA's and DOD's requirements are reflected in the instrument suite on board DMSP and POES satellites. For **exam--**ple, POES satellites use high-resolution infrared soundings complemented by microwave soundings for their weather models, whereas DMSP satellites use only the lower-resolution microwave soundings.[33] NOAA plans to introduce an ad-

29 SSM/I is particularly useful in monitoring the pacific Ocean, where it has replaced more costly aerial reconnaissance as a way to track typhoons. Although sometimes characterized as a "Navy" sensor, SSM/I is used by many federal agencies and serves a diverse user community. Workshop participants at a joint DOD-NOAA conference on DMSP retrieval products were, in fact, primarily civilian and international users. See R.G. Isaacs, E. Kalnay, G. Ohring, and R. McClatchney, "Summary of the NMC/NESDIS/DOD Conference on DMSP Retrieval Products," *Bulletin of the American Meteorology Society* 74(1):87-91, *1993.*

30 S-12 *is* already *in* orbit. S-15 *is designated as a* 5D-3 *design* because it uses the 5D-3 spacecraft bus. However, its instrument package is identical to that found on 5D-2 satellites.

31 1992 dollars. 5D-2 satellites cost approximately $120 million in 1992 dollars. These figures refer only to recurring costs of the spacecraft and sensors. They do not include one-time initial startup costs such as RDT&E (for research, development, test, and evaluation), nor do they include costs associated with the ground segment, such as the costs of ground terminals and of the satellite command, control, and communications network.

32 The POES satellites have an on-orbit design life of 2 years, but they generally last longer.

33 Microwave sounders complement infrared sounders because they can penetrate clouds. For example, recent POES satellites have combined data from infrared sounders HIRS/2 and SSU, with MSU, a four-channel radiometer (sounder) that makes passive microwave measurements in the 5.5-mm oxygen band. DOD, having less need forhigh-resolution soundings and being most interested in an "all-weather" capability, has pioneered the development of microwave sounders (for example, the SSM/I). T'he infrared and microwave instruments on POES satellites are capable of resolving temperature differences in the vertical structure of the atmosphere of approximately 1.5 to 2 degrees kelvin {K), even in the presence of clouds. DMSP instruments can resolve approximately 3 K. Note that the all-weather capability of DMSP does not refer to seeing through precipitation. The millimeter wave instruments carried by DMSP will operate through clouds, but not rain. In fact, this property can be used to estimate rainfall.

vanced microwave sounder, AMSU, which will have a higher resolution than DOD microwave instruments. DMSP and POES satellites are also built differently for at least three other reasons:

1. The DMSP system must meet DOD's specification that it provide global visible and infrared cloud data through all levels of conflict. Therefore, components in DMSP must meet requirements for hardening and survivability that are not present in POES.
2. DMSP satellites are built to military specifications ("mil-spec'').[34]
3. DMSP satellites contain specialized electronics, such as those needed to implement encryption schemes that support DOD's requirement to control real-time access to data.

This last difference affects NOAA's and DOD's attitudes toward international data exchanges. In contrast to DOD's approach, the Department of Commerce's **weather forecasting (through NOAA) relies on international partnerships to fulfill its data needs and those of other U.S. agencies, including DOD.** Indeed, these partnerships, which have their historical basis in U.S. decisions to treat meteorological data as a public good, have been part of U.S. foreign policy since the Kennedy Administration.

As noted above, the primary sensor carried on every DMSP satellite is the Operational Linescan System (OLS). OLS provides day and night cloud imagery from two sensors, which operate in the visible and longwave-infrared regions .[35] OLS has several features that distinguish it from the AVHRR on NOAA's POES satellites. First, OLS has a photomultiplier that allows DOD to generate visible imagery from scenes illuminated at low light levels (as 1ittle as the light from a one-quarter moon).[36] Second, OLS is the only operational imager capable of nearly constant spatial resolution across its data swath width (box 3-4).[37] Constant resolution and other unique features of OLS result in expedited delivery of images directly to the field and reduced time for weather forecasts.[38] Third, the sensor cooler on OLS is designed to operate at a range of sun angles, allowing operation at different equator crossing times and, therefore, at different sun angles with respect to the spacecraft as needed. Thus, OLS is somewhat more flexible than AVHRR with respect to the orbits it can support.

The current series of DMSP and the POES TIROS-N satellites are built with a similar spacecraft "bus"[39] and several subsystems (an exception is the command and data-handling subsystem).

[34] DMSP is also built to last longer than POES, but this added cost may be balanced by the need for fewer satellites during the course of the program. For a detailed comparison of POES and DMSP, see National Oceanic and Atmospheric Administration, *ENVIROSAT-2000 Report: Comparison of Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Operational Environmental Satellite (POES) Program*, op. cit.

[35] OLS is used to provide cloud imagery, cloud-top temperature, sea-surface temperature, and auroral imagery. OLS's visible-near-infrared sensor operates in the 0.4-1. I -pm band; the infrared sensor operates in the 10-13-μm band. Three spectral bands are chosen to enhance the ability to distinguish among clouds, ground, and water. The extension of the visible band to near-infrared wavelengths is chosen to enhance the ability to distinguish tropical vegetation from water.

[36] OLS's low-light capability is no longer considered advanced technology. In fact, it is a feature of the recently launched NOAA GOES-8. However, design studies will be-needed to determine whether this feature can easily be incorporated into an instrument that replaces AVHRR and 01.S on a converged NOAA and DOD satellite.

[37] OLS is operated to produce a nearly constant ().6-km spatial resolution across its approximate) 3,000-km data swath. Direct readout data at fine (0.6-km) and "smoothed' " (2.8-km) resolution can be received at tactical terminals; data can also be recorded on board the spacecraft at both fine and smoothed resolution for transmission to central receiving stations. Low -light-level nighttime v isible data are at 2.8-km resolution.

[38] For example constant resolution simplifies the ground processing that would otherwise be needed, especially if a user received imagery data at the edge of the field of view of the OLS (see discussion and figure in box 3-4).

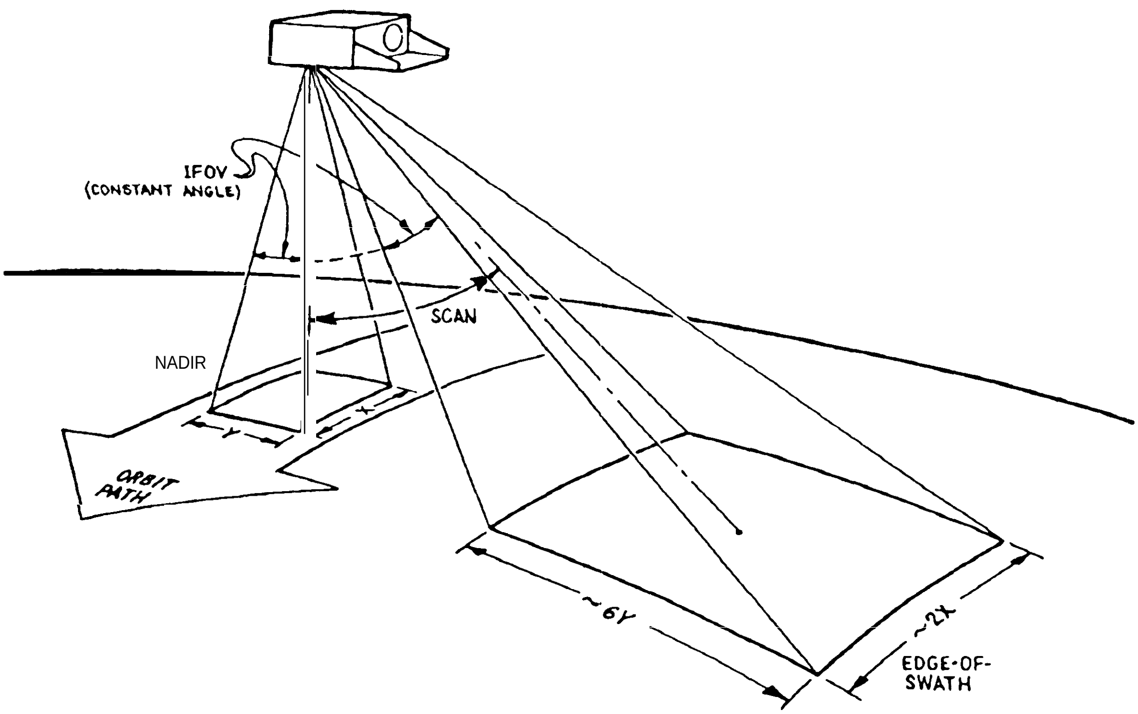
[39] The spacecraft bus carries the payload and includes systems and subsystems that provide several "housekeeping" functions, including propulsion; electrical power generation, conditioning, and distribution; communications (tracking, telemetry, and command): attitude determination and control: thermal control; and command and data handling. See E. Reeves, "Spacecraft Design and Sizing." *Space Mission Analysis and Design*, W.J. Larson and JR. Wertz (eds.) (Torrance, CA: Microcosm, Inc., 1992).

BOX 3-4: Constant Ground Resolution: A Unique Feature of DOD's Operational Linescan System

A cross-track scanner, such as NOAA's Advanced Very High Resolution Radiometer (AVHRR), has a ground "footprint" that grows coarser with increasing scan angle. Scan angle is measured from nadir; AVHRR and the Operational Linescan System (OLS) scan from 0° (nadir) to 55.4° and 56.2°, respectively. The AVHRR instantaneous field of view (IFOV), measured in angular units such as degrees, is maintained constant as the scan angle increases off-nadir. However, as shown in the figure below, the ground footprint increases with increasing scan angle.

In the cross-track direction (perpendicular to orbit path), this increase is larger by approximately a factor of 3 than the increase in the in-track direction (parallel to orbit path). The overall footprint area on the ground increases by more than 10-fold at a 57° scan angle, the approximate maximum scan for OLS and AVHRR. This is acceptable for civil and science applications, but, until now, has been unacceptable to the DOD user community. DOD's OLS imager has a nearly constant ground resolution because it uses a special scanning pattern that, in effect, reduces the angular IFOV with increasing scan angle.

A converged operational meteorology program will have to reconcile DOD's requirement for nearly constant ground resolution with NOAA's requirement for high-sensitivity calibrated imagery. Moreover, a converged program that is implemented in 2005 or later would be expected to satisfy the requirements planned for NOAA's follow-on Polar-orbiting Operational Environment Satellite System (NOAA-O, -P, and -Q) and DOD's follow-on Defense Meteorological Satellite Program (Block 6 upgrade). It may be possible to develop a single instrument that would, in effect, replace the planned AVHRR and OLS follow-ons. Alternatively, a converged satellite might be able to accommodate two separate instruments—an option likely to be less technically challenging. The practicality of either option cannot be established until the Integrated Program Office completes design-tradeoff studies. For example, narrowing the IFOV at the edge of the scan to meet DOD's constant ground resolution requirement decreases the available signal, which in turn might necessitate larger aperture, more costly optics to meet NOAA requirements.



SOURCES: Office of Technology Assessment, 1994; C.V. Scheuler, Hughes Santa Barbara Research Center, presentation at an OTA workshop, *A National Strategy for Civilian Space-Based Remote Sensing*, Washington, DC, Feb. 10, 1994.

Before the Clinton Administration's convergence proposal was announced, the Air Force had been planning a block change for DOD's meteorological satellites. Like NOAA, DOD planned to initiate this upgrade after the satellites in storage and under construction had been exhausted. Although recent DMSP and POES satellites have increased their use of common systems and subsystems, the follow-ons that DOD and NOAA had planned would have resulted in systems with less in common than the current series. For example, Block 6 DMSP and NOAA-O, -P, -Q satellites would likely have been built with different buses and would have had a greater number of different components and subsystems. These differences are noteworthy because they suggest that before the Administration's convergence proposal was made, the two agencies had been on a course that would have resulted in distinctive meteorological satellites and perhaps fewer opportunities for program savings through economies of scale.

NASA's Weather- and Climate-Related Programs

The Administration has involved NASA in proposals to converge operational meteorology programs for three reasons. First, NASA is funding and developing the Earth Observing System of satellites, which carry instruments that may later be modified for use on operational weather satellites. Second, NASA currently develops the POES satellites for NOAA. Third, NASA has historically been the agency that funds, develops, and demonstrates prototype advanced remote sensing technologies for civil applications. Once proven, these technologies are candidates for NOAA's operational missions.

The principal spacecraft in the EOS program are comparatively large, multi-instrument platforms designated AM, PM, and CHEM. Plans call for the 5-year lifetime AM, PM, and CHEM spacecraft to be flown successively three times. Under the current schedule, the first flight of AM would occur in 1998 (figure 3-2), the first flight of PM would occur in 2000, and the first flight of CHEM spacecraft would be in approximately 2002.[40] Instruments on AM are intended primarily for Earth surface observation (characterization of the terrestrial and oceanic surfaces; clouds, radiation, and aerosols; and radiative balance); instruments on PM are intended primarily for study of global climate (clouds, precipitation, and radiative balance; terrestrial snow and sea ice; sea-surface temperature; terrestrial and oceanic productivity; and atmospheric temperature); and instruments on CHEM are intended primarily for study of atmospheric dynamics and chemistry (ocean-surface stress and atmospheric chemical species and their transformations).[41]

EOS program officials have stated that they expect some research instruments to evolve into the next generation of instruments for routine and long-term data collection. In particular, the EOS PM series, scheduled for launch beginning in 2000,[42] will fly instruments that have potential application for operational weather and climate data collection.[43] (However, as discussed below, NOAA officials express concern about the high cost of flying EOS instruments as part of a system for long-term, routine data collection.) Consideration of converging EOS PM satellites with

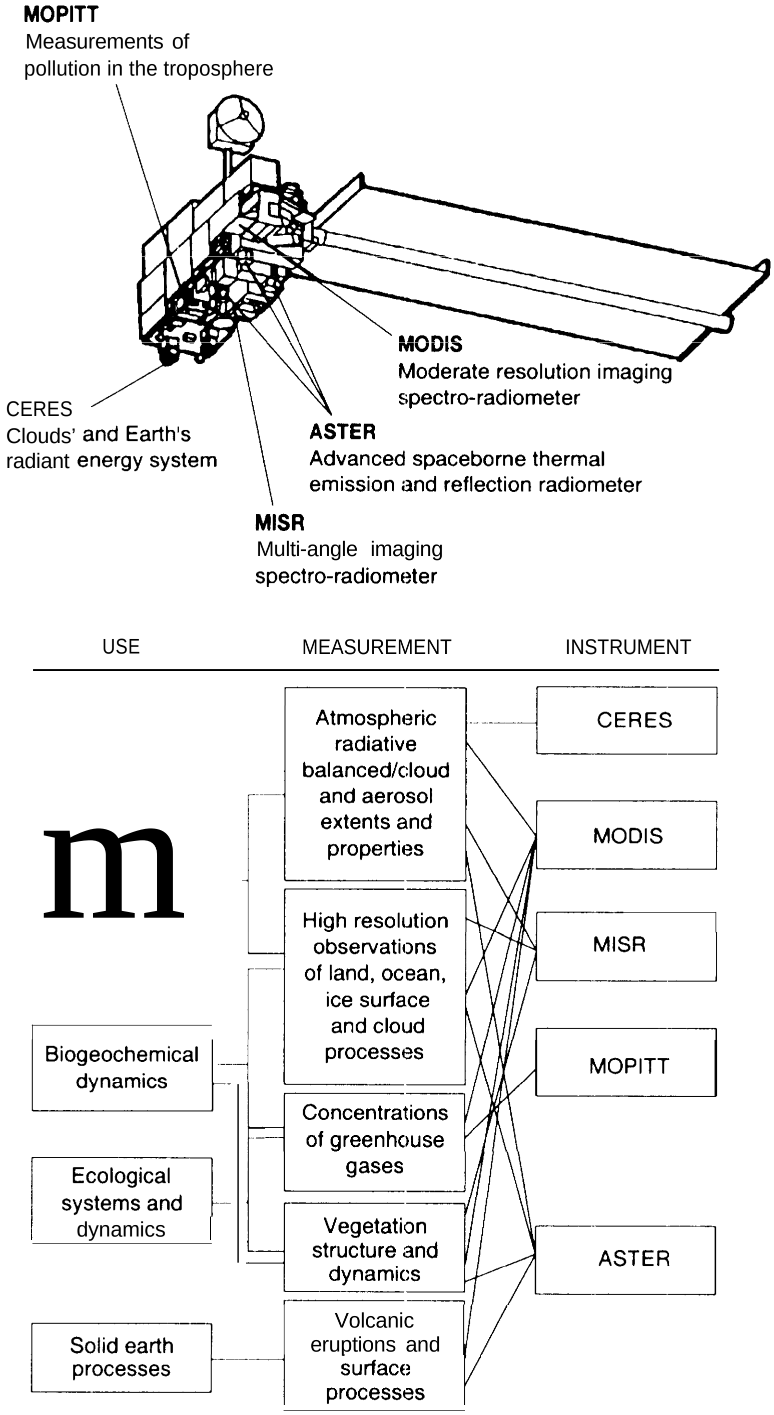
40 Rescoping the EOS Program has particularly affected the CHEM mission. See G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook* (Washington, DC: NASA Earth Science Support Office, 1993).

41 For a description of EOS spacecraft and instruments, see G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook*, ibid.

42 However, tight EOS budgets may force NASA to delay PM-1 by at least 9 months.

43 PM climate monitoring instruments include an atmospheric infrared sounder to measure Earth's outgoing radiation (AIRS); an advanced microwave radiometer to provide atmospheric temperature measurements from the surface to some 40 km (AMSU); and a microwave radiometer to provide atmospheric water vapor profiles (MHS). AMSU, which is actually three modules, will replace the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU) on POES satellites, starting with NOAA-K. MHS is a European instrument that will be flown on the European morning polar weather satellite, METOP.

FIGURE 3-2: EOS AM-1, Instruments and Measurements



SOURCE Martin Marietta Astrospace, 1993

NOAA and DOD operational satellites might occur starting with PM-2 or PM-3, which are scheduled for launch in approximately 2005 and 2010, respectively. This plan would allow PM- 1 to serve as a demonstrate ion platform for subsequent operational instruments. The year 2005 also lies within the approximate period when DOD and NOAA had been considering block changes in their current programs. In principle, PM-1 could be designed to meet both the needs of the research community and the needs of NOAA and DOD for operational weather data: however, NASA, NOAA, and DOD have concluded that employing unproven research instruments in operational uses is too risky.

NASA is also sponsoring competitive "Phase B" studies aimed at developing a common spacecraft for EOS PM-1, CHEM- 1, and AM-2,3. These studies are examining the possibility of launching EOS payloads on either an intermediate-class expendable launch vehicle (IELV), such as the Atlas IIAS planned for AM-1, or a smaller medium-class expendable launch vehicle (MELV), such as the Delta II. Although these studies are independent of convergence studies, they are driven by a similar necessity to accommodate constrained budgets. As discussed below, an EOS PM series adapted for launch on an MELV might allow for a common spacecraft bus to be developed for EOS PM and a converged NOAA-DOD meteorological satellite.

Efforts To Converge NOAA's and DOD's Polar Weather Satellite Programs[44]

The United States has conducted Earth environmental remote sensing satellite programs for over 30 years: for most of this period, the programs have been under the auspices of NOAA, DOD, and NASA. These agencies have generally succeeded in providing a workable mix of capabilities to meet their own needs: DOD has managed the operational and research and development (R&D) programs dedicated to national security purposes; NASA has undertaken the sometimes risky development of the enabling technologies for new remote sensing programs; and NOAA has used the technical services of both NASA and DOD to develop and operate the civil operational environmental satellite system. On occasion, NOAA and DOD have provided backup capabilities in support of each other's programs.

Management and operation of the nation's civil operational weather satellite system has historically been vested in NOAA.[45] In general, the technologies that NOAA needs to conduct its satellite operations are the products of the R&D work already completed by NASA and DOD. NOAA also depends on the resources of NASA and DOD to procure and launch its spacecraft. For example, NASA administers the contracts for NOAA's satellites, and Air Force crews launch NOAA's polar-orbiting satellites from Vandenberg Air Force Base.

NOAA reimburses NASA and DOD for the personnel and other costs they incur when helping NOAA meet its space mission. Overall and specific agreements between NOAA and NASA and between NASA and DOD (launch agreements are between NASA and DOD) govern the responsibilities and costs of the support provided to NOAA. NOAA is responsible for determining the requirements of users of its satellite services, specifying the performance of the systems needed to satisfy requirements, and obtaining the necessary funds to build and operate both the space and ground segment of its systems. These arrangements are an

44 This section draws on material prepared for OTA by R. Koffler.

45 The world's first operational weather satellite, ESSA-1 (for Environmental Sciences Services Administration- 1; ESSA was the predecessor to NOAA), was launched on February 3, 1966. The system was brought to full operational capability with the launch of ESSA-2 on February 28, 1966. The operational *weather* satellite program has been in continuous existence since these launches; however, as its capabilities were upgraded, it was referred to as the operational *environmental* satellite program. NOAA'S policy to allow unrestricted collection of weather information by any ground station in the line of sight of its satellites dates to policies enunciated by President John F. Kennedy.

outgrowth of agreements first reached by the three agencies in the 1960s.

The distinction between NOAA operational satellites and NASA research satellites dates to 1963, when NOAA rejected NASA's NIMBUS satellite as the basis for an operational program because of delays in its development and because it was judged too complex and expensive. Throughout the 1960s, DOD was developing weather satellites specific to its needs. By 1972, the DMSP weather satellite system, which for the first time included atmospheric sounders in addition to cloud imagers, was supporting centralized and field ground stations. At the same time, NOAA was launching the first of a series of second-generation operational satellites (denoted as the Improved TIROS Operational Satellite (ITOS)).[46] Development of a third-generation series of operational satellites was also under way—an atmospheric-sounder instrument array, in part provided by the United Kingdom, was under development; an upgraded visible-infrared imager was being designed; and plans called for the use of a data-collection system that would be provided by France.

In 1973, a national space policy study led by the Office of Management and Budget and the National Security Council examined the fiscal and policy implications of conducting separate DOD and NOAA operational weather satellite programs. Before the study, some officials had anticipated that a merged system could meet both agencies' requirements (because each had a similar requirement to acquire imagery of clouds) while providing an overall savings to the government. As noted above, however, NOAA and DOD weather systems acquire different kinds of data at different times of day to support different users.

The 1973 study based assessments of the technical feasibility and costs of a converged system on NOAA, NASA, and DOD analyses. The study concluded that no option could maintain current performance levels while providing significant cost reductions. In addition, policy concerns argued for the two programs to remain separate.[47] The 1973 review did, however, result in the Nixon Administration directing NOAA to use the DMSP Block SD spacecraft bus, then under development by the Air Force, as the basis for the next-generation series of polar-orbiting satellites. In addition, NOAA and DOD were instructed to coordinate the management of the separate programs more closely.

On eight occasions since 1972, the Departments of Commerce and Defense have studied convergence and implemented recommendations designed to increase coordination and avoid unnecessary duplication in their respective polar-orbiting environmental programs. The 1973 study and subsequent studies have resulted in programs that have similar spacecraft with numerous common subsystems and components. In addition, both programs now use a common launch vehicle and share responsibility for creating products derived from the data. The two programs also work together closely on R&D efforts and provide complement environmental information. However, until now, foreign policy and national security concerns have precluded full convergence.[48]

The latest proposal to consolidate NOAA's and DOD's meteorological programs is more likely to

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46 In 1972, ITOS/NOAA-2 became the first operational polar-orbiting satellite to convert from the use of a television camera to a scanning radiometer, permitting day and night imaging and quantitative sea-surface and cloud-top temperature measurements.

47 DMSP data were not shared with other nations. However, the United States had pledged to maintain an open civil weather satellite system. Additionally, the NOAA system was a visible demonstration of the U.S. "open skies" policy, and it satisfied long-standing U.S. obligations to exchange Earth data with the meteorological agencies and scientific organizations of other nations.

48 D.J. Baker, Under Secretary for Oceans and Atmosphere, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, testimony before the Subcommittee on Space of the Committee on Science, Space, and Technology, House of Representatives, U.S. Congress, Nov. 9, 1993.

succeed than past attempts because of the confluence of several factors, including:

- ***Extremely tight agency budgets in an era of fiscal austerity.*** Officials from NOAA, NASA, and DOD agree that this is the most important factor spurring convergence.
- ***Calls from members of Congress and the President to streamline government and effect cost savings.*** Satellite environmental remote sensing programs were among the programs targeted for cost savings in the President's National Performance Review.[49]
- ***Plans to make substantial upgrades ("block changes") in both the DMSP and POES programs during approximately the same period after the turn of the century.***
- ***A changed international security environment.*** The importance of this factor is uncertain. DOD requirements for meteorological data have not changed in the post-Cold War era. Nevertheless, some analysts believe the changed security environment has encouraged DOD to moderate its historical objection to shared military-civil systems.

Two other factors influencing the current convergence effort are: 1) the involvement of NASA, especially through the potential use of its EOS PM instruments, and 2) the involvement of foreign governments. especially through the planned use of Europe's METOP satellite.

Issues and Options for Convergence[50]

Satellite environmental remote sensing systems consist of both a ground and a space segment; therefore, consolidation of separate programs (convergence) could involve a range of options. For example, convergence could occur at the level of data processing and dissemination if common data requirements, standards, and distribution systems were established. Convergence might also occur at the instrument level if common requirements and designs for the acquisition of instruments were mandated. At a still higher level, convergence could involve the merging of operational programs under the direction of a single agency or a single new organizational entity. Finally, a fully converged system would do all of the above and use common spacecraft and instruments to satisfy what are now separate operational and research needs.

There are two principal scenarios for consolidating meteorological programs. The first would, in effect, involve combining plans for DOD DMSP Block 6 with NOAA-O, -P, and -Q meteorological satellites. The principal technical challenge in this convergence scenario would be meeting DOD's requirement for constant-resolution imaging and NOAA's requirement for calibrated imaging and atmospheric sounding. For example, DOD and NOAA have both studied concepts that would improve their respective imagers; convergence would require a new study to determine whether a single imager could be developed to meet both agencies' needs at an acceptable cost, or whether to fly two separate imagers would be more practical.

The second scenario would involve developing a common satellite and spacecraft bus and modified EOS sensors that would satisfy NOAA's and

49 A. Gore, "From Red Tape to Results: Creating a Government That Works Better and Costs Less," report of the National Performance Review (Washington, DC: Office of the Vice president, Sept. 7, 1993). See also National Performance Review, Office of the Vice President, *National Aeronautics and Space Administration: Accompanying Report of the National Performance Review* (Washington, DC: Office of the Vice President, September 1993).

50 This section draws on interviews and briefings from NOAA, NASA, DOD, and industry officials. It also draws on briefing papers provided by attendees of an OTA Workshop, *A National Strategy for Civilian Space-Bared Remote Sensing,* held Feb. 10, 1994. For a review of technical and policy issues specifically related to the Clinton Administration's convergence plan, see D. Blersch, *DMSP/POES: A Post Cold War Assessment (A Re-Examination of Traditional Concerns in a Changing Environment)* (Washington, DC: ANSER Corp., June 1993); and H. Kottler, J.R. Lifsitz, J.J. Egan, and N.D. Hulkower, *Perspectives on Convergence,* Project Report NOAA-10 (Lexington, MA: Massachusetts Institute of Technology Lincoln Laboratory, Feb. 8, 1994). See also U.S. Department of Commerce, Office of the Inspector General, *National Strategy for Remote Sensing Is Needed,* AIS-0003-0-0006 (Washington, DC: U.S. Department of Commerce, February 1991).

DOD's operational requirements and NASA's science research missions. Attention has focused on NASA's planned PM series of satellites because these satellites will carry instruments that have previously been identified as candidates for future NOAA weather and climate monitoring needs. NASA is studying the practicality of reconfiguring EOS payloads into smaller MELV Delta II-class expendable launch vehicles. This "three-way" convergence scenario would offer greater savings to the government than NOAA-DOD convergence because it would use a common bus and might use EOS instruments to satisfy both operational and research objectives. Several economies of scale would also result if a converged Delta II-class spacecraft and bus were suitable for all three agencies.

The Clinton Administration's convergence proposal combines the two scenarios outlined above. It seeks to consolidate NOAA's and DOD's meteorological programs while capitalizing on NASA's EOS technologies. Any convergence plan—whether the Administration's or one of its many permutations-has several generic elements that raise a common set of issues. The following section provides an overview of these issues, giving particular attention to questions about program synchronization, program implementation, and the effect of combining U.S. civil and military programs with European civil programs. The future of Landsat, options for converging future land remote sensing programs with the EOS AM series, and potential ocean monitoring systems are not part of the Administration's proposal. They are discussed in this report because, as noted earlier, land and ocean monitoring systems would be an essential part of any comprehensive long-term plan for U.S. satellite-based environmental remote sensing.

National Security Considerations and the Role of International Partners

Historically, meteorological programs at NOAA and DOD have differed in their reliance on cooperative international ventures and in their policies toward sharing data. NOAA has a long record of international cooperation in its environmental remote sensing programs. Indeed, international cooperation has proved essential to NOAA in its geostationary operational environmental satellite system (GOES). By an agreement signed in July 1993, ESA and Eumetsat are making METEOSAT-3 available to replace the failed NOAA geostationary satellite, GOES-6.[51] Similarly, by international agreement, meteorological data from NOAA's POES satellites are provided to the U.S. National Weather Service and to foreign weather services. As noted ealier, convergence has not altered the U.S. intent to use European METOP satellites to satisfy a requirement for an AM polar orbiter. Plans call for METOP to carry U.S.-supplied sounders and imagers as well as European payloads.[52]

In addition to the foreign policy benefits usually associated with successful international ventures, foreign cooperation in meteorological and climate monitoring programs may benefit the United States by reducing expenditures for operational programs (e.g., METOP replaces NOAA AM satellites) and by increasing opportunities to flight-test advanced technologies (on METOP-1

51 Currently, five geostationary Satellites orbit Earth; two are operated by Europe, and the United States, Japan, and India each operate one. If GOES-6 had not failed, the United States would be operating two satellites to monitor regions of Earth of interest to NOAA weather forecasters.

52 Europe Originally planned to launch a polar-orbiting Earth observation satellite, denoted as POEM. METOP, whose primary mission is operational meteorology, and ENVISAT, which is primarily an atmospheric chemistry mission, resulted when the POEM platform was divided into two smaller platforms. Before the Administration's convergence proposal was announced, the United States had planned to fly the following instruments on METOP- 1: AVHRR/3 (Advanced Very High Resolution Radiometer); AMSU-A (Advanced Microwave Sounding Unit-A, a U.S. instrument that will be flown on NOAA POES satellites beginning with NOAA-K in 1996 andon EOS PM- 1 in 2000); and HIRS/3 (High-Resolution Infrared Sounder). VIRSR (Visible and Infrared Scanning Radiometer), an upgraded version of AVHRR/3, had been scheduled for inclusion on METOP-2. It could be replaced by anew sensor to match the needs of both NOAA and its partner in convergence, DOD. However, partly to achieve economies of scale, ESA may wish to make METOP-2, in effect, a clone of METOP-1.

and its successors). European, Japanese, and Canadian cooperation is also essential if the long-term objectives of NASA's Mission to Planet Earth and the U.S. Global Change Research Program are to be fulfilled (chapter 4).[53]

Plans to use European satellites for NOAA's AM mission—in effect, an international "convergence''—were in place well before the Administration initiated its convergence studies. It is not known yet whether a convergence plan that combines NOAA's and DOD's meteorological programs with European programs will require changes in the U.S.-supplied portion of METOP's payload. In particular, the question of whether successors in the METOP series would carry an instrument combining the functions now performed by NOAA's AVHRR and DOD's OLS remains unresolved. This issue is independent of the more general question of whether Eumetsat will agree to U.S. conditions regarding control of data from U.S. instruments on board METOP.[54]

Maintaining international cooperative relationships in environmental remote sensing is an important consideration in **any convergence proposal.** Therefore, any convergence proposal must address the following questions:

- What contingency plans are needed if delays arise from the U.S. development of a combined payload-spacecraft for NOAA, DOD, and, perhaps, EOS PM?
- Does the plan reconcile European desires for self-sufficiency in sensors and spacecraft with U.S. needs for data consistent among spacecraft? Although the United States and Eumetsat plan to fly three U.S. sensors on METOP-1 and METOP-2, Europe plans to develop its own sensors for future METOP spacecraft. To maintain consistent data, U.S. officials will have to coordinate closely with Eumetsat and ESA officials concerning the technical characteristics of new sensors. Issues related to technology transfer may also arise, especially if the United States concludes that meeting NOAA's and DOD's requirements in a converged program will require that METOP carry a new advanced visible and infrared imager.
- Does the plan address European concerns about data access while satisfying DOD needs for data protection during times when U.S. national security interests would be threatened by open access? Who decides when such times exist? What happens if an agreement cannot be reached?
- What contingency plans are needed should delays occur in the launch of METOP- 1, and what contingency plans are needed to maintain service should a launch or on-orbit failure occur? In particular, when should METOP-2 be available to ensure continuity with METOP- 1, and what are the European plans beyond METOP-2?

The Administration's convergence proposal answers many of these questions. However, one issue in particular remains unresolved: DOD's approval of European involvement in the converged program is subject to Europe's acceptance of several conditions relating to data access and control.

Program Synchronization

The last satellite in the current NOAA POES series is scheduled for launch near the end of 2005. Similarly, the last of the current series of DOD DMSP satellites under development or contract (S11-S20) may be launched around this time or later. This schedule focuses attention on the possibility of redesigning NOAA-N and -N as merged

[53] See G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook, op. cit.*

[54] Most likely, it is already too late to develop new instruments for inclusion on METOP-1, which is under development, with a scheduled launch in 2000. Whether Eumetsat would agree to a new instrument in METOP-2 was unknown at the time this report was completed (July 1994). METOP-2 is also under development; its scheduled launch is 2005, However, if DOD and NOAA merge their weather programs, the United States may ask that METOP-2 be available sooner to ensure continuity of service with METOP- 1. This would reduce the time available to make changes in METOP. In addition, for reasons noted above, European space officials may be reluctant to change METOP-2.

NOAA and DOD meteorological satellites.[55] It also raises such issues as whether it would be cost-effective to redesign DMSP satellites for joint missions,[56] whether a new spacecraft should be developed, and whether instruments on NASA's PM satellites could be adapted to satisfy NOAA's and DOD's operational requirements. PM-2 is scheduled for launch in approximately 2005; therefore, it and PM-3 would be the most likely candidates for inclusion in a combined research-operational satellite program. An added complication in these issues is the possibility that NOAA's and DOD's satellites will exceed their expected lifetimes.

To meet NOAA's and DOD's requirements, the Administration's convergence plan calls for three polar-orbiting satellites, with local equator crossing times of 0530, 0930, and 1330, to replace the current constellation of four satellites. Europe's METOP satellite is scheduled to assume the morning NOAA mission beginning in 2000 (assuming the successful resolution of ongoing negotiations). National security and other considerations unique to DOD missions (see above) effectively foreclose the possibility y of a combined DMSP-METOP AM mission. Therefore, it is most likely that convergence would result in a system architecture consisting of both U.S. and European AM satellites, with the U.S. satellite designed to satisfy DOD's imagery needs and the European AM satellite (carrying U.S. instruments) designed to satisfy NOAA's and DOD's sounding needs. Depending on the results of ongoing studies, the PM satellite could either be a NOAA-DOD meteorological satellite or a combined NOAA-DOD-NASA satellite that would satisfy current and anticipated needs for operational meteorological and climatological data.

Land remote sensing is *not* part of the current convergence effort, but it could be part of a future effort to coordinate polar Earth observation programs. NASA hopes to launch Landsat 7 by the end of 1998. Assuming a 5-year satellite lifetime, a Landsat 8 might follow in approximately 2004. Given the advanced state of preparations for EOS AM-1, scheduled for launch in 1998, AM-2, scheduled for launch in approximately 2003, would be the first opportunity to converge land remote sensing programs. The many issues associated with developing follow-ons in the Landsat series are discussed below.

Impact of NASA's Redesign of EOS

Originally, NASA planned to launch the largest EOS satellites—AM-l,2,3; PM-1,2,3; and CHEM-1,2,3-on intermediate-class expendable launch vehicles such as the Atlas IIAS. As noted above, NASA is now determining whether these missions (except AM- 1, which is too far into development) can be launched on a smaller MELV such as a Delta II. However, the more restrictive volume and weight constraints of the Delta II might force NASA to reduce the size, weight, and capability of instruments such as MODIS and AIRS.[57] Such "descoping" might also prove necessary even if NASA retains IELVS because the

[55] NOAA-N and -N' were "gap-fillers" that were intended to maintain continuity between NOAA's last scheduled PM spacecraft in the current ATN series and the block change. They are now supposed to serve as gap-fillers before the first launch of a converged satellite. Currently, NOAA and DOD do not plan to attempt to redesign N or N' as a converged satellite.

[56] For example, according to a DMSP official, the SD-3 bus was not designed to carry the heavier NOAA instruments.

[57] AIRS an instrument designed for determining global atmospheric temperature and humidity profiles, would effectively be a much more capable version of NOAA's HIRS (box 2-4). Its improved capabilities include an increase by a factor of 2 in ground resolution (13 km looking nadir). These and other improvements would support NOAA's desire to extend its weather predictions to 7 to 8 days. MODIS is considered a "keystone" instrument for the EOS program. It is a multispectral instrument for measuring, on a global basis every 1 to 2 days, biological and physical processes on the surface of Earth, in the oceans, and in the lower atmosphere. MODIS may be thought of as a highly advanced, or next-generation, AVHRR. It is being designed with 36 visible and infrared bands (from 0.41 to 14.4 pm) compared with AVHRR'S five bands and will incorporate extensive on-board "end-to-end" calibration features. These calibration features, which are not present on AVHRR, are designed to give MODIS unprecedented spatial and radiometric accuracy across its spectral bands. As a result, MODIS should be able to distinguish instrument effects from subtle changes in the various processes researchers hope to study. Modifications to the MODIS focal plane and scanning mode might also allow it to serve as a replacement for DOD's OLS.

AIRS and MODIS original y planned for flight by NASA had capabilities that exceeded NOAA's "core" requirements and would have strained NOAA's budget. Operational programs typically require the launch of a series of spacecraft that acquire data over periods measured in decades.[58] In their original configuration, AIRS and MODIS would likely have been unaffordable. In addition, they would have strained NOAA's data-processing capabilities. These "descoping" options affect convergence proposals because AIRS and MODIS have long been identified as candidates for future operational instruments.

Several options would satisfy NASA's desire to accommodate its EOS payloads on a smaller, less expensive launch vehicle and the Administration's goal to consolidate polar-orbiting satellite programs. For example, PM-1 could be developed and launched on an IELV as currently planned in 2000, but that experience could be used to determine the practicality of modifying EOS research instruments to make them smaller, less expensive, but highly reliable operational instruments suitable for converged spacecraft launched on an MELV. The end result of such an exercise would be to develop versions of PM-2,3 that satisfy the needs of both research and operational users of environmental data. A critical, as yet unresolved, question is whether such a payload suite is practical.

Instrument Convergence

A converged meteorological satellite will have to satisfy DOD's needs for advanced imagery sensors and NOAA's requirements for highly calibrated operational and affordable sounders (table 3-2).[59] Accommodating some of the EOS tech-

TABLE 3-2: Key Sensors and Priorities for NOAA's and DOD's Polar Meteorological Programs

Agency and mission	Sensor[a]	Attributes
NOAA		
Multispectral Imagery (cloud, vegetation)	AVHRR	Calibrated, multispectral imagery
Temperature and humidity (initialize numerical weather prediction models)	TOVS	High spatial resolution, cross-track scanning (PM equator crossing)
DOD		
Visible and infrared cloud imagery (cloud-detection forecast, tactical imagery dissemination)	OLS	Constant field of view, low-light (early AM equator crossing)
Microwave imagery (ocean winds, precipitation)	SSM/I	Conical scan
Temperature and humidity (electro-optical propagation, initialize numerical weather prediction models	SSM/T- 1 SSMT-2	Low spatial resolution, cross-track scanning

[a] AVHRR = Advanced Very High Resolution Radiometer, TOVS = TIROS Operational Vertical Sounder, OLS = Operational Linescan System SSM/ I = Special Sensor Microwave/Imager Special Sensor Microwave/T-1 = SSM/Temperature Sounder Special Sensor Microwave T-2 = SSM Water Vapor Sounder

SOURCE: Office of Technology Assessment 1994

[58] version of AIRS now planned for flight on EOS satellites will be supplied by LORAL Infrared and Imaging Systems. AIRS was "descoped" in 1992 to reduce its cost; the current design will better match NOAA's requirements than the original EOS design (the changes involved a reduction in the spectral coverage, but not the sensitivity}. of the instrument). NASA's EOS MODIS instrument will be supplied by Hughes Santa Barbara Research Center. MODIS has not been redesigned; NASA scientists envision flying MODIS to determine how best to design a version suitable for operational missions.

[59] A combined environmental satellite would likely also carry instruments for search and rescue and space environment monitoring, but these instruments are small and do not appear to present significant technical challenges.

nology demonstration and science research programs in an operational satellite program would add to this challenge. Issues related to the development of an appropriate suite of instruments for converged environmental satellites cannot be fully **resolved until the technical requirements for a joint program are finalized.** If convergence efforts were to be integrated into a broader effort to coordinate operational, scientific, and commercial remote sensing efforts (that is, if convergence was subsumed into a larger national strategic plan), then the NOAA and DOD search for a common set of requirements would also require consultation with the broader scientific community and with other users of remotely sensed data (see chapter 2). However, several reviewers of a draft of this report expressed concern that broadening the focus of convergence would complicate the already difficult process of determining joint-agency operational requirements.

The principal technical challenge in designing a suite of instruments to meet the current NOAA and DOD requirements is the imager for supplying data now provided by AVHRR and OLS (box 3-4). Another issue is how to meet DOD's and NOAA's needs for high-resolution wide-area microwave imaging and high-resolution sounding, respectively. DOD now uses the SSM/I to meet its microwave-imaging needs. An upgraded version of SSM/I, whose features include a wider ground coverage, is also under development by DOD.[60] However, the scanning method used by these instruments differs from the type of scanning NOAA sounders use. Because NOAA requirements dictate the use of their particular scanning method, instrument designers would face a problem designing a common DOD-NOAA microwave imager-sounder.[61] Separating NOAA and DOD instruments on a converged satellite maybe possible, but not without weight and volume penalties. This scan-method mismatch has its roots in the instrument heritage and acquisition strategy peculiar to NOAA and DOD. It maybe viewed as a manifestation of the cultural differences that have developed between the two agencies.

Another issue relates to the possible U.S. use of MIMR (Multi-frequency Imaging Microwave Radiometer), a more capable version of SSM/I being developed in Europe for use in both METOP and, under a Memorandum of Understanding between NASA and ESA, for use on EOS PM-1. MIMR uses advanced millimeter-wave technology. Millimeter-wave environmental sensing is a DOD technology that is highly developed in DMSP spacecraft. Some experts in this technology expressed concern about ceding its continuing development to a foreign partner.

Implementing a combined NOAA-DOD operational program with NASA's EOS PM science research program would add both opportunities and complications to instrument and spacecraft bus design. A tri-agency converged satellite program would present challenges that include the need to:

- satisfy operational requirements for data continuity with comparatively unproved instruments;
- accommodate the different production standards and the different data and communication protocols that heretofore have distinguished operational and research instruments;
- develop instruments that meet NASA's research needs but are affordable to NOAA and DOD;
- develop instruments that meet the more limited space and volume requirements of a medium-class expendable launch vehicle; and

60 SSM/IS will replace SSM/I, SSM/T-1, and SSM/T-2 on DMSP 5D-3 spacecraft. It will have improved equatorial coverage, which is particularly important to the Navy because storms originate in the equatorial regions.

61 NOAA weather forecast models require near-simultaneous infrared and microwave sounding measurements through a particular column of air. Because the NOAA infrared sounder on recent POES satellites, HI RS, uses a "cross-track" scan, the NOAA microwave sounder, MSU (and the AMSU to be flown on NOAA's K-N series), is also a cross-track scanner. However, DOD's microwave imager, SSM/I, and its planned upgrade, SSM IS, execute a conical scan to generate images.

- accommodate technology demonstration and prototyping on operational spacecraft.

Program Funding and Management

The overriding consideration in the current round of convergence proposals is reducing program costs. If implemented successfully, convergence might also lead to more effective programs as talent and resources are pooled. Perhaps as important as cost savings, however, would be the opportunity to strengthen the relationship between NASA and NOAA to enable them to develop the technology that will be needed for future operational spacecraft. Historically, NASA funded, developed, and demonstrated space technology and flight-worthy instruments and spacecraft that were then used for operational missions. Currently, NOAA has the lead role in managing operational programs, but it lacks the funds and in-house expertise to develop the instruments and spacecraft it will need to carry out new missions, such as ocean monitoring and long-term monitoring of Earth's climate.

Convergence also poses risks, especially the disruption in operational programs that, by definition, are designed to provide stable data products on a routine basis. **The principal challenges in implementing converged operational satellite remote sensing programs are not technical (that is, developing an instrument suite and spacecraft suitable for joint programs). Instead, the challenges are likely to be centered in program management and program funding.**

Developing joint program management structures that will mesh with existing congressional and executive branch budgeting procedures may prove particularly challenging. Currently, NOAA's, NASA's, and DOD's environmental remote sensing programs originate within separate parts of the Office of Management and Budget and are submitted yearly for authorization to several different congressional authorization committees in the Senate and the House of Representatives.[62] Budgets are then authorized by three different appropriations subcommittees in the House of Representatives and three different appropriations subcommittees in the Senate. OMB, NOAA, NASA, and DOD can develop mechanisms for integrating budget submissions; however, the congressional authorization and appropriations process would still involve multiple subcommittees.

The current authorization and appropriations process is not designed to formulate a national weather and environmental satellite system. **There is no congressional organizational structure parallel to that of the executive branch, where the Office of Science and Technology Policy and the Office of Management and Budget seek to coordinate policy across the different departments and agencies.**[63] Currently, congressional committees long familiar with NOAA, NASA, and DOD oversee each agency's particular needs and problems. Thus, joint management of satellite programs will add new elements of uncertainty in the authorization and appropriations process. Disputes between different committees that result in a shortfall in one agency's budget would affect all participating agencies.

Under the current congressional authorization and appropriations process, a joint program would, in effect, be considered in pieces, with each agency contribution analyzed in the context of the agency's overall budget, rather than in the

[62] In the House of Representatives, oversight for R&D activities related to Landsat and NOAA operational satellite programs (POES and GOES) lies in the House Committee on Science, Space, and Technology (HSST). NASA R&D activities are also overseen in the House by HSST. However, HSST does not have jurisdiction over basic research conducted by DOD, which is overseen by the House Armed Services Committee, A similar situation exists on the Senate side, with the Committee on Commerce, Science, and Transportation (SCST) playing a role analogous to HSST's and the Senate Armed Services Committee playing a role analogous to the House Armed Services Committee's, See Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Congress: Organization and Procedural Reforms* (New York: Carnegie Commission on Science, Technology, and Government, February 1994).

[63] Ibid.

context of its contribution to the joint program. Historically, federal agencies have been reluctant to fund systems 1) that do not fit completely into the framework of their missions, **2)** that carry a price tag disproportionately high for the good they do for the agency, or 3) that commit large sums over many years to another agency's control. **The government has few examples of successful multiagency programs-recent problems with joint NASA-DOD management of the Landsat system suggest that proposals to consolidate operational programs should, at the very least, be scrutinized with great care.**

Before the announcement of the Clinton Administration's convergence proposal, NOAA, NASA, and DOD officials had stated that a single agency should lead a joint-agency environmental satellite program. NOAA's assignment as the lead agency was made, in part, to ensure the continuation of successful international partnerships in operational meteorology programs. The Administration's plan assigns NASA the lead role in technology transition efforts and DOD the lead role in system acquisition. This division of responsibilities represents a significant change from current practices only with respect to acquisition-currently, NASA manages satellite acquisition for NOAA.

The Administration's plan is organized with mutual interdependence and shared interests as key objectives. Such arrangements are designed to minimize the chances for a repeat of the breakdown in joint program management that occurred between NASA and DOD in the development of Landsat 7 (see box 3-5). Nevertheless, they still leave open the possibility that in a constrained fiscal environment, agencies or appropriations committees will fully fund only those programs perceived to be of highest priority ("burden shifting").

In a previous report, OTA described how the Committee on Earth and Environmental Sciences (CEES) coordinated the U.S. Global Change Re-

BOX 3-5: Developing Multiagency Programs

The Integrated Program Office proposed in the Clinton Administration's convergence plan (figure 1-4) would be funded by NASA, NOAA, and DOD. Each agency would take the lead on one function of the operational system—technology development (NASA), procurement (DOD), and operations (NOAA)—but each functional office would include representatives of all agencies. This arrangement is designed to institutionalize each agency's incentive to support the overall system. On the other hand, it is more bureaucratic than other management options, and it suffers the weakness of depending on three different sources of funding to support the system.

The traditional process for annual budget submission was not designed to develop integrated multiagency programs. For example, within the Office of Management and Budget, programs and budget submissions for NOAA, NASA, and DOD are reviewed by different branches. This structure makes an integrated review of agency requirements difficult because agency initiatives for upgrading or developing new systems are submitted to different budget examiners. Furthermore, budget submissions for agency initiatives may appear in different years.

The Administration's management plan is designed to avoid the problems that have plagued joint agency management of Landsat. Its weaknesses are unavoidable given the existing differences between executive branch and congressional mechanisms for developing and funding programs that cross agency budgets. These problems are exacerbated for operational programs, which place a premium on continuity of operations.

SOURCE: Office of Technology Assessment, 1994.

search Program (USGCRP).[64] The CEES mechanism for reducing redundancy and coordinating disparate efforts among some dozen federal agencies engaged in global change research is generally considered to have "worked," at least on the executive branch side. However, agencies participating in the USGCRP may have supported the CEES process, despite some loss of control over the global change portion of their budget, because CEES delivered increased funding through its multiagency "cross-cut" budget. In contrast, convergence is an effort to reduce overall government expenditures. Whether this will affect the success of the tri-agency management plan remains to be seen. Administration officials note the success of aground-based interagency remote sensing effort, NEXRAD (Next-Generation Weather Radar), as a model for how convergence might work. In NEXRAD, the Departments of Commerce, Transportation, and Defense cooperate on the purchase and operation of powerful radar systems. However, a joint-agency environmental satellite program would differ from NEXRAD in at least one important way: the nation is less dependent on NEXRAD radars than it is on its weather satellites. Furthermore, the failure of a single radar or a delay in the introduction of radar upgrades would affect the ground radar system to a far less degree than would a similar problem with the weather satellites.

Establishing Common Requirements

To implement a convergence plan, NOAA and DOD will have to establish a common set of requirements for converged operational environmental satellites. However, requirements for satellite data depend not only on the sensors, but also on how sensor data are analyzed (the "retrieval" algorithms used to translate measurements into useful information) and how data are assimilated into the models by users.[65] Thus, establishing a common set of requirements for NOAA's and DOD's meteorological systems will require an examination of the hardware and software involved—from data acquisition to data analysis—in both the space and ground segments of the POES and DMSP systems.

The differences between NOAA and DOD practices noted earlier-different priorities, different user communities, different perspectives, and different protocols with respect to acquisition and operations—will complicate the effort to arrive at a mutually satisfactory set of requirements. For example, NOAA had planned for its next-generation POES satellites (O, P, and Q) to provide improved global atmospheric temperature and humidity profiles to support state-of-the-art numerical weather prediction models.[66] However, DOD requirements for infrared sounding had been set only to meet those of the current 5D-3 satellites.[67] The resolution of this and similar differences will directly affect sensor selection and cost. As discussed below, another complication in setting requirements is determining the role of NASA in a tri-agency satellite program.

Cost Savings

The Administration expects convergence to achieve economies by developing and procuring common space hardware from a single contractor,

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[64] U.S. Congress, Office of Technology Assessment, *Global* Change *Research and NASA Earth Observing System,* op. cit. On November 23, 1993, President Clinton announced the establishment of the National Science and Technology Council. With this announcement, coordination of the USGCRP transferred from CEES to the newly formed Committee on Environmental and Natural Resources Research (CENR).

[65] The federal government operates three operational numerical weather prediction centers: NOAA'S National Meteorological Center (NMC), the Navy's Fleet Numerical Oceanographic and Meteorological Center (FNMOC), and the Air Force Global Weather Center (AFGWC). The way that satellite data is used by these centers is somewhat different; however, there is a Memorandum of Understanding coordinating a Shared Processing Network among the centers.

[66] For example, the requirements of the Atmospheric Infrared Sounder, which have been set to meet NOAA's requirements, call for vertical resolution of 1 km, temperature accuracy of I K, and ground resolution of 13 km—all approximately a factor of 2 better than what is now available. This will support NOAA's desire to extend its weather prediction models to 7 to 8 days.

[67] DOD's DMSP Block 6 upgrade emphasized cost savings and enhanced microwave-imaging capabilities over enhanced sounding capabilities.

reducing the number of spacecraft (the current total of four DOD and NOAA operational meteorological satellites in orbit simultaneously would be reduced to two), and reducing the cost of launch services. The Administration also expects savings to accrue from reductions in the cost of program and procurement staff, consolidation of ground control centers, and economies of scale related to data-receiving and -processing hardware and software. Common instruments and data formats would allow increased production volumes for data-capture terminals and related equipment that would service a broader community. However, in the next several years, convergence would offer only limited opportunities for savings—for example, from the termination of parallel design efforts for block changes and new spacecraft bus designs in both the POES and DMSP satellites. A tri-agency convergence plan would also consolidate some of NASA's planning for its PM satellites.

Implementing convergence would also require funding several new activities. Requirements studies, instrument-tradeoff studies, the development of new instruments, a new spacecraft bus (or the adaptation of an existing bus), and the possible adaptation of MELVs[68] to launch converged spacecraft would be "upfront" costs that would be incurred before the longer-term savings from convergence could accrue. Moreover, because the architecture and instrument complement of converged spacecraft programs are not finalized,[69] estimates of the savings expected from reduced numbers of launches and spacecraft are more uncertain than are estimates of the additional costs of implementing convergence. **Therefore, Congress may wish to examine estimates for the net savings of convergence with particular attention to the question of how these estimates would change if unexpected problems or delays occurred in the design or adaptation of sensors, spacecraft buses, and launch vehicles.**

Transition from Research to Operational Satellites

A principal requirement for operational satellite systems is the unbroken supply of data. Therefore, operational systems require backup capability in space and on the ground and a guaranteed supply of functioning 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. Historically, the transition from research instrumentation to operational instrumentation has been 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 (box 3-6).

During the 1960s and 1970s, the 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. 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 NIMBUS to replace its TIROS satellite and to develop into an operational series of weather satellites for NOAA. However, NOAA chose to

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68 For example, launching a converged EOS-PM/POES/DMSP satellite on a Delta II MELV might require redesigning and testing an enlarged fairing.

69 Even when program details are announced, there will still be uncertainty surrounding the introduction of technology to be demonstrated by EOS-PM. Technical studies to resolve issues such as how to meet DOD'S and NOAA's imaging and sounding requirements can be completed in less than 1 year; however, the on-orbit record of EOS PM instruments will not be available until 200 I or later.

BOX 3-6: NOAA Practices in Developing Operational Satellites

NOAA is chartered to provide environmental observations as a routine service to U.S. and foreign users. NOAA recognizes three practices as critical in planning for mission success:

- **Accommodating long lead times.** A "new" NOAA satellite, based on low-risk, proven technology, is generally representative of technology conceived of and developed a decade earlier by NASA or DOD. Because a NOAA satellite series can continue in operation for a decade or more, the last satellite may be based on technology that is 20 years old. NOAA's conservative philosophy toward the introduction of new technology was apparent as early as 1963 when NOAA rejected NASA's NIMBUS satellite as the basis for an operational satellite because its development was judged too complex and expensive.
- **Providing for data continuity.** NOAA's environmental data are provided as a public good. The agency makes the data available free of charge to national environmental service agencies in the United States and other countries and to a diverse group of scientific and other users here and abroad. Ground stations throughout the world receive NOAA data for purposes ranging from regional weather warnings to global numerical weather analysis, and from graduate- to hobby-level education. Many users rely on unbroken data flows and consistency in data characteristics. Therefore, when it introduces new satellite systems, NOAA's plans typically include system backups and overlapping operation (to assist in calibrating between satellites). As a rule, NOAA does not make abrupt changes in system characteristics.
- **Managing system cost.** NOAA's success is judged by its ability to deliver environmental data reliably at low cost. Historically, NOAA has operated under relatively flat budgets. Unlike NASA's or DOD's, NOAA's budgets have comparatively little allowance for budget increments to develop new technology or to meet special national security requirements.

SOURCE: Office of Technology Assessment, 1994.

develop TIROS as its operational system, in part to minimize technical risk. Both programs then went forward, with NASA developing NIMBUS 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.[70]

Throughout the 1970s and early 1980s, NASA also assisted with the development of NOAA operational satellites through its funding for OSIP. For example, NASA built and paid for the launch of the first two geostationary operational satellites (called SMS, for synchronous meteorological satellite) that NOAA operated. TIROS-N, the prototype for the modern NOAA POES satellite, also started out at NASA and was transferred to NOAA. OSIP ended in 1981 as NASA, faced with a tightly constrained budget (in part, the result of Shuttle cost overruns), withdrew from its interagency agreement with NOAA. NASA's support for NOAA operational programs continued but was carried out with NOAA reimbursing NASA. The end of the NASA-NOAA partnership may

70 For example, NIMBUS 7, launched in October 1978 and partially operational 15 years later, carried the Scanning Multi frequency Microwave Radiometer (SMMR) that became the SSM/I on DMSP. It also earned the Solar Backscatter Ultraviolet and Total Ozone Mapping Spectrometer (S BUV/TOMS) and the Coastal Zone Color Scanner (CZCS). SBUV is now carried on TIROS, and CZCS is the predecessor for the planned SeaWiFS ocean-color-monitoring instrument. Other NIMBUS 7 instruments were predecessors to instruments now flying on UARS or planned for EOS. 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.

have contributed to the subsequent difficulties NOAA experienced in the development of "GOES-Next" (GOES I through M).[71] It also marked a lessening of support within NASA for the development of operational meteorological instruments. Instead, as illustrated by the precursor and planned instruments for the EOS series, NASA became more focused on experimental research instruments designed to support basic scientific investigations.

Convergence **provides an opportunity to restore what had been a successful partnership between NASA and NOAA in the development of civil operational environmental satellites.** However, even with convergence, tensions will likely arise in the new relationship. NOAA and NASA will face difficulties in reconciling the inevitable differences in risk and cost between instruments designed for research and instruments designed for routine, long-term measurements. For example, NASA considers MODIS, a key EOS instrument, a potential successor to NOAA's AVHRR. However, MODIS is unlikely to fit within NOAA's budget.

NASA'S NIMBUS program **was successful in facilitating the transition between research and operational instruments because the instruments that flew on Nimbus did not require extensive modification after they were turned over to NOAA.** In contrast, EOS instruments such as MODIS would likely have to be restructured to be affordable to NOAA or other operational users. This raises the obvious question of whether it is more cost-effective to develop a new instrument designed for NOAA than it is to demonstrate a research instrument and then "descope" its capabilities.[72] Unlike NIMBUS, **NASA's EOS program was not conceived as a test bed for advanced technology.** EOS is primarily a system designed with the research and the policymaking communities in mind. With or without convergence, NASA, NOAA, and DOD will face challenges in adapting EOS programs to serve both research and operational needs.

As noted in the introduction to this chapter, future operational missions are likely to include monitoring the land surface and monitoring the oceans. The last two sections of this chapter discuss several issues related to the development of these programs, with particular attention to the Landsat program—a quasi-operational system that illustrates both the promise and the challenges of implementing new operational programs.

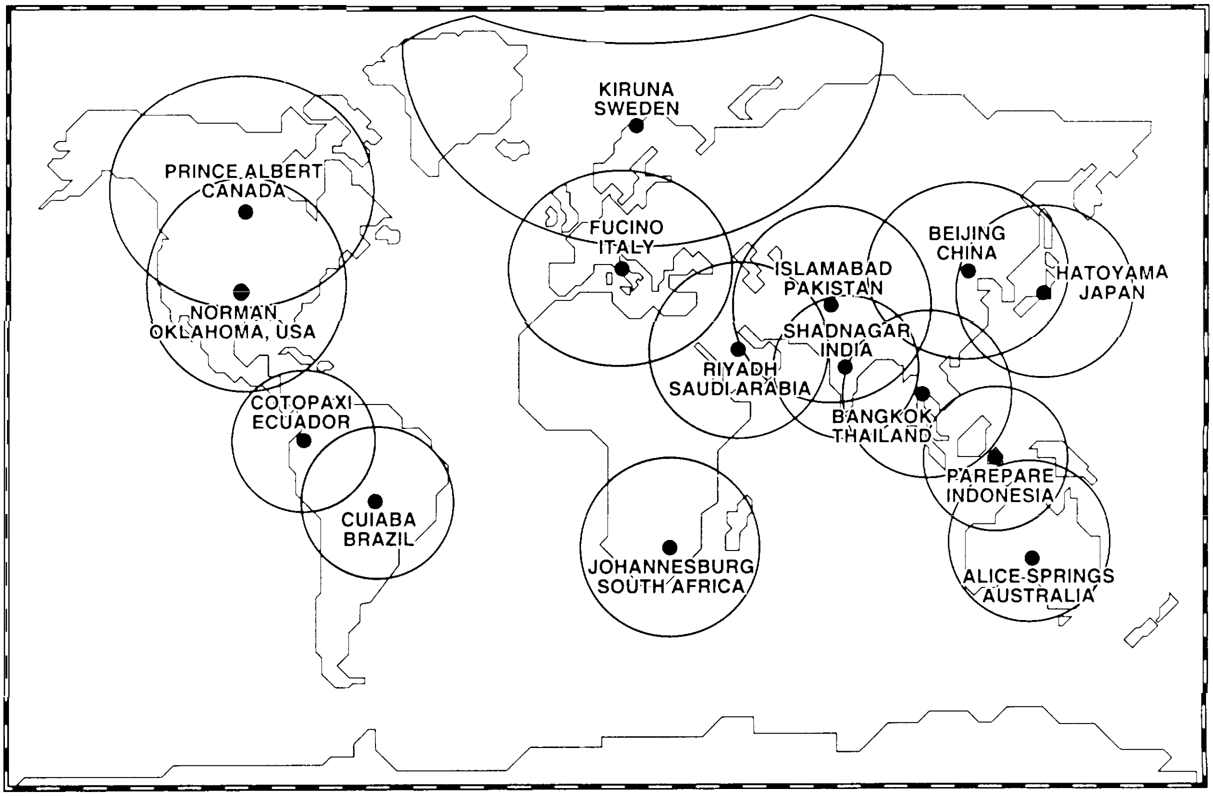
LAND REMOTE SENSING AND LANDSAT

Land remote sensing from satellites began in the late 1960s with the development of the Earth Resources Technology Satellite (ERTS). NASA launched ERTS-1, later renamed Landsat 1, in 1972. Throughout the 1970s, NASA and other U.S. agencies demonstrated the usefulness of satellite-based multispectral remote sensing for civil purposes, using expensive mainframe computers and complex software to analyze data from Landsat multispectral scanner (MS S). NASA also encouraged the development of Landsat receiving stations around the world (figure 3-3), both to col-

71 Problems with the GOES program began with the addition of a sounding capability to the visible and infrared spin scan radiometer (WSSR), which became the VISSR Atmospheric Sounder (VAS). See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space,* op. cit., pp. 38-39.

72 Reviewers of an early draft of this chapter raised two other issues. One stated, "If one accepts the earlier arguments about adding oceanic, terrestrial, and cloud imaging requirements to the operational satellites, there are two options to fulfill these requirements. First, building three independent instruments to meet specific requirements of each discipline (i.e., AVHRR, CSCZ/SeaWiFS and Landsat). Second, build a single instrument to meet all these requirements (i.e., MODIS). A cost, technology, and requirements analysis should reveal which option is optimum." A second reviewer noted, "Until MODIS, or some instrument with similar capabilities, is flown, it will not be possible to define the instrument that NOAA really needs. Only by using MODIS, with its high spectral resolution, high signal-to-noise ratio (SNR), and excellent calibration to acquire an extensive data set, can we establish what spectral bands, what SNRS, and what calibration accuracies are required for what applications. . . . Atmospheric remote sensing instruments can be designed almost from first principles . . . but the utility of land remote sensing instruments for many applications really cannot be assessed without acquiring the large-scale data sets that only satellites can provide."

FIGURE 3-3: Landsat Receiving Stations



SOURCE: EOSAT, 1994

lect data for U.S. needs and to encourage widespread use of the data.[73] For example, NASA and the U.S. Agency for International Development collaborated on Landsat demonstration projects and training in developing countries.[74] These efforts made the advantages of satellite data for mapping, resource exploration, and managing natural resources well known around the world.

Landsats 1, 2. and 3 carried the MSS. In the 1970s, NASA also developed the Thematic Mapper (TM), a sensor with more spectral bands and higher ground resolution (table 3-3).[75] Landsats 4 and 5, which were launched in 1982 and 1984, respectively, carried both the MSS and TM sensors. Until the first French Système pour l'Observation de la Terre (SPOT-1) satellite was launched in 1987, Landsat satellites provided the only widely available civil land remote sensing data in the world. The SPOT satellites introduced an element of market and technological competition by pro-

73 NASA's Landsat policy was a Cold War strategy to demonstrate the superiority of U.S. technology and to promote the open sharing of remotely sensed data.

74 For a discussion of several Landsat projects in developing countries, 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), app. A.

75 Users of MSS data had argued that more spectral bands and higher ground resolution would lead to wider use of remotely sensed data.

TABLE 3-3: Landsat Sensors

Sensor	Satellite	Spectral bands, resolution
Multispectral Scanner (MSS)	Landsat 1-5	2 visible, 80 m 1 shortwave Infrared, 80 m 1 Infrared, 80 m
Thematic Mapper (TM)	Landsat 4, 5	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal, 120 m
Enhanced Thematic Mapper (ETM)	Landsat 6 (failed to reach orbit)	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal, 120 m 1 panchromatic, 15 m
Enhanced Thematic Mapper Plus (ETM+)	Landsat 7	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal 60 m 1 panchromatic, 15 m
High Resolution Multispectral Stereo Imager (HRMSI) (proposed but since dropped from the satellite)	Landsat 7	2 visible, 10 m (stereo) 1 near Infrared, 10 m (stereo) 1 Infrared, 10 m (stereo) 1 panchromatic, 5 m (stereo)

SOURCE Off Ice of Technology Assessment, 1994

vialing data users with data of higher resolution and quasi-stereo capability.[76]

In the 1980s, the development of powerful desktop computers and geographic information systems (GIS) sharply reduced the costs of processing data and increased the demand by potential users in government, universities, and private industry. In the late 1980s, India entered into land remote sensing with its launch of the Indian Remote Sensing Satellite (IRS)[77] and the Soviet Union began to market data from its photographic remote sensing systems.[78]

During the 1990s, continuing improvements in information technology and the proliferation of on-line data-distribution systems have increased dramatically the accessibility of remotely sensed data and other geospatial data.[79] As a result of the maturation of the market for remotely sensed data and the development of lower-cost sensors and spacecraft technology, several U.S. private firms are now poised to construct and operate their own remote sensing systems. These firms expect to market remotely sensed data on a global basis. **De-**

76 The SPOT satellites are capable of collecting data of 10-m resolution (panchromatic) and 20-m resolution in four visible and near-infrared multispectral bands.

77 However until 1994, India had not made data from its system readily available beyond its borders. In fall 1993, Eosat signed an agreement with the National Remote Sensing Agency of India to market IRS data worldwide.

78 Through the Russian firm Soyuzkarta.

79 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. 2.

spite these technical advances and the steady growth of the market for data, the United States still lacks a coherent, long-term plan for providing land remote sensing data on an operational basis. This section explores the elements of a long-term plan for U.S. land remote sensing.

Future of the Landsat System

After more than two decades of experimentation with the operation of the Landsat system, during which the government attempted but failed to commercialize land remote sensing[80] (appendix E), the Clinton Administration has now decided to return the development and procurement of Landsat to NASA and has assigned NOAA the responsibility of operating the Landsat system. The U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center will distribute and archive data.[81] NASA plans to launch Landsat 7 (figure 3-4) in late 1998.[82]

Since 1972, Landsat satellites have imaged most of Earth's surface in different seasons at resolutions of 80 or 30 meters (m).[83] Because a spacecraft in the Landsat series has been in orbit continuously, the Landsat system now serves an established user community that has become dependent on the routine, continuous delivery of data. However, **the Landsat system is only quasi-operational and has been developed without the redundancy and backup satellites that characterize NOAA's and DOD's operational meteorological programs. As currently structured, the Landsat program is vulnerable to a launch system or spacecraft failure and to instability in management and funding.** Despite the Administration's resolve to continue the Landsat program, the earlier difficulties in maintaining the delivery of data from the Landsat system (appendix E) provide ample warning that the path to a fully operational land remote sensing system is full of obstacles.

- ***Technical vulnerabilities.*** As illustrated by the loss of Landsat 6, the existing Landsat system is vulnerable to total loss of a spacecraft in the critical phase of launch and spacecraft deployment. If historical patterns hold, even the most successful of expendable launch vehicles will occasional y suffer catastrophic failure and loss of payload.[84] Furthermore, the failure of NOAA-1 3 after a successful launch[85] demonstrates the additional risk of spacecraft hardware failure. The failed part was designed in the 1970s and had flown repeatedly without incident on earlier spacecraft. Despite attempts to design and build launch vehicles and spacecraft with a high degree of reliability, operations in space are inherently risky.

  In contrast to the Landsat system, in which designers planned to fly only a single satellite at any time[86] and did not plan for a backup satellite, the NOAA POES satellites have sufficient backup that NOAA can replace a failed satellite within a few months of the failure. The decision not to provide a backup Landsat satellite was driven by the relatively high costs of

80 see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., PP. 48-52.

81 Presidential Decision Directive NSTC-3, May 5, 1994.

82 Landsat 7 had been scheduled for launch in late 1997. The slip in schedule is the result both Of the recent policy turmoil and 'he ceed fit Landsat into NASA's budget for Mission to Planet Earth.

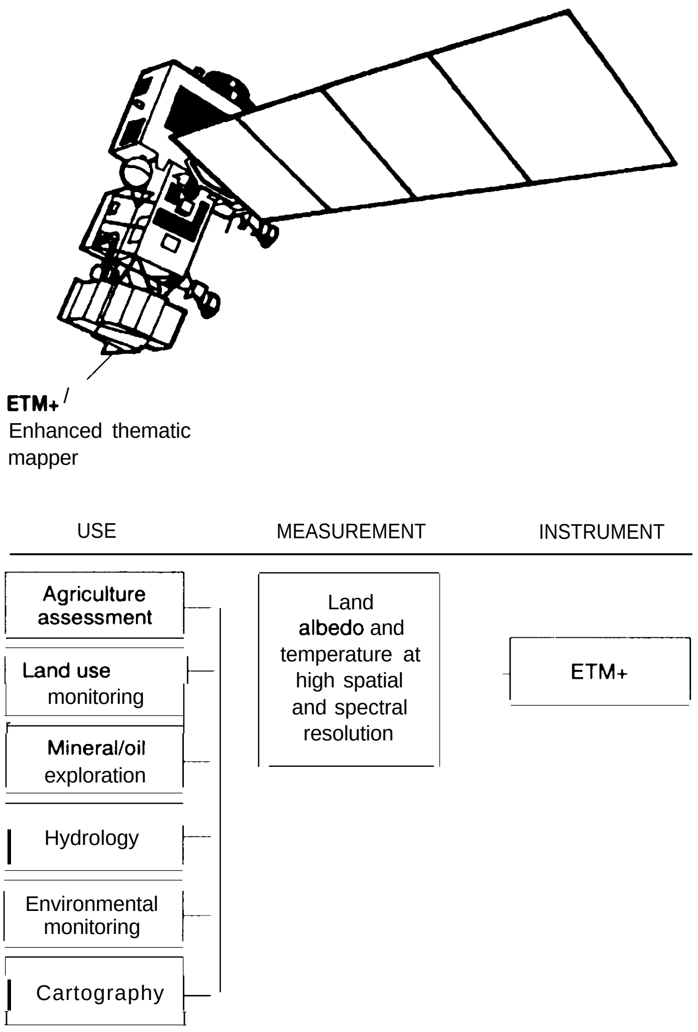
83 The Advanced Very High Resolution Radiometer sensors that have been orbited on NOAA's POES satellites have also provided multispectral imaging (two visible channels; three infrared channels) but at much lower resolution (1km and 4 km).

84 At a rate of approximately, 2 percent of total launches. See U.S. Congress, Office of Technology Assessment, *Access to Space: The Future of* L'. S, *Space Transportation Systems*, OTA-ISC-415 (Washington, DC: U.S. Government Printing Office, May 1990), p. 22.

85 NOAA-1 3 was launched on August 9, 1993. It suffered a failure on August 21, 1993.

86 Landsat 5 was launched only 2 years after Landsat 4 reached orbit because Landsat 4 had experienced a subsystem failure and NOAA was unsure how long it would continue to function.

FIGURE 3-4: Landsat 7



SOURCE: Martin Marietta Astrospace, 1993

the Landsat spacecraft compared with the documented need for the data. Lack of agreement within the U.S. government over the need for the Landsat system also influenced this decision. The mid- 1980s effort to commercialize Landsat also played a role in the decision to forego a Landsat backup.

Comparing the experiences of foreign governments in developing systems similar to Landsat is also instructive. Noting U.S. difficulties with Landsat, Centre National d'Études Spatiales (CNES), the French space agency, designed a cheaper, simpler system and Committed initially to building three satellites.

SPOT was a technical success, providing better resolution than Landsat's and the ability to gather quasi-stereo data.[87] In part because the system was designed from the start as a commercial venture, CNES officials also placed a premium on designing SPOT as an operational entity, capable of delivering data on a routine basis. Three SPOT satellites are now in orbit. SPOT-2 and SPOT-3 are operational. SPOT-1, which has been in orbit since 1989, can be reactivated to provide data during times of heavy use of the system, such as the spring growing season.

- ***Institutional vulnerabilities.*** The TM sensor aboard Landsats 4 and 5 was designed to gather data that would be appropriate for many uses. When combined with other remotely sensed data, such as the 10-m panchromatic data from SPOT, higher-resolution aircraft data, or other geospatial data,[88] TM multispectral data constitute a powerful analytic tool. Indeed, the data already serve most federal agencies in applications such as land-use planning; monitoring of changes in forests, range, croplands, and hydrologic patterns; and mineral resource exploration (chapter 2), However, the very diffuseness of the customer base for Landsat data has made the process of developing an operational system extremely difficult.

  DOD has historically been a large Landsat data user, but DOD officials do not want to be responsible for funding the entire system. Although NASA developed the Landsat system, it has not routinely generated and distributed operational data products to an established community of data users. Rather, as demonstrated by its long history of successfully operating the GOES and POES satellite systems (developed by NASA), NOAA has the requisite operational experience. However, NOAA has no established constituency of users either within or beyond the agency to defend its Landsat budget in competition with other agency priorities.

  The proposed arrangement for Landsat 7 was arrived at through consultations among NOAA, NASA, DOD, and the Department of the Interior, overseen by the Office of Science and Technology Policy. Although a Presidential Directive such as the one that President Clinton signed regarding the development and operation of Landsat 7[89] can be a powerful method for creating new interagency cooperative institutions, such institutions remain vulnerable to a change of Administration. As the experience with providing long-term funding for the USGCRP demonstrates, interagency cooperative programs are also vulnerable to changes in program balance as budgets are altered in congressional committees.[90] Therefore, ensuring the future of the Landsat program will require close and continuing cooperation among NASA, the Department of Commerce, and the Department of the Interior and among the three appropriations subcommitties.[91] procuring and launching Landsat 7

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87 The SPOT satellite is capable of pointing off nadir, which enables SPOT Image, the operating entity, to generate stereo images on different passes. However, the SPOT system has the limitation (compared with Landsat) of having only four spectral bands. It also covers an area of only 60-by-60 km per scene, compared with Landsat's 185-by-170-km coverage.

88 These might include data about soils, terrain elevation, zoning, highway networks, and other geospatial elements.

89 Presidential Decision Directive NSTC-3, May 5, 1994.

90 U.S. Congress, Office of Technology Assessment, The *U.S. Global Change* Research program *and NASA's Earth Observing System*, op. cit., p. 9.

91 NASA's appropriations originate in the House Appropriations Committee Subcommittee on Veterans Administration, Housing and Urban Development, and Independent Agencies; NOAA's appropriations originate in the House Appropriations Committee Subcommittee on Commerce, Justice, State, and the Judiciary; USGS appropriations originate in the House Appropriations Committee Subcommittee on Interior.

will cost NASA an estimated $423 million, spread over 5 years.[92] NOAA estimates that constructing the ground system and operating the satellite through 2000 will cost about $75 million.

- ***The need to improve Landsat program resiliency.*** Because the United States has never committed to a fully operational land remote sensing system, its land remote sensing effort faces the significant risk of losing continuity of data supply. In the long term, the United States may wish to develop a fully operational system that provides for continuous operation and a backup satellite in the event of system failure. In the past, high system costs have prevented the United States from making such a commitment. If system costs can be sharply reduced by inserting new, more cost-effective technology or by sharing costs with other entities, it might be possible to maintain the continuity of Landsat-type data delivery.

  Options for sharing costs include a partnership with a U.S. private firm, or firms (discussed below), and/or a partnership with another government. The high costs of a truly operational land remote sensing system have, from time to time, led observers to suggest the option of sharing system costs with another country.[93] However, national prestige and the prospect of being able to make such a service commercially viable[94] have generally prevented the United States and other countries from cooperating.
- ***The need to insert new technology into the Landsat program.*** The Land Remote-Sensing Policy Act of 1992 (P.L. 102-555) calls for a program to develop new technology for the Landsat series. According to the earlier Landsat Program Management Plan, Landsat 8 was anticipated in approximately 2003. Although still in the early stages, planners are considering advanced capabilities, such as greater numbers of spectral bands, stereo data, and much better calibration than the existing Landsat has. It is not too early to begin planning for the characteristics needed for a follow-on Landsat satellite.

  One option for demonstrating new technology will be available on Landsat 7. Landsat 7 was not redesigned after the DOD decision to withdraw from the program and the subsequent cancellation of the HRMSI (High-Resolution Multispectral Stereo Imager) sensor. As a result, the spacecraft will have the room and the electrical power needed to incorporate an additional sensor. NASA is offering to fly an experimental sensor paid for by other federal agencies or by private firms. This represents an opportunity for testing new technology at relatively low cost. The Department of Energy (DOE) laboratories have been exploring the development of different sensors that might be candidates. In addition, NASA is exploring the potential of using small satellites for Earth observation through its Small Satellite Technology Initiative. Recently, NASA awarded two contracts to teams led by TRW and CTA, both of whom will demonstrate advanced technology and rapid development in low-cost, Smallsat-based satellite remote sensing. A variety of technical developments, including increasing capabilities for on-board processing and the potential to fly small satellites in formation, may,

[92] R. Roberts, NASA Landsat Office, personal communication, August 1994.

[93] N. Helms and B. Edelson, "An International Organization for Remote Sensing," presented at the *42nd Annual Meeting of the International Astronautical Federation*, Montreal 1991 (IAF-9 I -1 I 2).

[94] However, systems that produce calibrated multi spectral data of moderate resolution-of greatest interest to global change scientists and other users who require coverage of large areas—may never be commercially viable. Should this be the case, the United States might find several partners to develop a system that would explicitly be designed to serve the public good. These include France, which is operating the SPOT system; Germany, which has developed several sensors but has no satellite system; Japan, which operates JERS - I; and Russia, which has a long history of using photographic remote sensing systems but whose multispectral digital systems have yet to prove themselves.

in the longer term, allow small satellites to perform some of the missions now accomplished with comparatively largr and expensive Earth observation satellites.[95]

Other future land sensors that the United States may wish to develop and operate include an operational synthetic aperture radar. The proposed EOS SAR, based on technology demonstrated in airborne and Space Shuttle experiments, was canceled in large part because of its high cost. The EOS SAR would have been capable of making multiangle, multifrequency, multi polarization measurements.[96] These capabilities allow more information to be extracted from an analysis of radar backscatter and have more general application than do currently operational Japanese and European single-frequency, single-polarization satellite-based SARS. The Canadian Radarsat, planned for launch in 1995, will also carry a single-frequency, single-polarization SAR. In contrast to the broad-based capabilities of an EOS SAR, which would be particularly suited to global change research. these SARS are designed for specific applications, such as mapping sea ice and snow cover.

Role of the Private Sector

By launching Landsat. NASA created the potential for a new market in remotely sensed data. However, as the policy history of the Landsat program demonstrates, commercial markets cannot be developed solely by government policy. Among other elements, growth in commercial data markets requires technological innovation and the ability to tailor production to user needs. Government policy can either impel or impede the development of markets that will support new technologies.[97]

Private firms have had an important part to play throughout the development of land remote sensing technologies. The information industry has developed powerful computers and software, capable of handling large remotely sensed data files quickly and efficiently. Through firms that convert raw data to information (so-called value-added firms), the information industry has also expanded the utility of remotely sensed data acquired from spacecraft. Aerospace firms have also served as contractors for government civil and classified remote sensing systems. Hence, they have contributed to the technology base that now enables private firms to develop their own remote sensing systems. Government laboratories pursuing related technologies have also assisted in the creation of this technology base.

Three privately financed land remote sensing systems are now under development (box S-7). These systems focus on providing data of comparatively high resolution with only one '-panchromatic" visible band, or a few multi spectral bands over relatively narrow fields of view. As a result. they cannot substitute for the Landsat system, which collects calibrated multi spectral data over a large field of view. The privately financed systems are not intended or designed to supply the repeat. multi spectral, global coverage that is the mainstay of Landsat. However, if these systems operate as planned, they will provide data for many applications, including those now served primarily by aircraft imaging firms. These systems especially target international markets that require digital data for mapping, urban planning, military planning, and other uses.[98]

For one or more of these systems to be successful. they will have to overcome hurdles of market acceptance. competition with systems from firms

[95] For example, see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B, "Developing Follow-ons in the Landsat Series."

[96] Ibid.

[97] For a discussion of the factors influencing market development, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., ch. 4.

[98] P. Seitz, "Imagery Firms Court Partners," *Space News*, May 16-22, 1994, pp. 3, 21.

that supply similar data acquired from aircraft, and competition among themselves. If they can deliver data in a timely manner and at low prices, one or more are likely to be highly successful. Ultimately, the U.S. government may wish to move to a new partnership with the private sector in providing land remote sensing and other data that have commercial value. Four broad options are possible:

- ***Contract with a private firm to operate a government-supplied system.*** Under this arrangement, the government would procure the satellite system and submit a request for proposal (RFP) for a private firm to operate the system and distribute data. Data would be made available at the cost of reproduction, according to the direction of OMB Circular A-130. This arrangement is very similar to current plans for Landsat 7 in which NOAA will operate the satellite and the EROS Data Center will archive and distribute the data.[99] Proponents of private-sector operation contend that such an arrangement would make the operation and distribution of Landsat data more efficient. However, when NOAA operated Landsat 4 and 5, much of the actual operation and the distribution of Landsat data was carried out by private firms under contract to NOAA and the EROS Data Center. Hence, some of the potential efficiency of private-sector involvement had already been realized.
- ***Return to an EOSAT-like arrangement in which government supplies a subsidy and specifies the sensor and spacecraft.*** This arrangement would capture most details of the existing EOSAT contract in which EOSAT operates Landsats 4 and 5 under contract with the Department of Commerce and markets data worldwide. Income from data sales and from the licensing of foreign Landsat ground stations pays for satellite operations and provides EOSAT'S profit. EOSAT is free to charge market rates for the data as long as it makes data available on a nondiscriminatory basis to all customers, according to U.S. remote sensing policy.[100]
- ***Create data-purchase arrangements.*** Under this arrangement, the government would specify data characteristics and would contract with industry to provide a stream of data for a specified period for an agreed-upon price. NASA has chosen this path in a contract with Orbital Sciences Corporation to provide data about the ocean surfaces. OTA has explored this option in two earlier reports.[101]

  DOD had expected to use the data from the HRMSI sensor aboard the earlier version of Landsat 7 to support its needs for mapping and other applications. If WorldView is successful in providing data from its 3-m/l 5-m system, these data may fit DOD's needs and be available 2 years before the HRMSI sensor would have flown under the previous interagency arrangement. In like manner, DOD may wish to purchase data with even higher resolution from either the Lockheed or the Eyeglass system, should either or both prove successful (box 3-7).
- ***Create government-private partnerships.*** In this arrangement, the government and one or more private firms would enter into a partnership to build, operate, and distribute data from a land remote sensing satellite. This partnership would have the advantage of enlisting private-sector innovation and ability to target applications markets while supplying the government's data needs. It would also have the advantage of reducing the financial risk of the private firm. The experience of the French

99 Presidential Decision Directive NSTC-3, May 5, 1994.

100 See U.S. Congress, Office of Technology Assessment, *Remotely Sensed* Data *from Space: Distribution, Pricing, and* Applications (Washington, DC: Office of Technology Assessment, International Security and Space Program, July 1992).

101 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., p. 5; U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* op. cit., ch. 4.

BOX 3-7: Existing and Potential Remote Sensing Satellite Firms

Orbital Sciences Corporation

The SeaStar satellite will carry the SeaWiFS sensor for measuring ocean color and other attributes of the ocean surface. SeaStar is scheduled for launch in January 1995 aboard a Pegasus launcher. Orbital Sciences Corporation (OSC) plans to market SeaWiFS data to fisheries, ocean shipping firms, and other ocean-related enterprises. However, OSC's primary customer is NASA, which will use the data for global change research.

WorldView Imaging Corporation

WorldView is developing a two-satellite, multispectral land remote sensing satellite system capable of 3-m resolution in stereo (3-m panchromatic, 15-m in three color bands). It received an operating license from the Department of Commerce in January 1993 and has begun to develop a satellite and data-distribution system. WorldView expects to launch its first satellite in late 1995 and the second in 1996.

Space Imaging, Inc.

Space Imaging, Inc., a subsidiary of Lockheed, Inc., is designing a multispectral stereo land remote sensing satellite system capable of achieving resolutions of 1 m (panchromatic). The Department of Commerce has granted Lockheed an operating license, and it expects to launch its first satellite by late 1997.

Eyeglass International, Inc.

Orbital Sciences Corporation, Itek, and GDE Systems, Inc. have entered into a joint venture to build and operate the Eyeglass Earth Imaging System, a stereo land remote sensing satellite system capable of gathering 1-m resolution panchromatic data. Eyeglass International received its operating license in May 1994. The consortium plans to begin operations in early 1997.

SOURCE: Office of Technology Assessment, 1994

space agency, CNES, and SPOT Image (figure 3-5) provides one possible model of such an arrangement. However, U.S. firms that are already building a remote sensing system would likely charge that such an arrangement would be unfair competition (unless the system's characteristics guaranteed them a niche in the data market). For example, NASA's contract with TRW to build a small satellite capable of gathering data of 30-m resolution in many spectral bands would serve the needs of the government and probably enhance the private market for such data. However, as noted in chapter 1, NASA's similar arrangement with CTA could actually impede commercial development unless the distribution of data from the satellite was severely restricted.

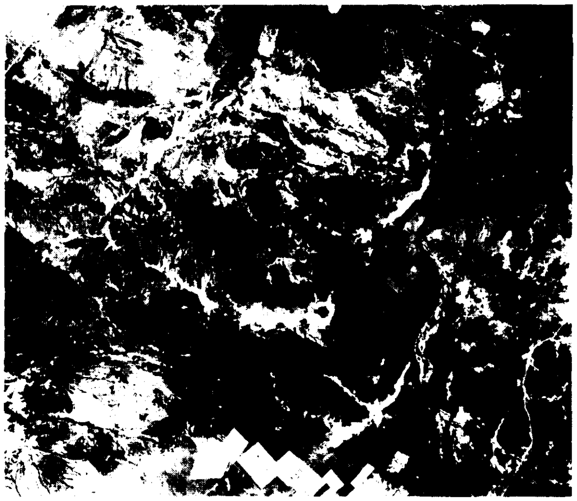
OCEAN REMOTE SENSING

The impetus for ocean monitoring comes from users of remotely sensed data in both the civil and military communities. As D. James Baker wrote: [102]

> The large-scale movement of water in the oceans, also called "general circulation," influences many other processes that affect human life. It affects climate by transporting heat from the equatorial regions to the poles. The ocean also absorbs carbon dioxide from the atmosphere, thus delaying potential warming, but how fast this occurs and how the ocean and atmos-

102 D.J. Baker, *Planet Earth: The View from Space*, op. cit., p.66

FIGURE 3-5: Image of Soviet Nuclear Testing Facility, Semipalatinsk, Russia



Visible are cable scars and access roads connecting with drill holes Ten-meter panchromatic image taken by the French SPOT satellite.

SOURCE: SPOT Image Corp., Reston, VA.

phere interact in this process depend on surface currents, upwelling, and the deep circulation of the ocean. Fisheries rely on the nutrients that are carried by ocean movement. Large ships, such as oil tankers, either use or avoid ocean currents to make efficient passage. The management of pollution of all kinds, ranging from radioactive waste to garbage disposal, depends on a knowledge of ocean currents. And the ocean is both a hiding place and a hunting ground for submarines.

Scientific, commercial, and government users of remotely sensed data have long argued for an operational ocean monitoring system. An ocean monitoring system would facilitate the routine measurement of variables related to ocean productivity,[103] currents, circulation, winds, wave heights, and temperature. In turn, these measurements would allow scientists to study and characterize a range of phenomena (figure 3-6), including those described above by Baker. The development of an operational system that would assist in the prediction of the onset of El Niño and the Southern Oscillation (ENSO) events (box 3-8) is of particular interest.

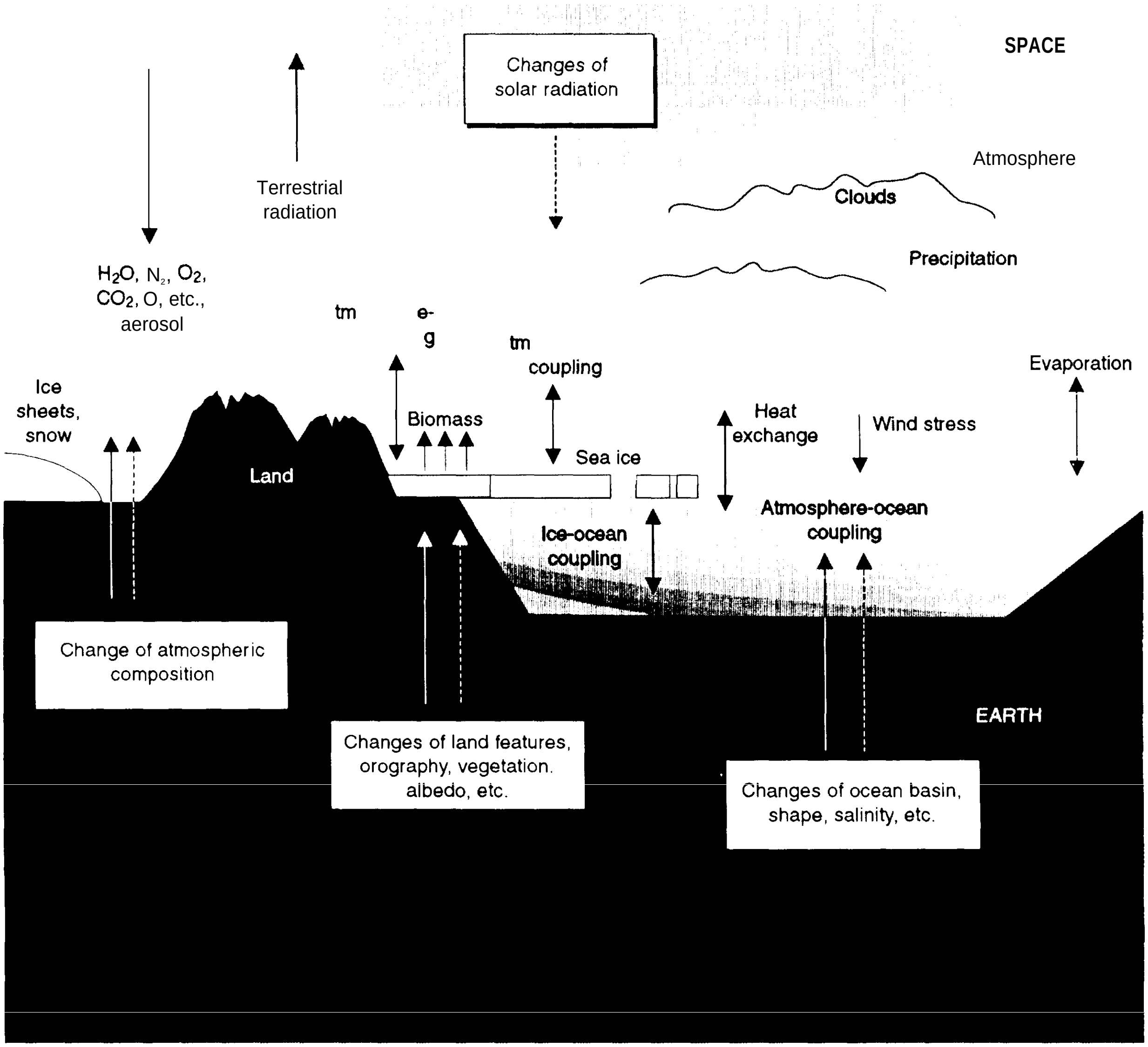
The distinction that is sometimes made between satellite-based "atmosphere," "ocean," and "land" remote sensing instruments is somewhat arbitrary.[104] U.S. ocean monitoring is currently carried out on a routine basis by sensors on POES and DMSP. In addition, ocean data are being provided by satellite-borne altimeters on board the TOPEX/Poseidon satellite, SARS that are part of the instrument suite on the European ERS-1 and the Japanese JERS-1, and Shuttle-based observat ions using the multi frequency, polarimetric SAR, SIR-C.[105] NOAA is especially interested in sea-surface temperature imagery, which is acquired by analyzing AVHRR data. Because its ships travel through and on the surface of the ocean, the Navy has a particular interest in DMSP (especially SSM/I) and altimetry data, which allow mapping of the ocean's topography and assist in detecting

103 In a process similar to photosynthesis on land, phytoplankton in the ocean convert nutrients into plant material through an interaction between sunlight and chlorophyll. Measurements of ocean color provide estimates of chlorophyll in surface waters and, therefore, of ocean productivity. Ocean-color measurements are also used to help detect ocean-surface features. Satellite ocean-color data have not been available since the failure of the Coastal Zone Color Scanner (CZCS) in 1986. NASA has contracted with Orbital Science Corporation (OSC) for the purchase of data resulting from OSC'S launch of SeaWiFS (Sea-viewing, Wide-Field-of-view Sensor), a follow-on to CZCS.

104 Although in some cases, orbit requirements differentiate one type from another. For example, an EOS rev iew committee recently concluded that "the science objectives of EOS land-ice altimetry and ocean altimetry dictate that these sensors be on separate spacecraft. Polar orbits with non-repeating or long-period repetition ground tracks are required for complete ice sheet surface topography, while lower inclination orbits with reasonable values for mid-latitude and equatorial ground track crossover angles are required to achieve optimal recovery of ocean surface topography." B. Moore III and J. Dozier, "A Joint Report: The Payload Advisory Panel and the Data and information System Advisory Panel of the Investigators Working Group of the Earth Observing System," Dec. 17, 1993. This report is available through NASA's Office of Mission to Planet Earth.

105 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B.

FIGURE 3-6: Schematic Diagram of Coupling Between Oceans, Atmosphere, and Land



Broken arrows indicate those influences external to the Earth or altered by human activities

NOTE Adapted from Joint Oceanographic Commission, Global Atmospheric Research Programme A Physical Basis for Climate and Climate Mod e ing *GARP Publ Ser 16* [1975)

BOX 3-8: The Links Among Earth's Systems: El Niño and the Southern Oscillation

Coastal Peru is arid enough so that sun-baked mud is often used to build houses. In the neighboring ocean, intense upwelling pumps nutrients to the surface to create one of the world's richest fisheries. In late 1982 the nutrient pump shut down, eliminating the local fishery. And the rains began: some normally arid zones received as much as 3 m [118 inches] of rain within a 6 month period. Mud houses dissolved, and much of the transportation infrastructure washed away. Almost 1,000 years ago, a similar climatic disaster destroyed a prosperous agricultural civilization rivaling the Incas.

Peru was not alone: the impact of the strange climatic events of 1982-83 was global. In Indonesia, vast areas of rainforest were destroyed in fires spawned by a devastating drought. Australia experienced the worst drought in its recorded history: firestorms incinerated whole towns, livestock herds had to be destroyed, and production of cotton, wheat, and rice was sharply reduced. In Brazil, an exceptionally poor rainy season distressed the impoverished Nordeste region, while southern Brazil and northern Argentina were hit with destructive flooding. Throughout southern Asia, poor monsoon rains in 1982 reduced crop yields and slowed economic growth. China saw drought over the northern part of the country and unusual winter floods in the south, leading to major losses in the winter wheat crop . . . Severe winter storms rearranged the beaches of California; spring floods covered the streets of Salt Lake City . . .—*M.A. Cane, 1991*

The events described above are an example of an irregularly recurring pattern known as ENSO. The abbreviation combines its oceanographic manifestation in the eastern tropical Pacific, El Niño, with its global atmospheric component, the Southern Oscillation. ENSO is an irregular cycle with extremes of variable amplitude recurring every 2 to 7 years. The 1982-83 events are a instance of its warm phase. Events of 1988, including catastrophic flooding of Bangladesh, demonstrate the impact of the cold phase. Historically, El Niño was the name given to the marked warming of coastal waters off Ecuador and Peru. It is now understood that during the ENSO warm phase, the warming covers the equatorial Pacific from South America to the dateline, fully one-quarter of the circumference of Earth.

SOURCE: M.A. Cane, Lamont-Doherty Geological Observatory, Columbia University, NY, unpublished remarks at the 1991 American Geophysical Union annual meeting.

large-scale ocean fronts and eddies, surface ocean currents, surface wind speed, wave height, and the edge of sea ice.[106] Radar altimetry data have also been used to estimate ice-surface elevations in polar regions.

U.S. efforts to develop satellites suitable for ocean monitoring have lagged behind those for land-surface monitoring. Seasat,[107] a notable success during its 3 months of operation, was followed by a NOAA, DOD, and NASA proposal for a similar National Oceanic Satellite System (NOSS). NOSS instruments included a SAR, a scatterometer, an altimeter, a microwave imager, and a microwave sounder. This effort was canceled in 1982, as was a subsequent proposal for a less costly Navy Remote Ocean Sensing Satellite (NROSS).[108]

As noted above, the only U.S. systems that routinely monitor the oceans are the weather satellites. Of particular interest for this report is the de-

[106] D.J. Baker, *Planet Earth: The View from Space*, op. cit., pp. 70-71.

[107] Seasat, which was designed in part to demonstrate the feasibility of using radar techniques for global monitoring of oceanographic phenomena, carried an altimeter, a scatterometer, a seaming multichannel microwave radiometer, a SAR, and a visible and infrared radiometer. An electrical failure caused the satellite to fail prematurely. See D.J. Baker, *Planet Earth: The View from Space*, op. cit., pp. 66-71.

[108] NROSS was canceled in 1986, reinstated in 1987, and terminated in 1988. NROSS would have been less costly than NOSS, primarily because of the elimination of the SAR.

velopment of new *operational* satellite-borne instruments for ocean monitoring. These include an altimeter, to continue the TOPEX/Poseidon mission; a scatterometer, to measure sea-surface wind vectors; a lidar (laser radar), to measure tropospheric winds; a SAR, for a variety of high-spatial-resolution measurements (meters to tens of meters) in ice-covered waters; and an ocean-color sensor, to monitor ocean productivity. Box 3-9 gives an overview of applications of radar altimeters and scatterometers for ocean monitoring. Applications of SAR and lidar are discussed in a previous OTA report. [109]

NOAA currently lacks the budget authority to undertake major expansion of its operational satellite program. Early in NASA's planning for

BOX 3-9: TOPEX/Poseidon and the NASA Scatterometer

TOPEX/Poseidon is a joint U.S.-French NASA-Centre National d'Études Spatiales (CNES) research satellite devoted primarily to highly accurate measurements (to an accuracy of about 2 cm) of the height of the oceans. Instruments on TOPEX/Poseidon include a radar altimeter and a microwave radiometer, which corrects for the effects of water vapor in the atmosphere. Accurate measurements of the ocean's topography may lead to better understanding of ocean circulation and a variety of other ocean-related quantities. In addition, an altimeter passing over polar regions acquires information about the topography of polar ice sheets and the formation and flows of glaciers (however, the orbit of TOPEX/Poseidon does not allow sampling above 66° latitude).

Radar altimeters have flown previously on NASA's GEOS-3 (1975-1978) and Seasat (July-October, 1978) and the Navy's Geosat (1985-1989). The Navy is currently developing a Geosat Follow-On (GFO) satellite for launch in 1996, and NASA is planning an altimetry mission, EOS-Alt, to be launched in approximately 2002. A 1998 launch of a TOPEX/Poseidon Follow-On (TPFO), which might replace or subsume EOS-Alt, is less certain because of budget problems. NASA's Payload Advisory Panel has recommended that the EOS project explore options that will ensure that "the important measurements provided by the current TOPEX/Poseidon mission be continued to bridge the gap between the end of TOPEX/Poseidon and the launch of EOS Ocean Alt [or, if funded and developed, a TPFO]." The Navy's GFO is a candidate for this "gap-filler," but it would require modifications in instrument complement and, possibly, orbit selection.

A scatterometer is a radar instrument that can be used to determine wind speed and direction over the ocean by analyzing the radar returns from wind-generated waves. Radar returns are affected by both the size of wind-generated waves and their orientation with respect to the radar signal (look angle). An analysis of the radar returns from multiple antennas yields multidirectional data that can be used to determine both wind speed and direction. NASA plans to fly a scatterometer (NSCAT) as part of its EOS program (on the Japanese Advanced Earth Observing Satellite (ADEOS) mission in 1996). ADEOS has a planned 3-year lifetime; a follow-on is expected to be launched in 1999. NASA is also developing a follow-on to NSCAT (NSCAT II). An important application of scatterometer, altimeter, and in situ measurements would be monitoring the ocean conditions associated with the onset and severity of El Niño.

SOURCES: Office of Technology Assessment, 1994; B. Moore III and J. Dozier, "A Joint Report: The Payload Advisory Panel and The Data and Information System Advisory Panel of The Investigators Working Group of the Earth Observing System," Dec. 17, 1993.

[109] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B.

EOS, when it was still a broad-based earth science program, the program appeared to be a vehicle for developing instruments that would become an operational ocean monitoring program. However, cutbacks to the EOS program and its subsequent "rescoping" to emphasize climate change [110] have resulted in the cancellation, deferral, or dependence on foreign partners of several instruments with oceanographic application. Rescoping actions include the cancellation of EOS SAR (less capable European and Japanese SARS are available and Canada plans to launch a SAR in 1995); transfer of the U.S. scatterometer to a Japanese satellite; and deferral of development of next-generation microwave-imaging radiometers (the United States will use European and Japanese instruments). In addition to scientific losses, several reviewers of this and previous OTA reports on Earth Observing Systems were concerned that allowing the U.S. lead to slip in these technologies would harm the nation technology base for environmental remote sensing.

Observing this situation, the Ocean Studies Board of the National Research Council wrote:111

> A major obstacle for marine science lies in the difficulty of development and managing space-borne instruments over the next decades. Historically, NASA developed meteorological spacecraft that evolved into operational systems managed by NOAA. However, for marine observations, apart from the long-standing efforts in the visible and infrared sea-surface temperature observations and microwave sea ice measurements (both of interest to short-term forecasting), there is no effective mechanism for the systematic development or transfer of technology from research to operations. Some mechanism must be found to routinely collect such observations that are important to the NOAA mission. NOAA will need additional funding to carry out these observations, and a partnership arrangement will be necessary to identify the essential variables to be observed.

In summary, with respect to ocean monitoring systems, OTA finds that the development of a national strategic plan for Earth environmental remote sensing offers an opportunity to:

- provide coherence, direction, and continuity to disparate programs that have previously suffered from fits and starts;
- assist in the selection and enhance the utilization of EOS sensors;
- assist in the development of advanced technologies; and
- restore a beneficial relationship between NASA and NOAA to manage the transition between research and operational instruments more effectively (the same benefit noted above for other environmental remote sensing instruments).

110 U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA'S Earth Observing System*, op. cit.

111 Ocean Research Council of the National Research Council, *Oceanography in the Next Decade: Building New Partnerships* (Washington, DC: National Academy Press, 1992).