Review of NOAA's Plan for the Scientific Stewardship Program

Committee on Climate Data Records from NOAA Operational Satellites, National Research Council

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

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PREFACE

To understand our climate system more completely, it is imperative that we have climate data records (CDR) that possess the accuracy, longevity and stability to facilitate credible climate monitoring. This includes CDRs from environmental satellites, which have been surveying our atmosphere, oceans and lands for the past four decades. Undersecretary of Commerce for Oceans and Atmosphere and National Oceanic and Atmospheric Administration (NOAA) Administrator Vice Admiral Conrad C. Lautenbacher, Jr., and others within NOAA are to be commended for accepting the mandate to better understand climate variability and change. Our committee was tasked with assisting NOAA as it designs a plan that should establish this agency as the chief steward of satellite CDRs. Following a series of committee teleconferences, an information gathering workshop was convened in August 2003, with several dozen scientists providing valuable input to the committee's endeavor. Numerous telecons, e-mails, and face-to-face meetings in Washington, D.C. and Boulder, Colorado followed, and the committee's first report was published in March 2004 (NRC, 2004). NOAA officials were briefed and, over the following year, took the report under advisement as they prepared the first draft of a Scientific Data Stewardship Implementation Plan. As originally tasked, the committee reconvened in March 2005, was briefed by NOAA officials, and subsequently prepared this short report in which we evaluate the efficacy of the draft plan.

Many individuals provided important information and insights as we prepared our reports. Thanks go to Mitch Goldberg, John Bates, George Ohring, and Thomas Karl for their CDR leadership within NOAA. On behalf of the entire committee, I want to express gratitude to Chris Elfring, Amanda Staudt, Sheldon Drobot, and Rob Greenway of the National Research Council's Board of Atmospheric Sciences and Climate for their unfailing support of our endeavor.

Finally, many thanks to my fellow committee members for their excellent contributions. As I stated in the preface to the 2004 report, this reflects their dedication to the science community and illustrates their belief that, by having the opportunity to help guide NOAA in the detailed development of an end-to-end CDR program, they can make a difference.

DAVID A. ROBINSON, *Chair*
Committee on Climate Data Records from
NOAA Operational Satellites

ACKNOWLEDGMENTS

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:

Mark Abbott, Oregon State University, Corvallis
Lee Branscome, Climatological Consulting Corporation, Palm Beach Gardens, Florida
Susan Ustin, University of California at Davis
Frank Wentz, Remote Sensing Systems, Santa Rosa, California
Steven J. Worley, University Corporation for Atmospheric Research, Boulder, Colorado

Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Christopher Justice of the University of Maryland, College Park. 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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INTRODUCTION

An integral component of the new mandate of the National Oceanic and Atmospheric Administration (NOAA) to "understand climate variability and change to enhance society's ability to plan and respond" involves creating a scientific data stewardship (SDS) plan to generate, analyze, and archive long-term satellite climate data records (CDRs) for assessing the state of the environment. As defined by the National Research Council (NRC, 2004), **a climate data record is a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change**. That report further defined fundamental climate data records (FCDRs), which are calibrated and quality-controlled sensor data that have been improved over time, and thematic climate data records (TCDRs), which are geophysical variables derived from the FCDRs, such as sea surface temperature and cloud fraction. More explanation of the differences between FCDRs and TCDRs along with examples of specific CDRs are provided in the committee's first report (NRC, 2004).

Not all time series of climate-related variables are designated as CDRs. Variables chosen for CDR development should address key questions about the climate system and lead to clear improvements in (1) scientific understanding of the climate system; (2) projections for future climate states; (3) regional, national and international climate assessments; and (4) the nation's ability to respond to climate variations. The CDRs should be based on the best scientific research and measurement capability available, and they should represent a consensus within the scientific community regarding what is to be monitored and measured over time. **It is critical that stewardship entails continuous overview and involvement by scientists to ensure that CDRs are properly generated and maintained.**

NOAA's new climate mandate is fundamentally different from its traditional weather forecasting mandate and raises a new set of challenges related to the stewardship of CDR data. To meet these challenges, NOAA asked the National Research Council (NRC) to convene a committee of experts to assist in designing a CDR program. The committee held several meetings, including an information gathering workshop attended by several dozen scientists. A questionnaire was also distributed to conference participants and to others via the Internet. Based on input from the scientific community and committee expertise, the NRC published *Climate Data Records from Environmental Satellites* (NRC, 2004) to provide NOAA with initial guidelines.[*] In particular, NRC (2004) identified 14 key elements for creating a CDR program (Box 1). As stated in that report, the committee believes that adherence to these elements would help NOAA to create CDRs that are based on the standards of the scientific community, while ensuring that they remain responsive to the needs of other users.

Underlying many of these elements of success is early attention to data stewardship, management, access and dissemination policies, and the actual practices implemented. Because a successful CDR program will ultimately require reprocessing, datasets and metadata should be preserved indefinitely in formats that promote easy access. The ultimate legacy of long-term CDR programs is the data left to the next generation, and the cost of data management and archiving must be considered an integral part of every CDR program.

This report is the second phase of the committee's activities, written to provide specific input to NOAA on its February 18, 2005 draft "Scientific Data Stewardship (SDS) Implementation Plan." The draft plan describes a new effort by NOAA "to create high-quality, operational long-term data sets of climate conditions—Climate Data Records—from satellite and supporting ground-based observations" (NOAA, 2005, p. 5). The new SDS program will take on the responsibility of processing, archiving, and distributing observations to users. These observations are intended for use in monitoring, diagnosing, understanding, predicting, modeling, and assessing climate variation and change.

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[*] See Appendix B of this report for the Executive Summary of NRC (2004). Copies of *Climate Data Records from Environmental Satellites* are available at *http://books.nap.edu/catalog/10944.html*.

BOX 1
Key Elements of Successful Climate Data Record Generation Programs

CDR Organizational Elements

1. A high-level leadership council within NOAA is needed to oversee the process of creating climate data records from satellite data.
2. An advisory council is needed to provide input to the process on behalf of the climate research community and other stakeholders.
3. Each fundamental CDR (FCDR) should be created by a specifically appointed team of CDR experts.
4. Science teams should be formed within broad disciplinary theme areas to prescribe algorithms for the thematic CDRs (TCDRs) and oversee their generation.

CDR Generation Elements

5. FCDRs must be generated with the highest possible accuracy and stability.
6. Sensors must be thoroughly characterized before and after launch, and their performance should be continuously monitored throughout their lifetime.
7. Sensors should be thoroughly calibrated, including nominal calibration of sensors in-orbit, vicarious calibration with in situ data, and satellite-to-satellite cross-calibration.
8. TCDRs should be selected based on well-defined criteria established by the Advisory Council.
9. A mechanism should be established whereby scientists, decision makers, and other stakeholders can propose TCDRs and provide feedback that is considered in the selection of TCDRs.
10. Validated TCDRs must have well-defined levels of uncertainty.
11. An ongoing program of correlative in situ measurements is required to validate TCDRs.

Sustaining CDR Elements

12. Resources should be made available for reprocessing the CDRs as new information and improved algorithms are available, while also maintaining the forward processing of data in near real time.
13. Provisions should be included to receive feedback from the scientific community.
14. A long-term commitment of resources should be made to the generation and archival of CDRs and associated documentation and metadata.

NOAA is to be commended for endorsing the CDR concept, embracing the importance of long-term CDR stewardship, and accepting the lead role in the generation and sustenance of critical climate records in coordination with agency, academic, and private sector partners. NOAA has taken the initiative in developing an implementation plan. Such a plan will be indispensable to the success of the forthcoming CDR program. The members of the NRC Committee on Climate Data Records from NOAA Operational Satellites are pleased to see NOAA's interest in engaging the broader satellite and climate communities in their plan. Furthermore, NOAA's positive response to panel recommendations regarding the organization, generation, management, and overarching stewardship of a CDR program is promising.

It is encouraging to see current and proposed NOAA budgetary support for an SDS program and for the Comprehensive Large Array-data Stewardship System (CLASS). Both are vital to the fulfillment of NOAA's climate mission, and neither can succeed independently. **However it is critical to maintain a distinction between the stewardship of scientific data and scientists having oversight of data stewardship. The former should be the responsibility of CLASS, while scientific vigilance should be within the province of SDS.** A close and on-going consultation is needed between those designing and building CLASS and the climate scientists who will use it.

Overall, the NRC committee finds Draft 3.1 of the SDS Implementation Plan (NOAA, 2005) to be sound and to include mechanisms for continued user involvement. The committee believes that the plan document should be revised in several ways to clarify its intent—for example, giving the discussion of implementing the program (currently found in Chapter 4 of the draft) more prominence by introducing it earlier in the draft and providing more specific details about implementation. The remainder of this report recommends ways to improve the NOAA (2005) SDS draft and enhance program implementation. As in the committee's earlier report (NRC, 2004), comments are addressed within the framework outlined in Box 1—namely, organizational, generation, and sustaining elements of a successful CDR program.

Although the committee recommends that the plan's authors revise the document, the committee believes that these revisions should not hinder implementation. Indeed, the plan embraces the committee's overarching recommendation from its first report, as well as the six supporting recommendations (see Box 2), indicating a level of consensus among the committee members and the NOAA authors about the value of these recommendations. These steps are essential to effective implementation of a climate data records programs. While the draft plan demonstrates that NOAA has a general understanding of the issues associated with developing a CDR program, serious thought is still needed in the details of implementing the plan. The committee expects that as NOAA moves forward it will have to revise the plan on a regular basis to incorporate new understanding based on experience as well as to accommodate anticipated growth in the program. **In short, NOAA should immediately begin implementing the scientific data stewardship program while revising it along the lines of the recommendations in this report.**

BOX 2
Recommendations from
***Climate Data Records from Environmental Satellites* (NRC, 2004)**

OVERARCHING RECOMMENDATION: NOAA should embrace its new mandate to understand climate variability and change by asserting national leadership for satellite-based Climate Data Record generation, applying new approaches to generate and manage satellite Climate Data Records, developing new community relationships, and ensuring long-term consistency and continuity for a satellite Climate Data Record generation program.

Supporting Recommendation 1: NOAA should utilize an organizational structure where a high-level leadership council within NOAA receives advice from an advisory council that provides input to the process on behalf of the climate research community and other stakeholders. The advisory council should be supported by instrument and science teams responsible for overseeing the generation of Climate Data Records.

Supporting Recommendation 2: NOAA should base its satellite-based Climate Data Record generation program on lessons learned from previous attempts, which point out several unique characteristics of satellite Climate Data Records, including the need for continuing calibration, validation, and algorithm refinements, all leading to periodic reprocessing and reanalysis to improve error quantification and reduce uncertainties.

Supporting Recommendation 3: NOAA should define satellite Climate Data Record stewardship policies and procedures to ensure that data records and documentation are inexpensive and easily accessible for the current generation and permanently preserved for future generations.

Supporting Recommendation 4: NOAA should develop new community relationships by engaging a broader academic community, other government agencies, and the private sector in the development and continuing stewardship of satellite Climate Data Records.

Supporting Recommendation 5: NOAA should consider existing U.S. multi-agency organizations for implementation of the Climate Data Record program, rather than devising a new structure. The most appropriate organization is the Climate Change Science Program.

Supporting Recommendation 6: NOAA should pursue appropriate financial and human resources to sustain a multidecadal program focused on satellite Climate Data Records.

SCIENTIFIC DATA STEWARDSHIP ORGANIZATIONAL ELEMENTS

In the committee's first report, organizational elements that are critical to successful CDR generation programs were identified (see Box 1). These organizational elements are standard processes and policies that lead to actions and improvements in CDR generation programs. They include mechanisms for providing scientific oversight and advice, encouraging feedback from user communities, and allowing opportunities to redirect the program based on advice and feedback. The committee recommended that a leadership council of NOAA management personnel be established to adopt responsibility for overall stewardship of the CDR program. In order to ensure participation of the broader community, this leadership council should be guided by an advisory council composed mainly of external members. The members should be from academia, the private sector, and other federal agencies, as well as some representatives from NOAA. Finally, teams of experts from the broad community, not just experts from NOAA, should be appointed to guide the creation and generation of both FCDRs and TCDRs.

The SDS Implementation Plan describes many different existing and proposed groups that would undertake these responsibilities. The following are examples of these various advisory committees, boards, and working groups:

- NOAA Data Stewardship Committee (formerly the National Environmental Satellite, Data, and Information Service [NESDIS] Data Archive Board)
- Archive Requirements Working Group under the Data Archive Board (a defunct NESDIS line office)
- NOAA Observing System Council
- NOAA Climate Board
- FCDR Teams
- TCDR Teams
- NOAA Science Advisory Board
- SDS Working Group
- Climate Working Group
- CLASS Working Group

The committee is pleased to see that NOAA takes seriously the need for input and oversight in the generation of CDRs. However, aside from the FCDR and TCDR teams (NOAA, 2005, p. 45), the functions and membership of each of these groups are not presented clearly in the plan. Also, it is not clear what the role of external communities will be in providing input and oversight to the generation of CDRs and in reviewing the accessibility and distribution of CDRs to the user community. In particular, the draft NOAA implementation plan does not provide clear mechanisms for engaging the broader academic community, private sector, or other federal agencies in the development and continuing stewardship of satellite CDRs. **The revised plan should present clear definitions of the multiple advisory groups providing oversight for CDR generation, their roles and responsibilities, their makeup, and mechanisms for selecting members.**

While the highest-level advisory groups such as the NOAA Science Advisory Board and the Climate Working Group already exist, other entities have to be created. In particular, the council to advise and oversee scientific components of implementing the FCDR and TCDR teams, as proposed in the committee's first report (NRC, 2004, p. 46), does not yet exist. The SDS Implementation Plan indicates that NOAA intends to establish such a group, called the SDS-CLASS Working Group (see Figure 4.3 in NOAA, 2005) to provide oversight of both the SDS and CLASS efforts. The committee believes that the objectives of CLASS and SDS are sufficiently distinct to require different types of expertise to advise on program implementation, thus warranting two separate advisory groups. Indeed an advisory council focused on the scientific dimension (i.e., the purview of SDS) rather than on computing requirements (i.e., the purview of CLASS) is consistent with the recommendations of the committee's first report. Of course, the separate SDS and CLASS working groups should be closely coordinated. **The committee recommends separating the working groups for SDS and CLASS, which have to be well coordinated but should function separately to advise their respective activities.**

Figure 1 of this report is a revised version of the Figure 4.3 from the SDS Implementation Plan and illustrates how the committee envisions the separate SDS and CLASS working groups fitting into the advising structure. The SDS Working Group provides external advice and input to the FCDR and TCDR teams, while these teams also exchange direct guidance and input with the NOAA managers of the SDS program, who in turn report up through NOAA management to both the climate and the observing system leadership. Through its interaction with the CLASS Working Group, the SDS Working Group provides input to CLASS operations and CDR generation. Because the SDS Working Group will have to coordinate with multiple other advisory groups, it will be necessary to develop mechanisms, such as overlapping membership, to facilitate these interactions.

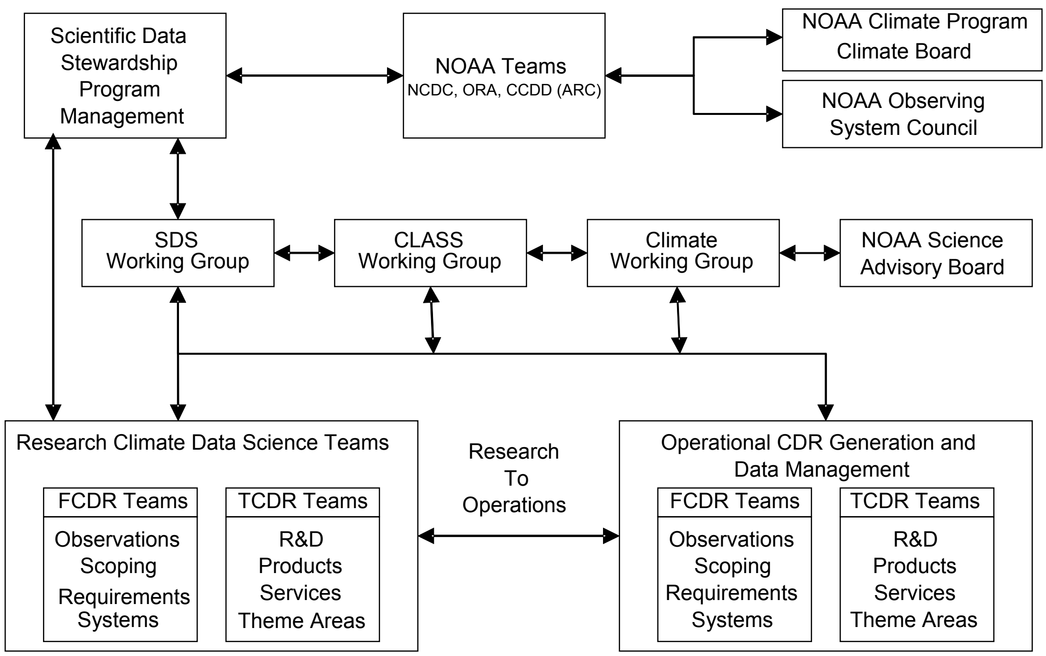

Figure 1 Revised chart showing SDS organizational elements. NOTE: NCDC = National Climatic Data Center, ORA = NOAA Satellites and Information Service Office of Research and Applications, CCDD (ARC) = NOAA's Climate Change Data and Detection program element and its Applied Research Center initiative.

CLIMATE DATA RECORD GENERATING ELEMENTS

Among the key elements of successful CDR generation programs identified in the committee's first report, seven were related specifically to CDR generation (see Box 1). These elements address the need for high accuracy and stability of FCDRs, met in part by thoroughly characterizing and calibrating sensors before launch and during their lifetime. Likewise, TCDRs should have well-defined levels of uncertainty and an ongoing program for validation. Another critical element of CDR generation is the development of well-defined criteria for selecting which TCDRs to produce, accompanied by processes and policies whereby scientists, decision makers, and other stakeholders can propose new TCDRs and provide feedback considered in the selection of TCDRs.

It is reassuring that many of these generation elements are included in the implementation plan. The descriptions of the FCDR and TCDR teams and their responsibilities are consistent with CDR generation elements 5, 6, 7, and 11. The committee strongly endorses a mix of centralized and distributed activities for CDR production identified in the draft plan (NOAA, 2005, p. 43).

Likewise, a plan for defining progressive levels of reduced uncertainty in the CDRs (Element 10) was described by the plan's authors when they briefed the committee, although it could have been explained more fully in the written document. **A plan for defining progressive levels of reduced uncertainty should be described explicitly in the written plan as well.**

Conversely, the plan lacks sufficient detail on how TCDRs are proposed and how feedback is provided for consideration in the selection of CDRs (element 9). As noted in the committee's first report (NRC, 2004, p. 56), this process should include input from scientists, decision makers, and other stakeholders. It may take place through the advisory structure discussed above or by external proposals submitted by individuals. One mechanism for soliciting wide community input would be to issue a formal Request for Information (RFI) soliciting proposed TCDRs. Final selection should be made by NOAA in consultation with its advisory structure. The SDS Working Group and NOAA program managers would then prioritize the TCDRs based on well-defined criteria (element 8). In developing these advisory mechanisms, NOAA should build upon the successes of NASA, which has longer experience in CDR generation, particularly in areas beyond NOAA's core observing strengths. **The revised implementation plan should state how FCDRs will be prioritized for their conversion to TCDRs and distribution to the science community.** Note that the prioritization of CDRs has to consider existing FCDRs and TCDRs produced by the Distributed Active Archive Centers (DAACs) and used widely by the research community, including the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder series and their Moderate Resolution Imaging Spectroradiometer (MODIS) continuations, as well as the Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave Imager (SSM/I), and Advanced Microwave Scanning Radiometer for NASA's Earth Observing System (AMSR-E) sea ice products.

Although it is addressed in sustaining CDR element 12, reprocessing is a vital part of generating and regenerating CDRs. New technology will allow much more rapid reprocessing than has occurred previously. It is important to maintain community interaction before, during, and after reprocessing by providing a rationale for and expected results of the reprocessing. Therefore, the plans to reprocess subsets prior to a full reprocessing are laudable. The reprocessing of FCDRs should be done in coordination with TCDR teams that use those FCDRs as their primary input.

While CLASS will be supporting a variety of data, the SDS will have the additional responsibility of merging data from multiple satellite platforms into NOAA CDRs. **The implementation plan needs more detail on how this process will be accomplished, including the involvement of the SDS Working Group and Science Teams.**

SUSTAINING CLIMATE DATA RECORDS PROGRAMS

To meet the stated objectives of the SDS and CLASS programs, the production and maintenance of CDRs have to be long-term activities. The committee's first report emphasized that "producing ongoing climate products (such as CDRs) is contingent on having stable funding both for obtaining data and for conducting the sustained scientific research that will necessarily underlie the production of CDRs" (NRC, 2004, p. 58). Specifically, the committee recommended that resources be made available for forward processing of data in near real time and for reprocessing the CDRs as new information and improved algorithms become available. Further, NOAA should make a long-term commitment of resources to the generation and archiving of CDRs and associated documentation and metadata in the context of national and international plans and standards.

NOAA is to be commended for its recognition of the importance of data management and preservation to a successful CDR program (NOAA, 2005, pp. 22-23). However, the implementation plan provides few details about how these goals would be achieved. In particular, responsibilities for creation of the metadata and documentation necessary to allow long-term understanding of the products, access to the data, and processes for external review need to be defined and periodically revisited.

The draft SDS Implementation Plan embraces this long-term commitment—for example in stating that the "overall goal of SDS is to create high-quality, long-term data sets of global climate conditions . . ." (NOAA, 2005, p. 17). The plan provides limited information about how NOAA plans to develop reasonable cost projections, what future resources will be available to the program, and how NOAA will prioritize among competing objectives given limited resources. Regarding cost projections, the plan briefly mentions a new cost estimation model that is under development; in briefings to the committee, NOAA representatives indicated that they did not feel that this model was sufficiently developed to present fully at this time. The President's budget request for fiscal year (FY) 2006 includes $6,541,000 for CLASS (NOAA Blue Book, 2005, available at *http://www.publicaffairs.noaa.gov/budget2006/pdf/bluebook2006.pdf*). Although it is not included in the Blue Book, comments by the plan's authors at the committee's meeting indicate that the FY 2006 request for SDS was about half of this amount.

The current proposed NOAA budget establishing a separate line item for SDS is a significant accomplishment and will enable this new organization to begin to address a number of core CDRs. The plan does not specify which CDRs or other activities among the wide range of responsibilities of the SDS program will receive priority. A prioritization strategy is especially important because the full scope of FCDRs and TCDRs described in the plan clearly cannot be sustained within the current budget level. Based on experience with similar efforts in the Pathfinder programs and other NASA programs, such as the Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS) project, the committee concludes that the current budget cannot fulfill the expectations for a NOAA leadership role in generating CDRs. A prioritization strategy can also help NOAA make decisions about how to balance funding for internal versus external research, operations versus research, and climate versus shorter-term forecasting needs. **A process for the specific prioritization of and methodologies for CDR generation, access, and preservation was described in the recommendations of the committee's first report (NRC, 2004) and should be applied to ensure that the limited resources are employed most effectively.**

If NOAA is to exert national leadership for satellite-based CDRs, it will have to address the growth of CDR programs resulting from the increased number of national and international satellites, an expanded suite of sensors, and more complex climate data products. SDS should plan for considerable growth beyond FY 2007 as NPOESS is launched and the United States takes on a larger role in the Global Earth Observation System of Systems (GEOSS) effort, as described in the *Strategic Plan for the U.S. Integrated Earth Observations System* (IWGEO, 2005). The SDS plan recognizes these needs and the need for integration of NOAA's observing systems, data, and quality control with other nations' efforts, especially through GEOSS. **The SDS program should develop more**

detailed estimates of future resource needs and seek the funding necessary to meet its stated objectives. The committee expects that this growth in resources to support the SDS program will be needed primarily in its initial phase because future economies of scale, improvements in the quality and stability of climate sensors, and further experience at sustaining perpetual climate observing systems will allow for a leveling off of support in the future. Once this leveling off takes place, intermittent spikes in funding may be necessary to accommodate major new initiatives or responsibilities.

CONCLUDING REMARKS

Draft 3.1 of the SDS Implementation Plan is sound and comprehensive; NOAA should immediately begin implementing the program while revising it along the lines of the recommendations in this report. The committee has identified several ways in which to improve the program plan, most importantly by clarifying advisory mechanisms, providing more detail about how NOAA will coordinate with important partners in generating CDRs, articulating how the program will prioritize its activities, and developing ways to realistically project future costs.

Clarifying Advisory Mechanisms:

- The revised plan should provide clear definitions of the advisory committees, their roles and responsibilities, and their makeup and selection.
- The committee recommends separating the proposed working groups for SDS and CLASS, which have to be well coordinated but should function separately to advise their respective activities.
- The FCDR and TCDR teams should be composed of NOAA and other scientists and engineers. Support for participation in this activity should be provided by NOAA and other agencies.

Coordinating with Important Partners:

- The committee suggests that NOAA organize its SDS partners (i.e., government agencies, universities, private industry, and international entities) into a matrix arrangement that illustrates the strengths of each organization relative to CDR generation and maintenance, and initiate collaborations and discussions at the earliest opportunities.

Improving Prioritization:

- The revised implementation plan should state how FCDRs will be prioritized for their conversion to TCDRs and distribution to the science community.
- The plan does not specify which CDRs or other activities among the wide range of responsibilities of the SDS program will receive priority. A process for the specific prioritization of and methodologies for CDR generation was described in the recommendations of the committee's first report (NRC, 2004) and should be applied to ensure that the limited resources are employed most effectively.

Developing Realistic Budget Projections:

- The SDS program should develop more detailed estimates of future resource needs and seek the funding necessary to meet its stated objectives. Detailed budget planning is important because the full scope of FCDRs and TCDRs described in the plan clearly cannot be sustained within the current budget level, especially if NOAA is to exert national leadership for satellite-based CDRs and to take on a larger role in international Earth observing efforts.

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APPENDIXES

A

COMMITTEE ON CLIMATE DATA RECORDS FROM NOAA OPERATIONAL SATELLITES

STATEMENT OF TASK

The ad hoc committee charged to conduct this study will assist the National Oceanic and Atmospheric Administration-National Environmental Satellite, Data, and Information Service (NOAA-NESDIS) as it designs a plan to create climate data records (CDRs) from existing and new instruments aboard NOAA satellites for understanding, monitoring, and predicting climate variations and changes. The committee will provide input to the plan by summarizing major needs for and uses of climate data records, examining different approaches and strategies for generating climate data records, and identifying key attributes of CDRs that have proven useful. NOAA would then use this information as guidance to develop its plan for producing CDRs from operational satellites. Once the plan is drafted, the committee will review the draft Climate Data Records Plan to ensure that it is sound, comprehensive, and includes mechanisms for continued user involvement, and it will recommend improvements to ensure that CDRs are processed according to established scientific methods and packaged in forms that are useful for real-time assessments and predictions of climate as well as retrospective analyses, re-analyses, and reprocessing efforts.

In phase I, the committee will organize and host a workshop to facilitate discussion of a NOAA white paper that will outline its preliminary ideas on satellite data utilization for climate applications, and it will write an interim report that

- Summarizes major needs for and uses of climate data records,
- Examines different approaches and strategies for generating CDRs, and
- Identifies key attributes of examples of successful attempts to create high quality CDRs from satellite data.

Questions to be addressed in the workshop and by the committee include:

- How does a CDR become a community standard (i.e., established as legitimate)?
- How can NOAA ensure that the CDRs are responsive to user needs?
- What are the key attributes of successful CDR generation programs?
- What are the advantages and disadvantages of different models or strategies for producing CDRs, such as using partnerships among government, academia, and the private sector; different blends of space-based and in situ data (e.g., all space-based versus some balance); or other approaches?
- How can NOAA learn from present and past efforts such as the NOAA-NASA Pathfinders, EOSDIS, etc.? What are the successes and failures, and how do we emulate the successes or avoid the pitfalls?

Phase 2 will begin when NOAA provides the committee with a draft of its Climate Data Records Plan (estimated to be approximately 3 months after delivery of the interim report).

B

EXECUTIVE SUMMARY OF *CLIMATE DATA RECORDS FROM ENVIRONMENTAL SATELLITES*[*]

At the dawn of the twenty-first century, NOAA's mission includes a bold new mandate to "understand climate variability and change to enhance society's ability to plan and respond." An integral component of NOAA's emphasis on climate involves creating a stewardship plan to generate, analyze, and archive long-term satellite climate data records (CDRs) for assessing the state of the environment. Although the concept of a "climate data record" has surfaced numerous times in recent literature (e.g. NRC, 2000c,e), the climate community has yet to settle on a consistent definition. In this report the committee defines a climate data record as **a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.** We further segment satellite-based CDRs into fundamental CDRs (FCDRs), which are calibrated and quality-controlled sensor data that have been improved over time, and thematic CDRs (TCDRs), which are geophysical variables derived from the FCDRs, such as sea surface temperature and cloud fraction.

To generate the best possible plan for creating satellite CDRs, NOAA asked the National Academies to conduct a two-phase study to provide advice on creating CDRs. In phase 1, the committee is providing an interim report with advice on the key elements of a satellite-based CDR program, including lessons learned from previous attempts, important considerations for identifying an appropriate organizational framework for long-term success and sustainability, suggested steps for generating and archiving CDRs, and the importance of partnerships. The objective of the interim report is to provide NOAA with general guidance about what needs to be included in its plan. More specific comments will be provided once NOAA writes the plan, expected to be completed in late summer of 2004.

NOAA's new climate mandate is fundamentally different from its traditional weather forecasting mandate and raises a new set of challenges owing to the varied uses of climate data, the complexities of data generation, and the difficulties in sustaining the program indefinitely. The task and structures being proposed for NOAA in this report are considerably more complex, costly, and demanding than those currently in place. A high level of commitment and a number of changes at multiple levels within the agency will be needed to institute and fund the various components of CDR stewardship. NOAA will not, however, be the first entity to generate climate-quality data and NOAA can learn many lessons from previous efforts; looking back on historical programs, some commonalities for success include science advisory panels, regular calibration and validation of data, adequate resources for reprocessing, user workshops to solicit advice on the future of the program, clear data storage and dissemination policies, and a willingness to form partnerships. Based on these historical lessons, community surveys, a workshop, and committee expertise, the committee identified 14 key elements for creating a climate data record program based mainly on satellites (Box ES-1). Adherence to these elements would help NOAA to create CDRs that are accepted as community standards, while ensuring that they remain responsive to user needs.

Underlying many of these elements of success is early attention to data stewardship, management, access and dissemination policies, and the actual practices implemented. Because a successful CDR program will ultimately require reprocessing, datasets and information used in their creation, such as metadata, should be preserved indefinitely in formats that promote easy access. The ultimate legacy of long-term CDR programs is the data left to the next generation, and the cost of data management and archiving must be considered as an integral part of every CDR program.

[*] NRC (2004).

BOX ES-1
Key Elements of Successful Climate Data Records Generation Programs

CDR Organizational Elements

1. A high-level leadership council within NOAA is needed to oversee the process of creating climate data records from satellite data.
2. An advisory council is needed to provide input to the process on behalf of the climate research community and other stakeholders.
3. Each fundamental CDR (FCDR) should be created by a specifically appointed team of CDR experts.
4. Science teams should be formed within broad disciplinary theme areas to prescribe algorithms for the thematic CDRs (TCDRs) and oversee their generation.

CDR Generation Elements

5. FCDRs must be generated with the highest possible accuracy and stability.
6. Sensors must be thoroughly characterized before and after launch, and their performance should be continuously monitored throughout their lifetime.
7. Sensors should be thoroughly calibrated, including nominal calibration of sensors in-orbit, vicarious calibration with in situ data, and satellite-to-satellite cross-calibration.
8. TCDRs should be selected based on well-defined criteria established by the Advisory Council.
9. A mechanism should be established whereby scientists, decision makers, and other stakeholders can propose TCDRs and provide feedback that is considered in the selection of TCDRs.
10. Validated TCDRs must have well-defined levels of uncertainty.
11. An ongoing program of correlative in situ measurements is required to validate TCDRs.

Sustaining CDR Elements

12. Resources should be made available for reprocessing the CDRs as new information and improved algorithms are available, while also maintaining the forward processing of data in near real time.
13. Provisions should be included to receive feedback from the scientific community.
14. A long-term commitment of resources should be made to the generation and archival of CDRs and associated documentation and metadata.

The new emphasis and importance of climate within NOAA's mission requires an increased focus on partnerships and new approaches as it relates to supporting extramural research. Many agencies and groups are interested and involved in creating, analyzing, and storing CDRs. By partnering with other government agencies, academia, and the private sector in development, analysis, and reprocessing of CDRs, NOAA can create and sustain a successful CDR effort; a high degree of interagency coordination on the requirements, definition, and implementation of CDRs is essential for satisfying the broad user communities of today and providing climate data stewardship for future generations.

OVERARCHING RECOMMENDATION: NOAA should embrace its new mandate to understand climate variability and change by asserting national leadership for satellite-based Climate Data Record generation, applying new approaches to generate and manage satellite Climate Data Records, developing new community relationships, and ensuring long-term consistency and continuity for a satellite Climate Data Record generation program.

NOAA is recognized as a national leader in weather information, including the management of a weather satellite program and creation of weather products. However, success in establishing and sustaining a CDR program requires a long-term commitment and a level of effort that goes beyond NOAA's weather program. A particularly key component of NOAA's success will be defining steps for creating FCDRs and TCDRs. NOAA's plan also needs to account for all of the data and metadata that must be stored in easily accessible, self-describing formats. Fortunately, NOAA should not feel obligated to generate all of the nation's CDRs, and by enhancing and expanding community involvement in the CDR program, NOAA can help to ensure community acceptance and creation of high-quality CDRs.

Supporting Recommendation 1: NOAA should utilize an organizational structure where a high-level leadership council within NOAA receives advice from an advisory council that provides input to the process on behalf of the climate research community and other stakeholders. The advisory council should be supported by instrument and science teams responsible for overseeing the generation of Climate Data Records.

An important step in maintaining a successful program is developing or utilizing an appropriate organizational framework that incorporates feedback and advice from user communities. The committee believes that NOAA will help to ensure success if it includes scientists interested in CDRs, assigns committed people to generate the CDRs, develops technical and science support for users, and creates science teams that are renewed regularly. In particular, NOAA should utilize an advisory council of internationally recognized climate experts to:

1. Recommend and prioritize the variables that are developed into TCDRs;
2. Oversee the calibration of FCDRs and validation of TCDRs;
3. Evaluate proposed new TCDRs as measurement capabilities improve or scientific insights change over time;
4. Review the utility and acceptance of TCDRs and recommend the elimination of those that are not successful; and
5. Review and oversee NOAA's stewardship of the CDR program.

The actual creation of FCDRs should be carried out by a team of engineers and scientists, who should monitor satellite characteristics and document their work extensively so that future generations can assess and understand their work. Additionally, TCDR science teams with broad interdisciplinary representation should define algorithms for TCDR development and oversee TCDR generation. These teams should include research scientists funded by or employed by NOAA and scientists from other agencies, academia, or private industry who use the data, and they should be competitively selected, with limited (but renewable) terms.

Supporting Recommendation 2: NOAA should base its satellite-based Climate Data Record generation program on lessons learned from previous attempts, which point out several unique characteristics of satellite Climate Data Records, including the need for continuing calibration, validation, and algorithm refinements, all leading to periodic reprocessing and reanalysis to improve error quantification and reduce uncertainties.

Because most of NOAA's operational satellites were created as weather rather than climate platforms, the committee stresses that NOAA should include nominal calibration, vicarious calibration monitoring, and satellite-to-satellite cross-calibration as part of the operational satellite system; this is important because orbital drift, sensor degradation, and instrument biases will affect the creation of consistent CDRs. Nominal calibration involves determining the calibration of a single sensor on a single platform, and while this is standard prelaunch practice, it is important to calibrate the sensor in orbit as well. Vicarious calibration monitoring involves measuring a known target or comparing the satellite signal with simultaneous in situ, balloon, radiosonde, or aircraft measurements; all instruments should undergo vicarious calibration monitoring at regular intervals, regardless of on-board nominal calibration, to prevent drifting of the data over time due to orbital drift and drift in the observation time, which aliases the diurnal cycle onto the record. Satellite-to-satellite cross-calibration involves adjusting several same-generation instruments to a common baseline, and this is particularly important for long-term studies, as each sensor will have slightly different baselines even if they are built to the same specifications.

An ongoing program of validation also should be carried out to determine the uncertainty associated with TCDRs. This is based on establishing rigorously derived uncertainties for the TCDR using independent correlative measurements conducted throughout the data record and over global scales, which in turn determines whether a trend can be detected. NOAA should establish a two-track generation program, including an upgradeable baseline CDR track and a second (mostly extramural) funded research program to validate, analyze, assess, and reduce uncertainties in future base versions. The two-track approach encourages a culture where scientists and users know that future improvements will be available over time.

Supporting Recommendation 3: NOAA should define satellite Climate Data Record stewardship policies and procedures to ensure that data records and documentation are inexpensive and easily accessible for the current generation and permanently preserved for future generations.

History reveals that programs are more successful when the data management system provides free and open access to data, facilitates the reprocessing of CDRs, allows for new satellite TCDRs to be created, and has an easy problem-reporting procedure. A clear data policy can ensure continuity in the data record, including the ancillary data used to reprocess CDRs, project and dataset documentation, and the science production software. NOAA also should ensure that the data management infrastructure can accommodate user requests and provide different data formats, given the large satellite data volumes that a CDR program will create. This system should include the capability for temporal searches and subsetting. NOAA also can ensure a more robust program if the data are available in self-describing formats appropriate for a variety of uses, including geospatial and socio-economic applications. NOAA should establish a process for scientifically assessing the long-term potential of data and data products. Scientific assessments of the data can help NOAA to organize its archive so that data dissemination is efficient and cost-effective.

Supporting Recommendation 4: NOAA should develop new community relationships by engaging a broader academic community, other government agencies, and the private sector in the development and continuing stewardship of satellite Climate Data Records.

One of the best methods NOAA can institute for gathering community input is to convene regular open science meetings where users share their research and discuss limitations and recommendations for improving the CDRs. It is important to hold these meetings regularly because research will improve data quality over time and the meetings will help to foster community support. These meetings could be held in conjunction with conferences held by such organizations as the American Meteorological Society or the American Geophysical Union, with benefits being cost savings and broader attendance. NOAA should actively encourage other agencies and user communities to assist in development, analysis, and reprocessing of CDRs because expertise for CDRs lies within many sectors. NOAA can create a more successful CDR program by developing these partnerships.

Supporting Recommendation 5: NOAA should consider existing U.S. multi-agency organizations for implementation of the Climate Data Record program, rather than devising a new structure. The most appropriate organization is the Climate Change Science Program.

Stewardship of CDRs is complex, costly, and demanding, and NOAA should aggressively seek partnerships to help to ensure a successful program. The committee does not believe that NOAA needs to invent and implement a new management structure for generating, analyzing, and archiving CDRs; for instance, the goals and management structure of the Climate Change Science

Program (CCSP) are similar to NOAA's climate goals, and NOAA may therefore be able to implement part of the CDR program under the CCSP. If NOAA were to volunteer to be the lead or executive agency (or delegate leadership to a partner) responsible for satellite CDRs under the CCSP umbrella, NOAA could advance its climate mandate and assert national leadership. Because the CCSP structure already has built-in interagency interactions, NOAA could also leverage them for the CDR program.

Supporting Recommendation 6: NOAA should pursue appropriate financial and human resources to sustain a multidecadal program focused on satellite Climate Data Records.

Developing a CDR program is fundamentally important to the nation, and it is imperative that the effort not be inhibited by a lack of human or financial resources. Even if NOAA leverages funds and personnel from other agencies, academia, and private industry, and even if it integrates the CDR program into CCSP, it will still have to be aggressive in seeking additional funds. This program will require a long-term vision and commitment, and it will be important to account for inflationary increases when outlining the human and infrastructure needs for successfully generating, analyzing, reprocessing, storing, and disseminating CDRs.

C

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS AND STAFF

David Robinson (*Chair*) is a professor in the Department of Geography at Rutgers University. He received his Ph.D. from Columbia University. Dr. Robinson has expertise in the collection and archiving of accurate climatic data, and he is interested in climate change (particularly state and regional climate issues), hemispheric snow cover dynamics, interactions of snow cover with other climate elements, and the dynamics of solar and terrestrial radiative fluxes at and close to the surface of the Earth. He is the author or coauthor of approximately 140 articles, more than half in peer-reviewed journals. Dr. Robinson is the state climatologist for New Jersey and recently served as president of the American Association of State Climatologists. Current committee assignments include NOAA's Integrated Surface Observing Systems, NOAA's Climate Change Data and Detection Research Element, and the American Meteorological Society's Applied Climatology.

Roberta Balstad is a senior research scientist at Columbia University and director of the university's Center for International Earth Science Information Network (CIESIN). Dr. Balstad has published extensively on science policy, information technology and scientific research, remote-sensing applications and policy, and the role of the social sciences in understanding global environmental change. She received her Ph.D. from the University of Minnesota and has been a senior fellow at Oxford University and a guest scholar at the Woodrow Wilson International Center for Scholars. Dr. Balstad has also been the director of the Division of Social and Economic Sciences at the National Science Foundation, the founder and first executive director of the Consortium of Social Science Associations, and president and Chief Executive Officer of CIESIN before it joined Columbia University. She has lectured widely both in the United States and abroad. She has been the vice president of the International Social Science Council and has served as chair of the NRC Steering Committee on Space Applications and Commercialization, the North Atlantic Treaty Organization (NATO) Advisory Panel on Advanced Scientific Workshops/Advanced Research Institutes, the American Association for the Advancement of Science's Committee on Science, Engineering, and Public Policy; and the Advisory Committee of the Luxembourg Income Study.

Roger Barry is a distinguished professor of geography and the director of the National Snow and Ice Data Center, World Data Center for Glaciology, Boulder, and he is rostered in the Cooperative Institute for Research in Environmental Sciences at the University of Colorado. He received his Ph.D. from the University of Southampton (U.K.). His research interests are in Arctic climate, cryosphere-climate interactions, mountain climate, and climatic change. He has published more than 200 scientific papers and several textbooks on weather and climate and is coauthor of a forthcoming book on *The Arctic Climate System*. Dr. Barry is a fellow of the American Geophysical Union and a foreign member of the Russian Academy of Natural Sciences. He serves as co-vice-chair of the Scientific Steering Group for the World Climate Research Programme's project on Climate and Cryosphere and is a member of the Terrestrial Observations Panel for Climate. He also serves on the editorial boards of *Advances in Atmospheric Science, Physical Geography,* and *Polar Geography*. Dr. Barry is fluent in French, German, and Russian, and he has been a Fulbright teaching scholar at Moscow State University in Russia. He has also held visiting appointments at the Laboratoire de Glaciologie et Geophysique de l'Environment, Genoble; the Swiss Federal Institute of Technology (ETH), Zurich; the Alfred Wegener Institute for Marine and Polar Research; the Climatic Research Unit at University of East Anglia, U.K.; the Institute of Astronomy and Geophysics at the University of Louvain-la-Neuve, Belgium; the Department of Geography at the University of Canterbury, New Zealand; and the Department of Biogeography and Geomorphology at the Australian National University, Canberra.

Janet Campbell and her research team are developing techniques for studying biological and biogeochemical processes in the ocean using satellite remote sensors. Their primary sources of data are ocean color satellite sensors such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiometer (MODIS). They are modeling the effects of phytoplankton, dissolved organic materials, suspended sediments, and other particles on the spectral radiance measured by these satellites and are exploring inversion techniques for using the satellite ocean color data to map these substances. Techniques are being developed for estimating primary productivity in coastal waters and for blending regional models for coastal applications. Dr. Campbell is a member of NASA's SeaWiFS and MODIS science teams. As a member of the MODIS team she is responsible for developing algorithms and strategies for monitoring chlorophyll and primary productivity in coastal ocean, estuarine, and inland waters. Dr. Campbell has been an associate research professor at the University of New Hampshire (UNH) since 1993 and is a member of the Graduate Faculty. Between 1997 and 1999, she served as the NASA program manager for ocean biology and biogeochemistry. Before coming to UNH she was a research scientist at the Bigelow Laboratory for Ocean Sciences in Boothbay Harbor, Maine (1982-1993), where she established and directed the remote-sensing computer facility. She previously worked as an aerospace technologist and engineer at the NASA Langley Research Center in Hampton, Virginia. She holds a Ph.D. in statistics from Virginia Polytechnic Institute.

Ruth DeFries is an associate professor at the University of Maryland, College Park, with joint appointments in the Department of Geography and the Earth System Science Interdisciplinary Center. She investigates the relationships between human activities, the land surface, and the biophysical and biogeochemical processes that regulate Earth's habitability. She is interested in observing land cover and land use change at regional and global scales with remotely sensed data and exploring the implications for such ecological services as climate regulation, the carbon cycle, and biodiversity. Dr. DeFries obtained a Ph.D. in 1980 from the Department of Geography and Environmental Engineering at Johns Hopkins University and a bachelor's degree in 1976 from Washington University with a major in Earth science. Dr. DeFries has worked at the National Research Council with the Committee on Global Change and has taught at the Indian Institute of Technology in Bombay. She is a fellow of the Aldo Leopold Leadership Program.

William J. Emery is a professor at the Colorado Center for Astrodynamics Research in the Department of Aerospace Engineering at the University of Colorado. He received his Ph.D. from the University of Hawaii. His research interests are in satellite remote sensing of the ocean and land surface vegetation. Ocean applications include skin sea surface temperature, the computation of surface currents from satellite images, mapping of geostrophic currents from satellite altimetry, and general air-sea interaction studies. The goal of Dr. Emery's research is to make satellite data a source of quantitative information that can be incorporated into numerical models of the phenomena controlling these systems. Dr. Emery has served on many panels looking into the creation of long-term climate records from satellite data.

Milton Halem holds an emeritus position as distinguished information scientist with the Earth Science Directorate at the NASA Goddard Space Flight Center (GSFC). Dr. Halem formerly served as assistant director for information sciences and as chief information officer for the GSFC. Dr. Halem has also served as chief of the Earth and Space Data Computing Division, where he was responsible for the development and management of the NASA Center for Computational Sciences, one of the world's most powerful complexes for scientific data-intensive supercomputing and massive data storage. He acquired his Ph.D. in mathematics from the Courant Institute of Mathematical Sciences at New York University in 1968. He joined NASA in 1971 as the Global Atmospheric Research Program project scientist and later headed up the Goddard Global Modeling and Simulation Branch. His personal achievements include more than 100 scientific publications in the areas of atmospheric and oceanographic sciences and computational and information sciences.

He is most noted for his groundbreaking research in simulation studies of space-observing systems and for the development of four-dimensional data assimilation for weather and climate prediction. He has earned numerous awards, including the NASA Medal for Exceptional Scientific Achievement (twice), the NASA Medal for Outstanding Leadership (NASA's highest award), the NASA Distinguished Service Medal, and an honorary doctorate from Dalhousie University (Canada).

James Hurrell is a senior scientist and director of the Climate and Global Dynamics Division (CGD) of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. His research has centered on empirical and modeling studies and diagnostic analyses to better understand climate, climate variability, and climate change. He has authored or coauthored more than 60 peer-reviewed journal articles and book chapters, as well as dozens of other planning documents and workshop papers. He has convened more than one dozen national and international workshops and has served several national and international science-planning efforts. Currently, he is extensively involved in the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR), and he serves as co-chair of Scientific Steering Committee of U.S. CLIVAR. He has also been involved in the assessment activities of the Intergovernmental Panel on Climate Change (IPCC). Dr. Hurrell received his Ph.D. in atmospheric science from Purdue University. He has received the Clarence Leroy Meisinger Award from the American Meteorological Society and Distinguished Alumnus Awards from both Purdue University and the University of Indianapolis. He was recognized as a Highly Cited Researcher by Thomson-ISI in 2004.

Arlene Laing is a scientist at the National Center for Atmospheric Research's Mesoscale and Microscale Meteorology Division. She received a Ph.D. in meteorology from Pennsylvania State University. Her research examines various aspects of convective precipitation including life cycles of precipitation, hurricane rainfall, flash flood forecasting and mitigation; mesoscale modeling of volcanic ash dispersal; and wildfire forecasting. Much of her research utilizes data from satellite sensors (infrared, passive microwave, and the Tropical Rainfall Measuring Mission [TRMM] precipitation radar). She is also a scientist with the Cooperative program for Operational Meteorology, Education, and Training (COMET). She was a postdoctoral fellow at the Cooperative Institute for Research in the Atmosphere (CIRA), a visiting scientist at NASA Goddard Space Flight Center, and an assistant professor at the University of South Florida. Dr. Laing received the Max Eaton Award from the American Meteorological Society and currently serves on its Committee on Satellite Meteorology and Oceanography.

Ranga Myneni is a professor with the climate and vegetation group in the Geography Department at Boston University. He received his Ph.D. in biology from the University of Antwerp in Belgium. Dr. Myneni's research examines vegetation cover over Earth as observed from satellites, and he recently has worked extensively with Advanced Very High Resolution Radiometer and Moderate Resolution Imaging Spectroradiometer data.

Richard Somerville's major research interest is global climate change. He is a specialist in computer modeling of the climate system. He obtained a Ph.D. in meteorology from New York University and has been a professor at Scripps Institution of Oceanography, University of California, San Diego since 1979. In recognition of his accomplishments in scientific research, Dr. Somerville has been elected a fellow of both the American Association for the Advancement of Science and the American Meteorological Society. He is also listed in *Who's Who in America*. The results of his research have been published in more than 100 technical papers. In addition, he has written a nontechnical book explaining topics such as the ozone hole and the greenhouse effect, titled *The Forgiving Air: Understanding Environmental Climate Change*. Among his many honors was his designation as the Walter Orr Roberts Lecturer in Interdisciplinary Sciences for 1999 by the American Meteorological Society, "in recognition of significant contributions to the understanding of atmospheric processes derived from multidisciplinary research activities."

Paul D. Try is the senior vice-president and program manager at Science and Technology Corporation (STC) and the past director of the International Global Energy and Water Cycle Experiment (GEWEX) Project Office. He received his Ph.D. in atmospheric sciences from the University of Washington. Dr. Try has expertise in meteorological in situ and remote sensors (satellite and radar), as well as data collection, processing, exchange, and archival. Before joining STC he served in the U.S. Air Force, where he provided oversight management of all Defense Department research and development in environmental sciences. Dr. Try is a fellow of the American Meteorological Society and was its president in 1996-97.

Thomas Vonder Haar is a distinguished professor in the Department of Atmospheric Science at Colorado State University (CSU). He received a Ph.D. in meteorology from the University of Wisconsin. Dr. Vonder Haar's research interests lie in the areas of global energy budget, remote sensing from satellites, local area forecasting, and geosciences. His work has included some of the first results of the direct solar irradiance measurements from satellites and the exchange of energy between Earth and space. Studies on the interaction of clouds and radiation and the general circulation have formed a basis for national and international plans leading to the Global Energy and Water Experiment and programs related to global change. Dr. Vonder Haar developed and directs CSU's Satellite Earth station to support research on storms at all scales. He recently coauthored the new textbook *Satellite Meteorology, an Introduction*, and he is the director of the Cooperative Institute for Research in the Atmosphere. He also is chairman of the World Climate Programme Working Group on Radiation Fluxes, a member of several NASA science teams, and a member of the GEWEX Science Steering Group. He has received the American Meteorological Society Second Half Century (Charney) Award, the Abell Faculty Research and Graduate Program Support Award, the Engineering Dean's Council Award, and the CSU Distinguished Professor designation. He sits on the Council and Executive Committee of the American Metrological Society and the Board of Trustees of the University Corporation for Atmospheric Research (UCAR). He was recently elected to membership in the National Academy of Engineering.

NRC STAFF

Sheldon Drobot is a research associate at the Colorado Center for Astrodynamics Research in the Department of Aerospace Engineering at the University of Colorado. He was a program officer at the Polar Research Board and the Board on Atmospheric Sciences and Climate from December 2002 through November 2004, and during this time, Dr. Drobot acted as the study director for the initial report entitled *Climate Data Records from Environmental Satellites*. He received his Ph.D. in geosciences (climatology specialty) from the University of Nebraska, Lincoln. Dr. Drobot has directed several NRC studies on polar and atmospheric research, including two related to the International Polar Year 2007-2008. His research interests include sea ice-atmosphere interactions, remote sensing, unmanned autonomous vehicles, statistics, and long-range climate outlooks. Dr. Drobot currently is researching interannual variability and trends in Arctic sea ice conditions and how low-frequency atmospheric circulation affects sea ice distribution; short-range forecasting of Great Lakes ice conditions; and long-range forecasting of summer ice conditions and U.S. Great Plains crop yields.

Amanda Staudt is a senior program officer with the Board on Atmospheric Sciences and Climate of the National Academies. She received an A.B. in environmental engineering and sciences and a Ph.D. in atmospheric sciences from Harvard University. Her doctorate research involved developing a global three-dimensional chemical transport model to investigate how long-range transport of continental pollutants affects the chemical composition of the remote tropical Pacific troposphere. Since joining the National Academies in 2001, Dr. Staudt has staffed the National Academies review of the U.S. Climate Change Science Program Strategic Plan and the long-standing Climate Research

Committee. Dr. Staudt has also worked on studies addressing air quality management in the United States, research priorities for airborne particulate matter, the NARSTO Assessment of the Atmospheric Science on Particulate Matter, weather research for surface transportation, and weather forecasting for aviation traffic flow management.

Rob Greenway has been a project assistant at the National Academies since 1998. He received his M.Ed. in English education and his A.B. in English from the University of Georgia.