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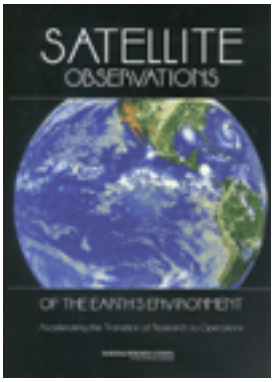

Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations

Committee on NASA-NOAA Transition from Research to Operations, National Research Council

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This report addresses the transition of research satellites, instruments, and calculations into operational service for accurately observing and predicting the Earth's environment. These transitions, which take place in large part between NASA and NOAA, are important for maintaining the health, safety, and prosperity of the nation, and for achieving the vision of an Earth Information System in which quantitative information about the complete Earth system is readily available to myriad users. Many transitions have been ad hoc, sometimes taking several years or even decades to occur, and others have encountered roadblocks—lack of long-range planning, resources, institutional or cultural differences, for instance—and never reached fruition. Satellite Observations of Earth's Environment recommends new structures and methods that will allow seamless transitions from research to practice.

Executive Summary

Observing and accurately predicting Earth's environment are critical for the health, safety, and prosperity of the nation. The United States invests heavily in making global measurements from satellites and in using these observations to create accurate weather forecasts and warnings, long-term climate records, and a variety of other environmental information products. Major opportunities exist for advances in prediction and in other weather, ocean, and climate information products. Realizing the potential benefits of the investments in satellites requires rapid, efficient transitions of measurement and modeling capabilities developed in the research community to the observing and prediction systems of the operational agencies. In the case of spaceborne environmental measurements, the National Aeronautics and Space Administration (NASA) conducts research into the development of measurement technologies and analysis techniques. The National Oceanic and Atmospheric Administration (NOAA) is responsible for civil operational observing systems and associated products, services, and predictions.

This report examines the NASA-NOAA research-to-operations transition process and provides recommendations for improvements that will lead to more rapid and efficient interagency transitions. The primary finding of the National Research Council's Committee on NASA-NOAA Transition from Research to Operations is that, while clear examples of successful transitions currently exist, the transition process in general is largely ad hoc. Some transitions are relatively successful, but many are less so, and no mechanism is available to ensure that the transition process in general is efficient and effective. The committee's primary recommendation is

that a high-level joint NASA-NOAA planning and coordination office should be established to focus specifically on the transition process.

The ability to observe and predict Earth's environment, including weather, space weather, and climate, and to improve the accuracy of those predictions in a complex society that is ever more dependent on environmental variability and change, has heightened the importance and value of environmental observations and information. These observations, and the predictions on which they are based, are now essential to many components of society—including national defense, industry, policy-making bodies, and the people and institutions that manage natural resources—as well as to the comfort, health, and safety of the public. It is estimated that as much as 40 percent of the $10 trillion U.S. economy is affected by weather and climate annually.

Because satellites can observe the entire Earth at relatively low cost, they play an essential role in contributing to the global database that describes the Earth system and that is necessary for prediction. Advances in remote sensing technology and research have put the dream of an *Earth Information System* (EIS)—which would make available to a myriad of users valuable quantitative digital data about the complete Earth system—within reach in the next few decades. The scientific and technological foundation for the vision of the EIS rests on the opportunity to observe the complete Earth system with unprecedented resolution and accuracy and to assimilate the diverse observations into complex models. Satellites will provide many, though not all, of the future observations required to describe Earth completely.

Realizing the vision of the EIS and the predictive capabilities that it supports, however, is neither easy nor guaranteed. It depends on transferring the advances in research and technology—many of which are accomplished by NASA and its university and private sector partners—to useful products, applications, and operations, which are primarily the responsibility of NOAA and the Department of Defense (DOD). How to improve this technology transfer, or "transitioning," process in the area of weather and climate is the subject of this report. Although the report focuses on weather and climate and on NASA and NOAA, the lessons learned and the recommendations presented here are likely to be relevant to other satellite applications and to other agencies.

In the more than 40 years since the launch of the first weather satellite, the Television Infrared Observation Satellite (TIROS-I), on April 1, 1960, there have been many successful transfers of NASA research into NOAA and DOD operations. These successful transfers have led to a steady increase in forecast accuracy and to a variety of beneficial applications for society, including the protection of life and

property as well as support for commerce, industry, resource management, the military, and personal activities.

Along with the successes, however—many of which have occurred in spite of a relatively ad hoc, unplanned, or inefficient process—there have been research missions with opportunities for practical applications that have been slow to be realized or that have gone unrealized altogether. Given the large cost (several billion dollars per year) of research satellites and operational weather and climate services and the increasing importance of and opportunities offered by satellite-based remote sensing, there is an increasing realization that greater attention should be paid to the technology transfer or transitioning process itself, in order to accelerate the rate of return on the research investment.

Transition pathways are the end-to-end set of processes assembled for achieving successful transitions. Each pathway requires a strong supporting infrastructure, which consists of a number of building blocks including a solid research foundation, laboratories, equipment, computers, algorithms, models, information technologies, and test beds. Robust and effective transition pathways are needed to bridge the *valley of death*—that is, the gap that can exist between research and operations for technologies with known applications—and the *valley of lost opportunities*—that is, unrealized potential in which unforeseen applications of new technologies are missed completely.

Bridging the valleys of death and lost opportunities can be done in various ways. It often depends on an appropriate balance between the "push" of new research results and opportunities from the research community and the "pull" from the perceived needs or requirements of the operational community and users. The process is hindered by a variety of obstacles, including these:

- Cultural differences between the research and operational communities,
- Organizational issues,
- Poor communication and coordination between the research and operational communities,
- Lack of adequate financial or educated human resources,
- Absence of effective long-range planning, and
- Inadequate scientific knowledge or technological capability.

The committee's examination of a sample of historical case studies in which the transition from NASA research to NOAA and DOD operations has occurred with varying degrees of success (see Appendix B) suggests ways to improve the transitioning process and so increase the rate at which the return to society on the research investment is achieved. These improvements include making the multiple

processes that support the transition from research to operations more flexible and efficient.

The committee's overarching recommendation is to establish a strong and effective joint NASA-NOAA office to plan, coordinate, and support the transitioning of NASA research to NOAA operations.[1] The planning and coordination should include an early evaluation of each research mission, including new sensor capability and potential operational utility. Every appropriate mission, as defined by the formal evaluation process, should have a flexible strategic plan for transferring the research to operations.

The committee recognizes, however, and strongly emphasizes that not all NASA research missions are or should be driven by operational needs or requirements—a major and essential part of the NASA mission is to increase fundamental understanding of Earth and the universe, regardless of foreseeable operational opportunities. However, many NASA missions have both a fundamental research component and the potential for applications of the science and technology for the benefit of society. This report focuses on that type of mission.

The improved transitioning process should be based on a balance between research push and operational pull. This balance, which will vary from one mission to another, can be achieved through increased dialogue between the two communities and through overlap within their respective missions (i.e., research missions that have an operational component and vice versa). The data from research missions should be tested in operational settings and the operational impact assessed. Conversely, the collection, processing, and archiving of operational data should take into consideration the needs of the research community as well as the operational impact of the data. Test beds, in which assimilation methods and algorithms using research results and data are developed and evaluated prior to and during research missions, are an important component of the transitioning process. These test beds not only will help determine how best to use the research data and evaluate their impact, but also will enable experimentation with new models and products in parallel with the operations.

The user community should be involved early in the planning for research missions, and each mission should have an education and training plan. This plan

[1]Following its charge, the Committee on NASA-NOAA Transition from Research to Operations is making recommendations to NASA and NOAA to form and to be the primary participating agencies in this joint transition office. However, the committee recognizes the value of cooperation between NASA, NOAA, and other partners, including the Department of Defense and international organizations. Consequently, this joint office is intended to be and is offered as a flexible institution so that NASA and NOAA could invite the DOD or other U.S. agencies to become full participants when and if appropriate. See Recommendation 1 in the next section in this Executive Summary and the discussion in Chapter 6 for greater detail regarding the structure of this transition office.

should take into account the operational, research, and academic communities, including students.

Adequate resources must be devoted to the transitioning process. The committee has not attempted to determine the amount of the resources required (which would vary from mission to mission) but believes that compared with the support currently provided for research and operations separately, the additional amount would be small—perhaps on the order of 5 to 10 percent of the research and operational budgets. The committee believes that this investment would pay large dividends in increasing the intrinsic value of research missions, improving existing operational products, and creating new ones.

RECOMMENDATIONS

Recommendation 1: A strong and effective Interagency Transition Office for the planning and coordination of activities of the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in support of transitioning research to operations should be established by and should report to the highest levels of NASA and NOAA.

The proposed Interagency Transition Office (ITO) should have broad responsibility (not specifically related to sensor capability) for ensuring that appropriate research is efficiently and effectively transitioned to operational uses. However, the ITO itself should not implement the transitioning activities. The implementation should be carried out by appropriate NASA or NOAA entities (such as the National Polar-orbiting Operational Environmental Satellite System [NPOESS] Integrated Program Office, with its current charter for the acquisition of polar operational satellite systems) or by their partners in the academic community and private sector. The ITO is intended to support and simplify transitions by augmenting, enabling, and leveraging the existing infrastructure within NASA and NOAA rather than by introducing duplicative capability or bureaucracy.

The ITO should have an independent, high-level advisory council consisting of representatives from the operational and research communities as well as from the public and private sectors. The council should also serve as a forum for regular discussions between the leaders of the research and operational organizations.

An executive board, envisioned by the committee as including the NASA and NOAA administrators and the President's Science Advisor at a minimum, should provide high-level oversight and review of the ITO. NASA and NOAA should consider including as executive board members representatives at an equivalent level from DOD (for example, the undersecretary of defense for acquisition and technology) and from other agencies when appropriate to the mission of the ITO.

Implementation of the following recommendations is needed in order to support the mission of the proposed ITO. However, these recommendations are not specifically tied to the establishment of the ITO. They stand on their own merit and are necessary to strengthen any transitioning mechanism or pathway.

Recommendation 2: NOAA and NASA should improve and formalize the process of developing and communicating operational requirements and priorities.

2.1 NOAA should continuously evaluate and define operational user needs and formally communicate them to NASA on a regular basis.

2.2 NASA should formally consider the requirements of NOAA and other operational agencies in establishing its priorities (the "pull" side of the transition process). NASA should establish appropriate programs and budgets as needed to respond to selected NOAA requirements.

Recommendation 3: All NASA Earth science satellite missions should be formally evaluated in the early stages of the mission planning process for potential applications to operations in the short, medium, or long term, and resources should be planned for and secured to support appropriate mission transition activities.

The evaluation process should include engaging in dialogue with the research and operational communities and obtaining input from possible users of the observations. For appropriate missions, as determined by the assessment, a flexible plan or architecture for a seamless transition pathway, including the necessary financial and human resources, should be developed, regularly reviewed, and updated as necessary.

For a mission that is identified as having significant potential for providing data useful to operations, the following activities should be supported:

3.1 NASA and NOAA should work together to strengthen the planning, coordination, and management components of the mission. Teams of people with appropriate research and operational expertise should be assigned to the mission. A culture fostering aggressive and challenging approaches, risk taking, acceptance of outside ideas and technologies, flexibility, and a "can-do" attitude should be encouraged.

3.2 Adequate resources should be provided in order to support all aspects of the transitioning activities, as determined by the assessment and plans. Consideration should be given to establishing guidelines and mechanisms for encouraging transition efforts. For example, a small fraction (e.g., 5 to 10 percent) of each sensor or mission project budget might be allocated to

transition activities. Principal investigators might be asked to submit plans or concepts for transitional activities, with significant points being allotted in scoring this aspect of the proposals.

3.3 Research into *how* to use new types of observations should be supported well in advance of the launch of the research or operational mission that acquires the observations. In parallel with the acquisition program, this research should include developing and testing algorithms to convert sensor data to environmental products (including environmental data records) and data-assimilation methods, as appropriate to the mission. The research may be carried out in a variety of institutions, including universities, national laboratories, cooperative institutes, and test bed facilities. The institutional mechanism(s) to conduct the research should be identified early in the mission.

3.4 Each research mission should have a comprehensive data-management plan. The plan should include the identification of potential users and approaches for processing the data, converting the raw data to information, creating metadata, distributing data and information to users in real time, and archiving and the subsequent accessing of data by users.

3.5 NASA and NOAA, through the ITO as defined in Recommendation 1, should develop a plan to include the use of NPOESS and Geostationary Operational Environmental Satellite (GOES-R) sensor data by the appropriate government agencies. A collaborative arrangement and at least one demonstration/pilot or benchmark project should be developed with each primary user agency (e.g., the U.S. Geological Survey [USGS], the U.S. Department of Agriculture [USDA], and the Environmental Protection Agency [EPA]) using NPOESS and GOES-R products.

3.6 Each research mission should have an associated education and training plan. This plan should be addressed to the operational, research, and academic communities, including students. It could include, for example, scientific visitor exchange programs, support for collaborative research, workshops, and a plan for the timely flow of research data to operational and academic institutions.

3.7 The evaluation process and resulting transition plans should consider potential roles in the research-to-operations transition process for the academic community (including principal-investigator-led projects) and the private sector, both of which have relevant capabilities and knowledge not available within NASA and NOAA.

Recommendation 4: NASA and NOAA should jointly work toward and should budget for an *adaptive* and *flexible* operational system in order to support the

rapid infusion of new satellite observational technologies, the validation of new capabilities, and the implementation of new operational applications.

4.1 Operational satellite programs should provide for the capability of validating advanced instruments in space and of cross-calibrating them with existing instruments, in parallel to the operational mission, by the most efficient means possible (e.g., by reserving approximately 25 percent of the payload power, volume, and mass capability; through "bridge" missions; and so on).

4.2 To the extent possible, observations from research missions should be provided in real time or near real time to researchers and potential users. Operational centers or associated test beds should use and evaluate the research observations in developing their products and should provide feedback to researchers. Test beds such as the Joint Center for Satellite Data Assimilation and the Joint Hurricane Testbed should be supported as a way to bridge the final steps in the gap between research and operations. The primary mission of such test beds should not be to conduct basic research or operations, but rather to develop and test new real-time modeling and data-assimilation systems to use the new observations. The test beds should include participation by the academic research community and should be quasi-independent from the operational agencies.

4.3 Senior personnel responsible for transition activities should be located at major operational centers of NOAA and at the major research segments of NASA.

Satellite Observations of the Earth's Environment

Accelerating the Transition of Research to Operations

Committee on NASA-NOAA Transition from Research to Operations

Space Studies Board
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

Board on Atmospheric Sciences and Climate
Division on Earth and Life Studies

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Preface

The operation of environmental data services is an important and challenging responsibility. The National Oceanic and Atmospheric Administration (NOAA), the agency charged with providing operational weather, climate, ocean, and space weather data, must ensure that these data are available 7 days a week, 24 hours a day, to a host of users around the world. Once of interest mainly to operational meteorological institutions and academic researchers, these data are now being used by a growing and increasingly diverse set of users for making business decisions, managing natural resources and the environment, mitigating and responding to hazards and emergencies, and planning recreational activities, among other uses. The growth in the number and types of data users is putting continued pressure on NOAA to meet new and evolving user needs and, at the same time, to satisfy the expanding requirements of existing data users.

The growing needs for environmental data are coupled with opportunities for more effective environmental information services, for new types of observations, and for improvements in prediction capabilities and in products offered by advanced technologies (both hardware and software) and by research that offers insights into improved understanding and use of the data. The National Aeronautics and Space Administration (NASA) plays a key role in this process as a provider of new technologies. Other agencies, such as the Department of Defense (DOD), have functioned both as technology providers to NOAA's environmental data system and as users of the system. How the process for transitioning NASA's research and technologies into NOAA's operational services could be improved is the subject of

this report. Two forces—the mission to meet operational requirements and the opportunities to improve and expand predictive capability and services—create a dynamic tension that is inherent in decisions about how and to what extent NASA research and technologies can be transitioned into NOAA's operational service system.

Transitioning research opportunities into operational service can occur in several ways. One possibility is that the infusion of new technologies, through instruments or advanced sensors, satellite designs, numerical models, or algorithms, will take place within an agency—for instance, between agency research and operational centers. The transition process also involves external agencies and organizations, such as academic institutions and research and development (R&D) laboratories. NASA and NOAA have a history of successful transitions of research that have led to improvements in weather forecasts and climate monitoring. However, these transitions have often been of an ad hoc nature, and many have taken a number of years. A more rapid transition process would pay dividends in that the opportunities for societal benefit from publicly supported research would be more quickly realized.

In April 2001, the Space Studies Board and the Aeronautics and Space Engineering Board hosted a pre-project planning meeting at which outside experts and NOAA representatives discussed a range of topics relevant to a long-range vision of the architecture, technology, and customer base of NOAA's meteorological satellite program. As a result of this meeting, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) requested that the National Research Council (NRC) convene a committee to study how to improve the process for transitioning research into operations at NOAA. NOAA invited NASA to become an equal partner in this endeavor, and the study was launched.

THE CHARGE

The NRC appointed the Committee on NASA-NOAA Transition from Research to Operations under the auspices of the Space Studies Board, together with the Board on Atmospheric Sciences and Climate and the Aeronautics and Space Engineering Board, to review the issue of the transition of research into operations and to recommend ways to improve the process. Specifically, NOAA/NESDIS and NASA tasked the committee to do the following:

- Review the potential layers of new users for future operational measurements and assess the implications of the future set of user communities in terms of future needs and approaches for transitioning from research to operations;
- Examine examples of the heritage of current NOAA satellite sensors, capture the lessons that can be gleaned from that history, and review possible approaches

that would smooth and speed the path from the conception of a research sensor to its eventual deployment in an operational satellite;

- Recommend principles for determining what levels of in-house capability will be required within NASA and NOAA and their government partners (including international partners) to ensure that there is a spannable distance between R&D experts and operational users;
- Identify opportunities for new approaches for evaluating new capabilities; and
- Identify possible approaches to enhance the infusion of new technology into the operational system in the future, and recommend means to implement a more systematic transition process that might shorten the cycle time for major program changes and make the system more responsive to user wishes. These might include still closer collaborations between NASA and NOAA, increased resources within NOAA for the conduct of instrument and satellite development, and the enlistment of international partners in a wide variety of possible roles.

STUDY APPROACH

In conducting its study, the committee held five meetings: the first three were devoted to gathering data, the fourth focused on preparing and revising the draft, and the final meeting was devoted to responding to reviewer comments. During these meetings, the committee considered input from a variety of sources. These included previous NRC reports; briefings and supplementary material provided by personnel from NASA, NOAA, and the DOD; discussions with individuals from international organizations such as the European Centre for Medium-Range Weather Forecasts, with representatives from private sector instrument and satellite development companies, and with public and private sector users of environmental data; discussions with representatives of the Office of Management and Budget and congressional staff; and the expertise and perspectives of members of the committee.

The committee's efforts have focused primarily on weather and climate because of the rich history of transitioning atmospheric research into weather forecasts and warnings, the importance of weather and climate to society, and the large amount of resources invested in weather and climate research and operations. However, the lessons learned and the recommendations contained in the report are likely to be applicable to transitions of research to operations concerning oceanographic and space weather data, and also to a broader range of federal government agencies, private sector companies, and other institutions.

The committee would like to acknowledge the many individuals who briefed the committee or provided other background material, information, or input. They include Ghassem Asrar, NASA Earth Science Enterprise (ESE); Ron Birk, NASA ESE

Applications Division; Dave Burridge, European Centre for Medium-Range Weather Forecasts (ECMWF); Marie Colton, NOAA Office of Research and Applications; Michael Crison, NOAA/NESDIS; Franco Einaudi, NASA Goddard Space Flight Center; Edward Frazier, TRW, Inc.; Wallace Harrison, NASA Langley Research Center; Jack Hayes, NOAA National Weather Service; Frank Herr, Office of Naval Research; Tony Hollingsworth, ECMWF; Sarah Horrigan, Office of Management and Budget, Science and Space Branch; Joseph Jenney, ITT (retired); Dave Jones, StormCenter Communications, Inc.; Jack Kaye, NASA ESE Research Division; Col. Lawrence Key, U.S. Air Force, Directorate of Weather, Air and Space Operations; Michael Luther, NASA ESE; Max Mayfield, National Weather Service, National Hurricane Center; Robert Murphy, NASA Goddard Space Flight Center; David Rogers, NOAA Office of Oceanic and Atmospheric Research; Richard Rood, NASA Goddard Space Flight Center; Stanley Scheidner, National Polar-orbiting Operational Environmental Satellite System Integrated Program Office; Ray Taylor, NASA Goddard Space Flight Center; William Townsend, NASA Goddard Space Flight Center; Louis Uccellini, NOAA National Centers for Environmental Prediction; Stan Wilson, NOAA/NESDIS; Robert Winokur, Earth Satellite Corporation; Greg Withee, NOAA/NESDIS; and Erin Wuchte, Office of Management and Budget, Commerce Branch.

Richard A. Anthes, *Chair*
Committee on NASA-NOAA
Transition from Research to Operations

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Farouk El-Baz, Boston University,
George J. Gleghorn, TRW Space and Technology Group (retired),
Brig. Gen. Albert J. Kaehn, Jr., U.S. Air Force (retired),
Ari Patrinos, Department of Energy,
Joyce Penner, University of Michigan,
Robert J. Plante, Raytheon Systems Company, and
Thomas Vonder Haar, Colorado State University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of

this report was overseen by Robert A. Frosch, Harvard University, and Maj. Gen. Eugene Fox, U.S. Army (retired). Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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