Extending the Effective Lifetimes of Earth Observing Research Missions

Committee on Extending the Effectiveness Lifetimes of Earth Observing Research Missions, National Research Council

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Extending the Effective Lifetimes of Earth Observing Research Missions

Committee on Extending the Effective Lifetimes of Earth Observing Research Missions
Space Studies Board
Division on Engineering and Physical Sciences
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Preface

This study was commissioned in 2002 at a time when the National Aeronautics and Space Administration (NASA) had no formal process for the extension of Earth science missions. The original charge (Appendix A) to the Committee on Extending the Effective Lifetimes of Earth Observing Research Missions (see Appendix B for biographies of committee members) was to identify such a process.

In August 2004, NASA merged its Earth and space sciences program offices into the Science Mission Directorate and began to prepare to apply the Senior Review process[1] to Earth science missions. At that time the committee's draft report already had recommendations that were supportive of adapting the Senior Review process for Earth science research missions. In response to the changes at NASA, the committee elected to modestly reinterpret the original charge. In its current form, this report (1) evaluates the effectiveness of the mission-extension paradigm as a means for managing mission life cycles, (2) assesses whether the Senior Review provides an appropriate foundation to implement an Earth science mission-extension process, and (3) identifies modifications to the Senior Review process that could enhance its value to Earth science missions.

The committee wishes to acknowledge the work of committee member William Gail, who led the effort to streamline this report from an earlier, longer version that was partially outdated.

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[1] The Senior Review process is an assessment of the scientific benefits of all potential mission extensions; it weighs the science to be accomplished, the plans for operating the extended mission, and the cost. Extension proposals undergo peer review of their scientific merit and a feasibility evaluation that covers technical issues, safety, cost, and risk criteria.

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 (NRC'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:

Susan K. Avery, University of Colorado,
Jack Fellows, University Corporation for Atmospheric Research,
Lennard Fisk, University of Michigan,
M. Patrick McCormick, Hampton University, and
Christopher Russell, University of California, Los Angeles.

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 Donald M. Hunten, University of Arizona. Appointed by the National Research Council, he was 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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APPENDIXES

Executive Summary

The Earth science missions of the National Aeronautics and Space Administration (NASA) are routinely planned and funded on the basis of a nominal mission lifetime. If the mission is still functioning at the end of this nominal lifetime, there are often strong scientific and operational reasons for extending it. But the decision to do so and commitment of the needed resources must be weighed against use of the same resources for developing new observational capabilities and research missions.

NASA has recently begun using the Senior Review process, developed for the space sciences,[1] to make decisions on extensions for Earth science missions. Previously, these decisions had been made ad hoc. This report by the National Research Council's Committee on Extending the Effective Lifetimes of Earth Observing Research Missions reviews the current process and provides recommendations for adapting this process to the specific needs of NASA's Earth science missions.

Finding. NASA's mission-extension paradigm for accomplishing research missions—which is based on planning and funding nominal operational lifetimes, with a separate decision process for extending operations when this nominal lifetime is exceeded—is fundamentally sound.

- Implementation of the mission-extension paradigm warrants a structured and uniformly applied process that balances the desirability of extending a mission against the feasibility of doing so.
- An effective mission-extension process must carefully reconcile the long lead times required for budget planning against the benefits of deciding as late as possible which missions will be extended.
- Earth science missions have unique considerations, such as future operational utility and interagency partnerships, that distinguish them from space science missions; these considerations should be explicitly included in a mission-extension decision-making process.

Recommendation. NASA should continue to formally plan and fund research missions on the basis of the mission-extension paradigm, but it should (1) ensure that the unique requirements of Earth science missions are satisfied and (2) investigate alternative approaches to mission life-cycle funding in particular cases.

Finding. The Senior Review, currently used as the basis for all NASA decisions on space and Earth science mission extensions, is a thorough and well-run process, but it does not adequately satisfy the unique considerations of Earth science missions.

Recommendation. NASA should retain the Senior Review process as the foundation for decisions on Earth science mission extensions, but should modify the process to accommodate Earth science's unique considerations.

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[1] The term *space science* as used here includes spaceborne investigations in the fields of astronomy and astrophysics, astrobiology, solar system exploration, and solar and space physics.

- The evaluation process should be expanded to complement the NASA-only evaluation with a parallel evaluation through which non-NASA partners can provide their assessment of the need for mission extension—the final NASA decision would be made on the basis of input from both paths.
- The overall process should be built around a 5-year rolling approach to evaluations (see Figure ES.1), involving incremental evaluations beginning several years in advance of the final decision, so as to increase community visibility and facilitate partner commitments, with a biennial status briefing that includes all potential partners.

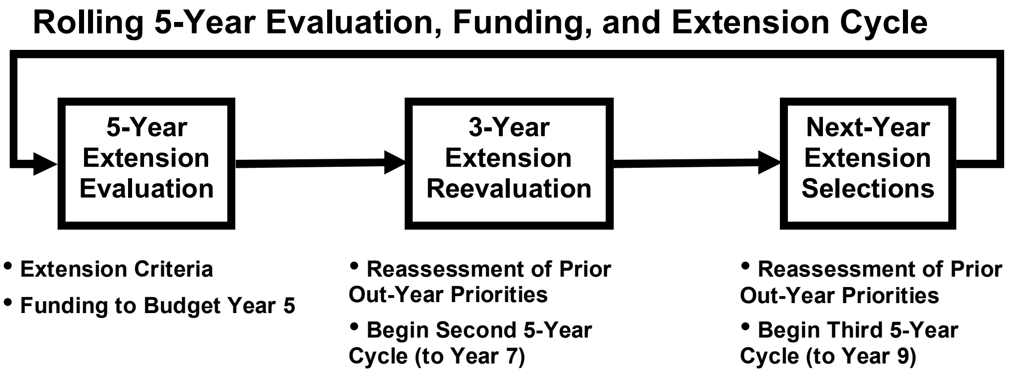

FIGURE ES.1 The rolling-wave planning approach to the mission-extension decision process, as recommended by the committee.

1
Introduction

Spaceborne observations enable a substantial portion of the research performed by the Earth and space science communities. Within the United States, most spaceborne observations intended for scientific research are funded by the National Aeronautics and Space Administration (NASA), although the ultimate beneficiaries include the greater scientific community, the broad spectrum of "users" employing applications derived from science, and the general public.

Traditionally, scientific satellite missions are planned and funded on the basis of a paradigm that assumes a nominal operational lifetime. It is common, however, for such missions to exceed their planned lifetime through a combination of good design and simple statistical luck.[1] Although the intended scientific objectives may have been completed within this period, the opportunity for providing additional science or other benefits at a relatively low cost by extending the mission is often significant.

Today, NASA operates within very constrained resources, and the budget needed for extended mission operations is typically not included in the nominal mission plan. If a decision is made to extend a mission, NASA must either seek new funding or reallocate funding from other programs. Even the relatively low cost of additional mission operations must be weighed on a mission-by-mission basis against the use of those resources for developing new observational capabilities.

A formal, uniformly applied review process for mission extension, known as the Senior Review, has been employed in the space sciences for many years.[2] In contrast, until recently, decisions at NASA on Earth science mission extensions have been made on a case-by-case basis without the benefit of a standardized process. While this approach has been adequate for many missions, the recent controversies over termination or extension of the Upper Atmosphere Research Satellite mission and the Tropical Rainfall Measuring Mission[3] placed the need for a structured mission-extension process in the spotlight. Furthermore, the successful launch of multiple Earth-observing missions over the past decade[4] has created a situation in which a large number of satellites will reach the end of their planned lifetimes in the near future. The establishment of a mission-extension process that is appropriate for the Earth sciences has thus become increasingly important to NASA.

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[1] For Earth science missions, nominal lifetimes are typically 1 to 5 years. Actual lifetimes are occasionally shorter, but usually exceed the nominal lifetime. For example, the Earth Radiation Budget Satellite mission, launched in 1984, had a design life of 2 years, but the nonscanning part of its Earth radiation budget experiment instrument and its Stratospheric Aerosol and Gas Experiment II instrument, which provides near-global measurements of atmospheric aerosols, ozone, nitrogen dioxide, and water vapor, are still operational.

[2] According to NASA briefings to the committee, the process was introduced for NASA astrophysics missions in 1988 and expanded in the 1990s for all space science disciplines.

[3] See *Physics Today*, "Cost Cuts Kill Climate Satellite," October 2001; and National Research Council, *Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission: A Perspective from the Research and Operations Communities, Interim Report*, Washington, D.C.: The National Academies Press, 2004.

[4] A total of 17 Earth science missions were in operation at the time this report was completed.

2
Evaluating the Effectiveness of the Mission-Extension Paradigm

The mission-extension paradigm is based on planning and funding missions only up through the end of a nominal lifetime, with a *mission-extension decision*, to determine whether operations will be extended, made as the mission approaches the end of this nominal lifetime. The Committee on Extending the Effective Lifetimes of Earth Observing Research Missions first looked at whether this process is indeed an effective approach to funding and managing missions over their life cycles. Other mission-planning and -funding paradigms can certainly be envisioned. For example, a simpler approach could be to fund missions for the planning horizon of the federal budget, operating them as long as they were functioning, unless a specific decision was made to terminate a mission.

REASONS FOR MISSION EXTENSION

It is common today for a well-designed mission—including its spacecraft and instruments—to be operating properly at the end of its design life. When this happens, there are often many reasons for extending operations. For Earth science, these generally fall into one of two categories.

The first category of reasons for extending operations covers scientific considerations. Completely new scientific capabilities often are identified by analyzing the data received during the nominal mission lifetime. It is also common to find that a measurement series started during nominal mission lifetime would have considerable scientific value if it were extended over a longer period of time. In some cases, other missions or measurements may be achieving significant benefit from synergy with the mission that has reached the end of its nominal lifetime. Finally, it is not unusual that highly desirable scientific investigations were simply eliminated from an original mission plan owing to cost constraints. Because the cost of extending mission operations is only a fraction of that required for developing new systems,[1] approving mission extensions provides a means for achieving high-quality science for relatively low cost in many cases. Box 2.1 provides historic examples of missions extended for scientific reasons.

The second category of reasons for extending operations is associated with the value of the measurements for applications, future operational use, and other-agency or international partners' objectives. For a number of missions today, the data are already used by the National Oceanic and Atmospheric Administration (NOAA) and other agencies on a quasi-operational basis, and mission extension serves to continue the availability of this type of national capability. For other missions, it may be of benefit to continue evaluating use of the data in order to determine if a future operational system is warranted. Box 2.2 provides historic examples of missions extended for applications and operational reasons. The dependence on international partners to fund missions also means that their objectives must be considered in any mission-extension decision.

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[1] Mission operations for small to medium Earth-orbiting missions are typically \$2 million to \$5 million per year.

BOX 2.1
Historic Examples of the Scientific Basis for Extending Missions

- *Data set extension and continuity through overlap.* Measurements of solar irradiance tell us how solar variations contribute to climate change. The sensitivity of these measurements is such that any increased overlap between older instruments, such as **ACRIM** on the **UARS** mission and **TIM** on the recently launched **SORCE** mission, provides substantially improved science. **TOPEX/Poseidon** was extended in 1996 because its successor, **Jason**, was not ready for launch. Ensuring an overlap between the two missions allowed for calibration in order to establish that both satellites were measuring the same physical phenomena, significantly increasing the value of the Jason data.
- *Improved sampling.* The **TOPEX/Poseidon** spacecraft also was moved to interleave between the ground tracks of **Jason**, providing improved spatial coverage and resolution.
- *Unique measurements.* **UARS** was launched in 1991 with a 3-year design life, but it has already been extended for more than a decade because its six operating instruments offer the sole capability of profiling atmospheric chlorine and fluorine for ozone monitoring.
- *Unanticipated science.* **QuikSCAT** was launched in 1999 to monitor ocean winds, but scientists are now exploring whether the scatterometer can also measure the freeze-thaw transition at high latitudes, which is a sensitive measure of climate change.
- *Synergy of multiple instruments.* The **MODIS** instrument on the **Terra** mission provides a global land cover data set. The higher spatial detail provided by the **ETM+** instrument on the **Landsat** mission, launched many years before the Terra mission, has proven essential to algorithm training for this data set.

NOTE: Definitions of the acronyms are provided in Appendix C.

BOX 2.2
Historical Examples of the Applications and Operational Basis for Extending Missions

- *Established operational utility.* The National Oceanic and Atmospheric Administration (NOAA) currently makes extensive use of the NASA **QuikSCAT** mission for providing ocean surface wind measurements. NOAA will provide these measurements itself using a radiometer instrument onboard **NPOESS**, but that capability is not expected to be available until at least 2010.
- *Demonstration of operational potential.* The **TRMM** mission, launched in 1997, monitors rainfall in the Tropics. The initial potential of TRMM for improving predictions of hurricane intensity, among other things, was demonstrated during the 3-year nominal lifetime of the mission. But its full potential and the strong need for a follow-on operational capability were only revealed as the extended mission life enabled the sampling of a greater number and variety of hurricanes and tropical cyclones.
- *Unanticipated applications.* Following the 1998 launch of **Terra**, scientists began to use **MODIS** data for discovering wildfires and monitoring their spread. The capability proved so useful that a rapid-response data communications system was established with a U.S. Forest Service center in Salt Lake City. This system has been expanded to include routine MODIS monitoring of the conditions that lead to wildfires.

NOTE: Definitions of the acronyms are provided in Appendix C.

UNIQUE CONSIDERATIONS FOR EARTH SCIENCE MISSIONS

As the examples in Box 2.2 illustrate, establishing a standardized process for extending missions involves additional factors for Earth science compared with the situation for space science. For space science, the community impacted by the mission-extension decision is largely limited to those scientists in research disciplines for which the mission was originally conceived and flown. For Earth science, however, NASA data often are used by numerous other government agencies, and many such missions are relied on by international or other partners as precursors to follow-on systems or activities.

TRADING DESIRABILITY AGAINST FEASIBILITY

A mission-extension decision is always a trade-off. From the mission perspective, one needs to balance the desirability of extending the mission's nominal lifetime against the feasibility of doing so. Critical considerations include (1) the ability to complete an extended mission, taking into account the functional status of the spacecraft and the instruments; (2) the cost of extending the mission; and (3) the risk of extending the mission, particularly with respect to de-orbiting issues. These issues are rarely equal in importance, and the ability to de-orbit safely has become a key factor in recent years.[2]

From an overall NASA perspective, the benefits of extending a particular mission also need to be balanced against the use of the same funds for another purpose, in particular for the development of new observational systems.[3] A mission-extension decision needs to address all of these complex issues. Mission-extension decisions thus warrant a formal, deliberate, and uniformly applied process that effectively balances benefits against costs and risks.

Despite the complexity and importance of the mission-extension decision itself, much of the challenge for any mission-extension process arises from longer-term NASA budgeting issues. The federal budget cycle, under which NASA operates, forces resource requirements to be identified effectively 3 years in advance of when the funds are expended. Yet the desirability and feasibility of a mission extension are typically most clear when the nominal mission is near its end. The tension between these two valid objectives—advanced budget planning and just-in-time decision making—presents a fundamental problem that must be addressed for an effective mission-extension process to be achieved.

USE OF THE MISSION-EXTENSION PARADIGM

The committee found that, when all factors are considered, the mission-extension paradigm provides an effective means to plan and fund mission life cycles. In particular, it allows NASA to dynamically reallocate resources on the basis of evolving priorities. Yet use of the mission-extension paradigm does not preclude other approaches to funding a mission life cycle, and NASA would benefit from considering other approaches in particular cases. Such cases could include missions for which it is known prior to launch that the mission will likely continue to provide substantial benefits if it exceeds its nominal lifetime. This is often true for missions with known operational utility but no funded operational follow-on mission.[4] It is also true for missions with science returns that are not expected to decline over time, such as those contributing to long time-series data sets.

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[2] NASA safety guidelines call for a controlled reentry when a satellite would pose a greater than 1 in 10,000 chance of harming people or damaging property on the ground if it were left to reenter in an uncontrolled manner.

[3] Much of the controversy around the extension of the Tropical Rainfall Measuring Mission (TRMM) has been associated with the trade-off between extending TRMM operations and using the resources to begin a TRMM follow-on mission.

[4] The NASA Quick Scatterometer (QuikSCAT) satellite is an excellent example: NOAA has routinely used QuikSCAT ocean surface wind data, but there are no plans for an operational active scatterometer.

Finding. NASA's mission-extension paradigm for accomplishing research missions—which is based on planning and funding nominal operational lifetimes, with a separate decision process for extending operations when this nominal lifetime is exceeded—is fundamentally sound.

- Implementation of the mission-extension paradigm warrants a structured and uniformly applied process that balances the desirability of extending a mission against the feasibility of doing so.
- An effective mission-extension process must carefully reconcile the long lead times required for budget planning against the benefits of deciding as late as possible which missions will be extended.
- Earth science missions have unique considerations, such as future operational utility and interagency partnerships, that distinguish them from space science missions; these considerations should be explicitly included in a mission-extension decision-making process.

Recommendation. NASA should continue to formally plan and fund research missions on the basis of the mission-extension paradigm, but it should (1) ensure that the unique requirements of Earth science missions are satisfied and (2) investigate alternative approaches to mission life-cycle funding in particular cases.

3
Assessing the NASA Senior Review Approach to Mission Extension

NASA currently plans and implements extensions of science missions on the basis of the mission-extension paradigm. A formal and structured biennial process known as the Senior Review is used to review candidates for mission extension and to decide which will be funded. This process has been used for space science missions since the mid-1990s, but it was first applied to Earth science missions following the reorganization of NASA in late 2004.

DESCRIPTION OF THE SENIOR REVIEW

A mission that is approaching the end of its nominal mission lifetime is a candidate for mission extension under the Senior Review process. To be approved for an extended mission, the mission team must submit a detailed proposal describing accomplishments to date, the scientific benefits of extension and the science to be accomplished, the plans for operating the extended mission, and the cost of extended operations. Also included are plans for continuing related education and public outreach activities.

These proposals then undergo peer review of their scientific merit and a feasibility evaluation that covers technical issues, safety, cost, and risk criteria. Selected proposals are expected to reduce their annual operating costs significantly as compared with costs during the nominal mission life period. Funding is provided on a biennial basis, with proposals required every 2 years for renewal. Historically, a substantial majority (around 80 percent) of candidate missions have been approved for extension during any Senior Review cycle, with levels of funding that may be modestly or even drastically reduced compared with funding levels during the prime mission lifetime.

The funding for all extended missions is held in a single line within the NASA budget. For the space sciences, the committee estimates that the average total of extended-mission funding for the 5-year period from fiscal year (FY) 1998 to FY 2003 was approximately $60 million per year. Funding of extended missions under this approach provides for advanced budget planning that is consistent with the needs of the federal budget process, but it allows NASA to make decisions regarding individual mission extensions as the needs arise.

ASSESSMENT OF THE SENIOR REVIEW

The committee found that the Senior Review provides an excellent starting point for a mission-extension process, although it does not fully address the particular needs of Earth science missions. In particular, the committee believes that the Senior Review's reliance on an open, structured, and documented process is highly commendable. The strong emphasis on peer review and community involvement is an essential element of the process. The use of fair and open competition among all missions requesting funding further establishes community confidence that all missions will receive an objective hearing. The requirement for reduced operations cost during the extended mission appropriately emphasizes that the primary science acquisition occurred during the nominal mission life. Finally, NASA's establishment of a funding line to support all mission extensions has resolved the conflict between advanced budgeting and last-minute decisions. If, as recommended in the following chapter, NASA elects to tailor the Senior Review to the particular needs of Earth science missions, these attributes of the process should be carefully protected.

Finding. The Senior Review, currently used as the basis for all NASA decisions on space and Earth science mission extensions, is a thorough and well-run process, but it does not adequately satisfy the unique considerations of Earth science missions.

4

Adapting the Senior Review Process to Earth Science Missions

With the NASA Senior Review process established as a solid foundation for making mission-extension decisions in general, the remaining task is to determine how this process can be applied or modified to meet the particular needs of Earth science missions. As noted previously, these additional needs arise largely from the potential for operational utility inherent in Earth science missions and the importance of both interagency and international partnerships as a result.

The committee found that the Senior Review process needs to be modified in two fundamental areas in order to meet the needs of Earth science. First, a comprehensive, formal mechanism is needed for alerting other agencies and partners to mission-extension opportunities. Second, the process needs to be adapted so as to solicit and consider the requirements of such agencies and partners as well as those of NASA. Three specific enhancements to the Senior Review are suggested to accomplish these adaptations: (1) the addition of a biennial mission-extension status briefing for NASA's (federal and other) partners, (2) the inclusion of a second review panel to represent the needs of partners, and (3) the modification of the process to provide a 5-year rolling-wave evaluation rather than a one-time review.

THE BIENNIAL STATUS BRIEFING AND TWO-PANEL STRUCTURE

Figure 4.1 shows an adaptation of the Senior Review process that incorporates the enhancements listed above. The dashed box on the left of the figure describes the recommended informational review to be used for communicating the status of existing Earth science missions and the potential needs for mission extension to other agencies, existing mission partners, and potential partners. This review should be scheduled several months in advance of the mission-extension selection process so that partners have the opportunity to fully evaluate their level of interest in mission extension.

The right-hand dashed box in Figure 4.1 describes the mission-extension selection process. The portion of this process labeled "NASA Panel Review" is similar to the current Senior Review, with the panel put into service as a peer review body that includes members of the non-NASA and academic communities. The breadth and diversity of this community make it challenging to select a small but representative group. This review provides NASA's assessment of the scientific merits of mission extension.

A second review path, the "External Panel Review," has been added by the committee. Members of this External Review Panel might include the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey, international partners, and even commercial companies[1]—any non-NASA entity interested in participating in the extended mission. This review provides an assessment of both the desire for mission extension among partners and their commitment to participate in and contribute resources to an extended mission.

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[1] The NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS) mission, for example, is considered to be part of NASA's Earth Observing System. But the commercial company OrbImage now owns the satellite (developed with the assistance of NASA funding). Any mission-extension decision relating to SeaWiFS is thus likely to involve the active participation of both NASA and OrbImage.

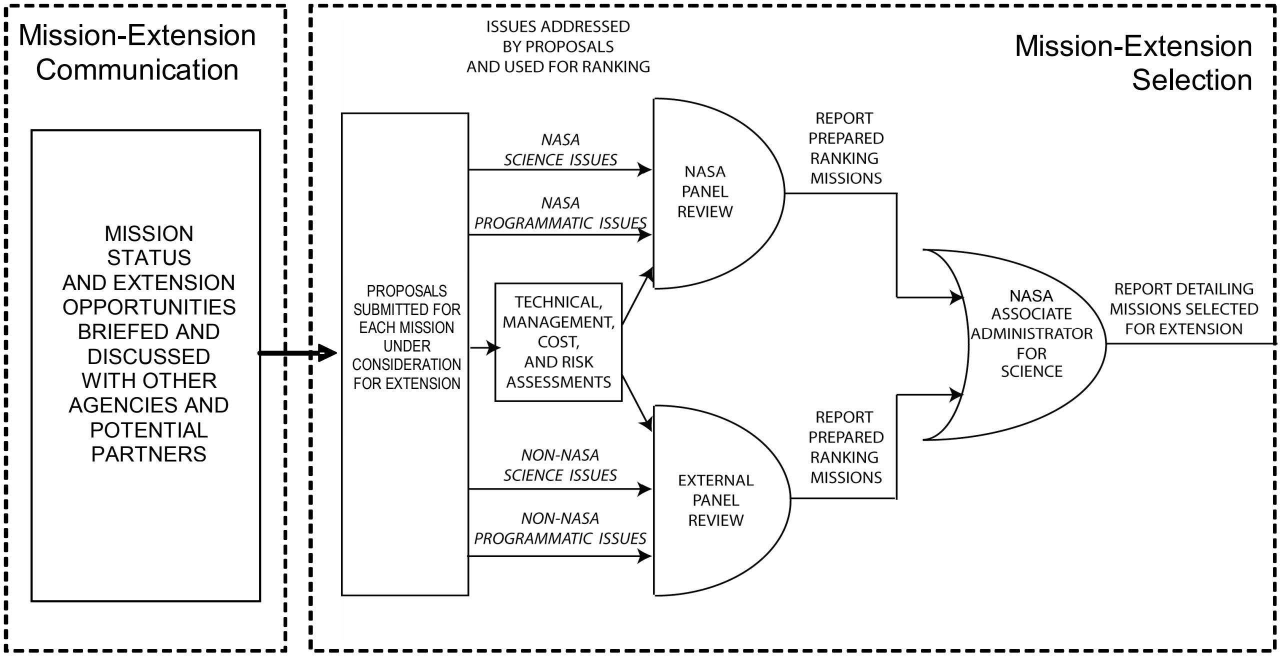

FIGURE 4.1 The Senior Review process adapted to Earth science missions, as recommended by the committee.

The supporting technical, management, cost, and risk assessments are performed once and fed into the reviews by both the NASA and the External Review Panels. The proposal process should include a presentation by representatives of the requesting mission (including non-NASA personnel involved in the mission) to the panels.

The selected decision official within NASA is provided with the recommendations from each of the two panels. That official selects missions for extension based on these recommendations, on overall NASA science strategy, and on available resources. In some cases, NASA may have agreed in advance to make such decisions jointly with its partners; the process is easily modified to reflect such an agreement.

The current Senior Review, based on advice from the present NASA Review Panel, provides recommendations about whether a mission should be extended, the conditions under which an extension should occur, the relative priorities of candidate missions, and even suggested funding levels. By adding the External Review Panel, the advice is likely to become more complex. Included will be issues associated with financial contributions from partners, the potential transfer of operational control to partners, new or emerging uses of the mission by partners, conflicts between objectives of NASA and mission partners, commitments to international partners, and many others.

The nature of the advice provided by the External Review Panel also is likely to be distinctly different from that provided by the NASA Review Panel. By virtue of how it is established, the External Review Panel will most probably reflect an aggregation of individual interests rather than a broad perspective. Rather than providing an overall prioritization, the External Review Panel's advice should be limited to individual mission recommendations that are then used by the decision-making official to establish the overall prioritization. It should also be recognized that one role of the External Review

Panel is to fill the void created by the lack of a formal mechanism for transitioning NASA research to operational use.[2]

The committee considered the possibility that a single panel could evaluate both the science and the needs of other agencies in one review. However, it identified two primary concerns: (1) The non-NASA voices would certainly be a minority on such a panel, raising the possibility that their perspective would be overwhelmed by NASA interests. (2) A single panel would mix scientific peer review and nonscientific considerations in a way that could compromise the scientific recommendations. The two-panel approach protects both the interests of non-NASA partners and the integrity of the scientific peer review.

ROLLING-WAVE PLANNING

To further enhance the communications aspect of the modified Senior Review process and to improve overall planning and budgeting, the committee recommends a rolling-wave approach to the entire process. Figure 4.2 illustrates this approach. Every other year, beginning two review cycles in advance of when a mission-extension decision was required (one cycle in advance for short-duration missions), missions would undergo the Senior Review. For those requesting an extension one or two cycles in advance of the need, the proposal process should also be significantly reduced in scope and detail, and the decision would place such proposals on a list of “anticipated but not approved” extensions.[3] Thus, each Senior Review would produce three prioritized mission lists: (1) a list of extensions to begin the following year, (2) a list of “anticipated” extensions for 3 years hence, and (3) a list of anticipated extensions for 5 years hence. Missions undergoing final extension review should thus all have been reviewed during previous cycles. The process that generates these lists of extensions would facilitate NASA budget planning and assist potential mission partners both in their own planning and in allocation of resources for an extended mission.[4] New information obtained at each review in the rolling-wave process would be used by NASA to determine which missions were to be retained on the anticipated-extensions lists and which were to be removed.[5] Decisions to fund extended missions would be valid for 2 years, or longer in special circumstances.

BENEFITS OF THE MODIFIED PROCESS

The biennial status briefing and two-panel approach, combined with the rolling-wave evaluation, would contribute substantial benefits to Earth science. The potential need for mission extension would be communicated to interested agencies or partners up to 5 years or more in advance of the need. In return, the desire of interested agencies or partners to extend a mission would be communicated to NASA with the same lead time, including the planned budget requests of the interested agencies or partners for supporting data utilization or mission operations. Indeed, the process itself could be used to identify needed budgets, or it could operate effectively within a fixed budget. Finally, last-minute or

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[2] See the recommendations on pages 5-8 in National Research Council, *Satellite Observations of the Earth’s Environment: Accelerating the Transition of Research to Operations*, Washington, D.C.: The National Academies Press, 2003.

[3] The committee recognizes the burden of this repeated proposal process and expects that NASA will seek ways to reduce the burden while retaining the benefits of the rolling-wave approach. For example, the list of “anticipated” missions may include all those that are realistic candidates for extension, with the expectation that the missions with lowest priority may ultimately not be funded if the budget is inadequate.

[4] Most of these federal partners have the same budget cycles and 3-year advanced planning needs as NASA.

[5] Missions might be removed because satellites or instruments failed, science priorities changed, the needs of partner agencies changed, or for a variety of other reasons.

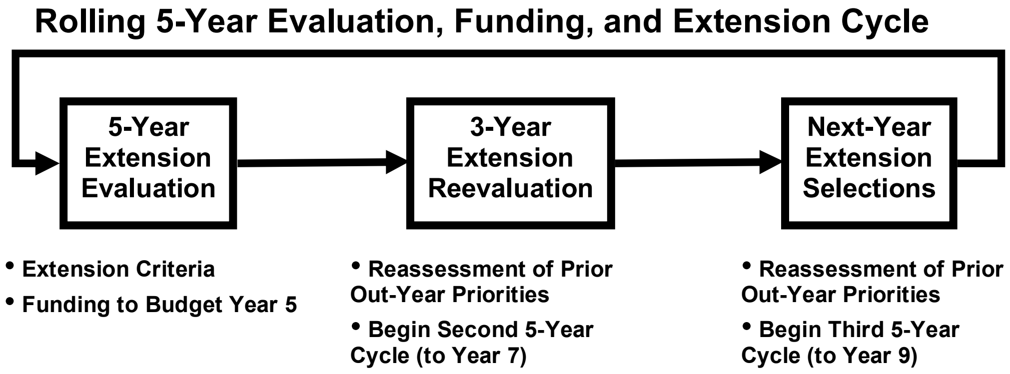

FIGURE 4.2 The rolling-wave planning approach to the mission-extension decision process, as recommended by the committee.

unanticipated requests for mission extension, while not eliminated, should be substantially reduced. Missions considered to fall within the field of Earth-Sun connections, which often have the potential for operational follow-on, would benefit from this modified process in the same way that Earth science missions would benefit.

Advanced planning encompassing several budget cycles would likely help NASA receive funding commitments from partners that otherwise would be unable to identify resources to support last-minute mission-extension decisions. If done properly, such agreements would be negotiated well in advance of the final mission-extension decision. While there are few examples of such successful negotiations to date, the 5-year planning window would provide the opportunity for examples to emerge.

The recommended process also retains many of the relevant valuable attributes of the Senior Review. Particular features of the Senior Review and their suggested adoption or modification for Earth science missions are summarized in Table 4.1. The flexibility of the Senior Review allows NASA to adjust continuously to changing national priorities and policies, such as the increased emphasis on de-orbiting safety over the past decade, and to evolve scientific criteria for mission extension. The use of peer review ensures that these criteria will be rooted in the science community and that extended missions will continue to produce data of high quality.

Recommendation. NASA should retain the Senior Review process as the foundation for decisions on Earth science mission extensions, but should modify the process to accommodate Earth science's unique considerations.

- The evaluation process should be expanded to complement the NASA-only evaluation with a parallel evaluation through which non-NASA partners can provide their assessment of the need for mission extension—the final NASA decision would be made on the basis of input from both paths.
- The overall process should be built around a 5-year rolling approach to evaluations (see Figure 4.2), involving incremental evaluations beginning several years in advance of the final decision, so as to increase community visibility and facilitate partner commitments, with a biennial status briefing that includes all potential partners.

TABLE 4.1 Adoption or Modification of Features of the Senior Review Process for Earth Science Missions

Current Senior Review Feature	Adopt/Modify for Earth Science Missions
Structured, open, and competitive process.	Adopt.
Peer review of anticipated science benefit.	Modify through two-panel structure to address value of applications or operational use.
Additional criteria considered (education and public outreach, and so on).	Adopt.
Great majority of proposed extensions (~80 percent) are funded.	Modify as needed to reflect the different nature of extended-mission decisions in the Earth sciences.
Reduced operational cost expected for extended missions.	Adopt for NASA-sponsored research; augment if requested and funded by other entities.
Proposal evaluations on 2-year centers with proposals for an extended mission at least 12 months prior to nominal end of mission.	Adopt.

Appendixes

A
Statement of Task

Many NASA Earth observing research satellites can continue to acquire useful data well past the end of their planned baseline missions. Extending these missions may benefit research, applications, and/or operational monitoring or prediction activities. While costs for extending on-orbit missions are small compared with development and implementation costs, they are not negligible, and it is not clear how the extension costs should be borne by the benefiting agencies. This study will examine the suite of multi-agency issues associated with (1) criteria for identifying missions that should be extended, and (2) principles for allocating multi-agency mission operations and mission support for extended missions.

BACKGROUND

Many NASA research satellites are fully functional and are routinely acquiring accurate data at the end of their planned baseline missions. Extending these missions can often benefit the ***research*** community and can enable unanticipated science investigations, beyond those used originally to justify the mission. In the case of some Earth observation missions, non-research ***applications*** for the measurements are developed during the baseline mission; extending the mission can allow the applications products to be improved, distributed broadly, and tested widely. This can include increased use of the data for monitoring and decision-making purposes.

Many Earth observing research missions deliver near-real-time data that can also be used to support ***operational*** predictions or decision making. Focused efforts to exploit the data from research missions for operational purposes often only begin well into the baseline mission, after the measurements have been validated and characterized by the research community. Assimilation techniques and utility demonstrations are often incomplete at the end of the baseline mission. Owing to cost considerations, other agencies are sometimes reluctant to conduct full-scale operational testing unless the near-real-time data stream is expected to continue for several years. Extending these research missions can enhance operational exploitation of their measurements and those of follow-on missions.

The marginal costs to extend on-orbit missions are generally small compared with the investments and risks associated with building and orbiting the satellite, developing and validating the research algorithms and products, and conducting the baseline NASA research mission. However, the operating and data production costs are not negligible, especially when multiplied by the increasing number of on-orbit missions. Indeed, the sum of operating costs can be significant when compared with the NASA technology investigations and research support necessary to ensure the development of future, more capable Earth observing missions.

The situation is further complicated by recent policies calling for mandatory end-of-mission deorbiting of spacecraft which pose significant damage or liability risk if allowed to re-enter in an uncontrolled fashion. Mission extensions increase the risks of spacecraft failures that could preclude controlled re-entry, which must be balanced against the benefits of the additional data.

NOTE: See the discussion in the Preface regarding changes to the committee's statement of task.

Decisions to extend or terminate NASA research satellite missions have historically been justified by NASA alone, and the extended mission costs have been borne by the NASA budget. Within the Office of Space Science, a Senior Review process has been formalized to examine mission continuation issues and implications. However, products from NASA Earth observation missions are used by (and often directly benefit) other agencies, and thus termination or extension decisions seem to require more extensive examinations. Key factors include ensuring that the overall research, applications, and operational benefits to the nation are maximized while providing that the communities and agencies that benefit from the data share the costs of extended missions equitably. To date, no national policies (and few examples) exist for guiding such multi-agency decisions. The situation is further complicated by short decision-making times. Baseline mission durations are typically 3-5 years, providing few budget cycles to develop and assess applications and operational prediction products, and then to negotiate multi-agency extended mission agreements and get budgetary approval for each agency.

While the most obvious near-term interagency collaborations involve NASA and NOAA (for research missions producing data that contribute to operational weather and environmental prediction), collaborations between NASA and one or more other agencies (such as the U.S. Geological Survey, Federal Emergency Management Agency, etc.) are likely to arise.

CHARGE TO THE COMMITTEE

The Space Studies Board will organize a study of the challenges, recommended principles, and potential processes for:

1. Identifying NASA research missions that should be extended; and
2. Establishing the necessary interagency coordination for supporting and implementing extended mission operations.

The committee will not make recommendations on whether specific missions should be extended or terminated.

The committee will consider issues including:

1. Mechanisms for ensuring the continued production of consistent, accurate research products during extended mission operations;
2. Implications of mandatory de-orbiting policies and responsibilities;
3. Methods for efficiently tracking and evaluating the direct use of data and information from NASA research missions by other agencies and the private sector; and
4. Challenges associated with multi-agency responsibilities for meeting the resource needs of extended missions or transfer of mission operations support from NASA to another agency.

The committee will also provide recommendations regarding

1. General criteria and approaches to assist NASA in assessing the continued *research* value and potential of mission continuation; and
2. General criteria and approaches to assist NOAA and other agencies in assessing the operational prediction and NOAA-relevant research value and potential of mission continuation.

B
Biographies of Committee Members and Staff

MICHAEL H. FREILICH, *Chair*, is a professor in the College of Oceanic and Atmospheric Sciences at Oregon State University. Dr. Freilich's research interests include microwave ocean remote sensing, especially surface-wind measurement and analysis techniques, surface-wave modeling, and nearshore processes. His current research focuses on the development of empirical models relating radar backscatter to near-surface winds, characterization of centimetric ocean-surface roughness and atmospheric mesoscale phenomena using satellite measurements, and the development and application of advanced statistical validation techniques. Dr. Freilich heads the Ocean Vector Wind Science Team on the National Aeronautics and Space Administration's (NASA's) Quick Scatterometer (QuikSCAT) mission. (QuikSCAT is a "quick recovery" mission—accomplished in 11 months—that is filling the gap created by the loss of data from the NASA Scatterometer (NSCAT)). Dr. Freilich served on the National Research Council's (NRC's) Oceans Studies Board from 1992 to 1995. He was also a member of the Panel on the National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean Program from 1993 to 1994.

ANTONIO J. BUSALACCHI, JR., is director of the Earth System Science Interdisciplinary Center (ESSIC) and professor of meteorology at the University of Maryland, College Park. ESSIC is operated jointly by the Departments of Meteorology, Geology, and Geography at the University of Maryland in collaboration with the Earth Sciences Directorate at NASA's Goddard Space Flight Center (GSFC). Dr. Busalacchi is a research scientist with past government laboratory experience. He has expertise in applying research instruments and data to operational oceanography, with particular emphasis on study of the response of tropical oceans to surface fluxes of momentum and heat and tropical ocean circulation and its role in the coupled climate system. Dr. Busalacchi began his professional career as an oceanographer at the NASA GSFC. In 1991, he was appointed chief of the NASA GSFC Laboratory for Hydrospheric Processes. In that capacity he furnished scientific direction to a broad, many-faceted program in Earth system science. Currently, Dr. Busalacchi serves as co-chair of the Scientific Steering Group for the World Climate Research Programme. He has extensive NRC experience, having served as a member of the Panel on the Tropical Ocean Global Atmosphere Program, the Panel on Ocean Atmosphere Observations Supporting Short-Term Climate Predictions, and the Climate Research Committee.

CAROL ANNE CLAYSON is an associate professor in the Department of Meteorology at Florida State University. From 1995 to 2001, she was an assistant and associate professor in the Department of Earth and Atmospheric Sciences at Purdue University. Dr. Clayson's research interests are in air-sea interaction, ocean and atmosphere boundary layers, numerical ocean and coupled ocean-atmosphere modeling, and remote sensing of air-sea surface fluxes. She was the recipient in 1996 of a National Science Foundation (NSF) career award and the recipient in 2000 of a Presidential Early Career Award for Scientists and Engineers, as well as an Office of Naval Research Young Investigator Award. Her professional service activities include serving as program chair for the 12th American Meteorological Society (AMS) Conference on Air-Sea Interactions, held in 2003; and membership on a number of committees and working groups, including the AMS Committee on Interaction of the Sea and Atmosphere; the AMS Board of Meteorological and Oceanographic Education in Universities; the NASA Tropical Rainfall Measuring Mission Science Team, Tropical Ocean Global Atmosphere/Coupled Ocean

Atmosphere Response Experiment (TOGA COARE) Air-Sea Flux Working Group, the TOGA COARE Radiation Working Group, and the AMS, the American Geophysical Union, and the Oceanography Society.

WILLIAM B. GAIL is vice president of Mapping and Photogrammetric Solutions at Vexcel Corporation, where he leads a global organization responsible for a wide range of systems and services associated with Earth information. Prior to joining Vexcel, he was director of Earth Science Advanced Programs at Ball Aerospace, where he led the development of spaceborne instrument and mission concepts for Earth science and meteorology. Dr. Gail received his undergraduate degree in physics and his Ph.D. in electrical engineering from Stanford University, focusing his research on the physics of Earth's magnetosphere. During this period, he spent a year as a field scientist at South Pole Station, managing experiments on cosmic rays and upper atmospheric physics. Dr. Gail is currently on the board of directors of Peak Weather Resources, Inc., a small company formed to transition weather research to the commercial market. He is also a member of the Administrative Committee of the Institute of Electrical and Electronics Engineers Geoscience and Remote Sensing Society and founder of its Industry Liaison Group. In addition, he is a member of the NASA Earth Science and Applications from Space Strategic Roadmap Committee. He is currently a member of the NRC Committee on Earth Studies and previously served on the Task Group on Principal Investigator-Led Earth Science Missions (2001-2003), the Committee on NASA-NOAA Transition from Research to Operations (2002-2003), and the Committee to Review the NASA Earth Science Enterprise Strategic Plan (2003).

WILLIAM C. GIBSON is vice president of the Space Science and Engineering Division, Southwest Research Institute. He has extensive experience in the management of projects involving the development of scientific instruments and support systems for use on the space shuttle, free-flying satellites, sounding rockets, and high-altitude research balloons. He is the project manager for SMART (Solving Magnetospheric Acceleration, Reconnection, and Turbulence), the science investigation payload for NASA's Magnetospheric Multiscale Mission. Mr. Gibson has managed such projects as the Space Experiment with Particle Accelerators (SEPAC) Interface Unit for Spacelab Mission I, the High Altitude Plasma Instrument for the Dynamics Explorer Satellite, the Fast Ion Mass Spectrometer for the Centaur Rocket Project, and the Balloon-Borne Ultraviolet Stellar Spectrometer. In addition to these projects, he has served as the project manager for the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) Medium-Sized Explorer (MIDEX) mission and is the project manager designee for the Waves Explorer MIDEX mission. His areas of technical specialization include the design of spacecraft data systems, spacecraft telemetry and control systems, and spacecraft heat-transfer systems. Mr. Gibson was the architect of the multiprocessor SEPAC On-Line Data Analysis real-time telemetry ground station used during Shuttle Transportation System-9 (STS-9) and the lead design engineer on the Johnson Space Center Stratospheric Ozone Experiment. Mr. Gibson has served as a member of NASA source selection boards and as chairman of the NASA Confirmation Review Board for the Galaxy Evolution Explorer Small Explorer mission. He also served as a member of the standing review board for the NASA Advanced Composition Explorer mission. He was a member of the NRC Task Group on Principal Investigator-Led Earth Science Missions (2001-2003).

SARAH T. GILLE is an associate professor at the Scripps Institution of Oceanography and in the Department of Mechanical and Aerospace Engineering, University of California, San Diego. Prior to her current position, she was assistant professor, Earth System Science, University of California, Irvine. Her research interests are in climate and ocean dynamics. She interprets satellite observations from altimetry and scatterometry, with the goal of understanding physical processes controlling ocean climate. She is a member of the NASA Jet Propulsion Laboratory (JPL) Ocean Vector Wind Science Team and the NASA JPL Jason Science Working Team. Dr. Gille served on the NRC Committee on Earth Studies (2000-2004) and the Committee to Review the NASA Earth Science Enterprise Strategic Plan (2003).

ROSS N. HOFFMAN is vice president of prediction and radiation studies and manager of the Numerical Weather Prediction Group at Atmospheric and Environmental Research (AER), Inc. Dr. Hoffman is an industry scientist with experience emphasizing data assimilation and uses rather than satellite mission development or operations. His principal areas of interest cover objective analysis and assimilation methods, atmospheric dynamics, climate theory, and atmospheric radiation. He has been the principal investigator of several projects at AER and has made significant contributions in the field of data assimilation, including the development of some variational techniques. Dr. Hoffman is a member of the NASA NSCAT Science Team and the Earth Observing System SeaWinds Science Team. He is also a member of the NRC Committee on Status and Future Directions in U.S. Weather Modification Research and Operations.

BRUCE D. MARCUS is a retired senior industry engineer with vast experience in space mission and instrument development and operations for the Department of Defense, NOAA, and NASA. Dr. Marcus's research interests included heat and mass transfer, heat pipes, thermosiphons, spacecraft thermal control, and the thermomechanical design of telescopes. Dr. Marcus also has extensive experience in the management of Earth observation programs. He served on the NRC Committee on Earth Studies from 1995 to 1999, on which he was a key committee member on several reports. In addition, Dr. Marcus served on the NRC Committee on the Continuing Assessment of Technology Development in NASA's Office of Space Science (1999-2000), the Space Studies Board (2000-2004), and the NRC Task Group on Principal Investigator-Led Earth Science Missions.

STEVEN W. RUNNING is a professor of forest ecology and director of the Numerical Terradynamic Simulation Group in the School of Forestry at the University of Montana. His research interests include the modeling of forest ecosystem processes, terrestrial ecosystem modeling theory, and the regional hydrologic and carbon balance of forests in response to global climate change. Dr. Running has served on several panels of the International Geosphere-Biosphere Program and the World Climate Research Program. He is a member of the science team for NASA's Moderate Resolution Imaging Spectroradiometer and is chair of NASA's Land Panel for the Earth Observing System. Dr. Running has served on numerous committees, including the International Geosphere-Biosphere Program, Biospheric Aspects of the Hydrologic Cycle (vice chair, 1991-1996); NASA Earth Observing System, Land Science Panel (chair, 1994-1998); the Terrestrial Observation Panel for Climate of the World Climate Research Program, and the World Meteorological Organization (1995-1998). He also served on the Climate Research Committee of the NRC Board on Atmospheric Sciences and Climate (1996-1999), the Panel on Climate Observing Systems Status (1998-1999), and the Committee to Review NASA's Earth Science Enterprise Science Plan (2000). Dr. Running has extensive experience with how and why space data users use measurements for research and applications to forest ecology and hydrology.

CARL F. SCHUELER is chief scientist at Raytheon Santa Barbara Remote Sensing. His experience and expertise are in satellite remote sensing. Dr. Schueler has led numerous advanced-sensor development studies and proposals for polar and geosynchronous Earth observation, as well as planetary exploration. He also managed the mid-1990s Defense Meteorological Satellite Program Block 6 studies and the Polar-orbiting Operational Environmental Satellite studies in 2000 that led to Raytheon's participation in the NPOESS program, and led Raytheon's successful efforts for the Aerosol Polari-Meter Sensor to be flown on NASA's Glory Mission and NPOESS. In the mid-1980s, Dr. Schueler served 2 years as start-up director of the Institute for Technology Development's Center for Commercial Development of Space at Stennis Space Center, focused on remote sensing. More recently, he served on a number of working groups for Congressional Studies in Remote Sensing led by the former Office of Technology Assessment. He currently serves on the advisory committee of the University of California at Santa Barbara's Institute for Computational Earth System Science and as an executive adviser to the Environmental Research Institute of Michigan's International Conference Series on Remote Sensing of Marine and Coastal Environments. Dr. Schueler served on the NRC Task Group on Principal Investigator-Led Earth Science

Missions (2000-2003), the Committee to Review the NASA Earth Science Enterprise Strategic Plan (2003), and he was a member of the Committee on Earth Studies (1999-2002).

ROBERT A. SHUCHMAN is senior vice president and chief technical officer of Altarum, Inc. Prior to his appointment at Altarum, Dr. Shuchman was vice president for government products and services as well as director of the Earth Sciences Group at ERIM International. At Altarum, he is responsible for providing collaboration and overall technical direction and for facilitating technical exchanges between business lines in order to create new business opportunities and the collaboration of teams across those business lines. Dr. Shuchman manages corporate R&D, utilizing inputs from the Science Advisory Council (SAC) and business line presidents. Altarum's Emerging Technologies Group also reports to Dr. Shuchman. He has no direct involvement in individual space missions. Dr. Shuchman is an expert in the uses of remote sensing for Geographic Information Systems applications, including forestry, coastal, and marine management, among other commercial applications. His NRC service includes membership on the Panel on the Implications of Future Space Systems for the U.S. Navy (1985-1993) and the Advanced Radar Technology Panel and the Task Group 5—Space Inputs (1994-1996).

ROY W. SPENCER serves as principal investigator on the Global Precipitation Studies with Nimbus-7 and Defense Meteorological Satellite Program Special Sensor Microwave/Imager at the Earth System Science Center of the University of Alabama in Huntsville. Dr. Spencer has been a member of several science teams: the Tropical Rainfall Measuring Mission's (TRMM's) Space Station Accommodations Analysis Study Team, the Science Steering Group for TRMM, the Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder Pathfinder Working Group, and the NASA Headquarters Earth Science and Applications Advisory Subcommittee. Since 1992, Dr. Spencer has been the U.S. team leader for the Multichannel Imaging Microwave Radiometer (MIMR) team and the follow-on Advanced Microwave Scanning Radiometer-Earth Observing System (EOS) (AMSR-E) team. In 1994 he became the AMSR-E science team leader. Dr. Spencer received the NASA Exceptional Scientific Achievement Medal in 1991, the Marshall Space Flight Center Director's Commendation in 1989, and the American Meteorological Society's Special Award in 1996. He served on the NRC Panel on Reconciling Temperature Observations (1999-2000).

WILLIAM STONEY is principal engineer at Mitretek Corporation. Following service with NASA in various capacities, including as director of engineering for the Apollo Program, Mr. Stoney began his career in satellite remote sensing as director of NASA's Earth Observation Program in 1972, the year that Landsat 1 was launched. His tenure at NASA included the development and launch of Landsats 2 and 3, the Thematic Mapper, NOAA's TIROS, and Goddard EOS satellites and sensors. Since leaving NASA, Mr. Stoney has worked for Radio Corporation of America and General Electric, supporting the development of the EOS program; and for MITRE, and now Mitretek, supporting the current and future Landsat systems. Recently, he has been closely involved with the Stennis Science Commercial Data Buy Program.

JAN SVEJKOVSKY is the founder and president of Ocean Imaging, Inc., where he is responsible for managing and directing all scientific and corporate developments. His company focuses on the acquisition, processing, and analysis of aerial and satellite-derived environmental data, with much of its work centering on monitoring the ocean environment, as well as coastal areas, wetlands, and lakes. Dr. Svejkovsky is principal investigator on research grants from NOAA, NASA, NSF, the U.S. Navy, the State of California, and corporations. His prime interest is in identifying potential new markets for remote sensing technology and in developing customized products and services for those markets. In recent years, he has directed the advanced development and commercialization of satellite and nonsatellite oceanographic techniques for diverse research and coastal applications, including the monitoring of sewage, storm runoff, and other pollution effluent (using optical, infrared, and SAR sensors); high-resolution surface-current detection (using infrared, SAR, and optical imagery); and multispectral algorithms for bathymetry surveys and bottom substrate mapping. Since mid-1998, Ocean Imaging has operated its own multispectral aerial sensor for coastal research and environmental monitoring and, since 1999, rapid-response agricultural remote sensing.

KURT THOME is an associate professor in the Optical Sciences Center at the University of Arizona. His current research activities focus on NASA's EOS. This work includes developing algorithms for the absolute radiometric calibration after launch of the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer, Landsat-7 Enhanced Thematic Mapper+ (ETM+), and Moderate-resolution Imaging Spectroradiometer (MODIS). He is also involved in developing atmospheric correction algorithms for the ASTER radiometer and ETM+ and is a member of the ASTER, MODIS, and Landsat-7 science teams.

JOHN R.G. TOWNSHEND holds a joint appointment as a professor in the Institute for Advanced Computing Studies and the Department of Geography at the University of Maryland. He is also a member of the Department of Geography's Laboratory for Global Remote Sensing Studies. Dr. Townshend's research centers on the use of remote sensing and advanced computing methods for improvements in the characterization of regional and global land cover. He has been a member of NASA's MODIS science team (since 1996), and he is a principal investigator on the Landsat Pathfinder Project for monitoring Earth's tropical moist forests. Dr. Townshend has also been chair of the Joint Scientific and Technical Committee of the Global Climate Observing System. His previous NRC service includes membership on the Committee on Geophysical and Environmental Data (1992-1998) and on the Board on Earth Sciences and Resources (1999). He also served as a member of the NRC Committee for Review of the Science Implementation Plan of the NASA Office of Earth Science.

Staff

ARTHUR CHARO, study director, received his Ph.D. in physics from Duke University in 1981 and was a postdoctoral fellow in chemical physics at Harvard University from 1982 to 1985. Dr. Charo then pursued his interests in national security and arms control at Harvard University's Center for Science and International Affairs, where he was a fellow from 1985 to 1988. From 1988 to 1995, he worked in the International Security and Space Program in the U.S. Congress's Office of Technology Assessment (OTA). Dr. Charo has been a senior program officer at the Space Studies Board (SSB) of the NRC since OTA's closure in 1995. His principal responsibilities at the SSB are to direct the activities of the NRC Committee on Earth Studies and the NRC Committee on Solar and Space Physics. Dr. Charo is a recipient of a MacArthur Foundation Fellowship in International Security (1985-1987) and was the American Institute of Physics's 1988-1989 American Association for the Advancement of Science Congressional Science Fellow. In addition to directing studies that have resulted in some 28 reports from the NRC, he is the author of research papers in the field of molecular spectroscopy; reports to Congress on arms control and space policy; and the monograph *Continental Air Defense: A Neglected Dimension of Strategic Defense* (University Press of America, 1990).

THERESA M. FISHER is a senior program assistant with the Space Studies Board. During her 25 years with NRC she has held positions in the executive, editorial, and contract offices of the National Academy of Engineering. She has also held positions with several NRC boards, including the Energy Engineering Board, the Aeronautics and Space Engineering Board, the Board on Atmospheric Sciences and Climate, and the Marine Board.

CATHERINE A. GRUBER is an assistant editor with the Space Studies Board. She joined SSB as a senior program assistant in 1995. Ms. Gruber came to the NRC in 1988 as a senior secretary for the Computer Science and Telecommunications Board and has also worked as an outreach assistant for the

National Academy of Sciences-Smithsonian Institution's National Science Resources Center. She was a research assistant (chemist) in the National Institute of Mental Health's Laboratory of Cell Biology for 2 years. She has a B.A. in natural science from St. Mary's College of Maryland.

C
Acronyms

ACRIM	Active Cavity Radiometer Irradiance Monitor
ETM+	Enhanced Thematic Mapper Plus
Landsat	Land Remote Sensing Satellite
MODIS	Moderate-resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	National Research Council
QuikSCAT	Quick Scatterometer
SAR	synthetic aperture radar
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SORCE	Solar Radiation and Climate Experiment
TIM	Total Irradiance Monitor
TOPEX/Poseidon	Ocean Topography Experiment Poseidon
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite
VIIRS	Visible/Infrared Imager/Radiometer Suite