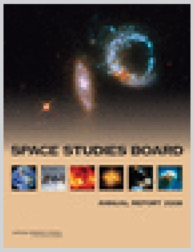


# Space Studies Board Annual Report 2008

National Research Council

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2009

# *Space Studies Board*

# *Annual Report*

# 2008

NATIONAL RESEARCH COUNCIL
*OF THE NATIONAL ACADEMIES*

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Washington, D.C.
**www.nap.edu**

The Space Studies Board is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical questions of national importance. The National Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear through its volunteer advisory committees.

Support for the work of the Space Studies Board and its committees was provided by the National Aeronautics and Space Administration contract NNH06CE15B, National Oceanic and Atmospheric Administration Contract DG133R07SE1940, and National Reconnaissance Office Contract NRO000-04-C-0174.

# *From the Chair*

The year 2008 was an historic one for both our country and the Space Studies Board (SSB). The United States elected a new president. His first task has been to cope with an economic crisis of historic proportions. In the same year, the United States celebrated the 50th anniversary of its first spaceflight, and the SSB celebrated its 50th anniversary. As we in the space community looked back, we also looked forward. The year 2008 was truly a year of transition, for the country and for the space enterprise.

Under Lennard Fisk's continued leadership, the SSB completed its year-long seminar series, Forging the Future of Space Science, which highlighted the accomplishments of space science over the past 50 years and looked ahead to the next 50 years of discoveries that await us. During the first half of the year, events were held in Tallahasse, Florida; Austin, Texas; Paris, France (in conjunction with the Committee on Space Research, which is headquartered here); Boulder, Colorado; and Fairmont, West Virginia. The series culminated in a celebration at the National Air and Space Museum in Washington, D.C., on June 26—50 years to the day after the SSB was created. At that event, the Board presented its first James A. Van Allen Lectureship to Frank McDonald. The Board is grateful to the sponsors of the seminar series—the National Academies, the National Aeronautics and Space Administration, the Aerospace Corporation, ATK, Ball Aerospace, Boeing, Lockheed Martin, Northrop Grumman, and Orbital—and to the Richard Lounsbery Foundation for sponsoring the SSB James A. Van Allen Lectureship.

I became SSB chair on July 1, 2008, at the conclusion of the SSB's seminar series and before the economic crisis burst upon the world. The crisis made it obvious—if it was not before—that the U.S. economy does not stand alone. The global economy is becoming more and more integrated. The space enterprise cannot avoid this trend. In November, the SSB conducted a workshop in conjunction with the Aeronautics and Space Engineering Board entitled "Future International Space Cooperation and Competition in a Globalizing World." Its goals were to assess the current state of international cooperation and competition in space and to discuss ways in which new and emerging space powers might be better integrated into the global space community.

We in the space community look forward to an uncertain future, confident in our accomplishments, dedicated to our fundamentals, and ready to shape the opportunities that periods of uncertainty inevitably bring. The SSB is ready to do its part.

Charles F. Kennel
*Chair*
Space Studies Board

# *Space Studies Board Chairs and Vice Chairs*

**CHAIRS**

Lloyd V. Berkner (deceased), Graduate Research Center, Dallas, Texas, 1958–1962

Harry H. Hess (deceased), Princeton University, 1962–1969

Charles H. Townes, University of California at Berkeley, 1970–1973

Richard M. Goody, Harvard University, 1974–1976

A.G.W. Cameron (deceased), Harvard College Observatory, 1977–1981

Thomas M. Donahue (deceased), University of Michigan, 1982–1988

Louis J. Lanzerotti, American Telephone & Telegraph Co., Bell Laboratories, 1989–1994

Claude R. Canizares, Massachusetts Institute of Technology, 1994–2000

John H. McElroy (deceased), University of Texas at Arlington, 2000–2003

Lennard A. Fisk, University of Michigan, 2003–2008

Charles F. Kennel, Scripps Institution of Oceanography at the University of California, San Diego, 2008–

**VICE CHAIRS**

George A. Paulikas, The Aerospace Corporation (retired), 2003–2006

A. Thomas Young, Lockheed Martin Corporation (retired), 2006–

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# 1
# *Charter and Organization of the Board*

## THE ORIGINS OF THE SPACE SCIENCE BOARD

The National Academy of Sciences (NAS) was created in 1863 by an Act of Congress, signed by President Abraham Lincoln, to provide scientific and technical advice to the government of the United States. Over the years, the breadth of the institution has expanded, leading to the establishment of the National Academy of Engineering (NAE) in 1964 and the Institute of Medicine (IOM) in 1970. The National Research Council (NRC), the operational arm of the National Academies, was founded in 1916. The NAS, NAE, IOM, and NRC are collectively referred to as "The National Academies." More information is available at http://nationalacademies.org.

The original charter of the Space Science Board was established in June 1958, three months before the National Aeronautics and Space Administration (NASA) opened its doors. The Space Science Board and its successor, the Space Studies Board (SSB), have provided expert external and independent scientific and programmatic advice to NASA on a continuous basis from NASA's inception until the present. The Board has also provided such advice to other executive branch agencies, including the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the U.S. Geological Survey (USGS), and the Department of Defense, as well as to Congress.

The fundamental charter of the Board today remains that defined by NAS president Detlev W. Bronk in a letter to Lloyd V. Berkner, first chair of the Board, on June 26, 1958, which established the SSB:

> We have talked of the main task of the Board in three parts—the immediate program, the long-range program, and the international aspects of both. In all three we shall look to the Board to be the focus of the interests and responsibilities of the Academy-Research Council in space science; to establish necessary relationships with civilian science and with governmental science activities, particularly the proposed new space agency, the National Science Foundation, and the Advanced Research Projects Agency; to represent the Academy-Research Council complex in our international relations in this field on behalf of American science and scientists; to seek ways to stimulate needed research; to promote necessary coordination of scientific effort; and to provide such advice and recommendations to appropriate individuals and agencies with regard to space science as may in the Board's judgment be desirable.
>
> As we have already agreed, the Board is intended to be an advisory, consultative, correlating, evaluating body and not an operating agency in the field of space science. It should avoid responsibility as a Board for the conduct of any programs of space research and for the formulation of budgets relative thereto. Advice to agencies properly responsible for these matters, on the other hand, would be within its purview to provide.

The Space Science Board changed its name to the Space Studies Board in 1989 to reflect its expanded scope, which now includes space applications and other topics. Today, the SSB exists to provide an independent, authoritative forum for information and advice on all aspects of space science and applications, and it serves as the focal point within the National Academies for activities on space research. It oversees advisory studies and program assessments, facilitates international research coordination, and promotes communications on space science and science policy among the research community, the federal government, and the interested public. The SSB also serves as the U.S. National Committee for the Committee on Space Research (COSPAR) of the International Council for Science.

## THE SPACE STUDIES BOARD TODAY

The SSB is a unit of the NRC's Division on Engineering and Physical Sciences (DEPS). DEPS is one of six major program units of the NRC through which the institution conducts its operations on behalf of NAS, NAE, and IOM. Within DEPS there are a total of 13 boards that cover a broad range of physical science and engineering disciplines and mission areas.

Members of the DEPS Committee on Engineering and Physical Sciences (DEPSCOM) provide advice on Board membership and on proposed new projects to be undertaken by ad hoc study committees formed under the SSB's auspices. Every 3 years, DEPSCOM reviews the overall operations of each of the DEPS Boards. The next review of the SSB will take place in 2010.

The SSB encompasses the Board itself, its standing committees (see Chapter 2), its ad hoc study committees (see Chapter 3), and its staff. The Board is composed of prominent scientists, engineers, industrialists, scholars, and policy experts in space research appointed for 2-year staggered terms. They represent seven space research disciplines: space-based astrophysics, heliophysics (also referred to as solar and space physics), Earth science, solar system exploration, microgravity life and physical sciences, space systems and technology, and science and technology policy. In 2008, there were 23 Board members. The chairs of the SSB's standing committees are members of the Board and of its Executive Committee (XCOM). The chair of the NRC's Aeronautics and Space Engineering Board (ASEB) and the U.S. representative to COSPAR are ex officio members. A standing liaison arrangement also has been established with the European Space Science Committee (ESSC), part of the European Science Foundation, and the NRC's Ocean Studies Board.

### Organization

The organization of the SSB in 2008 is illustrated in Figure 1.1. Taken together, the Board and its standing and ad hoc study committees generally hold as many as 40 meetings during the year.

### Major Functions of the Space Studies Board

The Board provides an independent, authoritative forum for information and advice on all aspects of space science and applications and serves as the focal point within the National Academies for activities on space research. The Board itself does not conduct studies, but it oversees advisory studies and program assessments conducted by ad hoc study committees (see Chapter 3) formed in response to a request from a sponsor. All projects proposed to be conducted by ad hoc study committees under the auspices of the SSB must be reviewed and approved by the chair and vice chair of the Board (as well as other NRC officials).

Decadal surveys are a signature product of the Board, providing strategic direction to NASA, NOAA, and other agencies on the top priorities over the next 10 years in astronomy and astrophysics, solar system exploration, solar and space physics, and Earth science. (The astronomy and astrophysics decadal survey is a joint effort with the NRC's Board on Physics and Astronomy.)

The Board serves as a communications bridge on space research and science policy among the scientific research community, the federal government, and the interested public.

The Board ordinarily meets three times per year (March, June, and November) to review the activities of its committees and to be briefed on and discuss major space policy issues. The November Board meeting typically involves a workshop on a topic of current interest and results in a workshop report. In 2008, in collaboration with ASEB, that topic was international space cooperation and competition in a globalizing world (see Chapter 4).

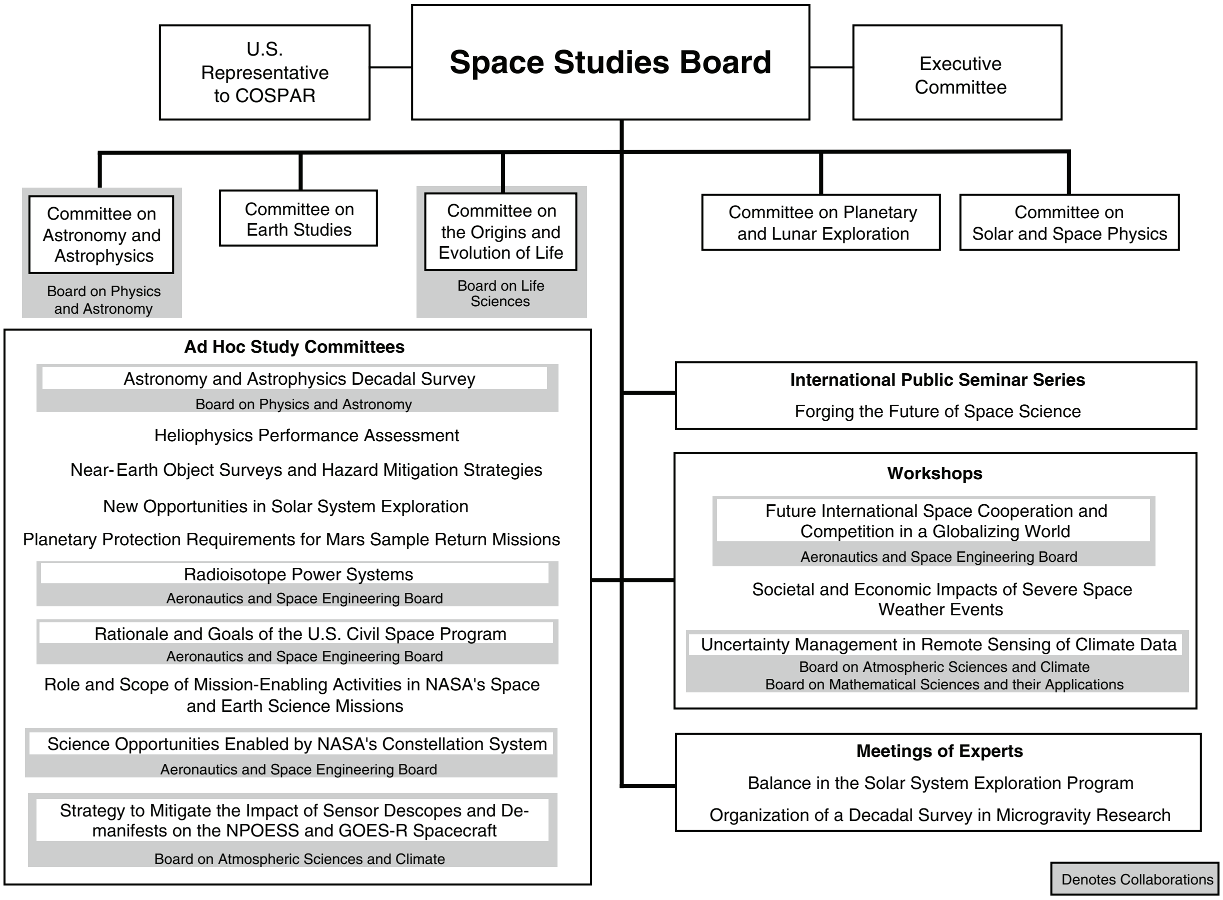


FIGURE 1.1 Organization of the Space Studies Board, its standing committees, ad hoc study committees, and workshops and special projects in 2008. Shaded boxes denote activities performed in cooperation with other National Research Council units.

## International Representation and Cooperation

The Board serves as the U.S. National Committee for COSPAR, an international, multidisciplinary forum for exchanging space science research. Board members may individually participate in COSPAR scientific sessions to present their research or, occasionally, present the results of an SSB report to the international community, or conduct informal information exchange sessions with national entities within COSPAR scientific assemblies.

The Board also has a regular practice of exchanging observers with the ESSC, which is part of the European Science Foundation (see http://www.esf.org/).

## Space Studies Board Committees

### *Executive Committee*

The Executive Committee (XCOM), composed entirely of Board members, facilitates the conduct of the Board's business, permits the Board to move rapidly to lay the groundwork for new study activities, and provides strategic planning advice. XCOM meets annually for a session on the assessment of SSB operations and future planning. Its membership includes the chair and vice chair of the Board, the chairs of the standing committees, and one Board member for each discipline that does not have a standing committee.

### *Standing Committees*

Discipline-based standing committees are the means by which the Board conducts its oversight of specific space research disciplines. Each standing committee is composed of about a dozen specialists, appointed to represent the broad sweep of research areas within the discipline. Like the Board itself, each standing committee serves as a communications bridge with its associated research community and participates in identifying new projects and prospective members of ad hoc study committees. Standing committees do not, themselves, write reports, but oversee reports written by ad hoc study committees created under their auspices.

During 2008, SSB had five standing committees:

- Committee on Astronomy and Astrophysics
- Committee on Earth Studies
- Committee on the Origins and Evolution of Life
- Committee on Planetary and Lunar Exploration
- Committee on Solar and Space Physics

### *Ad Hoc Study Committees*

Ad hoc study committees are created by NRC action to conduct specific studies at the request of sponsors. These committees typically produce NRC reports that provide advice to the government and therefore are governed by Section 15 of the Federal Advisory Committee Act (FACA). Ad hoc study committees usually write their reports after holding two or three information-gathering meetings, although in some cases they may hold a workshop in addition to or instead of information-gathering meetings.

In other cases, workshops are organized by ad hoc study committees that serve as organizers only, and the workshop report is written by a rapporteur and does not contain findings or recommendations. In those cases, the study committee is not governed by FACA Section 15 since no NRC advice results from the workshop.

The ad hoc study committees that were in place during 2008 are summarized in Chapter 3.

## COLLABORATION WITH OTHER NATIONAL RESEARCH COUNCIL UNITS

Much of the work of the Board involves topics that fall entirely within its principal areas of responsibility and can be addressed readily by its members and committees. However, there are other situations in which the need for breadth of expertise, alternative points of view, or synergy with other NRC projects leads to collaboration with other units of the NRC.

The SSB has engaged in many such multi-unit collaborations. Among the NRC boards with which the SSB works most often are the ASEB, the Board on Physics and Astronomy, the Board on Atmospheric Sciences and Climate, the Board on Life Sciences, and the Ocean Studies Board. This approach to projects has the potential to bring more of the full capability of the National Academies to bear in preparing advice for the federal government and the public. Multi-unit collaborative projects also present new challenges—namely, to manage the projects in a way that achieves economies of scale and true synergy rather than just adding cost or complexity. Collaborative relationships between the SSB and other NRC units during 2008 are illustrated in Figure 1.1.

## ASSURING THE QUALITY OF SSB REPORTS

A major contributor to the quality of the SSB reports (Table 1.1 lists the 2008 releases) is the requirement that NRC reports are peer reviewed. Except for the *Space Studies Board Annual Report—2007,* all of the reports were subjected to extensive peer review, which is overseen by the NRC's Report Review Committee (RRC). Typically 4 to 7 reviewers (occasionally as many as 15 or more) are selected on the basis of recommendations by NAS and NAE section liaisons, SSB members, and staff. The reviewers are subject to approval by the NRC. The identities of external reviewers are not known to a report's authors until after the review has been completed and the report has been approved by the RRC. The report's authors, with the assistance of SSB staff, must provide some response to every specific comment from every external reviewer. To ensure that appropriate technical revisions are made to

TABLE 1.1 Space Studies Board Reports Released in 2008

| Report Title | Sponsors | Oversight Committee or Board[a] | Principal Audiences[b] | | | | |
|---|---|---|---|---|---|---|---|
| | | | NASA/ SMD | NASA/ ESMD | NOAA | NSF | Other |
| Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring | NASA NOAA | CES | X | | X | | USGS |
| Launching Science: Science Opportunities Provided by NASA's Constellation System | NASA | COMPLEX | X | X | | | |
| Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity | NASA | COMPLEX | X | | | | |
| Satellite Observations to Benefit Science and Society: Recommended Missions for the Next Decade [booklet] | NASA NOAA | CES | X | | X | | USGS |
| Science Opportunities Enabled by NASA's Constellation System: Interim Report | NASA | SSB | X | | | | |
| Severe Space Weather Events—Understanding Societal and Economic Impacts: Workshop Report | NASA | CSSP | X | | X | X | |
| Space Science and the International Traffic in Arms Regulations: Summary of a Workshop | NASA | SSB | X | X | X | X | DOE USGS |
| Space Studies Board Annual Report—2007 | NASA | SSB | X | X | X | X | DOE USGS |
| United States Civil Space Policy: Summary of a Workshop | NASA | SSB | X | X | X | X | DOE USGS |

[a]Oversight committee or board within the National Research Council

| | |
|---|---|
| CES | Committee on Earth Studies |
| COMPLEX | Committee on Planetary and Lunar Exploration |
| CSSP | Committee on Solar and Space Physics |
| SSB | Space Studies Board |

[b]Principal audiences: Federal agencies that have funded or shown interest in SSB reports.

| | |
|---|---|
| DOE | Department of Energy |
| NASA | National Aeronautics and Space Administration |
| NASA/ESMD | NASA Exploration Systems Mission Directorate |
| NASA/SMD | NASA Science Mission Directorate |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF | National Science Foundation |
| USGS | U.S. Geological Survey |

the report and that the revised report complies with NRC policy and standards, the response-to-review process is overseen and refereed by an independent arbiter that is knowledgeable about the report's issues. In some cases, there is a second independent arbiter that has a broader perspective on policy issues affecting the National Academies. All of the reviews emphasize the need for scientific and technical clarity and accuracy and for proper substantiation of the findings and recommendations presented in the report. Names of the external reviewers, including the monitor (and coordinator if one was appointed), are published in the final report, but their individual comments are not released.

Another important method to ensure high-quality work derives from the size, breadth, and depth of the cadre of experts who serve on SSB and its committees or participate in other ways in the activities of the Board. Some highlights of the demographics of the SSB in 2008 are presented in Tables 1.2 and 1.3. During 2008, a total of 277 individuals from 81 colleges and universities and 54 other public or private organizations served as formally

TABLE 1.2 Experts Involved in the Space Studies Board and Its Committees, January 1, 2008, to December 31, 2008

| | Number of Board and Committee Members | Number of Institutions or Agencies Represented |
|---|---|---|
| Academia | 169 | 81 |
| Government and national facilities | 22 | 13 |
| Private industry | 35 | 21 |
| Nonprofit and other[a] | 51 | 20 |
| Total[b,c] | 277 | 135 |

[a]Other includes foreign institutions and entities not classified elsewhere.
[b]Includes 35 NAS, NAE, IOM members.
[c]Includes 28 Board members, 249 committee members.

TABLE 1.3 Summary of Participation in Space Studies Board Activities, January 1, 2008, to December 31, 2008

| | Academia | Government and National Facilities | Private Industry | Nonprofit and Other | Total Individuals |
|---|---|---|---|---|---|
| Board/committee members | 169 | 22 | 35 | 51 | 277 |
| Guest experts | 56 | 68 | 22 | 44 | 190 |
| Reviewers | 34 | 3 | 4 | 16 | 57 |
| Workshop participants | 20 | 42 | 20 | 28 | 110 |
| Total | 279 | 135 | 81 | 139 | 634 |

NOTE: Counts of individuals are subject to an uncertainty of ±3 due to possible miscategorization.

| | |
|---|---|
| Total number of NAS, NAE, and/or IOM members | 48 |
| Total number of non-U.S. participants | 8 |
| Total number of countries represented, including United States | 8 |
| Total number of different institutions represented | |
| Academia | 84 |
| Government and national facilities | 27 |
| Private Industry | 35 |
| Nonprofit and other | 38 |

appointed members of the Board and its committees. Over 300 individuals participated in SSB activities either as presenters or as invited workshop participants. The report review process is as important as the writing of reports, and during 2008, 57 different external reviewers contributed to critiques of draft reports. Overall, approximately 634 individuals from 84 academic institutions, 73 industry or nonprofit organizations, and 27 government agencies or offices participated in SSB activities. That number included 48 members of NAS, NAE, or IOM. Being able to draw on such a broad base of expertise is a unique strength of the NRC advisory process.

## SSB AUDIENCE AND SPONSORS

The SSB's efforts have been relevant to a full range of government audiences in civilian space research—including NASA's Science Mission Directorate (SMD), NASA's Exploration Systems Directorate (ESMD), NSF, NOAA, USGS, and the Department of Energy (DOE). Reports on NASA-wide issues were addressed to multiple NASA offices or the whole agency; reports on science issues, to SMD; and reports on exploration systems issues, to ESMD. Within NASA, SMD has been the leading sponsor of SSB reports. Reports have also been sponsored by or of interest to agencies besides NASA—for example, NOAA, NSF, DOE, and the USGS.

## SSB OUTREACH AND DISSEMINATION

Enhancing outreach to a variety of interested communities and improving dissemination of Board reports remains a high priority for the SSB. In 2008, the SSB continued to distribute its quarterly newsletter by electronic means to subscribers.

The Board teamed with other NRC units (including the Division on Earth and Life Studies, the Board on Physics and Astronomy, the National Academies Press, the Office of News and Public Information, and the *Proceedings of the National Academy of Sciences*) to take exhibits to national meetings of the American Geophysical Union and the American Astronomical Society. Popular versions of four of the decadal surveys (*Astronomy and Astrophysics in the New Millennium*, *New Frontiers in the Solar System*, *The Sun to the Earth—and Beyond,* and *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*) continue to be widely distributed to the science community and the general public. Over 2,000 reports were disseminated in addition to the copies distributed to study committee members, the Board, and sponsors.

Formal reports delivered to government sponsors constitute one of the primary products of the work of the SSB, but the dissemination process has a number of other important elements. The Board is always seeking ways to ensure that its work reaches the broadest possible appropriate audience and that it has the largest beneficial impact. Copies of reports are routinely provided to key executive branch officials, members and staffs of relevant congressional committees, and members of other interested NRC and federal advisory bodies. Members of the press are notified about the release of each new report, and the Board maintains a substantial mailing list for distribution of reports to members of the space research community. The SSB publishes summaries of all new reports in its quarterly newsletter. The Board also offers briefings by committee chairs and members or SSB staff to officials in Congress, the executive branch, and scientific societies. Reports are posted on the SSB Web home page at http://www7.nationalacademies.org/ssb and linked to the National Academies Press Web site for reports at http://www.nap.edu.

## INTERNSHIP PROGRAM

The SSB has operated a very successful competitive summer internship program since 1992. The general goal of each internship is to provide a promising undergraduate student an opportunity to work in civil space research policy in the nation's capital, under the aegis of the National Academies. Interns work with the Board, its committees, and staff on one or more of the advisory projects currently under way. Other interns, paid or unpaid, also join the Board staff on an ad hoc basis.

As part of its celebration of the 50th anniversary of its founding, SSB expanded the scope of the Space Policy Intern program in the fall of 2007 by initiating the Lloyd V. Berkner Space Policy Internships. Dr. Berkner, the Board's first chair, played an instrumental role in creating and promoting the International Geophysical Year, a global effort that made it possible for scientists from around the world to coordinate observations of various geophysical phenomena.

For intern opportunities at the SSB, and a list of past SSB interns, visit the SSB Web site at http://www7.nationalacademies.org/ssb/Berkner_Space_Policy_Internships.html.

# 2
# *Board and Standing Committees: Activities and Membership*

During 2008, the Space Studies Board (SSB) had five standing committees representing various disciplines: the Committee on Astronomy and Astrophysics (jointly with the Board on Physics and Astronomy), the Committee on Earth Studies, the Committee on the Origins and Evolution of Life (jointly with the Board on Life Sciences), the Committee on Planetary and Lunar Exploration, and the Committee on Solar and Space Physics. The Board and its standing committees provide strategic direction and oversee activities of ad hoc study committees (see Chapter 3), interact with sponsors, and serve as a communications conduit between the government and the scientific community. They do not provide formal advice and recommendations, and therefore are not subject to the Federal Advisory Committee Act, Section 15.

## SPACE STUDIES BOARD

### HIGHLIGHTS OF SPACE STUDIES BOARD ACTIVITIES

#### First Quarter

The SSB held its 155th meeting at the National Academies' Keck Center in Washington, D.C., on March 10-12, 2008. The first day was devoted to briefings on relevant agency budgets for fiscal year (FY) 2008 and the requests for FY 2009. Guest speakers included Alan Stern, NASA Science Mission Directorate (SMD); Jitendra Joshi, NASA Exploration Systems Mission Directorate (ESMD); Mary Kicza, National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS); Wayne van Citters and Richard Behnke, National Science Foundation (NSF); Dennis Kovar, Department of Energy Office of Science–High Energy Physics; Paul Shawcross and Amy Kaminski, Office of Management and Budget; Damon Wells, John Henry Scott, and Jean Cotton-Allen, Office of Science and Technology Policy; and congressional staff, including Dick Obermann, House Science and Technology Subcommittee on Space and Aeronautics; Ed Feddeman, House Science and Technology Subcommittee on Space and Aeronautics; and Chan Lieu, Senate Commerce Committee. The Board continued the discussion of the FY 2009 budget request on the second day with reports on its impacts from the chairs of the SSB standing committees and a board member from the microgravity life and physical sciences. The Board also met with NASA administrator Mike Griffin.

### Second Quarter

The Board held its 156th meeting at the National Academies' Keck Center in Washington, D.C., on June 25, 2008. This one-day meeting included an update on NASA's SMD from Ed Weiler, the new associate administrator for science, and Paul Hertz, SMD chief scientist; an update on NASA's Constellation Program from Jim Norman (NASA/ESMD); an industry panel on Launch Vehicle Options for Delta 2-class space science missions with Dan Collins (United Launch Alliance), Bob Richards (Orbital Sciences Corporation), and Larry Williams (Space Exploration Technologies Corporation); and an update on the National Academies' study on Climate Change Adaptation and Mitigation from Chris Elfring, director of the National Research Council (NRC) Board on Atmospheric Sciences and Climate.

### Third Quarter

The Board did not meet during this quarter; however, the SSB Executive Committee (XCOM) did meet on August 18-20, 2008, at the J. Erik Jonsson Woods Hole Center in Woods Hole, Massachusetts, for its annual strategic planning session. The XCOM spoke with congressional representatives from the Senate Commerce, Science, and Transportation Committee and the House Committee on Science and Technology on the outlook from Capitol Hill.

The committee continued general discussion on the roles and operations of the Board and its standing committees, ad hoc committees, the financial status of the Board, the NRC efforts to streamline internal processes, and planning for the November SSB meeting and workshop. The latter included presentations by Mary Kicza, assistant administrator for NOAA/NESDIS; John Boright, executive director of the NRC's Office of International Affairs, and Marc Allen, assistant associate administrator for strategy, policy, and international of NASA's SMD. In addition to the current chair Charlie Kennel and the current director Marcia Smith, the XCOM was joined during this meeting by four former chairs, Len Fisk, Claude Canizares, Lou Lanzerotti, and Richard Goody and two former directors, Joe Alexander, and Marc Allen.

### Fourth Quarter

At the Board's meeting at the Arnold and Mabel Beckman Center in Irvine, California, on November 18, 2008, the chair and vice chair reported on discussions held at the Board's XCOM meeting in August. Board members were presented with the status of several SSB activities, including a presentation by the chair of the astronomy and astrophysics decadal survey (Astro2010). The annual balance and composition discussion was also held. The meeting ended with a brief discussion of the objectives for the Board-sponsored "Workshop on Future International Space Cooperation and Competition in a Globalizing World." The workshop is discussed in Chapter 4 of this report.

## SPACE STUDIES BOARD MEMBERSHIP

**July 1, 2007–June 30, 2008**

Lennard A. Fisk, University of Michigan (chair)
A. Thomas Young, Lockheed Martin Corporation (retired) (vice chair)
Daniel N. Baker, University of Colorado, Boulder
Steven J. Battel, Battel Engineering
Charles L. Bennett, Johns Hopkins University
Elizabeth R. Cantwell, Los Alamos National Laboratory
Alan Dressler, Observatories of the Carnegie Institution
Jack D. Fellows, University Corporation for Atmospheric Research
Fiona A. Harrison, California Institute of Technology
Tamara E. Jernigan, Lawrence Livermore National Laboratory
Klaus Keil, University of Hawaii, Manoa
Molly K. Macauley, Resources for the Future, Inc.
Berrien Moore III, University of New Hampshire
Kenneth H. Nealson, University of Southern California
James A. Pawelczyk, Pennsylvania State University
Soroosh Sorooshian, University of California, Irvine
Richard H. Truly, National Renewable Energy Laboratory
Joan Vernikos, Thirdage LLC
Joseph F. Veverka, Cornell University
Warren M. Washington, National Center for Atmospheric Research
Charles E. Woodward, University of Minnesota
Gary P. Zank, University of California, Riverside

**July 1, 2008–June 30, 2009**

Charles F. Kennel, University of California, San Diego (chair)
A. Thomas Young, Lockheed Martin Corporation (retired) (vice chair)
Daniel N. Baker, University of Colorado, Boulder
Steven J. Battel, Battel Engineering
Charles L. Bennett, Johns Hopkins University
Yvonne C. Brill, Aerospace Consultant
Elizabeth R. Cantwell, Oak Ridge National Laboratory
Dr. Andrew B. Christensen, Dixie State College
Alan Dressler, Observatories of the Carnegie Institution
Jack D. Fellows, University Corporation for Atmospheric Research
Fiona A. Harrison, California Institute of Technology
Joan Johnson-Freese, U.S. Naval War College
Klaus Keil, University of Hawaii
Molly K. Macauley, Resources for the Future, Inc.
Berrien Moore III, Climate Central
Robert T. Pappalardo, Jet Propulsion Laboratory
James A. Pawelczyk, Pennsylvania State University
Soroosh Sorooshian, University of California, Irvine
Joan Vernikos, Thirdage LLC
Joseph F. Veverka, Cornell University
Warren M. Washington, National Center for Atmospheric Research
Charles E. Woodward, University of Minnesota
Ellen G. Zweibel, University of Wisconsin

### *Ex Officio and Liaison Members*

Raymond S. Colladay, Lockheed Martin Astronautics (retired) (ex-officio, chair, NRC Aeronautics and Space Engineering Board)
Jean-Pierre Swings, Institute d'Astrophysique (liaison, chair of the European Space Science Committee)
Jay S. Pearlman, Institute of Electrical and Electronics Enginners, Inc. (ex-officio, member of the NRC Ocean Studies Board)
Edward C. Stone, California Institute of Technology (liaison, U.S. representative to the Committee on Space Research)

***Membership of the 2006 SSB Executive Committee***

**July 1, 2007–June 30, 2008**

Lennard A. Fisk, University of Michigan (chair)
A. Thomas Young, Lockheed Martin Corporation (retired) (vice chair)
Daniel N. Baker, University of Colorado, Boulder
Charles L. Bennett, Johns Hopkins University
Molly K. Macauley, Resources for the Future, Inc.
Berrien Moore III, University of New Hampshire
Kenneth H. Nealson, University of Southern California
James A. Pawelczyk, Pennsylvania State University
Joseph F. Veverka, Cornell University

**July 1, 2008–June 30, 2009**

Charles F. Kennel, University of California, San Diego (chair)
A. Thomas Young, Lockheed Martin Corporation (retired) (vice chair)
Daniel N. Baker, University of Colorado, Boulder
Charles L. Bennett, Johns Hopkins University
Molly K. Macauley, Resources for the Future, Inc.
Berrien Moore III, University of New Hampshire
Robert T. Pappalardo, Jet Propulsion Laboratory
James A. Pawelczyk, Pennsylvania State University
Joseph F. Veverka, Cornell University

***Staff***

Marcia S. Smith, Director
Brant L. Sponberg, Senior Program Officer and Associate Director (from March)
Joseph K. Alexander, Senior Program Officer
Arthur A. Charo, Senior Program Officer
Sandra J. Graham, Senior Program Officer and Interim Associate Director (to February)
Ian W. Pryke, Senior Program Officer (from June)
Robert L. Riemer,[†] Senior Program Officer
David H. Smith, Senior Program Officer
Brian D. Dewhurst,[†] Program Officer
Dwayne A. Day, Program Officer
Victoria Swisher, Research Associate
Barbara S. Akinwole, Information Management Associate (to October)
Celeste A. Naylor, Senior Program Assistant
Tanja Pilzak, Administrative Coordinator (to July) and Manager, Program Operations (from August)
Christina O. Shipman, Financial Associate (to March) and Financial Officer (from April)
Sandra Wilson, Financial Assistant (from August)
Catherine A. Gruber, Assistant Editor
Carmela J. Chamberlain, Program Associate
Theresa M. Fisher, Program Associate
Rodney N. Howard, Senior Program Assistant
Linda Walker, Senior Project Assistant (from April)

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[†]Staff from other NRC Boards who are shared with the SSB.

***Consultants***

Diana Alexander (to July)
Johannes Loschnigg (to April)
Ian W. Pryke (to June)

***2008 Lloyd V. Berkner Space Policy Interns***

Kayleigh Ayn Bohemier, Summer
Laura M. Delgado, Summer
Lewis Groswald, Autumn

### U.S. NATIONAL COMMITTEE FOR COSPAR

The Committee on Space Research (COSPAR) of the International Council of Science conducted its annual business meetings—including meetings of the COSPAR Publications Committee, COSPAR Program Committee, COSPAR Scientific Advisory Committee, and COSPAR Bureau—at CNES Headquarters in Paris, France, on March 25-28, 2008. Activities focused on the final preparations for the biannual COSPAR Scientific Assembly.

COSPAR held its biennial scientific assembly in Montreal, Canada, on July 13-19, 2008. Edward Stone, COSPAR vice president and U.S. representative to COSPAR, and staff of the U.S. National Committee for COSPAR participated in the July 12 preassembly and July 20 postassembly meetings of the COSPAR Council. Major items discussed and approved by the COSPAR Council included the initiation of a new program of capacity-building fellowships and changes in COSPAR planetary protection policies relating to the Moon, Venus, and Mars special regions and human exploration activities. Future COSPAR activities include the annual business meetings to be held in Paris in March 2009, and the scientific assemblies to be held in Bremen, Germany, in 2010 and Mysore, India, in 2014.

Edward C. Stone, California Institute of Technology (U.S. representative to COSPAR)
David H. Smith, Senior Program Officer, Space Studies Board (executive secretary for COSPAR)
Carmela J. Chamberlain, Program Associate, Space Studies Board

## STANDING COMMITTEES

### COMMITTEE ON ASTRONOMY AND ASTROPHYSICS

The Committee on Astronomy and Astrophysics (CAA), which operates under the joint auspices of the SSB and the Board on Physics and Astronomy (BPA), was on a hiatus until the completion of the next astronomy and astrophysics decadal survey, Astro2010, and did not meet in 2008.

A historical summary of reports from CAA and related committees is presented in Figure 2.1.

***Membership***†

Charles L. Bennett,† Johns Hopkins University (co-chair)
C. Megan Urry,‡ Yale University (co-chair)
Michell C. Begelman,† University of Colorado, Boulder
Adam S. Burrows,† University of Arizona
Lynne Hillenbrand,† California Institute of Technology
Charles McGruder III,† Western Kentucky University

***Staff***

David Lang, Program Officer, Board on Physics and Astronomy
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

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†Term ended June 30, 2008.
‡Term ended December 31, 2007.

### COMMITTEE ON EARTH STUDIES

The Committee on Earth Studies (CES) resumed activities following a long hiatus while the decadal survey, "Earth Science and Applications from Space: A Community Assessment and Strategy for the Future," and the follow-on decadal survey activities—the Panel on Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft and the ad hoc Committee on A Strategy to Mitigate the Impact of Sensor Descopes and Demanifests on the NPOESS and GOES-R Spacecraft were under way. As the first quarter ended, the committee was making final preparations for its first meeting in 2008.

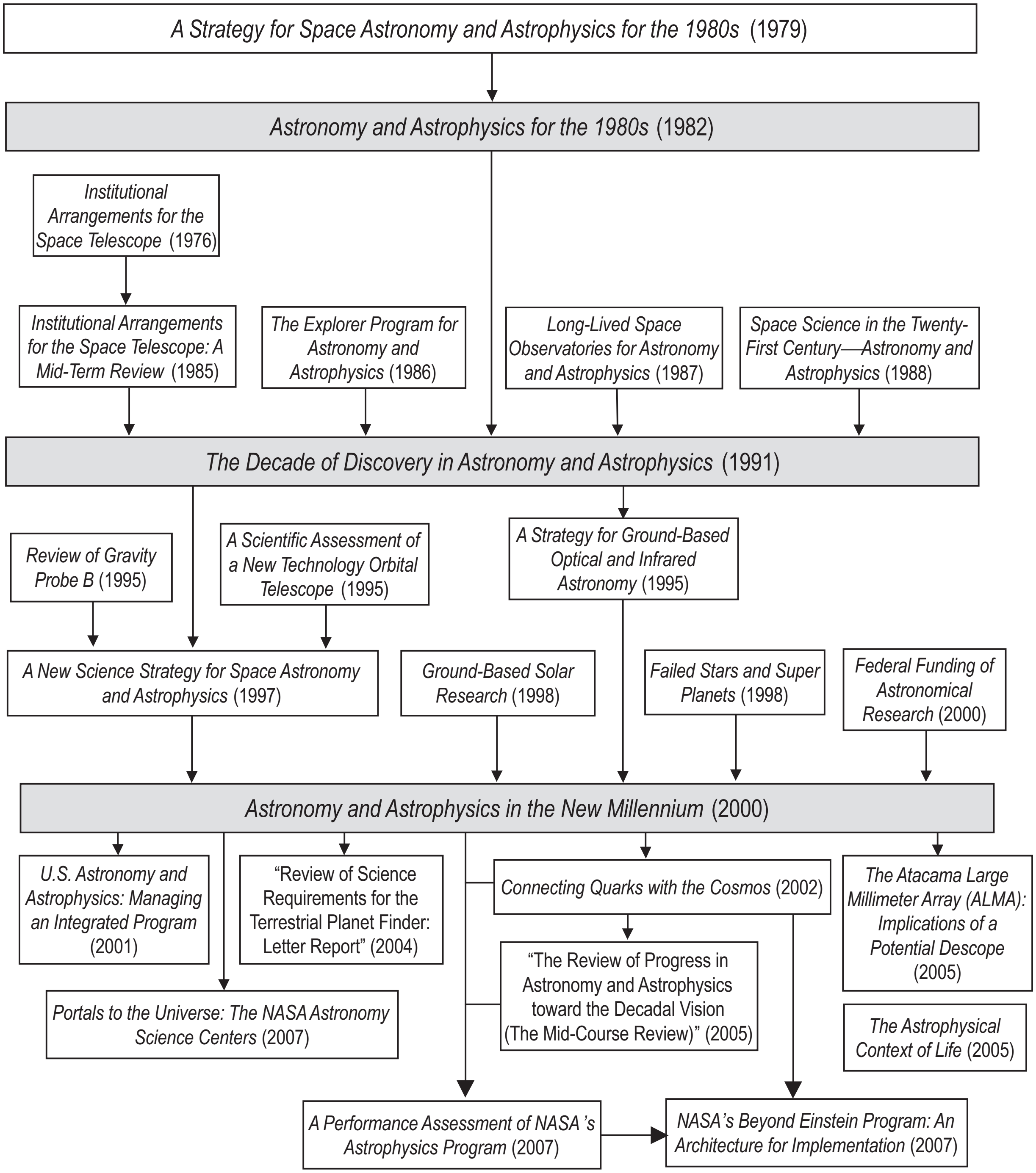


FIGURE 2.1 SSB-NRC advice on astronomy and astrophysics (1979-2007).

At the April 7-8, 2008, CES meeting in Washington, D.C., guests included the director of NASA's Earth Science Program, Michael Freilich, and the head of NOAA/NESDIS, Mary Kicza. In addition to receiving updates on the status of NASA and NOAA Earth observation programs, Dr. Freilich and Ms. Kicza led discussions of potential new studies for ad hoc committees of the SSB.

At the CES meeting in September 22-23, 2008, in Boulder, Colorado, the committee received a background briefing on the COSMIC mission and updates on progress in implementing the decadal survey-recommended missions ICESat-II and CLARREO. SSB member Jack Fellows (University Corporation for Atmospheric Research) summarized a recently published report that provides program, management, and budget recommendations to the next administration and Congress on R&D needs to meet our nation's energy and climate change challenges. The report includes recommendations on how to make the nation more resilient to severe weather and climate change. By teleconference, the committee spoke at length with Michael Freilich (NASA) and Mary Kicza (NOAA). In addition to receiving updates on the status of NASA and NOAA Earth observation programs, Dr. Freilich and Dr. Kicza led discussions of potential new studies for ad hoc committees of the SSB. The committee also spoke by teleconference with former NOAA administrator Jim Baker regarding a proposed Earth systems science agency.

The committee did not meet during the fourth quarter; however, members and staff were active in developing new study prospectuses, and members participated in the following NRC activities:

- The committee worked with the Board on Atmospheric Sciences and Climate to organize a December 8, 2008, program planning meeting to consider the utility of a possible NRC study on attribution of climate change, with a focus on solar influences.
- The committee collaborated with other units in the NRC to organize the December 4, 2008, workshop "Uncertainty Management in Remote Sensing of Climate Data" (see Chapter 4 of this report).
- Several committee members participated in the planning of the National Academies' study on Climate Change Adaptation and Mitigation, entitled America's Climate Choices, a major initiative focusing on providing decision makers with near-term options related to mitigation and adaption to anticipated climate change. (See http://dels.nas.edu/basc/climate-change/index.shtml.)

A historical summary of reports from CES and related committees is presented in Figure 2.2.

### *Membership*

Berrien Moore III,† Climate Central (chair)
Ruth S. DeFries,† Columbia University (vice chair)
Mark R. Abbott, Oregon State University
Richard A. Anthes, University Corporation for Atmospheric Research
Philip E. Ardanuy, Raytheon Information Solutions
Steven J. Battel, Battel Engineering
Antonio J. Busalacchi, Jr., University of Maryland, College Park
Heidi M. Dierssen,‡ University of Connecticut, Avery Point
Hung-Lung Allen Huang, University of Wisconsin, Madison
Anne W. Nolin, Oregon State University
Jay S. Pearlman, Institute for Electrical and Electronics Engineers, Inc.
Thomas H. Vonder Haar, Colorado State University

### *Staff*

Arthur A. Charo, Senior Program Officer, Space Studies Board
Theresa M. Fisher, Program Associate, Space Studies Board

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†Term began November 6, 2007.
‡Term began March 27, 2008.

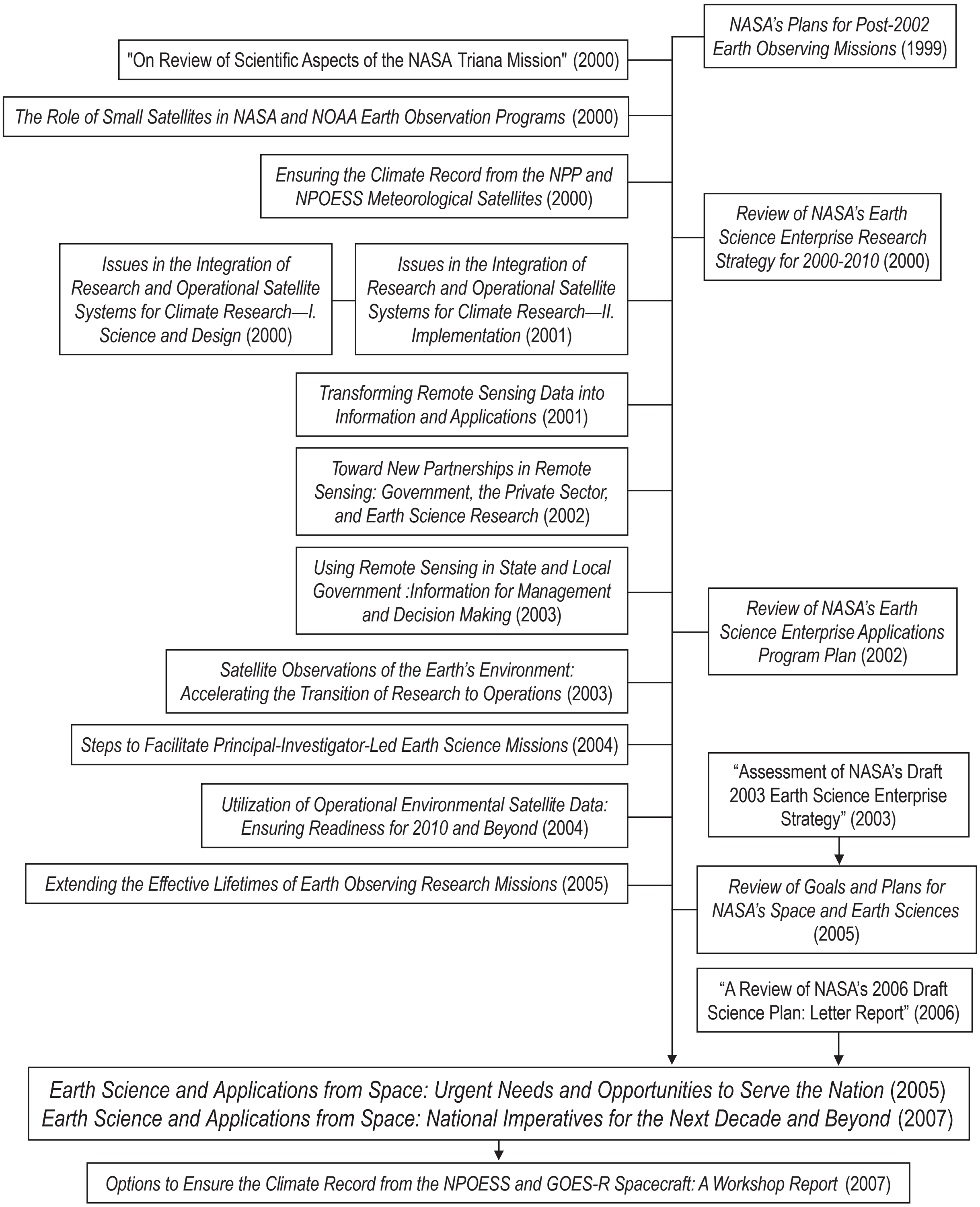


FIGURE 2.2 SSB-NRC advice on Earth science and applications in space (1979-2007).

## COMMITTEE ON THE ORIGINS AND EVOLUTION OF LIFE

The Committee on the Origins and Evolution of Life (COEL), which operates under the joint auspices of the SSB and the Board on Life Sciences, met on February 13-15, 2008, at the National Academies' Keck Center in Washington, D.C. In addition to briefings on the current status of NASA's Astrobiology and related programs, the committee devoted a significant amount of time to presentations, discussions, and deliberations concerning NASA's planning for an outer solar system flagship mission. In response to a request from SSB, committee members drafted an assessment of the current status of NASA's Astrobiology program in light of the agency's enacted budget for FY 2008 and proposed budget for FY 2009. Astrobiology studies being planned or organized by COEL included (1) a review of the planetary protection requirements for Mars sample return missions, (2) an astrobiology strategy for the exploration of the outer solar system, and (3) the origins and evolution of life: a science strategy for the 21st century.

At COEL's May 13-15, 2008, meeting at the National Academy of Sciences in Washington, D.C., in addition to briefings on the current status of NASA's Astrobiology and related programs, the committee devoted a significant amount of time to presentations, discussions, and deliberations concerning the origins and early evolution of life.

The committee's October 28-30, 2008, meeting at the National Academies' Arnold and Mabel Beckman Center in Irvine, California, was notable in that it was presided over by the incoming co-chair Robert T. Pappalardo and the soon-to-depart co-chair Kenneth H. Nealson. Dr. Nealson's successor and six new members are in the process of being appointed. The meeting was primarily devoted to various aspects of the NASA Astrobiology Institute's (NAI's) activities, including presentations from Mary Voytek, the acting director of NASA's Astrobiology program; Carl Pilcher, the director of NAI; the principal investigators of several of the recently selected new NAI teams; the chairs of several of the NAI's astrobiology focus groups; and a selected group of participants devoted to current and forthcoming Mars exploration activities.

A historical summary of reports from COEL and related committees is presented in Figure 2.3.

### *Membership*

**July 1, 2007–June 30, 2008**

Kenneth H. Nealson, University of Southern California (co-chair)
Bruce M. Jakosky, University of Colorado, Boulder (co-chair)
Jan P. Amend, Washington University
Stanley M. Awramik, University of California, Santa Barbara
Michael H. Carr, U.S. Geological Survey (retired)
Paul G. Falkowski, Rutgers, The State University of New Jersey, New Brunswick
Antonio Lazcano, Universidad Nacional Autonoma de Mexico
Ralph D. Lorenz, Johns Hopkins University, Applied Physics Laboratory
Harry Y. McSween, Jr., University of Tennessee, Knoxville
John C. Priscu, Montana State University
Sara Seager, Massachusetts Institute of Technology
Barbara Sherwood Lollar, University of Toronto
Everett Shock, Arizona State University
Andrew Steele, Carnegie Institution of Washington
Meenakshi Wadhwa, Arizona State University

**July 2008–June 30, 2009**†

Robert T. Pappalardo, Jet Propulsion Laboratory (co-chair)
Stanley M. Awramik,‡ University of California, Santa Barbara
Paul G. Falkowski,‡ Rutgers, The State University of New Jersey, New Brunswick
Antonio Lazcano,‡ Universidad Nacional Autonoma de Mexico
Ralph D. Lorenz,‡ Johns Hopkins University, Applied Physics Laboratory
Kenneth H. Nealson,* University of Southern California
John C. Priscu,‡ Montana State University
Sara Seager,‡ Massachusetts Institute of Technology
Everett Shock,‡ Arizona State University

†Appointment of a new co-chair and new members is pending.
‡Term began October 22, 2007.
*Term ended December 31, 2008.

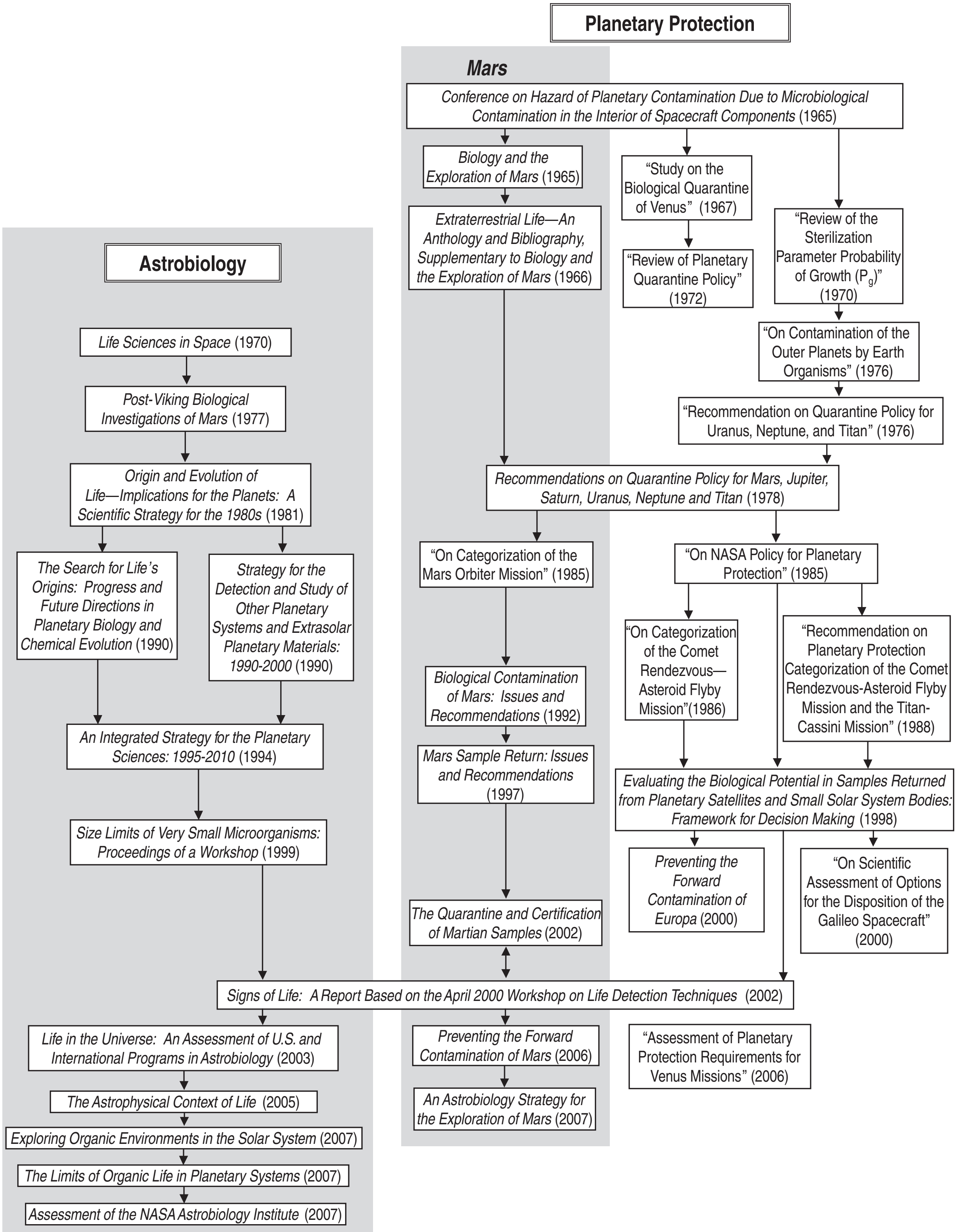


FIGURE 2.3 SSB-NRC advice on astrobiology and planetary protection (1965-2007).

### *Staff*

David H. Smith, Senior Program Officer, Space Studies Board
Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy
Rodney N. Howard, Senior Program Assistant, Space Studies Board

## COMMITTEE ON PLANETARY AND LUNAR EXPLORATION

The Committee on Planetary and Lunar Exploration (COMPLEX) met on March 19-21, 2008, at the National Academies' Keck Center in Washington, D.C. In addition to briefings on the status of NASA planetary sciences, the presentations and discussions of the committee were primarily focused in three areas: (1) understanding funding and development issues related to the Mars Science Laboratory mission; (2) potential commercial capabilities for launching small planetary science missions in the future; and (3) understanding NASA's needs for the upcoming NRC decadal survey on solar system exploration. Other presentations included briefings on NSF plans for the Arecibo Observatory, Stirling cycle technology for radioisotope-powered missions, and early results from the Messenger flyby of Mercury.

COMPLEX met August 20-22, 2008, in Woods Hole, Massachusetts, to plan for the next decadal survey on solar system exploration. The meeting included open discussions that examined lessons learned from past decadal studies, with previous key participants such as Mark Sykes from the Planetary Science Institute, Michael Belton of Belton Space Exploration Initiatives, and Joseph Burns of Cornell University. The committee also discussed with Jim Green of NASA and Vern Pankonin of NSF the perspectives and needs of their respective agencies. In addition, the committee heard presentations on lessons learned from experts in mission cost estimating. The committee later utilized these various inputs in discussing a statement of task for the study, a general work plan, critical areas of expertise needed, and potential study participants. Following the meeting a draft statement of task was forwarded to NASA for review. The committee will stand down during the period of the upcoming decadal study, which is expected to begin in early 2009.

A historical summary of reports from COMPLEX and related committees is presented in Figure 2.4.

### *Membership*†

Joseph F. Veverka, Cornell University (chair)
W. Bruce Banerdt, Jet Propulsion Laboratory
Penelope J. Boston, New Mexico Institute of Mining and Technology
Donald E. Brownlee, University of Washington
Bonnie J. Buratti, Jet Propulsion Laboratory
Roger N. Clark, U.S. Geological Survey
Michael R. Combi, University of Michigan
John Grant, Smithsonian Institution, National Air and Space Museum
Timothy J. McCoy, Smithsonian Institution, National Museum of Natural History
Alfred S. McEwen, University of Arizona
Francis Nimmo, University of California, Santa Cruz
Louise M. Prockter, Johns Hopkins University, Applied Physics Laboratory
Darrell F. Strobel, Johns Hopkins University
Dawn Y. Sumner, University of California, Davis

### *Staff*

Sandra J. Graham, Senior Program Officer, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

†Terms end December 31, 2008.

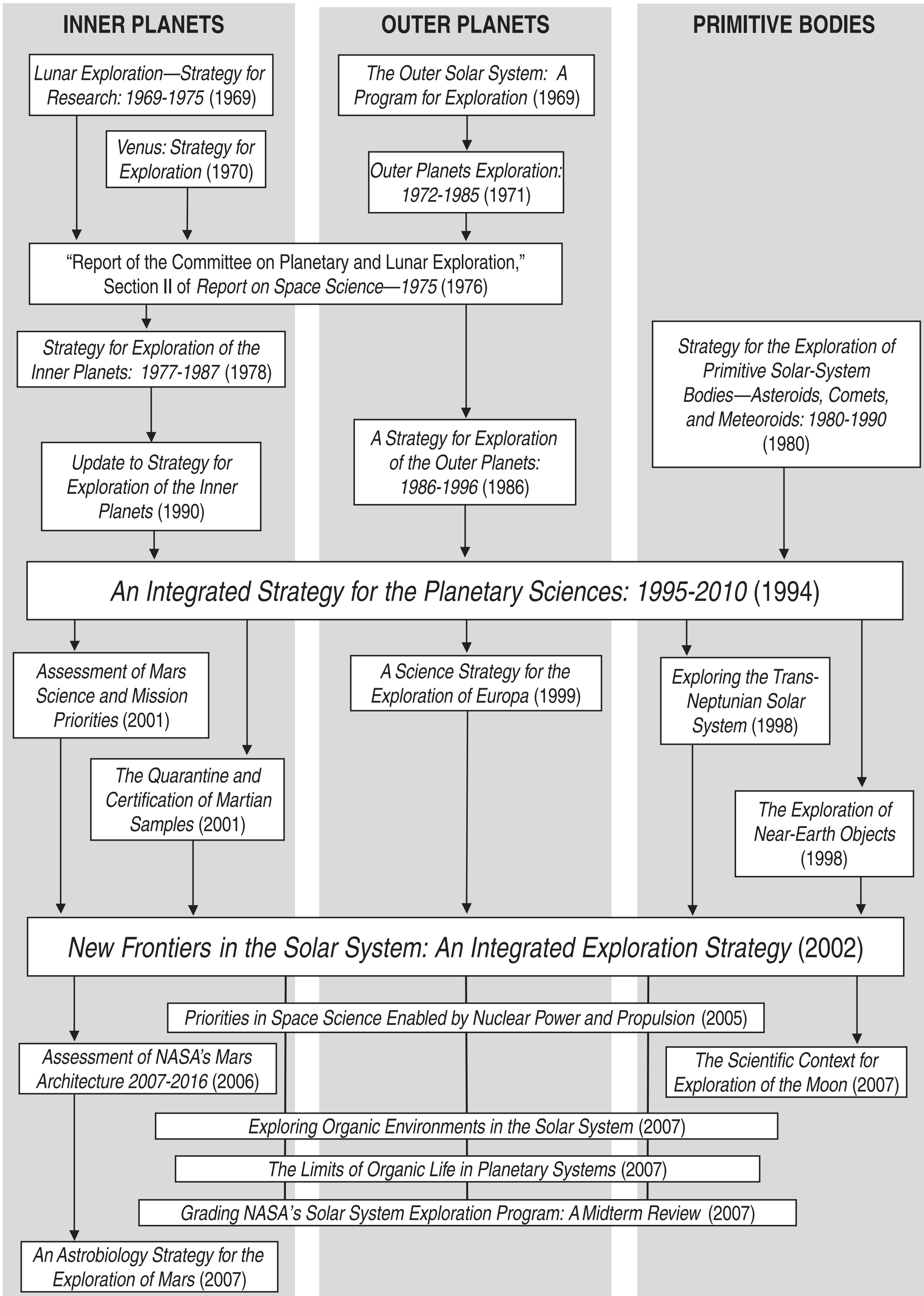


FIGURE 2.4 SSB-NRC advice on solar system exploration (1969-2007). Origins of life topics are covered in Figure 2.3.

### COMMITTEE ON SOLAR AND SPACE PHYSICS

The Committee on Solar and Space Physics (CSSP) held its first meeting of 2008 at the National Academies' Keck Center in Washington, D.C., on April 1-2, where it received presentations on the current state of NASA's and NSF's solar and space physics programs, NASA's research and analysis grant program, ground-based neutron monitors, and an economic analysis of the impacts of space weather.

At its December 3-4, 2008, meeting in the National Academies' Keck Center in Washington, D.C., the committee spoke with congressional staff from the House Committee on Science and Technology regarding the legislative and budget outlook from Capitol Hill. The committee also discussed the status of NASA's Heliophysics programs with Richard Fisher and the status of relevant NSF Upper Atmosphere Research programs with Richard Behnke. David Cummings briefed the committee on the Universities Space Research Association and its current and planned activities. The committee also received presentations from Peter Klupar on small spacecraft activities at NASA's Ames Research Center and from Kent Bress on international agreements managed by NASA Headquarters' Office of External Relations.

A historical summary of reports from CSSP and related committees is presented in Figure 2.5.

#### *Membership*

Daniel N. Baker, University of Colorado, Boulder (chair)
Thomas H. Zurbuchen, University of Michigan (vice chair)
Joseph F. Fennell,[†] The Aerospace Corporation
Maura E. Hagan,[‡] National Center for Atmospheric Research
Jack R. Jokipii, University of Arizona
Krishan Khurana,[†] University of California, Los Angeles
William S. Lewis, Southwest Research Institute
Dana Warfield Longcope, Montana State University
Ramon E. Lopez,[‡] University of Texas, Arlington
Kristina A. Lynch,[†] Dartmouth College
Richard A. Mewaldt,[†] California Institute of Technology
Merav Opher,[‡] George Mason University
Howard J. Singer, National Oceanic and Atmospheric Administration
Ronald E. Turner,[†] ANSER Corporation

[†]Term ended December 31, 2008.
[‡]Term began January 31, 2008.

#### *Staff*

Brant L. Sponberg, Associate Director and Senior Program Officer, Space Studies Board (from May)
Johannes Loschnigg, Consultant, Space Studies Board (to April)
Theresa M. Fisher, Program Associate, Space Studies Board

## SPACE RESEARCH DISCIPLINES WITHOUT STANDING COMMITTEE REPRESENTATION

Although there are no longer standing committees representing microgravity research or space biology and medicine, a life and microgravity decadal survey will be conducted in 2009-2010. A historical summary of NRC-SSB advice in space biology and medicine is presented in Figure 2.6, and a historical summary of NRC-SSB advice on microgravity research is presented in Figure 2.7.

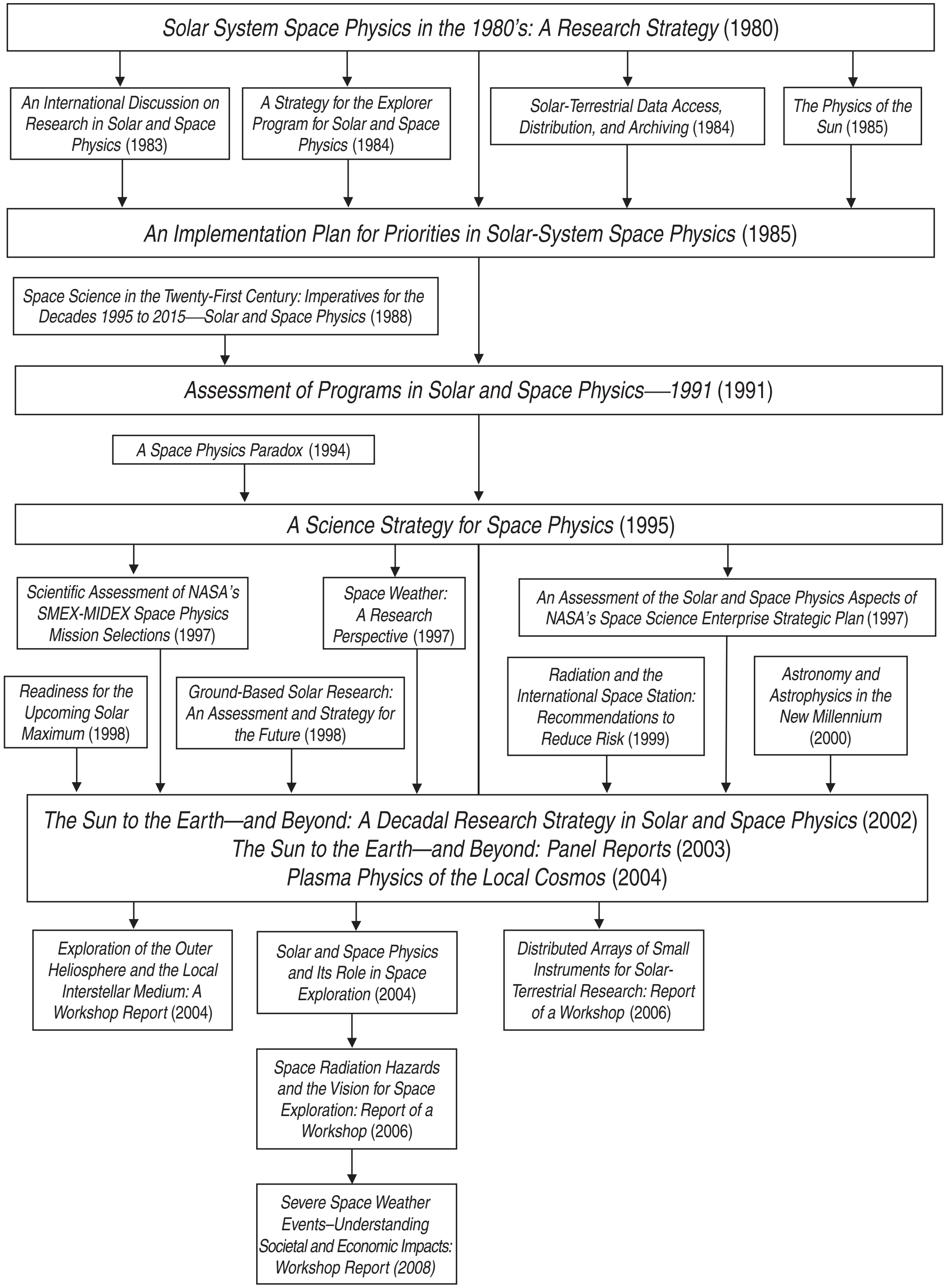


FIGURE 2.5 SSB-NRC advice on solar and space physics (1980-2008).

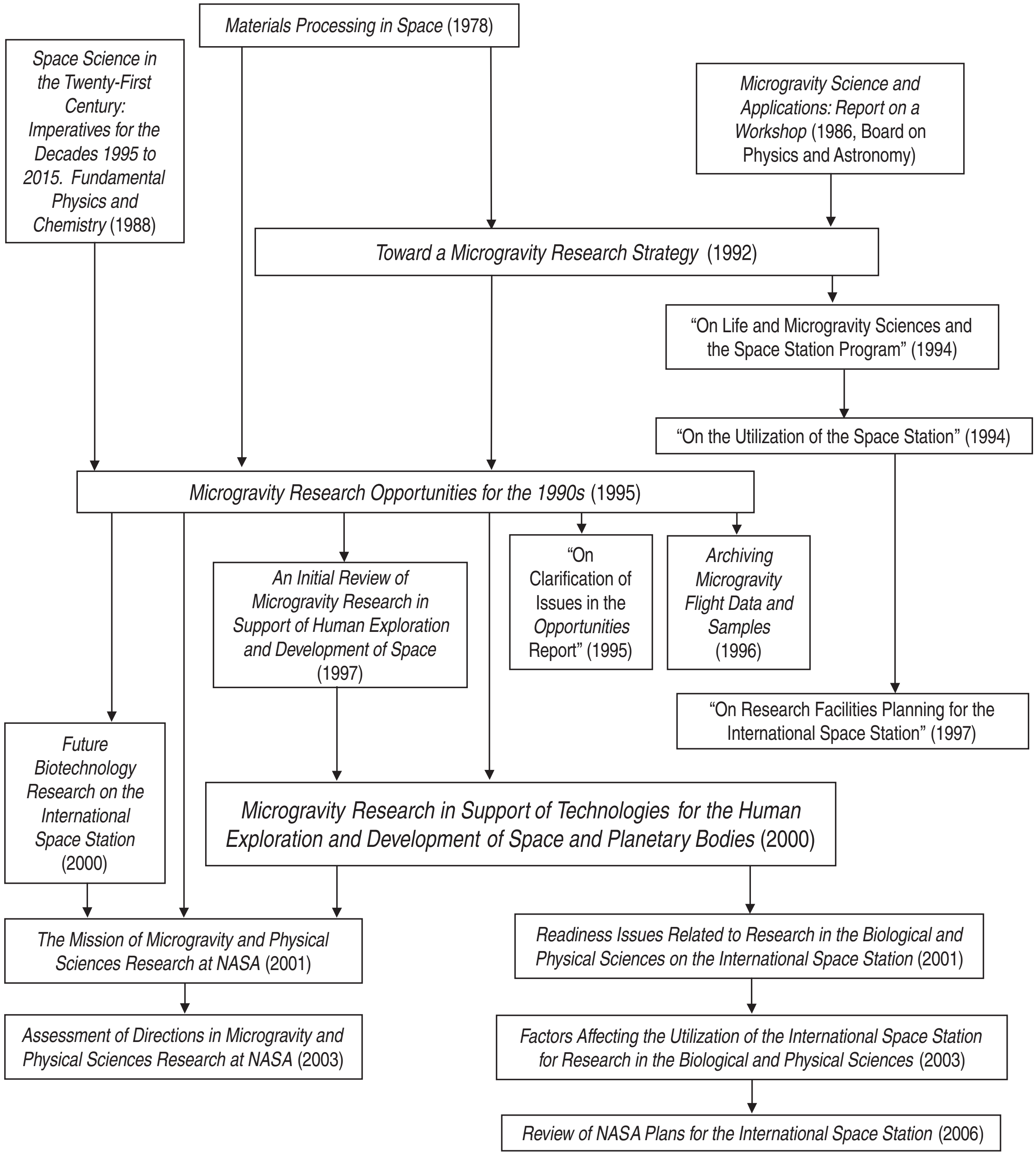


FIGURE 2.6 SSB-NRC advice on microgravity research (1978-2006).

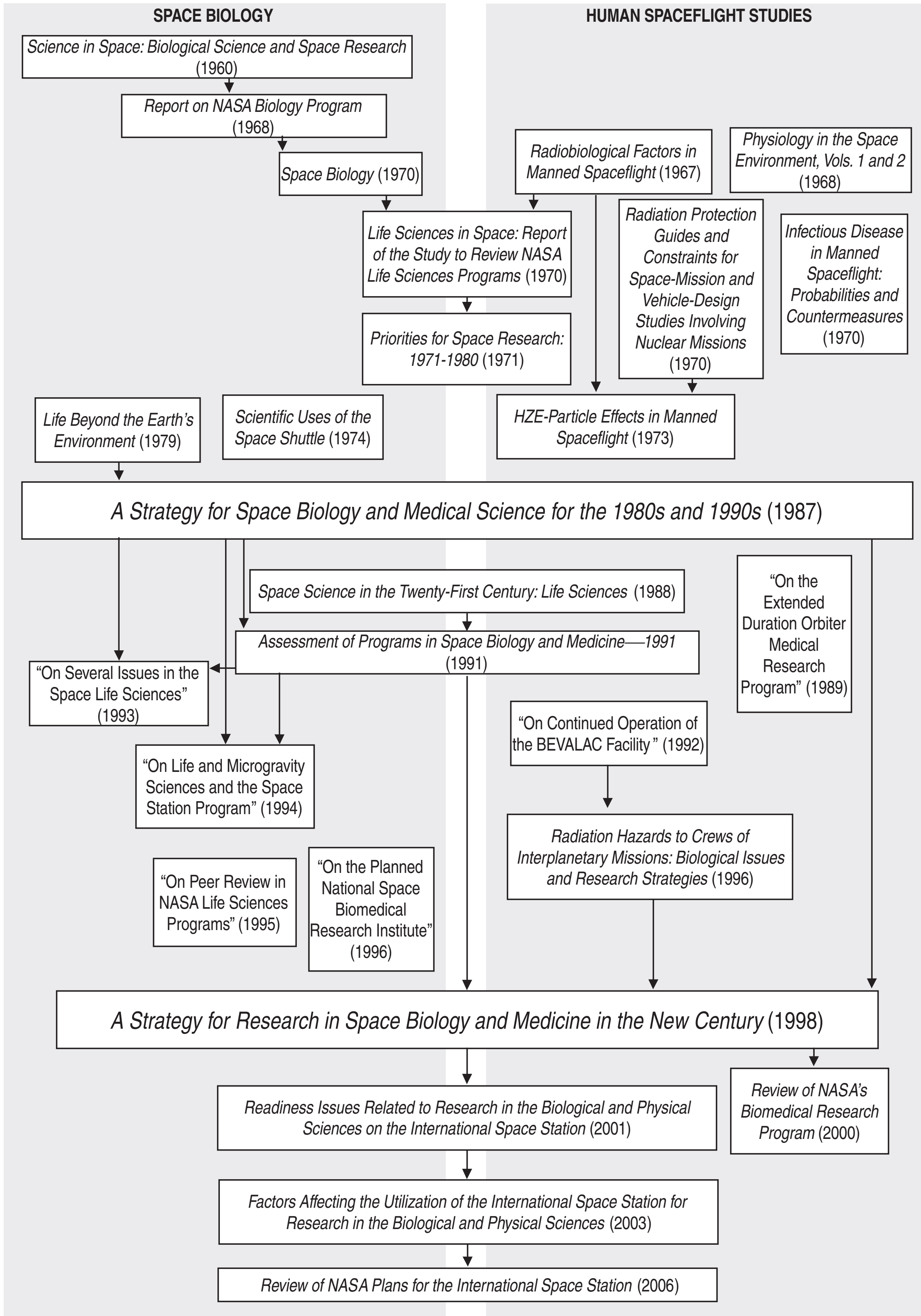


FIGURE 2.7 SSB-NRC advice on space biology and medicine (1960-2006).

# 3
# Ad Hoc Study Committees: Activities and Membership

When a sponsor requests that the Space Studies Board (SSB) conduct a study, an ad hoc committee is established for that purpose. The committee terminates when the study is completed. These study committees are subject to the Federal Advisory Committee Act, Section 15, because they provide advice and recommendations to the federal government. The SSB and/or one of its standing committees provide oversight for ad hoc study committee activities. Ten ad hoc committees were organized, met, or released studies during 2008. (Activities and membership are summarized below.)

In addition, two ad hoc committees that produced reports in 2007 were formally disbanded in 2008: the Committee on Assessing the Solar System Exploration Program and the Committee to Review the NASA Astrobiology Institute. Their reports were summarized in the 2007 annual report.

In December 2008, the National Research Council (NRC) Governing Board Executive Committee approved the prospectus for a study on the National Aeronautics and Space Administration's (NASA's) suborbital research activities. The SSB is now in the process of forming a committee to conduct a study of suborbital flight activities, including the use of sounding rockets, aircraft, and high-altitude balloons, and suborbital reusable launch vehicles, as well as related training, education, and workforce issues.

Preparation for a decadal survey in life and physical sciences space research got under way in December 2008 with widely disseminated solicitations for steering committee nominations in fields ranging from developmental biology to spacecraft engineering. The decadal survey is expected to establish priorities and provide recommendations for life and physical sciences space research, including research that will enable exploration missions in microgravity and partial gravity for the 2010-2020 decade.

## ASTRONOMY AND ASTROPHYSICS DECADAL SURVEY COMMITTEE (ASTRO2010)

The Board on Physics and Astronomy (BPA), in cooperation with SSB, began preparations for the next decadal survey for astronomy and astrophysics, Astro2010. Astro2010 will survey the field of space- and ground-based astronomy and astrophysics, recommending priorities for the most important scientific and technical activities of the decade 2010-2020.

In September 2008, former SSB member and Committee on Astronomy and Astrophysics co-chair Roger Blandford was appointed to chair the Astro2010 survey committee. Dr. Blandford, NRC staff, and members of BPA and SSB prepared a slate of nominations for the rest of the committee.

The Astro2010 survey committee held its first meeting December 5-6, 2008, in Washington, D.C. The committee discussed congressional and White House perspectives on the decadal survey with staff from the Senate Committee on Commerce, Science, and Transportation; the House Committee on Science and Technology; the Office of Science and Technology Policy; and the Office of Management and Budget. The committee also received briefings from agency sponsors, including John Morse, NASA Headquarters; Craig Foltz, National Science Foundation; and Dennis Kovar, Department of Energy. The committee provided an opportunity for public comment during the meeting and established a Web site, including calls for community input.

The steering committee will be assisted in its work by a series of nine panels that will address various topics. The committee will be responsible for synthesizing the panel inputs, determining priorities and recommendations, and preparing the final report which will have two volumes (a main committee report and a volume that will contain reports from the panels).

### *Steering Committee Membership*

Roger D. Blandford, Stanford University (chair)
Martha P. Haynes, Cornell University (co-vice chair)
John P. Huchra, Harvard-Smithsonian Center for Astrophysics (co-vice chair)
Marcia J. Rieke, University of Arizona (co-vice chair)
Steven J. Battel, Battel Engineering
Lars Bildsten, University of California, Santa Barbara
John E. Carlstrom, University of Chicago
Debra M. Elmegreen, Vassar College
Joshua Frieman, Fermi National Accelerator Laboratory
Fiona A. Harrison, California Institute of Technology
Timothy M. Heckman, Johns Hopkins University
Lynne Hillenbrand, California Institute of Technology
Robert C. Kennicutt, Jr., University of Cambridge
Jonathan I. Lunine, University of Arizona
Claire E. Max, University of California, Santa Cruz
Dan McCammon, University of Wisconsin, Madison
Steven M. Ritz, NASA Goddard Space Flight Center
Juri Toomre, University of Colorado, Boulder
Scott D. Tremaine, Institute for Advanced Study
Michael S. Turner, University of Chicago
Neil de Grasse Tyson, American Museum of Natural History
Paul Adrian Vanden Bout, National Radio Astronomy Observatory
A. Thomas Young, Lockheed Martin Corporation (retired)

Donald C. Shapero, Director, Board on Physics and Astronomy
Michael Moloney, Associate Director, Board on Physics and Astronomy (study director)
Brant Sponberg, Associate Director, Space Studies Board
Robert Riemer, Senior Program Officer, Board on Physics and Astronomy
Brian Dewhurst, Program Officer, Aeronautics and Space Engineering Board
David Lang, Program Officer, Board on Physics and Astronomy
Carmela Chamberlain, Program Associate, Space Studies Board
Caryn Knutsen, Program Associate, Board on Physics and Astronomy
LaVita Coates-Fogle, Senior Program Assistant, Board on Physics and Astronomy

## HELIOPHYSICS PERFORMANCE ASSESSMENT

The ad hoc Heliophysics Performance Assessment Committee was formed to study the alignment of NASA's Heliophysics Science Division with previous NRC advice—primarily the 2003 solar and space physics decadal survey, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*. Addressing, in particular, how well NASA's current program addresses the strategies, goals, and priorities outlined in the decadal survey and other relevant NRC reports; NASA's progress toward realizing these strategies, goals, and priorities; and any actions that could be taken to optimize the science value of the program in the context of current and forecasted resources available. The study does not revisit or alter the scientific priorities or mission recommendations provided in the 2003 decadal survey, but may provide guidance about implementing the recommended mission portfolio in preparation for the next decadal survey.

The Heliophysics Performance Assessment Committee met on April 22-24, 2008, at the National Academies' Keck Center in Washington, D.C., to receive presentations from and conduct discussions with congressional staff, NASA staff, and former members of the committees that produced the solar and space physics decadal survey and two other NRC mid-decade surveys in astronomy and astrophysics and solar system exploration.

The committee held its second meeting June 9-11 at the High Altitude Observatory in Boulder, Colorado, where it received presentations from NASA's Mission Operating Working Groups, the National Oceanic and Atmospheric Administraiton's (NOAA's) Space Environment Center, and the NRC's Committee on Solar and Space Physics. The committee also conducted site visits to the NASA Goddard Space Flight Center and the Johns Hopkins University Applied Physics Laboratory on May 13, where it received briefings on relevant programs and missions.

The committee met August 25-27 at the National Academies' Beckman Center in Irvine, California, to begin writing its report. The committee finished writing its report in late December. The report has entered review and is expected to be released in early February 2009.

### *Membership*

Stephen A. Fuselier, Lockheed Martin Advanced Technology Center (co-chair)
Roderick A. Heelis, University of Texas, Dallas (co-chair)
Thomas Berger, Lockheed Martin Solar and Astrophysics Laboratory
George Gloeckler, University of Maryland, College Park
Jack R. Jokipii, University of Arizona
Krishan Khurana, University of California, Los Angeles
Dana Warfield Longcope, Montana State University
Gang Lu, High Altitude Observatory
Kristina A. Lynch, Dartmouth College
Frank B. McDonald, University of Maryland, College Park
Michael Mendillo, Boston University
Robert E. Palmer, Independent Consultant
Gary P. Zank, University of California, Riverside

Brant L. Sponberg, Associate Director and Senior Program Officer, Space Studies Board (study director)
Arthur A. Charo, Senior Program Officer, Space Studies Board
Carmela J. Chamberlain, Program Associate, Space Studies Board

## NEAR-EARTH OBJECT SURVEYS AND HAZARD MITIGATION STRATEGIES

An ad hoc Committee on Near-Earth Object Surveys and Hazard Mitigation Strategies was formed under the auspices of the SSB and the Aeronautics and Space Engineering Board (ASEB) to undertake a two-phase study to review the two NASA reports, *2006 Near-Earth Object Survey and Detection Study* and *Near-Earth Object Survey and Deflection Analysis of Alternatives: Report to Congress,* and other relevant literature and provide recommendations that will address two major issues: (1) determining the best approach to completing the near-Earth object (NEO) census required by Congress to identify potentially hazardous NEOs larger than 140 meters in diameter by the year 2020 and (2) determining the optimal approach to developing a deflection strategy and ensuring that it includes a significant international effort. Both tasks will include an assessment of the costs of various alternatives, using independent cost estimating. Task 1 will be addressed by the Survey/Detection Panel, and Task 2 will be addressed by the Mitigation Panel.

The steering group held its first meeting at the National Academies' Keck Center on December 9-11, 2008. The steering group's second meeting will take place at Arecibo, Puerto Rico, in May 2009. The Survey/Detection Panel held its first meeting at the National Academies' Keck Center on January 28-30, 2009, and will hold its second meeting April 20-22 at the Lunar and Planetary Laboratory in Tucson, Arizona. The committee's Mitigation Panel will be appointed in early March and will hold its first meeting in late March 2009.

***Steering Group Membership***

Irwin I. Shapiro, Harvard-Smithsonian Center for Astrophysics (chair)
Michael A'Hearn, University of Maryland, College Park (vice chair)
Faith Vilas, Multiple-Mirror Telescope Observatory at Mt. Hopkins, Arizona (vice chair)
Andrew F. Cheng, Johns Hopkins University, Applied Physics Laboratory
Frank Culbertson, Jr., Orbital Sciences Corporation
David C. Jewitt, University of Hawaii, Manoa
Stephen Mackwell, Lunar and Planetary Institute
H. Jay Melosh, University of Arizona
Joseph Rothenberg, Universal Space Network

Dwayne A. Day, Program Officer, Space Studies Board (co-study director)
Paul Jackson, Associate Program Officer, Aeronautics and Space Engineering Board (co-study director)
David H. Smith, Senior Program Officer, Space Studies Board
Rodney N. Howard, Senior Program Assistant, Space Studies Board

## NEW OPPORTUNITIES IN SOLAR SYSTEM EXPLORATION

The ad hoc Committee to Review New Opportunities in Solar System Exploration was formed to conduct an analysis of a number of issues that relate to NASA's next New Frontiers Announcement of Opportunity (AO) and provide criteria and guiding principles for determining the list of candidate missions. At the request of the sponsor, NASA's Science Mission Directorate (SMD), the study's statement of task was revised to reflect SMD's new interest in possibly including Mars in the New Frontiers program. In addition to its original requirements, the study will make recommendations about whether Mars mission proposals should be considered in the New Frontiers AO, or remain separate, as has been true historically.

The committee delivered its report, *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity,* to NASA on March 4 and publicly released the report on March 12, 2008. On the day of its public release, Planetary Science Division director Jim Green announced that NASA had accepted all of the report's recommendations, which increase the number of mission options for the next New Frontiers AO. However, NASA later announced that it would not follow the recommendation for considering other options outside of the eight recommended in the report. The final version of the New Frontiers AO may be delayed due to budget considerations.

***Membership***

Reta F. Beebe, New Mexico State University (co-chair)
Warren W. Buck, University of Washington (co-chair)
Douglas P. Blanchard, NASA Johnson Space Center (retired)
Robert D. Braun, Georgia Institute of Technology
Bernard F. Burke, Massachusetts Institute of Technology
Alan Delamere, Ball Aerospace and Technologies Corporation (retired)
Rosaly M. Lopes-Gautier, Jet Propulsion Laboratory
Stephen Mackwell, Lunar and Planetary Institute
Timothy J. McCoy, Smithsonian Institution
Ralph L. McNutt, Jr., Johns Hopkins University, Applied Physics Laboratory
Sandra Pizzarello, Arizona State University
Gerald Schubert, University of California, Los Angeles
Donna L. Shirley, Managing Creativity
John Spencer, Southwest Research Institute
Elizabeth P. Turtle, Johns Hopkins University, Applied Physics Laboratory

Dwayne A. Day, Program Officer, Space Studies Board (study director)
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

## PLANETARY PROTECTION REQUIREMENTS FOR MARS SAMPLE RETURN MISSIONS

An ad hoc Committee on Planetary Protection Requirements for Mars Sample Return Missions was formed to review and update the 1997 NRC report *Mars Sample Return: Issues and Recommendations* in the light of new findings about Mars and recent advances in the biological sciences.

The committee met twice in 2008—at Arizona State University in Tempe, Arizona, on August 12-14, 2008, and at the National Academy of Sciences Building in Washington, D.C., on September 8-10, 2008. Both meetings were devoted to presentations on planetary protection policies and practices, planning activities for a Mars sample return mission, biosecurity issues, scientific advances in the study of the martian environment, and life in extreme terrestrial environments. A draft of the committee's report, *Assessment of Planetary Protection Requirements for Mars Sample Return Missions,* was sent out to external reviewers for comment in early December. Delivery of the report to NASA is expected in the first quarter of 2009.

### *Membership*

Jack D. Farmer, Arizona State University (chair)
James F. Bell III, Cornell University
Kathleen C. Benison, Central Michigan University
William V. Boynton, University of Arizona
Sherry L. Cady, Portland State University
F. Grant Ferris, University of Toronto
Duncan MacPherson, Jet Propulsion Laboratory
Margaret S. Race, SETI Institute
Mark H. Thiemens, University of California, San Diego
Meenakshi Wadhwa, Arizona State University

David H. Smith, Senior Program Officer, Space Studies Board (study director)
Rodney N. Howard, Senior Program Assistant, Space Studies Board

## RADIOISOTOPE POWER SYSTEMS

Radioisotope power systems, such as radioisotope thermoelectric generators, provide electric power to NASA spacecraft traveling to the outer planets and on other missions where solar arrays are not a viable option. An ad hoc Committee on Radioisotope Power Systems was formed to assess the technical readiness and programmatic balance of NASA's radioisotope power systems technology portfolio in terms of its ability to support NASA's near- and long-term mission plans. In addition, the study will also examine related public and private infrastructure and the effectiveness of other federal agencies involved in relevant R&D. The study will also review strategies for reestablishing domestic production of plutonium-238 (Pu-238), which serves as the fuel for radioisotope power systems.

The committee held three meetings in 2008: September 18-19 at the National Academies' Keck Center in Washington, D.C.; October 27-29 at the Jet Propulsion Laboratory in Pasadena, California; and December 11-12 at the National Academy of Sciences Building in Washington, D.C. During these meetings, the committee collected information on NASA's needs for radioisotope power systems; related research and development by NASA, the Department of Energy, and industry; and the options available to the Department of Energy for meeting NASA's needs for Pu-238. The committee also prepared a tentative set of findings and recommendations and a preliminary draft of its final report. As part of the information collection effort, small groups of committee members also conducted site visits at NASA's Glenn Research Center (October 10), the Idaho National Laboratory (October 15), and the Oak Ridge National Laboratory (November 13). The committee's final meeting will be held January 12-13, 2009, at the National Academies' Arnold and Mabel Beckman Center in Irvine, California.

### *Membership*

William W. Hoover, Independent Consultant (co-chair)
Ralph L. McNutt, Jr., Johns Hopkins University, Applied Physics Laboratory (co-chair)

Douglas M. Allen, Schafer Corporation
Samim Anghaie, University of Florida
Reta F. Beebe, New Mexico State University
Warren W. Buck, University of Washington
Beverly A. Cook, Jet Propulsion Laboratory
Sergio B. Guarro, The Aerospace Corporation
Roger D. Launius, Smithsonian Institution
Frank B. McDonald, University of Maryland, College Park
Alan R. Newhouse, Independent Consultant
Joseph A. Sholtis, Jr., Sholtis Engineering and Safety Consulting
Spencer R. Titley, University of Arizona
Emanuel Tward, Northrop Grumman Space Technology
Earl Wahlquist, U.S. Department of Energy (retired)

Alan C. Angleman, Senior Program Officer, Aeronautics and Space Engineering Board (study director)
Dwayne A. Day, Program Officer, Space Studies Board
Sarah M. Capote, Program Associate, Aeronautics and Space Engineering Board (through November 2008)
Celeste A. Naylor, Senior Program Assistant, Space Studies Board (from November 2008 through January 2009)
Andrea M. Rebholz, Senior Program Assistant, Aeronautics and Space Engineering Board (from February 2009)

## RATIONALE AND GOALS FOR THE U.S. CIVIL SPACE PROGRAM

An ad hoc Committee on Rationale and Goals for the U.S. Civil Space Program was organized under the auspices of the SSB and the ASEB, with funding support from The National Academies Presidents' Committee, to prepare a report to advise the nation on key goals and critical issues in 21st century U.S. civil space policy. The committee will, inter alia, analyze the rationale for U.S. efforts in space and the elements comprising leadership in this area; examine the balance and interfaces between fundamental scientific research in space, human space exploration, and applications of space technology and civil space systems for societal benefits; assess the role that commercial space companies can play in fulfilling national space goals and the proper role of the government in facilitating the emergence and success of commercial space companies; and recommend options for government attention to address and potentially resolve problems that the committee might identify. The committee will identify issues that are critically important to the future vitality and progress of the U.S. civil space program and recommend options to address and resolve critical issues.

At its information-gathering and discussion meetings on October 5-7, 2008, and December 3-5, 2008, the committee heard perspectives from several federal agencies (NASA, NOAA, the Department of Defense, and the Federal Aviation Administration) and other guest experts on a wide range of topics—including Earth observations, space exploration and science, advanced technology, national security, entrepreneurship, foreign policy, and public interest—all in the context of the study charge. The committee will meet again on January 13-15, 2009.

### *Membership*

Lester L. Lyles, The Lyles Group (chair)
Raymond S. Colladay, Lockheed Martin Astronautics (retired) (co-vice chair)
Lennard A. Fisk, University of Michigan (co-vice chair)
Jay Apt, Carnegie Mellon University
James B. Armor, Jr., The Armor Group, LLC
Wanda M. Austin, The Aerospace Corporation
David Baltimore, California Institute of Technology
Robert Bednarek, SES NEW SKIES
Joseph A. Burns, Cornell University
Pierre Chao, Renaissance Strategic Advisors
Kenneth S. Flamm, University of Texas, Austin
Joan Johnson-Freese, U.S. Naval War College

Paul D. Nielsen, Carnegie Mellon University
Michael S. Turner, University of Chicago
Thomas H. Vonder Haar, Colorado State University
George T. Whitesides,* National Space Society

Joseph K. Alexander, Senior Program Officer, Space Studies Board (co-study director)
Brian D. Dewhurst, Program Officer, Aeronautics and Space Engineering Board (co-study director)
Carmela J. Chamberlain, Program Associate, Space Studies Board
Lewis Groswald, Policy Intern, Space Studies Board
Victoria Swisher, Research Assistant, Space Studies Board

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*Resigned from committee November 2008.

## ROLE AND SCOPE OF MISSION-ENABLING ACTIVITIES IN NASA'S SPACE AND EARTH SCIENCE MISSIONS

The ad hoc Committee on the Role and Scope of Mission-Enabling Activities in NASA's Space and Earth Science Missions was formed to study mission-enabling activities, which traditionally encompass much of NASA's research and analysis programs and which include support for theory, modeling, and data analysis; suborbital flights and complementary ground-based programs; and advanced mission and instrumentation concept studies. The committee will identify the appropriate roles for mission-enabling activities and metrics for assessing their effectiveness; evaluate how, from a strategic perspective, decisions should be made about balance between mission-related and mission-enabling elements of the overall program; and evaluate the balance between various elements within the mission-enabling component. The committee held a conference-call organizational meeting on October 28, 2008, and the first full committee meeting will be at the National Academies' Beckman Center in Irvine, California, on January 21-23, 2009.

### *Membership*

Lennard A. Fisk, University of Michigan (chair)
Bruce H. Margon, University of California, Santa Cruz (vice chair)
Mark R. Abbott, Oregon State University
Steven J. Battel, Battel Engineering
Yvonne C. Brill, Independent Consultant
Donald Brownlee, University of Washington
Richard Chapas, Battelle Eastern Science and Technology Center
Martin H. Israel, Washington University
Conilee G. Kirkpatrick, HRL Laboratories, LLC
Jennifer A. Logan, Harvard University
Robyn Millan, Dartmouth College
Richard R. Paul, Boeing Phantom Works (retired)
Guenter Riegler, NASA Ames Research Center (retired)
Mark V. Sykes, Planetary Science Institute

Joseph K. Alexander, Senior Program Officer, Space Studies Board (study director)
Victoria Swisher, Research Associate, Space Studies Board
Linda Walker, Senior Project Assistant, Space Studies Board

## SCIENCE OPPORTUNITIES ENABLED BY NASA'S CONSTELLATION SYSTEM

The ad hoc Committee on Science Opportunities Enabled by NASA's Constellation System was formed under the auspices of SSB and ASEB to assess potential space and Earth science mission concepts that could take advantage of the capabilities of the Constellation System of launch vehicles and spacecraft that is being developed by NASA. The committee analyzed mission concepts provided by NASA and mission concepts submitted in response to a Request for Information from the committee to the space and Earth science communities.

At its February 20-22, 2008, meeting at the Keck Center in Washington, D.C., the committee was briefed on the Ares I and Ares V rockets and the results of 11 "Vision Mission" studies conducted for NASA from 2005 to 2006. The committee's March 17-19, 2008, meeting at the Beckman Center in Irvine, California, was entirely devoted to writing the committee's interim report. The interim report, *Science Opportunities Enabled by NASA's Constellation System: Interim Report,* was delivered to NASA in late April and publicly released in early May.

At its June 9-11, 2008, meeting in Boulder, Colorado, the committee evaluated responses from the scientific community to its request for information. At its August 4-6, 2008, meeting in Woods Hole, Massachusetts, the committee heard briefings on the value of Ares V for planetary missions from Tom Spilker, Jet Propulsion Laboratory, and on robotic servicing of the Orbital Express mission from Tracey Espero, Boeing. The remainder of the meeting was devoted to report writing.

The committee delivered a prepublication version of its final report, *Launching Science: Science Opportunities Provided by NASA's Constellation System,* to NASA on November 14, 2008; a published version is expected in February 2009.

***Membership***

George A. Paulikas, The Aerospace Corporation (retired) (chair)
Kathryn C. Thornton, University of Virginia (vice chair)
Claudia J. Alexander, Jet Propulsion Laboratory
Steven V.W. Beckwith, University of California System
Mark A. Brosmer, The Aerospace Corporation
Joseph A. Burns, Cornell University
Cynthia A. Cattell, University of Minnesota, Minneapolis
Alan Delamere, Ball Aerospace and Technologies Corporation (retired)
Margaret Finarelli, George Mason University
Todd Gary, Tennessee State University
Steven Howell, National Optical Astronomy Observatories
Arlo U. Landolt, Louisiana State University and Agricultural and Mechanical College
Franklin D. Martin, Martin Consulting, Inc.
Spencer R. Titley, University of Arizona
Carl Wunsch, Massachusetts Institute of Technology

Dwayne A. Day, Program Officer, Space Studies Board (study director)
Rodney N. Howard, Senior Program Assistant, Space Studies Board

## STRATEGY TO MITIGATE THE IMPACT OF SENSOR DESCOPES AND DEMANIFESTS ON THE NPOESS AND GOES-R SPACECRAFT

The ad hoc Committee on A Strategy to Mitigate the Impact of Sensor Descopes and Demanifests on the NPOESS and GOES-R Spacecraft was formed shortly before the SSB held a June 2007 workshop on Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft. NASA and NOAA requested that the NRC form this ad hoc committee to carry out a fast turn-around follow-on study that would (1) prioritize capabilities, especially those related to climate research that were lost or placed at risk following recent changes to NPOESS and the GOES-R series of polar and geostationary environmental monitoring satellites and (2) present strategies to recover these capabilities.

The committee met in October and December 2007 and released a prepublication version of its report in July 2008. In late August 2008, a final version of the report, *Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring,* was published. For convenience, this report also has an appendix that reproduces the final, edited version of the report from the June 2007 workshop, *Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft: A Workshop Report*. The report's Summary is reprinted in Chapter 5.

***Membership***

Antonio J. Busalacchi, Jr., University of Maryland, College Park (chair)
Philip E. Ardanuy, Raytheon Information Solutions
Judith A. Curry, Georgia Institute of Technology
Craig J. Donlon, Meteorological Office Hadley Centre for Climate Prediction and Research
Judith L. Lean, Naval Research Laboratory
Berrien Moore III, Climate Central
R. Steven Nerem, University of Colorado, Boulder
Anne W. Nolin, Oregon State University
Jay S. Pearlman, Institute of Electrical and Electronics Engineers, Inc.
Joyce E. Penner, University of Michigan
James F.W. Purdom, Colorado State University
Carl F. Schueler, Raytheon Company (retired)
Graeme L. Stephens, Colorado State University
Christopher S. Velden, University of Wisconsin, Madison
Robert A. Weller, Woods Hole Oceanographic Institution
Frank J. Wentz, Remote Sensing Systems

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Theresa M. Fisher, Program Associate, Space Studies Board

# *4*
# *Workshops, Symposia, Meetings of Experts, and Other Special Projects*

In 2008, the Space Studies Board (SSB) convened three workshops (two in collaboration with other National Research Council [NRC] units), one colloquium, five public seminars, and two meetings of experts. (Projects are summarized below.) The planning committees for these projects do not provide advice and, therefore, are not governed by the Federal Advisory Committee Act, Section 15.

Summary reports were published in 2008 for two 2007 workshops—the September 2007 Workshop to Promote Dialog on Space Science Activities and International Traffic in Arms Regulations and the November 2007 SSB-Aeronautics and Space Engineering Board (ASEB) Workshop on U.S. Civil Space Policy. These reports were summarized in the 2007 annual report.

## BALANCE IN THE SOLAR SYSTEM EXPLORATION PROGRAM

On March 14-15, 2008, the National Aeronautics and Space Administration (NASA) held a meeting of experts on balance in the solar system exploration program, convened by the NRC. The meeting involved approximately a dozen experts in the field of solar system exploration offering candid off-the-record advice to Associate Administrator Alan Stern and several of his advisors on various issues concerning the future of solar system exploration. Under the rules of the meeting, the NRC does not take minutes or prepare any written materials for NASA. At the time of the meeting, three additional meetings on other space science topics were planned. These meetings did not occur and no further meetings of experts are expected.

Dwayne A. Day, Program Officer, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

## FORGING THE FUTURE OF SPACE SCIENCE

The Forging the Future of Space Science international public seminar series commemorated the 50th anniversary of the International Geophysical Year and SSB, engaging the public and the scientific community about the advances that have been achieved over the past 50 years in space science, and the discoveries that await us in the next 50 years. In this context, "space science" incorporates space-based astrophysics, heliophysics, Earth science, solar system exploration, and microgravity life and physical sciences.

In 2008, the series continued with five public seminars and an all-day colloquium. Each seminar involved a panel session addressing the future of space science in various disciplines and a featured lecture. The featured lectures were delivered by Carl Walz, NASA astronaut and director, Advanced Capabilities, NASA Exploration Mission Systems Directorate (*Leaving the Planet—Science and Technology Development Results on the Inter-*

*national Space Station,* January 16, 2008, Tallahassee, Florida); Christopher Chyba, professor of astrophysical sciences and international affairs, Woodrow Wilson School, Princeton University (*The Possibility of Life Elsewhere in the Universe,* February 20, 2008, Austin, Texas); Christopher Rapley, director, Science Museum, London, England (*Understanding the Poles of the Earth, Moon and Mars,* March 27, 2008, Paris, France; the Paris venue was selected to underscore the international character of space science and was organized in conjunction with the Committee on Space Research); Edward C. Stone, president, International Academy of Astronautics, and professor of physics, California Institute of Technology (*Understanding the Sun: Voyager's Continuing Journey of Discovery,* April 14, 2008, Boulder, Colorado); and Charles Elachi, director, Jet Propulsion Laboratory (*The Future of Space and Earth Robotic Exploration: Scientific Administrator Technological Challenges,* April 25, 2008, Fairmont, West Virginia).

The all-day public colloquium, held in Washington, D.C., on June 26, 2008, was followed by an invitation-only reception at the National Air and Space Museum. During the reception, the SSB awarded its James A. Van Allen Lectureship to Frank B. McDonald. Dr. McDonald lectured on *Explorer 1: Gateway to the Never Ending Wonders of Space Science*.

Details about the series, along with webcasts, podcasts, and presentation files, can be found at http://www7.nationalacademies.org/ssb/International_Public_Seminar_Series.html.

## FUTURE INTERNATIONAL SPACE COOPERATION AND COMPETITION IN A GLOBALIZING WORLD

The ad hoc Planning Committee for the Future International Space Cooperation and Competition in a Globalizing World: A Workshop, under the auspices of the SSB and the ASEB, organized a public workshop to review past and present cooperation and coordination mechanisms for space and Earth science research and space exploration, identify significant lessons learned, and discuss how those lessons could best be applied in the future. The workshop was held on November 18-20, 2008, concurrent with the SSB meeting at the Arnold and Mabel Beckman Center in Irvine, California, and featured invited presentations, panel discussions, and four discussion groups, each dedicated to a specific topic. Approximately 50 individuals participated, including the majority of the SSB and one member of the ASEB. A report summarizing the panel sessions and the output of the four discussion groups, prepared by the rapporteur and SSB staff, is expected to be released in March 2009. The workshop agenda and the two workshop keynotes can be found at http://www7.nationalacademies.org/ssb/International CooperationWorkshop2008.html.

### *Planning Committee Membership*

Charles F. Kennel, Scripps Institution of Oceanography at the University of California (chair)
A. Thomas Young, Lockheed Martin Corporation (retired)
Daniel N. Baker, University of Colorado, Boulder
David Goldston, Harvard University
Joan Johnson-Freese, U.S. Naval War College
Richard H. Kohrs, Independent Consultant
Molly K. Macauley, Resources for the Future, Inc.
Berrien Moore III, Climate Central
Joan Vernikos, Thirdage LLC
Warren M. Washington, National Center for Atmospheric Research

Ian W. Pryke, Senior Program Officer, Space Studies Board
Carmela J. Chamberlain, Program Associate, Space Studies Board

## ORGANIZATION OF A DECADAL SURVEY IN MICROGRAVITY RESEARCH

A meeting of experts on the organization of a decadal survey in microgravity research was held on May 15-16, 2008, at the National Academy of Sciences in Washington, D.C. Invited experts in physical and life sciences research heard presentations from NASA's Exploration Systems Mission Directorate program on the agency's strategy for implementing its exploration program and on the history of NASA's space life and physical sciences research over the last 5 years. Subsequent discussion between the invited experts and NASA representatives focused on the potential scope of a congressionally requested study in microgravity research, the opportunities and barriers to science community input and participation in the study, the organization of the study's steering committee and panels, and the likely utilization of the report. The comments of the invited experts at the meeting were considered by NASA and the NRC in the later development of a task statement for the decadal survey. Following approval and funding, work began on the decadal study in December with the solicitation of nominations for a steering committee.

Sandra J. Graham, Senior Program Officer, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

## SOCIETAL AND ECONOMIC IMPACTS OF SEVERE SPACE WEATHER EVENTS

An ad hoc planning committee for the Societal and Economic Impacts of Severe Space Weather Events Workshop was formed in 2007 to organize a workshop to examine the nation's current and future ability to manage the effects of space weather events on a wide range of critical infrastructures, and their resulting societal and economic impacts. The planning committee's February 19-21, 2008, meeting at the National Academies' Keck Center in Washington, D.C., was devoted to data gathering and planning for the workshop. Members of the committee and invited experts provided briefings on space weather effects on various infrastructure systems including GPS, aviation, satellites, and the electrical power grid. Speakers from NASA and the National Oceanic and Atmospheric Administration briefed the committee on their space weather programs and services, and the committee also heard briefings on economic approaches to evaluating space weather impacts. As arranged, most of the speakers and invited participants remained for a full day of discussion with the committee on the workshop goals, topics, and issues. The final day of the meeting was held in closed session and the committee developed a preliminary agenda outline and potential list of speakers for the workshop. The committee continued to meet via conference call to develop activities for the workshop sessions and to identify, solicit, and coordinate with speakers and other participants.

The workshop was held at the Washington Plaza Hotel in Washington, D.C., on May 22-23, 2008. Approximately 80 representatives from industry, government agencies, and academia were in attendance. The workshop was divided into topic panels that focused on understanding specific impacts of past events on various critical infrastructures, the systems currently in place to forecast events and mitigate their effects, and the societal and technical trends likely to affect the nation's vulnerability to space weather impacts in the future. About 25 invited speakers discussed issues for specific systems such as satellites, communications, the power industry, and airlines. The workshop was successful in generating a vigorous information exchange and discussion among its diverse participants. The planning committee met in closed session immediately following the workshop and adjourned on May 25. Presentations from the workshop are posted online.

A report summarizing the information presented and discussions from the workshop, *Severe Space Weather Events—Understanding Societal and Economic Impacts: Workshop Report,* was prepared by the workshop planning committee. The workshop report does not contain conclusions or recommendations. Copies of the report were delivered to NASA on December 18, 2008, with public release in January 2009. The report has generated a great degree of media interest due to the broad public impact of the scenarios discussed at the workshop.

### *Planning Committee Membership**

Daniel N. Baker, University of Colorado, Boulder (chair)
Roberta Balstad, Columbia University
J. Michael Bodeau, Northrop Grumman Space Technology
Eugene Cameron, United Airlines, Inc.
Joseph F. Fennell, The Aerospace Corporation
Genene M. Fisher, American Meteorological Society
Kevin F. Forbes, Catholic University of America
Paul M. Kintner, Cornell University
Louis G. Leffler, North American Electric Reliability Council (retired)
William S. Lewis, Southwest Research Institute
Joseph B. Reagan, Lockheed Missiles and Space Company, Inc. (retired)

Arthur A. Small III, Pennsylvania State University
Thomas A. Stansell, Stansell Consulting
Leonard Strachan, Jr., Smithsonian Astrophysical Observatory

Sandra J. Graham, Senior Program Officer, Space Studies Board
Theresa M. Fisher, Program Associate, Space Studies Board

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*All terms expire in 2008.

## UNCERTAINTY MANAGEMENT IN REMOTE SENSING OF CLIMATE DATA

Under the auspices of the Board on Atmospheric Sciences and Climate, the Board on Mathematical Sciences and their Applications, and the SSB, an ad hoc committee was formed to plan and conduct the Workshop on Uncertainty Management in Remote Sensing of Climate Data that took place at the Doubletree Hotel in Washington, D.C., on December 4, 2008.

Convened jointly by the Climate Research Committee, the Committee on Applied and Theoretical Statistics, and the Committee on Earth Studies, the workshop explored uncertainty management in remote sensing of climate information. Through invited presentations and discussion, participants examined sources of uncertainty throughout satellite and other remote data collection systems, including issues of sampling, scale, processing, and validation; described the statistical methods currently used to quantify these sources of uncertainty for climate-relevant data; and explored how modern statistical methods might be used to provide a more powerful framework for characterizing and propagating these uncertainties.

A summary of the proceedings, prepared by a designated rapporteur, is expected to be released June 2009.

### *Planning Committee Membership*

Amy Braverman, Jet Propulsion Laboratory (chair)
Philip E. Ardanuy, Raytheon Information Solutions
John J. Bates, National Oceanic and Atmospheric Administration
James A. Coakley, Jr., Oregon State University
Karen Kafadar, Indiana University
Douglas Nychka, National Center for Atmospheric Research
Joyce E. Penner, University of Michigan
Steven E. Platnick, NASA Goddard Space Flight Center

Martha C. McConnell, Associate Program Officer, Board on Atmospheric Sciences and Climate (study director)
Arthur A. Charo, Senior Program Officer, Space Studies Board
Scott T. Weidman, Director, Board on Mathematical Sciences and their Applications
Katie Weller, Research Associate, Board on Atmospheric Sciences and Climate
Shelly Freeland, Program Assistant, Board on Atmospheric Sciences and Climate

# 5
# *Summaries of Major Reports*

This chapter reprints the summaries of reports that were released in 2008 (note that the official publication date may be 2009).

Two reports released in 2007 but published in 2008—*Assessment of the NASA Astrobiology Institute* and *Grading NASA's Solar System Exploration Program: A Midterm Review*—the summaries were reprinted in *Space Studies Board Annual Report—2007*.

# 5.1 Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring

A Report of the Ad Hoc Committee on a Strategy to Mitigate the Impact of Sensor Descopes and Demanifests on the NPOESS and GOES-R Spacecraft

## Summary

The nation's next-generation National Polar-orbiting Operational Environmental Satellite System (NPOESS) was created by the Presidential Decision Directive/National Science and Technology Council (NSTC)-2 of May 5, 1994, that merged the military and civil meteorological programs into a single program.[1] Within NPOESS, the National Oceanic and Atmospheric Administration (NOAA) is responsible for satellite operations, the Department of Defense (DOD) is responsible for major acquisitions, and the National Aeronautics and Space Administration (NASA) is responsible for the development and infusion of new technologies.

In 2000, the NPOESS program anticipated purchasing six satellites for $6.5 billion, with a first launch in 2008. By November 2005, however, it had become apparent that NPOESS would overrun its cost estimates by at least 25 percent, triggering a Nunn-McCurdy review by the DOD. The results of that review were announced in June 2006;[2] among the notable changes in the "certified" NPOESS program were the following:

- The planned acquisition of six spacecraft was reduced to four.
- The planned use of three Sun-synchronous orbits was reduced to two, with data from the European Meteorological Operational (MetOp) satellites provided by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) providing data for the canceled mid-morning orbit.
- The launch of the first spacecraft, NPOESS C1, was delayed until 2013.
- Several sensors were canceled (in common parlance, "demanifested") or degraded ("descoped") in capability as the program was refocused on "core" requirements related to the acquisition of data to support numerical weather prediction. "Secondary" (non-core) sensors that would provide crucial continuity to certain long-term climate records, as well as other sensors that would have provided new measurement capabilities, were not funded in the certified NPOESS program.

Since the 1970s, NOAA has operated geostationary satellites that provide images and data on atmospheric, oceanic, and climatic conditions over the continental United States and Hawaii from ~22,000 miles above the equator. NOAA's next generation of geostationary weather satellites will commence with the launch of GOES-R in 2015.[3] Originally, plans for this series included four satellites—GOES-R through GOES-U. However, in September 2006, following significant cost growth and estimates that the total program cost would nearly double,[4] NOAA

NOTE: "Summary" reprinted from *Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring*, The National Academies Press, Washington, D.C., 2008, pp. 1-9.

[1]Presidential Decision Directive/NSTC-2, "Convergence of U.S.-Polar-Orbiting Operation Environmental Satellite Systems," May 5, 1994, available at http://www.ipo.noaa.gov/About/NSTC-2.html.

[2]See U.S. House of Representatives Committee on Science, Hearing Charter, "The Future of NPOESS: Results of the Nunn-McCurdy Review of NOAA's Weather Satellite Program," June 8, 2006, available at http://gop.science.house.gov/hearings/full06/June%208/charter.pdf.

[3]Following program changes in September 2006, it was announced that launch of the first spacecraft in the GOES-R satellite series would be delayed until December 2014. However, a reduction in funds included in the FY 2008 enacted budget resulted in an additional delay until April 2015. See Chapter 4, "Procurement, Acquisition and Construction," in *NOAA FY 2009 Budget Summary*, available at http://www.corporateservices.noaa.gov/~nbo/09bluebook_highlights.html.

[4]The cost growth resulted in part from the risk reduction achieved by a deliberate shift from a 50 percent cost probability to the more conservative 80 percent probability, based on lessons learned from NPOESS.

reduced the scope of the program, removed a key instrument on the spacecraft, the Hyperspectral Environmental Suite (HES),[5] and revised the procurement process so that only two satellites are guaranteed.[6]

These events prompted a request from NASA and NOAA for two National Research Council (NRC) efforts. The first, a workshop titled "Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft" and held in Washington, D.C., on June 19-21, 2007, gave participants an opportunity to discuss options to recover measurement capabilities, especially those related to climate research, that were lost as a result of the Nunn-McCurdy actions and the cancellation of the HES on GOES-R. Some 100 scientists and engineers from academia, government, and industry attended the workshop, commenting on a draft mitigation plan developed by NASA and NOAA[7] as well as exploring options not included in the NASA-NOAA report. A prepublication version of the workshop report (NRC, 2008) was released in October 2007.

The second NRC effort, a study documented in the present report, builds on the information gathered at the June 2007 workshop. In their request for this study (Appendix A), NASA and NOAA asked that a committee of the NRC "prioritize capabilities, *especially those related to climate research*, that were lost or placed at risk following recent changes to NPOESS and the GOES-R series of polar and geostationary environmental monitoring satellites" [emphasis added].

The Committee on a Strategy to Mitigate the Impact of Sensor Descopes and Demanifests on the NPOESS and GOES-R Spacecraft understands "climate" to be "the statistical description in terms of the mean and variability of relevant measures of the atmosphere-ocean system over periods of time ranging from weeks to thousands or millions of years" (Climate Change Science Program and the Subcommittee on Global Change Research, 2003, p. 12). In the present study, the committee primarily considered climate-related physical, chemical, and biological processes that vary on interannual to centennial timescales. It is also important to note that the committee did not a priori assume a longer-duration measurement record would be assigned a higher priority than a shorter-duration measurement record. Instead, the committee considered each measurement's value to climate science in a more comprehensive sense as described in the section below on prioritization. The committee interprets the information needed for climate research broadly to be that which enables:

- Detection of variations in climate (through long-term records),
- Climate predictions and projections,[8] and
- Improved understanding of the physical, chemical, and biological processes involved in climate variability and change.

In performing its prioritization, the committee was cognizant of the scientific importance of maintaining long-term records of climate forcing *and* improving understanding of the climate system through starting or continuing records of climate responses. It also recognized the challenges of finding an appropriate balance between observations of climate forcing and response on the one hand, and sustained observations and improved "process" understanding on the other. The committee notes that its interpretation of the research agenda for climate-related issues is consistent with the five goals of the U.S. Climate Change Science Program (Box S.1).

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[5]The Hyperspectral Environmental Suite consisted of two components: an advanced hyperspectral sounder and a coastal waters imager. The hyperspectral sounder was intended to greatly advance current operational geostationary sounding capability; its cancellation will instead end the long-term geostationary sounding record started by GOES-I. The coastal waters imager component was planned primarily to benefit coastal monitoring, management, and remediation applications.

[6]Oversight Hearing on the Government Accountability Office Report on NOAA's Weather Satellite Program Before the Committee on Science, U.S. House of Representatives, September 29, 2006, available at http://science.house.gov/publications/hearings_markups_details.aspx?NewsID=1194.

[7]Outlined in a presentation titled "Mitigation Approaches to Address Impacts of NPOESS Nunn-McCurdy Certification on Joint NASA-NOAA Climate Goals," available at http://www7.nationalacademies.org/ssb/ NPOESSWorkshop_Cramer_NRC_06_19_07_final.pdf and also reprinted in Appendix C of the June 2007 workshop report. A final version of the NASA-NOAA report has not been released; a widely cited December 11, 2006, draft was posted by Climate Science Watch at http://www.climatesciencewatch.org/file-uploads/NPOESS-OSTPdec-06.pdf.

[8]Prediction (climate) is a probabilistic description or forecast of a future climate outcome based on observations of past and current climatological conditions and quantitative models of climate processes (e.g., a prediction of an El Niño event) and projection (climate) is a description of the response of the climate system to an assumed level of future radiative forcing. Changes in radiative forcing may be due to either natural sources (e.g., volcanic emissions) or human-induced causes (e.g., emissions of greenhouse gases and aerosols, or changes in land use and land cover). Climate "projections" are distinguished from climate "predictions" in order to emphasize that climate projections depend on scenarios of future socioeconomic, technological, and policy developments that may or may not be realized (Climate Change Science Program and the Subcommittee on Global Change Research, 2003, p. 12).

**BOX S.1**
**Goals of the U.S. Climate Change Science Program**

**Goal 1:** Improve knowledge of Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

**Goal 2:** Improve quantification of the forces bringing about changes in Earth's climate and related systems.

**Goal 3:** Reduce uncertainty in projections of how Earth's climate and related systems may change in the future.

**Goal 4:** Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

**Goal 5:** Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

SOURCE: The U.S. Climate Change Science Program Factsheet, available at http://www.climatescience.gov/infosheets/factsheet3/CCSP-3-StratPlanOverview14jan2006.pdf.

## APPROACH TO AND SCOPE OF PRIORITIZATION

Conducted during its December 17-19, 2007, meeting, the committee's prioritization of capabilities lost in program restructuring was guided by the following overarching principles:

- The objective of the committee's deliberations would be to prioritize for the restoration of *climate* capabilities. For example, although a sensor with the capability to improve resolution of fast climate processes is of interest to both the weather forecasting and the climate research communities, it is the value to the latter that would inform the committee's ranking.
- The particular strategy for recovery and the cost of recovery of a measurement/sensor would not be a factor in the ranking.[9]
- Measurements/sensors on NPOESS would not be ranked against measurements/sensors on GOES-R; however, the criteria used in ranking measurements/sensors for either program would be identical.
- When it was relevant, the measurement objectives of a particular sensor, and not the sensor itself, would be the basis for consideration. Thus, for example, members of the committee considered the importance of radar altimetry to climate science, rather than the importance of the particular implementation of this capability on NPOESS, that is, the ALT instrument.

Prior to the meeting, one or more committee members with the requisite expertise was assigned the task of preparing a detailed review of the issues associated with the descoping or demanifesting of a particular NPOESS or GOES-R measurement capability, guided by questions 1 through 9, below. These questions, which were developed at the committee's first meeting, follow from the committee's interpretation of what constitutes climate science and the associated requirements for climate observations (see above); they allow a prioritization across the diverse information requirements for climate science, for example, long-term measurements, new measurements, measurements of climate forcings and responses, measurements to improve scientific understanding and reduce key uncertainties, and measurements to improve climate predictions. The questions are also consistent with the

[9]The committee did not have access to the ongoing NASA-NOAA study for OSTP that is examining the cost of various recovery strategies.

ranking criteria employed by the panels of the NRC *Earth Science and Applications from Space* decadal survey (NRC, 2007), although in that study societal benefits and cost considerations were included as ranking factors.[10]

By design, the questions were open-ended in order to provoke a more nuanced discussion of the value of the measurements. For example, rather than merely listing the duration of the measurement records at risk as a proxy for value, the committee considered the value of a long-term record in a more holistic manner via questions 1 and 5, which in turn prompted an in-depth exploration of the value of the long-term record, the impact of the record on global climate studies, the relative impact/consequences of a gap in the record, the maturity of related data assimilation, and sensor heritage. Such an analysis was considered important in the prioritization process in order to appropriately balance the need to continue very-long-duration measurements with shorter-duration measurements. The former would benefit with better scores for measurement/sensor maturity and the value of maintaining the long-term record. The latter measurements, although perhaps less mature, might result in greater consequences associated with a prospective measurement gap (for example, those related to climate forcing/response parameters with larger uncertainties for which longer trend data can greatly constrain future climate predictions).

1. To what extent are the data used both to monitor and to provide a historical record of the global climate? Is there a requirement for data continuity? If so, discuss the consequences of a measurement gap.
2. To what extent is this measurement important in reducing "uncertainty"—for example, in reducing error bars in climate sensitivity forcing and monitoring? In making these judgments, refer also to the priorities of the Climate Change Research Program.
3. Consider the importance of the measurement's role in climate prediction and projections (forcing/response/sensitivity).
4. To what extent is the measurement needed for reanalysis?
5. Describe the measurement's maturity—for example, its readiness to be assimilated into a particular model(s)—and its heritage. If discussing a sensor, discuss its technical maturity and heritage.
6. Are other sensors and ancillary data required to make the measurement useful? Is this measurement unique? Are there complementary international sensors? If so, please list them and assess their capabilities. Discuss any data issues you may be aware of.
7. To what extent are the data used by, for example, the Intergovernmental Panel on Climate Change and the Climate Change Science Program (in developing synthesis and assessment products)?
8. Provide a qualitative assessment of the measurement's role in contributing to an overall improved understanding of the climate system and climate processes.
9. To what extent does the measurement contribute to improved understanding in related disciplines?

Following each reviewer presentation, committee members actively discussed the measurement objective under consideration in relation to each of the nine questions. *The committee's prioritization was developed on the basis of numerical scoring of the importance of each measurement capability to the needs of the climate research community (questions 1-8) and the importance of the measurement to related disciplines (question 9). Each of the responses to questions 1 through 9 was given equal weight in determining an overall ranking.*[11]

The committee had extensive discussions regarding whether a simple average of committee member rankings of the responses to questions 1 through 9 should be used for an overall ranking, or whether rankings with respect to particular questions should be given more weight. In part because there was no consensus among committee members on how a particular weighting scheme might improve what was already a subjective evaluation (in mapping the study statement of task to the questions, and in assigning individual numerical rankings for each question), the committee determined that the use of an unweighted average was advisable. Given that the committee was not provided any information concerning costs, relative or absolute, for any of the proposed mitigations, its prioritization of measurement capabilities was based entirely on climate science value as determined by consideration of the nine questions above. Lacking the information by which to determine the financial implications of its recommendations, the committee did not include implementation costs in its rankings. The committee notes, however, that had costs been provided, a more far-reaching set of recommendations might have been developed

[10]See Box 2.2 in *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (NRC, 2007), p. 40.

[11]The committee was aware of a similar prioritization exercise conducted by NASA and NOAA in late 2006/early 2007. NASA and NOAA reached a somewhat different prioritization, which the present committee attributes in large part to their giving additional weight to the factors noted in question 1, that is, measurement continuity and the importance of avoiding a data gap.

in which cost/benefit was taken into consideration. It is also important to recognize that important nonscientific factors were not, by design, part of the committee's analysis.

Before restructuring, each of the lost or degraded measurement capabilities had been considered both practicable and of high importance. In the case of NPOESS, a tri-agency under-secretary-level executive committee provides overall program direction and ensures that both civil and national security requirements are satisfied.[12] GOES-R requirements had been established by NOAA following a formal process that determined and prioritized user requirements; various senior management committees oversaw this process.[13] As is evident in the "Highlights of Analysis" sections in Chapter 3, the committee also found great merit in each of the climate-related measurement capabilities under consideration. However, given that a wholesale reversal of the programs' changes is not feasible, it became the committee's difficult task to provide a prioritized set of recommendations for restoration of climate measurement capabilities.

## SUMMARY OF PRIORITIES AND MITIGATION OPTIONS

The committee prioritized all of the climate-related measurement capabilities that were lost or diminished as a result of NPOESS and GOES-R program restructuring rather than limiting its recommendations to the demanifested sensors as was done in the NASA-NOAA draft report prepared for the Office of Science and Technology Policy (OSTP).[14] The committee's approach is consistent with input received from the community as part of the NRC's June 2007 workshop. Specifically, with respect to changes in the NPOESS program, the committee considered:

- Aerosol properties and the Aerosol Polarimetry Sensor (APS),
- Earth radiation budget and the Clouds and Earth's Radiant Energy System/Earth Radiation Budget Sensor (CERES/ERBS),
- Hyperspectral diurnal coverage and the Cross-track Infrared Sounder (CrIS),
- Microwave radiometry and the Conical Scanning Microwave Imager/Sounder (CMIS),
- Ocean color and the Visible/Infrared Imager/Radiometer Suite (VIIRS),
- Ozone profiles and the Ozone Mapping and Profiler Suite-Limb (OMPS-L) sensor,
- Radar altimetry and the ALT sensor, and
- Total solar irradiance and the Total Solar Irradiance Monitor (TIM)/spectrally resolved irradiance and the Solar Spectral Irradiance Monitor (SIM).

With respect to the changes in the GOES-R program, the committee considered:

- Geostationary coastal waters imagery and the HES-CWI sensor, and
- Geostationary hyperspectral sounding and the HES sensor.

As a result of the prioritization process, the measurements and sensors listed above are divided into four groups, which the committee designates, in descending order of priority, as Tier 1 through Tier 4 (Figure S.1). *As noted above, sensors from the NPOESS and GOES-R programs were not prioritized head-to-head.* However, it can be roughly stated that considering climate science contributions alone, geostationary hyperspectral sounding compares to the NPOESS capabilities prioritized as Tier 2, and coastal waters imagery falls into Tier 4.

After completing the relative prioritization, the committee considered a wide range of options for recovery of the lost capabilities, including the remanifesting of sensors onto NPOESS platforms, accommodation of sensors on free flyers or flights of opportunity, and the use of formation flight to combine multiple, synergistic, measurement types without incurring the cost, complexity, and risk of large facility-class observatories. The committee's recommendations for mitigation recovery of the lost capabilities are detailed in the main text and are summarized in Table S.1.

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[12]Presidential Decision Directive/NSTC-2, "Convergence of U.S.-Polar-Orbiting Operation Environmental Satellite Systems," May 5, 1994, available at http://www.ipo.noaa.gov/About/NSTC-2.html.

[13]See Jim Gurka, "The Requirement Process in NOAA GOES-R Mission Definition," April 12, 2007, available at http://osd.goes.noaa.gov/documents/Requirements_Process.pdf.

[14]See footnote 7 above.

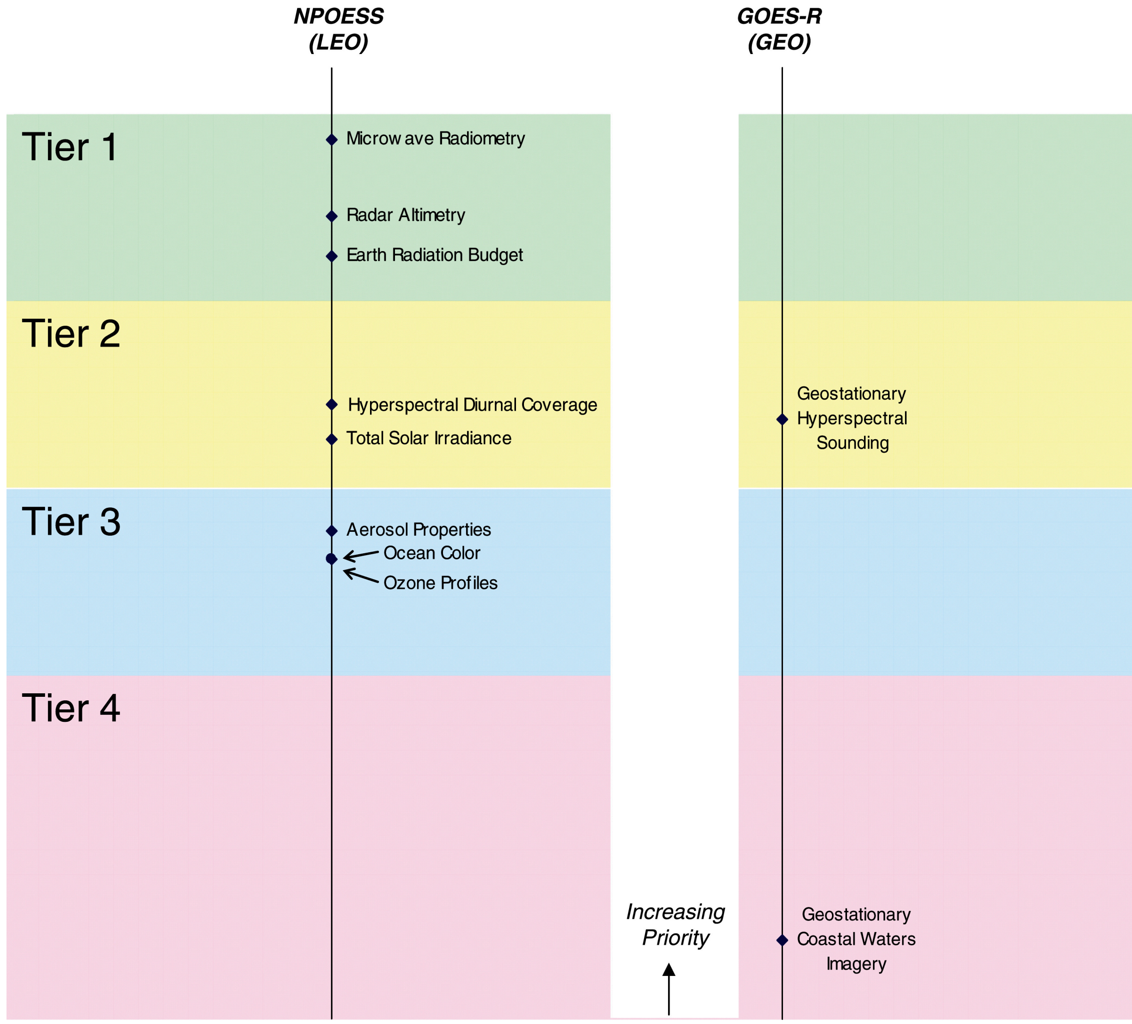


FIGURE S.1 Graphical depiction of overall rankings, showing the clustering of scores into what the committee defined as Tiers 1-4, for recovery of both NPOESS (low Earth orbit) and GOES-R (geostationary Earth orbit) lost or degraded climate capabilities.

The color coding used in Figure S.1 and Table S.1—green, yellow, blue, and pink shading to indicate Tier 1, Tier 2, Tier 3, and Tier 4 prioritization, respectively—is used as an interpretive aid in Chapter 3.

## ELEMENTS OF A LONG-TERM CLIMATE STRATEGY: A WAY FORWARD

The committee has developed and recommends a prioritized, short-term strategy for recovery of crucial climate capabilities lost in the NPOESS and GOES-R program descopes. However, mitigation of these recent losses is only the first step in establishing a viable long-term climate strategy—one that builds on the lessons learned from the well-intentioned but poorly executed merger of the nation's weather and climate observation systems. The key elements of such a long-term strategy are discussed in Chapter 4 and are summarized here.

### Sustained Climate Observations

In developing an effective long-term climate strategy, it is critical to consider the similarities in and differences between research, operational, and sustained measurements in order to take advantage of synergies when

TABLE S.1 Summary Recommendations for Mitigation of Lost or Degraded Climate Capabilities

| Lost or Degraded Climate Capability in NPOESS Low Earth Orbit | Recommendation |
|---|---|
| **Tier 1** | |
| Microwave Radiometry | • NASA and NOAA should initiate a study as soon as practicable to address continuity of microwave radiometry and to determine a cost-effective approach to supplement the AMSR-2, carried on the Japanese spacecraft GCOM-W, with another microwave radiometer of similar design. The agencies should also consider the feasibility of manifesting a microwave radiometer on a flight of opportunity or free flyer to cover the microwave radiometry gap anticipated with a delay in accommodation of MIS until NPOESS C2.<br>• The agencies should provide funding for U.S. participation in an AMSR-2 science team to take full advantage of this upcoming microwave radiometer mission.<br>• The NPOESS Integrated Program Office should continue with its plans to restore a microwave sounder to NPOESS C2 and subsequent platforms, with an emphasis on SUAG priorities 1 through 3 (core radiometry, sounding channels, and soil moisture/sea surface temperature).<br>• NASA and NOAA should devise and implement a long-term strategy to provide sea-surface wind vector measurements. The committee finds important limitations in the planned reliance on a polarimetric radiometer for this measurement; instead, the preferred strategy is timely development and launch of the next-generation advanced scatterometer mission, that is, the Extended Ocean Vector Winds Mission (XOVWM) recommended in the 2007 NRC decadal survey *Earth Science and Applications from Space*. |
| Radar Altimetry | A precision altimetry follow-on mission to OSTM/Jason-2 (i.e., Jason-3) should be developed and launched in a time frame to ensure the necessary mission overlap. The agencies' long-term plan should include a series of precision altimetry free flyers in non-Sun-synchronous orbit designed to provide for climate-quality measurements of sea level. |
| Earth Radiation Budget | To minimize the risk of a potential data gap, the committee reiterates the recommendation of the 2007 *Earth Science and Applications from Space* decadal survey to manifest the CERES FM-5 on NPP. The agencies should further develop an ERB instrument series and provide for subsequent flights on Sun-synchronous platforms to continue the Earth radiation budget long-term record. |
| **Tier 2** | |
| Hyperspectral Diurnal Coverage | The CrIS/ATMS instrument suite should be restored to the 05:30 NPOESS orbit to provide improved hyperspectral diurnal coverage and support atmospheric moisture and temperature vertical profile key performance parameters. |
| Total Solar Irradiance | The agencies should consider use of an appropriate combination of small, low-cost satellites and flights of opportunity to fly TSIS (or at least TIM) as needed to ensure overlap and continuity of measurements of total solar irradiance. |
| **Tier 3** | |
| Aerosol Properties | • NASA should continue its current plan to fly the APS on Glory.<br>• NASA and NOAA should continue to mature aerosol remote sensing technology and plan for the development of operational instruments for accommodation on future platforms and/or flights of opportunity. |
| Ocean Color | • The NPOESS Integrated Program Office should consider any practical mechanisms to improve VIIRS performance for NPP and ensure that all specifications are met or exceeded by the launch of NPOESS C1.<br>• The agencies should ensure that adequate post-launch calibration/validation infrastructure is in place, including oversight by the scientific community, to ensure the production of viable ocean color imagery.<br>• To address reduced sensor coverage, the agencies should work with their international partners toward flying a fully functioning VIIRS or a dedicated sensor on a mission of opportunity in Sun-synchronous orbit. The agencies should also work with international partners to ensure community access to ocean color and ancillary calibration/validation data from international platforms during the gap likely to be experienced prior to launch of NPOESS C1. |
| Ozone Profiles | The committee supports current agency plans to reintegrate OMPS-Limb on NPP. The agencies should consider the relative cost/benefit of reintegration of OMPS-Limb capabilities for NPOESS platforms carrying OMPS-Nadir based on the degree of integration inherent in the instrument's original design. |

| Lost or Degraded Climate Capability in GOES-R Geostationary Earth Orbit | Recommendation |
|---|---|
| **Tier 2** | |
| Geostationary Hyperspectral Sounding | NASA and NOAA should plan an earliest-possible demonstration flight of a geostationary hyperspectral sounder, supporting *operational* flight in the GOES-T time frame. |
| **Tier 4** | |
| Geostationary Coastal Waters Imagery | Provision for coastal waters imaging should be considered by the agencies based on non-climate applications. |

appropriate while avoiding incompatible observing system requirements. Sustained measurements needed to detect climate trends can, for example, impose tighter requirements for calibration, characterization, and stability, or impose orbit constraints different from what would otherwise be required for operational applications. A long-term climate strategy must provide for the essential characterization, calibration, stability, continuity, and data systems required to support climate applications.

### National Policy for Provision of Long-Term Climate Measurements

Much of climate science depends on long-term, sustained measurement records. Yet, as has been noted in many previous NRC and agency reports, the nation lacks a clear policy to address these known national and international needs. For example, an ad hoc NRC task group (NRC, 1999b, p. 4) stated as follows:

> No federal entity is currently the "agent" for climate or longer-term observations and analyses, nor has the "virtual agency" envisioned in the [U.S. Global Change Research Program] succeeded in this function. The task group endorses NASA's call for a high-level process to develop a national policy to ensure that the long-term continuity and quality of key data sets required for global change research are not compromised in the process of merging research and operational data sets.[15]

A coherent, integrated, and viable long-term climate observation strategy should explicitly seek to balance the myriad science and applications objectives basic to serving the variety of climate data stakeholders. The program should, for example, consider the appropriate balance between (1) new sensors for technological innovation, (2) new observations for emerging science needs, (3) long-term sustainable science-grade environmental observations, and (4) measurements that improve support for decision makers to enable more effective climate mitigation and adaptation regulations (NRC, 2006). The various agencies have differing levels of expertise associated with each of these programmatic elements, and the long-term strategy should seek to capitalize on inherent organizational strengths where appropriate. Elements of this needed national policy include clear roles and responsibilities for agencies, international coordination, and community involvement in the development of climate data records.

#### Clear Agency Roles and Responsibilities

In the NRC decadal survey *Earth Science and Applications from Space*, the authors stated, "The committee is concerned that the nation's civil space institutions (including NASA, NOAA, and USGS) are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources: institutional mandates are inconsistent with agency charters, budgets are not well matched to emerging needs, and shared responsibilities are supported inconsistently by mechanisms for cooperation. These are issues whose solutions will require action at high levels of the federal government" (NRC, 2007, p. 13). In turn, this prompted one of the report's most important recommendations: "The Office of Science and Technology Policy, in collaboration with the relevant agencies and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs" (p. 14). **The present committee fully endorses the need for clarified agency roles and responsibilities, consistent with inherent agency strengths, and reiterates this important recommendation of the decadal survey.**

#### International Coordination

The committee recognizes the importance of international cooperation in obtaining climate-quality measurements from space; the absence of an internationally agreed upon and ratified strategy for climate observations

[15] A similar view was expressed in *Adequacy of Climate Observing Systems*, which stated, "There has been a lack of progress by the federal agencies responsible for climate observing systems, individually and collectively, toward developing and maintaining a credible integrated climate observing system" (NRC, 1999a, p. 5).

from space remains an area of grave concern. **The research and operational agencies should coordinate their development, operations, standards, and products with international partners.**

### Community Involvement in the Development of Climate Data Records

The NRC has produced a number of reports on the subject of climate data records (CDRs), many having been motivated by concerns over the future availability of satellite-based climate-quality data records. The implied demise of climate-focused satellite observations from NPOESS, a consequence of the Nunn-McCurdy certification, adds to the ongoing concern about the lack of organized commitment to CDR development. It has been stressed in many NRC and other reports that generation of CDRs requires considerable scientific insight, including the blending of multiple sources of data; error analysis; and access to raw data. On the basis of its review of previous NRC studies and its own experience, the committee identified a number of particularly important elements for a sustained long-term program dedicated to developing credible CDRs. These elements are discussed in Chapter 4.

Finally, it is important to note that community concerns about the adequacy of NPOESS for climate research existed even before the 2006 program restructuring. For example, in the 2007 NRC decadal survey *Earth Science and Applications from Space* (NRC, 2007, p. 263), the report from the Panel on Climate Variability and Change concluded that, "Regardless of the descoping, the NPOESS program lacks essential features of a well-designed climate-observing system."

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# 5.2 Launching Science: Science Opportunities Provided by NASA's Constellation System

A Report of the Ad Hoc Committee on Science Opportunities Enabled by NASA's Constellation System

## Summary

In 2004 NASA began implementation of the first phases of a new space exploration policy.[1] This implementation effort included the development of a new human-carrying spacecraft, known as Orion; the Altair lunar lander; and two new launch vehicles, the Ares I and Ares V rockets—collectively called the Constellation System (described in Chapter 5 of this report). The Altair lunar lander, which is in the very preliminary concept stage, is not discussed in detail in this report. In 2007 NASA asked the National Research Council (NRC) to evaluate the science opportunities enabled by the Constellation System. To do so, the NRC established the Committee on Science Opportunities Enabled by NASA's Constellation System. In general, the committee interpreted "Constellation-enabled" broadly, to include not only mission concepts that required Constellation, but also those that could be significantly enhanced by Constellation.

The committee intends this report to be a general overview of the topic of science missions that might be enabled by Constellation, a sort of textbook introduction to the subject. The mission concepts that are reviewed in this report should serve as general examples of kinds of missions, and the committee's evaluation should not be construed as an endorsement of the specific teams that developed the mission concepts or of their proposals. Additionally, NASA has a well-developed process for establishing scientific priorities by asking the NRC to conduct a "decadal survey" for a particular discipline. Any scientific mission that eventually uses the Constellation System will have to be properly evaluated by means of this decadal survey process.

The committee was impressed with the scientific potential of many of the proposals that it evaluated. However, the committee notes that the Constellation System has been justified by NASA and selected in order to enable human exploration beyond low Earth orbit—not to enable science missions. Virtually all of the science mission concepts that could take advantage of Constellation's unique capabilities are likely to be prohibitively expensive. Several times in the past NASA has begun ambitious space science missions that ultimately proved too expensive for the agency to pursue. Examples include the Voyager-Mars mission and the Prometheus program and its Jupiter Icy Moons Orbiter spacecraft (both examples are discussed in Chapter 1).

**Finding: The scientific missions reviewed by the committee as appropriate for launch on an Ares V vehicle fall, with few exceptions, into the "flagship" class of missions. The preliminary cost estimates, based on mission concepts that at this time are not very detailed, indicate that the costs of many of the missions analyzed will be above $5 billion (in current dollars). The Ares V costs are not included in these estimates.**

All of the costs discussed in this report are presented in current-year (2008) dollars, not accounting for potential inflation that could occur between now and the decade in which these missions might be pursued. In general, preliminary cost estimates for proposed missions are, for many reasons, significantly lower than the final costs. Given the large cost estimates for many of the missions assessed in this report, the potentially large impacts on NASA's budget by many of these missions are readily apparent.

### SCIENCE MISSIONS THAT ARE ENABLED OR ENHANCED BY THE CONSTELLATION SYSTEM

The committee evaluated a total of 17 mission concepts for future space science missions (11 were "Vision Missions" studied at the initiation of NASA between 2004 and 2006; the remaining 6 were submitted to the committee in response to its request for information).[2] The committee based its initial evaluation of each mis-

NOTE: "Summary" reprinted from *Launching Science: Science Opportunities Provided by NASA's Constellation System*, The National Academies Press, Washington, D.C., 2009, pp. 1-9; approved for release in 2008.

[1]See http://www.whitehouse.gov/space/renewed_spirit.html.

[2]In its interim report, the committee selected 7 of the 11 Vision Mission concepts as "worthy of further study as a Constellation mission." See National Research Council, *Science Opportunities Enabled by NASA's Constellation System: Interim Report*, The National Academies Press, Washington, D.C., 2008.

sion concept on two criteria: (1) whether the concept offered the potential for a significant scientific advance and (2) whether or not the concept would benefit from the Constellation System. The committee determined that all of the concepts offered the possibility of a significant scientific advance, but it cautions that such an evaluation ultimately must be made by the NRC's decadal survey process referred to above. *This report's evaluations should not be considered to be an endorsement of the scientific merit of these proposals, which must of course be evaluated relative to other proposals.*

The committee determined that 12 of the 17 mission concepts would benefit from the Constellation System, whereas 5 would not. See Table S.1 for a summary of the mission concepts, including their cost estimates, technical maturity, and reasons why they might benefit from the Constellation System.

The five mission concepts that the committee deemed not worthy of further study as Constellation missions according to its evaluation criteria simply do not require, or do not appear to benefit highly from, use of the Constellation System (see Table S.1). In several cases they should easily fit within existing launch vehicles. In one case, that of Super-EUSO (Extreme Universe Space Observatory), the committee questions the cost-effectiveness of a flagship-class space mission as compared with the expansion of existing ground-based facilities.

Notably, the committee did not receive any proposals in the Earth sciences. The committee lacked sufficient data to determine why it did not receive any such proposals, although it notes that the Vision Mission effort that sponsored many of the mission concepts evaluated in this study did not include Earth science, which at the time was separated organizationally within NASA from space science. It is possible that, if invited to consider the matter, the Earth science community may find uses for Constellation that are not readily apparent.

TABLE S.1 Summary of Mission Concepts Evaluated by the Committee

| Mission | Cost Estimate[a] (billions of current-year [2008] $) | Technical Maturity[b] | Worthy of Further Study as a Constellation Mission? | Notes |
|---|---|---|---|---|
| Advanced Compton Telescope (ACT)[c] | ~1 | Medium | No | This mission does not benefit from the Constellation System. It can fit in an existing Evolved Expendable Launch Vehicle (EELV). |
| Advanced Technology Large-Aperture Space Telescope (ATLAST)[d] | >5 | Low for mirror technology (including mass)<br>Medium for detectors and thermal control | Yes | The 16-meter folded telescope design can only fit in an Ares V payload fairing. |
| Dark Ages Lunar Interferometer (DALI)[d] | >5 | Medium for rovers and interferometrics<br>Low for reducing mass and for deploying and operating in a remote location | Yes | The large antennas must be landed on the lunar farside. This requires both the Ares V launch vehicle and the Altair lunar lander. |
| 8-Meter Monolithic Space Telescope[d] | 1-5 | High for mirror and structure<br>Low for coronagraphic observation | Yes | The 8-meter-diameter telescope can only fit inside an Ares V payload fairing. |
| Exploration of Near Earth Objects via the Crew Exploration Vehicle[d] | >5 | High for instruments<br>Low for human factors such as radiation | Yes | The Orion vehicle is the only U.S. spacecraft envisioned that will be capable of operating beyond low Earth orbit. The mission also will require substantial payload capability. This mission fits better within the purview of the Exploration Systems Mission Directorate than as a mission of the Science Mission Directorate. |

TABLE S.1 Continued

| Mission | Cost Estimate[a] (billions of current-year [2008] $) | Technical Maturity[b] | Worthy of Further Study as a Constellation Mission? | Notes |
|---|---|---|---|---|
| Generation-X (Gen-X)[c] | >5 | Low for mirror development and operations | Yes | One Ares V launch of one 16-meter telescope is significantly simpler than the early proposed configurations. The cost estimates are weak. The additional mass capability could significantly reduce mirror development costs. |
| Interstellar Probe[c] | 1-5 | High for science, instruments, and mission concept | Yes | Further study is needed of the benefits of Ares V—in particular, of alternative propulsion options. |
| Kilometer-Baseline Far-Infrared/ Submillimeter Interferometer[c] | >5 | Low | No | This mission should be able to fit on an existing EELV; therefore the need for Constellation is questionable, except for human servicing. |
| Modern Universe Space Telescope (MUST)[c] | >5 | High for instruments<br>Low for coronagraph and mirror assembly | Yes | A large, one-piece central mirror rather than a robotically assembled mirror is possible with Ares V. |
| Neptune Orbiter with Probes[c] | >5 | High for mission concept and instruments<br>Low for propulsion and possibly lander | Yes | Ares V could possibly obviate the need for aerocapture and/or nuclear-electric propulsion. |
| Palmer Quest[c] | >5 | Low | No | This mission does not benefit from Constellation. It can fit in an existing EELV. |
| Single Aperture Far Infrared (SAFIR) Telescope[c] | >5 | Medium for mission concept<br>Low for cooling and detectors | No | This mission does not benefit from Constellation. It can fit in an existing EELV. However, it could benefit from human servicing. |
| Solar Polar Imager[c] | ~1 | High for instruments<br>Propulsion not studied in sufficient detail | Yes | Propulsion options enabled by Ares V should be considered. |
| Solar Probe 2[d] | 1-5 | High for science, instruments, and mission concept | Yes | Ares I and Ares V launch vehicles could enable spacecraft to be placed in an orbit that could bring it close to the Sun, accomplishing the major science goals. |
| Stellar Imager[c] | >5 | Low for formation flying | Yes | Larger mirrors (2 meters versus 1 meter) and a second hub could be launched on a single Ares V launch. |
| Super-EUSO (Extreme Universe Space Observatory)[d] | 1-5 | Low for mirror | No | This mission does not benefit from Constellation. Significant advances in this science can be made using ground-based and alternative approaches. |
| Titan Explorer[c] | >5 | High for instruments<br>Medium for blimp | Yes | Launch on Ares V may enable propulsive capture rather than aerocapture and may shorten transit time. |

NOTE: The mission concepts are listed in alphabetical order. All of the missions listed are robotic missions, with the exception of the proposal for Exploration of Near Earth Objects via the Crew Exploration Vehicle.

[a]Cost estimates are based on data estimates provided to the committee, with modifications based on expertise within the committee.
[b]Technical maturity is based on data provided to the committee.
[c]This is 1 of 11 Vision Mission studies initiated by NASA between 2004 and 2006.
[d]This study proposal was submitted in response to the committee's request for information.

**Finding: The committee did not receive any Earth science proposals and found it impossible to assess the potential of the Constellation System to meet the future needs of Earth-oriented missions.**

The mission concepts reviewed during this study lacked the level of detail necessary for a full evaluation. In particular, the cost estimates were extremely rough. The lack of Earth science concepts also concerned the committee. NASA is still in the early stages of identifying the potential benefits of the Constellation System to the space science program and has not made a dedicated effort to evaluate the potential of the Constellation System for space and Earth science missions. As a result, the committee determined that the agency needs to continue efforts to attract and advance ideas for space and Earth science missions in general, and should develop a method for soliciting potential mission concepts.

**Recommendation: NASA should solicit further mission concepts that are most likely to benefit from the capabilities of the Constellation System in each of the space and Earth science disciplines: astronomy and astrophysics, Earth science, heliophysics, and planetary science. The agency should seek mission concepts that are studied in a uniform manner with regard to design, system engineering, and costing.**

The committee focused on the 12 mission concepts that, as shown in Table S.1, it determined are worthy of further study as Constellation missions. Because the committee was charged with determining which studies are "most deserving" of further study, it divided the list of 12 mission concepts into "more deserving" and "deserving" categories. All 12 of these concepts show great promise, but the committee determined that, as indicated in the recommendations below, several in particular serve as examples of what Constellation could provide to space science. The committee's criteria for determining if a mission concept is more deserving or simply deserving of further study are as follows:

- *Criterion 1: Mission Impact on Science in the Field of Study*—The mission concept must present well-articulated science goals that the committee finds compelling and worthy of the investment needed to develop the technology.
- *Criterion 2: Technical Maturity*—The mission concept must be sufficiently mature in its overall conception and technology. If the technology for accomplishing the mission does not currently exist at a high technology readiness level, the mission must provide a clear path indicating how it will be developed.

If a mission concept satisfied both criteria to a moderate or high degree, it was designated more deserving of further study. (These criteria are fully explained in Chapter 2.) As a result of these evaluations, the committee identified five missions that it determined are more deserving of further study.

**Recommendation: NASA should conduct further study of the following mission concepts, which have the most potential to demonstrate the scientific opportunities provided by the Constellation System: 8-Meter Monolithic Space Telescope, Interstellar Probe, Neptune Orbiter with Probes, Solar Polar Imager, and Solar Probe 2.**

Several of the missions named above, particularly the heliophysics missions, are well defined scientifically and do not require significant study of instruments or related issues. Further study should focus primarily on the relationship between the Ares V capabilities and the missions' propulsion requirements. Because these are narrow requirements, NASA may have the ability to give further study to other possible Ares V science missions that the committee placed in the "deserving" category. The seven missions in the "deserving" category are also promising and offer great potential science return, but greater amounts of effort will be required to bring them to a similar level of maturity.

**Recommendation: NASA should consider further study of the following mission concepts: Advanced Technology Large-Aperture Space Telescope, Dark Ages Lunar Interferometer, Exploration of Near Earth Objects via the Crew Exploration Vehicle, Generation-X, Modern Universe Space Telescope, Stellar Imager, and Titan Explorer.**

Two missions that were placed in the category of "deserving" to be considered for further study did not receive the higher rating (i.e., they were not placed in the "more deserving" category) for reasons largely beyond the control of the proposing teams. Exploration of Near Earth Objects using astronauts is an intriguing and exciting potential future use of the Constellation System. This mission also has significant exploration benefits. Because exploration benefits were not part of the evaluation criteria, the committee could not place this mission in the "more deserving" category despite its strengths. Similarly, the Titan Explorer mission concept evaluated for this report was developed before Cassini reached Saturn, so it reflects an older series of science assumptions and questions; Ares V has great potential for Titan missions.

## MISSION COSTS

The committee accepted the cost estimates provided in the proposals themselves or by the study representatives who presented the proposals to the committee, but with some modifications based on the expertise of the committee. Nevertheless, the committee concluded that these cost estimates are preliminary and are likely to be significantly lower than the actual cost of the missions. The committee is concerned that even according to the preliminary estimates, the costs of these missions will be as high as those of flagship-class missions (i.e., several billion dollars each), if not substantially higher than previous flagship-class missions. The committee was asked to consider missions that could be flown during the period 2020 to 2035; very few such large missions could possibly be funded during that period.

However, the committee also heard arguments that the larger payload capability of the Ares V could also possibly balance increased costs by simplifying mission design. Many of the mission concepts evaluated in this study do not require the full mass capabilities of the Ares V, and it is therefore possible that mission concepts could make use of these capabilities to reduce mission cost. This subject remains conjectural and therefore requires further study.

**Recommendation: NASA should conduct a comprehensive systems-engineering-based analysis to assess the possibility that the relaxation of weight and volume constraints enabled by Ares V for some space science missions might make feasible a significantly different approach to science mission design, development, assembly, integration, and testing, resulting in a relative decrease in the cost of space science missions.**

## INTERNATIONAL COOPERATION

Virtually all of the mission concepts evaluated by the committee are large, complex, and costly. Several are similar to studies currently being undertaken by traditional international partners of the U.S. space program in space science and exploration. As a result, there are opportunities for NASA to undertake joint missions in some of these areas.

**Finding: International cooperation could provide access to international scientific expertise and technology useful for large, complex, and costly mission concepts and could reduce costs through provision of instruments and infrastructure by international partners.**

## TECHNOLOGY ISSUES

The committee was charged with identifying the benefits of using the Constellation System's unique capabilities relative to alternative implementation approaches. Such approaches include technologies that may allow a mission to be accomplished without the Constellation System, such as the Atlas and Delta launch vehicles that were used as the baseline for many of the Vision Mission studies that the committee evaluated. Such approaches also include technologies like in-space propulsion that might not be necessary if a launch vehicle such as the Ares V is available. The committee notes that the majority of mission concepts evaluated in this study (the NASA-funded Vision Missions) were originally designed to use launch vehicles—the Atlas and Delta—often in combination with technology options (such as ion propulsion) that were necessary because of the lack of mass or change in velocity provided by those launch vehicles. The Constellation System may offer an alternative to those launch vehicles and technologies.

During this study, the committee concluded that even the Constellation System alone might be insufficient for some of the missions that it evaluated, and that additional technological developments would be required. NASA currently lacks a technology development strategy for science missions, a gap previously identified by the NRC as a shortcoming,[3] and the committee concluded that some of the missions would be enhanced with the availability of additional technology developments.

**Finding: Advanced in-space propulsion technology may be required for some science missions considered for using the Constellation System.**

Virtually all of the missions evaluated in this report would introduce substantial new demands on the Deep Space Network (DSN). The committee was briefed on the current demands and plans for the DSN and became concerned about the future of the DSN, but determined that this subject was beyond the committee's base of expertise or purview. Nevertheless, future Constellation science missions will have a major impact on the DSN. (Technology issues are further discussed in Chapter 3.)

**Finding: Science missions enabled by the Constellation System will increase the strain on the capabilities of the Deep Space Network.**

## HUMAN AND ROBOTIC SERVICING

Various proposers of observatory mission concepts suggested to the committee that large, expensive observatories might benefit from servicing, which would allow them to operate for decades and to be upgraded with the latest instruments. The Orion spacecraft, unlike the space shuttle, offers the possibility of human servicing of spacecraft beyond low Earth orbit, although it lacks the mass and volume required to conduct such missions alone. However, recent developments in robotic servicing also demonstrate that this technology is now reaching a mature stage and could provide an alternative method of servicing future spacecraft. (Human and robotic servicing issues are discussed in Chapter 4.)

**Finding: The Constellation System and advanced robotic servicing technology make possible the servicing and in-space assembly of large spacecraft.**

**Finding: Designing spacecraft components for accessibility is essential for in-space servicing and is also advantageous for preflight integration and testing.**

The committee was informed that one of the lessons that NASA has learned from decades of spacecraft servicing is that it is far easier to service spacecraft specifically designed for access and easy replacement of equipment. This approach has other benefits as well, such as prelaunch servicing and maintenance that may be required during integration and testing. However, because NASA largely abandoned the concept of the human servicing of spacecraft and because robotic servicing was not a developed technology, for many years the agency did not consider designing new spacecraft that could benefit from servicing. The new capabilities provided by the Constellation System and robotic servicing technologies highlight the importance of devoting new attention to this subject.

**Recommendation: NASA should study the benefits of designing spacecraft intended to operate around Earth or the Moon, or at the libration points for human and robotic servicing.**

## SPACECRAFT AND LAUNCH VEHICLES

The alternative implementation approaches that the committee was charged with evaluating include technologies that allow the use of launch vehicles smaller than Ares V. Although the Ares V offers significant capabilities not available from other vehicles, the Ares I launch vehicle does not offer capabilities significantly different from

[3] National Research Council, *Grading NASA's Solar System Exploration Program: A Midterm Review*, The National Academies Press, Washington, D.C., 2008, pp. 11 and 59-61.

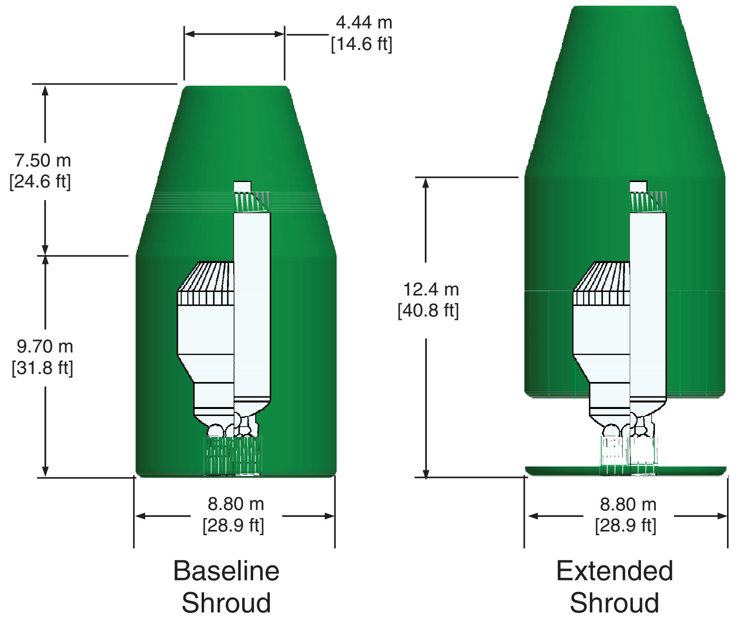


FIGURE S.1 Two possible configurations of the Ares V shroud—the current baseline shroud and a proposed extended shroud. Shown inside the shrouds are two possible Centaur upper-stage configurations: the Titan IV Centaur (left) and the Atlas V Centaur III Dual Engine Configuration (right). Any spacecraft carried atop an upper stage would have severely restricted volume constraints. Neither shroud option takes advantage of the width of the Ares V shroud. SOURCE: Adapted courtesy of NASA.

those currently available with the Evolved Expendable Launch Vehicle (EELV) family of launch vehicles for science missions. (Launch vehicles are discussed in Chapter 5.) The Ares I is required for launching the Orion spacecraft, and so any science missions that require astronauts will use the Ares I.

**Finding: The Ares I will not provide capabilities significantly different from those provided by existing launch vehicles.**

Although the Orion spacecraft is being designed primarily for transporting astronauts to and from the International Space Station and to and from the Moon, it will possess additional capabilities, such as the ability to carry secondary payloads, including deployable satellites. During the Apollo program, the Apollo service module was equipped with a bay for carrying science instruments for use while the spacecraft was in orbit around the Moon. NASA is currently seeking to incorporate a similar capability in the Orion spacecraft and has provided for mass and volume reserves in its current design.

Although the Ares V offers the greatest potential value to science, the launch vehicle must be made capable of accommodating science payloads. Science missions are more likely to take advantage of the Ares V if these capabilities are designed into the vehicle rather than their needing to be added later.

A potentially serious issue for using Ares V for planetary missions concerns the need for a dedicated upper stage to provide high excess escape velocities for spacecraft (velocity squared per second squared, known as C3).[4] Neither the current most likely upper stage, the Atlas V Centaur III Dual Engine Configuration, nor the previous Titan IV Centaur would make efficient use of the Ares V payload shroud volume and may present other design problems such as load (weight)-bearing capability (see Figure S.1). Planetary missions could better use an upper stage that is shorter and takes advantage of the full width of the Ares V; however, the development of such a stage could be expensive. In order for Ares V to be attractive for future science missions, vehicle designers will have to consider the requirements of potential science missions.

[4] C3 is $km^2/s^2$ the square of the hyperbolic excess velocity—in other words, the amount of velocity that the vehicle can provide to the spacecraft beyond that needed to escape Earth's gravitational field.

**Recommendation: If NASA wishes to use the Constellation System for science missions, it should preserve the capability for Orion to carry small scientific payloads and should ensure that the Ares V development team considers the needs of scientific payloads in system design.**

The Constellation System offers great potential for space science missions, but the costs of the types of missions evaluated in this report may be unaffordable. Many of these missions have such large costs that they might require that funds be taken from numerous other, smaller science missions, which could create imbalances in the science programs in the individual disciplines. These missions will have to be evaluated carefully within the NRC's decadal survey process. NASA will have to proceed with caution as it develops these new capabilities.

# 5.3 Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity

A Report of the Ad Hoc Committee on New Opportunities in Solar System Exploration: An Evaluation of the New Frontiers Announcement of Opportunity

## Summary

In 2007 NASA began planning to initiate a new competition for a New Frontiers mission. Because NASA has now selected two of the five missions recommended by the National Research Council's (NRC's) decadal survey *New Frontiers in the Solar System*,[1] and because the decadal survey recommended that the agency ask the NRC for further advice on the New Frontiers Program after several selections had been made, in March 2007 NASA asked the NRC to:

> [P]rovide criteria and guiding principles to NASA for determining the list of candidate missions. These issues include the following:
>
> - Should the next New Frontiers solicitation be completely open relative to any planetary mission, or should it state a candidate list of missions as was done in the previous AO?
> - If a candidate list of missions is preferred, what is the process by which candidate missions should be determined? Specifically, there is a need to review the mission categories identified in the previous AO and see if the list needs to be revised or augmented in light of developments since the release of the last AO. Should consideration be given to a candidate list of appropriate science themes from the NRC decadal survey on solar system exploration rather than to specific missions?[2]

The original statement of task for the Committee on New Opportunities in Solar System Exploration: An Evaluation of the New Frontiers Announcement of Opportunity included the words "excluding Mars" in the first question. In September 2007 NASA amended the statement of task so that Mars could be considered in a discussion of the future direction of the New Frontiers Program.

NASA's New Frontiers Program is a series of principal-investigator-led solar system exploration missions with a cost cap of $750 million. These missions are larger than the principal-investigator-led Discovery-class missions (with a cost cap of $425 million) but smaller than "flagship" missions, which are led by a NASA center and are defined as larger than $750 million, but in actuality cost several billion dollars. New Frontiers is operated as a *program*, similar to the Discovery- and Mars Scout-class missions, meaning that Congress and the White House have agreed to support the existence of a class of missions, and NASA does not have to seek special approval for each individual mission.

The New Frontiers Program was created at the recommendation of the NRC's solar system exploration decadal survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy* (hereafter the "decadal survey").[3] The decadal survey recommended that in order to optimize solar system exploration, NASA's solar system exploration program required a series of principal-investigator-led missions larger than the Discovery-class missions, but not as large as flagship missions. When teams led by a principal investigator compete, their proposed missions are often innovative and unique, producing ingenious solutions to difficult challenges and demonstrating many of the best characteristics of U.S. science. However, unlike Discovery, New Frontiers missions must be firmly grounded in scientific priorities established by the decadal survey without relying on new scientific or technology developments.

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NOTE: "Summary" reprinted from *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity*, The National Academies Press, Washington, D.C., 2008, pp. 1-5.

[1]National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003.

[2]Colleen N. Hartman, Acting Associate Administrator for Science Mission Directorate, letter to Lennard A. Fisk, Chair, Space Studies Board, March 21, 2007.

[3]National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003.

The decadal survey specified five mission candidates and ranked them according to priority:

- Kuiper Belt Pluto Explorer,
- South Pole-Aitken Basin Sample Return,
- Jupiter Polar Orbiter with Probes,
- Venus In Situ Explorer, and
- Comet Surface Sample Return.

The decadal survey stated that although this list was ranked by scientific priority, NASA should not automatically select on the basis of that priority and should first consider the overall viability of the proposed mission. NASA followed this advice. For the 2005 New Frontiers announcement of opportunity, NASA clearly stated that the "'strawman' missions are in no order of priority," and in fact the announcement of opportunity did not list them in the same order as the decadal survey. In addition, for the 2005 competition NASA selected the Jupiter polar mission instead of the scientifically higher-ranked (in the decadal survey) lunar mission.

To date two New Frontiers missions have been selected: the New Horizons mission to Pluto and the Kuiper Belt and the Juno mission to orbit Jupiter. New Horizons was launched in 2006, flew past Jupiter in early 2007, and is scheduled to fly past Pluto in 2015. Juno is scheduled for launch in 2011 and to reach Jupiter in 2015. Both missions will address fundamental science goals defined in the decadal survey and will significantly enhance scientific understanding of our solar system.

The decadal survey listed five additional missions that were not recommended for reasons of "mission sequencing, technological readiness, or budget."[4] These missions, listed in the following order in the decadal survey, were *not* ranked according to scientific priority:

- Network Science,
- Trojan/Centaur Reconnaissance,
- Asteroid Rover/Sample Return,
- Io Observer, and
- Ganymede Observer.

Notably, Mars was not included in the New Frontiers Program. In essence, New Frontiers was created to ensure that a medium-size class of missions for the rest of the solar system (excluding Mars) was funded. The decadal survey treated Mars as a separate program with its own integrated list of scientific priorities and missions, some of which were in the same cost range as the New Frontiers missions. In particular, the decadal survey identified the Mars Long-Lived Lander Network as its second-highest-priority medium-size Mars mission, after the Mars Science Laboratory, which is currently scheduled for launch in 2009.

In drafting this report, the committee used the decadal survey as its guide and the decadal survey's list of other potential medium-size solar system missions as its starting point. The committee solicited information from a broad range of sources, including NASA's own solar system advisory groups, and heard about other possible missions and science that were not included in the decadal survey's review of medium-size missions.

The committee recognized that it lacked the scope and time of the decadal survey and did not have the expertise or authority to substantially question the decadal survey. As a result, the committee deferred to the insight and authority of the decadal survey whenever possible. However, the committee noted that scientific discoveries have been made since the decadal survey was presented to NASA in summer 2002, and new technologies and technological approaches may be available today.

During its deliberations, the committee also recognized that including Mars in the New Frontiers Program was outside the scope considered in the development of the decadal survey. The decadal survey treated Mars as a program, and the committee sees no reason why that should change.

Furthermore, the committee believes that allowing any medium-size Mars mission to compete in the New Frontiers Program would run the risk of undercutting the overall Mars Exploration Program, and thus be counter to the decadal survey. The committee believes that this action would be bad for both the New Frontiers Program and the Mars Exploration Program. However, the committee ultimately determined that within the context of

[4] *New Frontiers in the Solar System*, p. 197.

comparative terrestrial planetology (i.e., network seismic *and* meteorological science) the New Frontiers Program is open to Mars missions.

**The committee strongly believes that the New Frontiers Program is a valuable and vital part of NASA's solar system exploration program. The committee's philosophy was to provide NASA with sufficient options and to provide potential proposers with sufficient flexibility in their proposals to enable NASA to select a mission that can be done within the constraints of the New Frontiers Program, particularly the cost cap. The health of the New Frontiers Program was an overriding priority for the committee. New Frontiers has so far been successful in selecting missions that accomplish science that is not possible under the Discovery Program. These missions will make fundamental contributions to scientific understanding of the formation and evolution of the solar system.**

In reviewing the decadal survey, and listening to presentations by proposers in the previous New Frontiers competition, the committee was concerned that the mission options presented in the decadal survey were overly specific about the methods of accomplishing the science missions—the so-called "mission architectures." For example, the Jupiter Mission with Probes described in the decadal survey essentially required atmospheric probes to return data from Jupiter's atmosphere rather than specifying the information to be gained and leaving the method of obtaining it to those intending to propose a mission. Ultimately, the mission selected, named Juno, utilizes microwave radiometry only to return data on the water abundance in the atmosphere.

The committee was concerned that such constraints could make it impossible for anyone to propose a mission that could be accomplished within the cost cap. The committee heard statements that allowing proposers greater latitude in how to return data not only increases ingenuity, but more importantly, also provides the flexibility required to fit missions within the cost and other constraints. The committee determined that rather than specifying mission architectures, NASA should emphasize the science to be returned from such a mission and leave the implementation specifics to the teams competing for the opportunity.

**Recommendation 1: In drafting the rules for the next New Frontiers announcement of opportunity, NASA should emphasize the science objectives and questions to be addressed, and not specify measurements or techniques for the implementation.**

The committee determined that the three remaining potential missions in the decadal survey's list—South Pole-Aitken Basin Sample Return, Venus In Situ Explorer, and the Comet Surface Sample Return—still have substantial scientific merit and should remain among the options in the next announcement of opportunity. However, the committee also determined that the list of candidate missions should be expanded to include the five other medium-size mission options identified in the decadal survey: Network Science, Trojan/Centaur Reconnaissance, Asteroid Rover/Sample Return, Io Observer, and Ganymede Observer. The committee also determined that an additional open option should be made available, which is discussed below.

The committee notes that compared to the original five New Frontiers missions identified in the decadal survey, the other five medium-size missions were discussed in less detail. Because of this, the committee has sought to devote significant attention to discussing the background and objectives of these missions in this report. In particular, the Io Observer and Ganymede Observer missions were not discussed in great detail in the decadal survey, and so the committee has devoted more attention to them in Chapter 2 of this report in order to explain their inclusion.

Expanding the list accomplishes several important goals: it provides NASA with more options for the next mission selection; it provides potential proposers with more options to produce interesting, innovative, and competitive missions; it expands the cadre of participants and the science that will be evaluated by potential proposers, enabling the applicant pool to grow for future competitions; and it provides options to be considered by the next decadal survey. As with prior competitive mission opportunities, *NASA should select from this set of missions based both on science priority and on overall mission viability.*

**Recommendation 2: NASA should expand the list of potential missions in the next New Frontiers announcement of opportunity to include the three remaining candidate missions—South Pole-Aitken Basin Sample Return, Venus In Situ Explorer, and Comet Surface Sample Return—and also the five additional medium-size missions mentioned in the decadal survey: Network Science, Trojan/Centaur Reconnaissance, Asteroid Rover/Sample Return, Io Observer, and Ganymede Observer. There is no recommended priority for these**

**missions. NASA should select from this set of missions based both on science priority and on overall mission viability.**

The committee has not prioritized its list of eight missions. Each of these missions is discussed in greater detail in Chapter 2. The committee has also provided mission-specific recommendations for the science goals of each. The lists of goals are as comprehensive as possible but should not be interpreted as all-encompassing. In some cases those mission-specific recommendations introduce significant changes into the possible mission, notably in defining the parameters for the Venus In Situ Explorer and the Network Science missions. The committee noted that these science goals may not all be achievable in a single mission but believes that the choice and prioritization of goals are best left to those proposing and evaluating the missions.

The committee was also impressed with arguments it heard about the importance of innovation not only in individual missions, but also in the overall New Frontiers Program, and about the risks of being overly specific on how to accomplish the goals of the decadal survey. Thus, in addition to the eight identified missions, the committee believes that NASA should offer an additional option for other missions in the same size class that can acquire compelling information answering high-priority science questions from the decadal survey. The committee believes that this approach not only will provide an opening for innovation but also might enable the applicant pool for future missions to grow. The committee believes that any such mission will have to meet a very high standard of scientific proof. Possible examples of such missions could include—but are not limited to—shallow atmospheric probes for the outer planets.

The committee realized that the New Frontiers mission line is a hybrid, incorporating aspects of both the Discovery- and the flagship-class missions. As such, the committee concluded that the mission options for the next announcement of opportunity cannot be drawn strictly from the decadal survey but rather should be interpreted in light of scientific discoveries made since the decadal survey was conducted in 2002. New discoveries made about several of the targets evaluated in this mission class in some cases enhance the importance of these scientific questions, and in other cases may undercut the original rationale for investigating a target. Planetary exploration is an ongoing endeavor advanced by paradigm-shifting scientific discoveries and mission-enabling technological developments. NASA's New Frontiers Program will have to adapt to include them.

New technologies and technological methods may now exist that were not available even 5 years ago. These technologies could include instrumentation (such as new seismic sensors) or mission-enabling equipment (such as radiation-hardened electronics). The committee concluded that it is important to the health of the program that a method exist for including such innovations, while acknowledging that those proposing missions will have a high standard to meet.

**Recommendation 3: NASA should consider mission options outside the three remaining and five additional medium-size missions described in the decadal survey that are spurred by major scientific and technological developments made since the decadal survey. As with any New Frontiers mission, these proposals must offer the potential to dramatically advance fundamental scientific goals of the decadal survey and should accomplish scientific investigations well beyond the scope of the smaller Discovery Program. Both mission-enabling technological advances and novel applications of current technology could be considered. However, *NASA should limit its choices to the eight specific candidate missions unless a highly compelling argument can be made for an outside proposal.***

The basis for these overarching recommendations is discussed further in Chapter 1. However, the mission sections in Chapter 2 provide information that will be vital for drafting the next New Frontiers announcement of opportunity, and this report must be read in its entirety in order to understand the committee's findings and recommendations. The mission-specific recommendations in Chapter 2 are also included in Chapter 3 for ease of reference. Finally, the committee notes that the New Frontiers Program is intended to be both strategic—based on the science goals established in the decadal survey—and adaptable to new discoveries. The committee believes that it is important for NASA to find a method for incorporating new discoveries into the goals of the program for announcements of opportunity made several years after a decadal survey has been produced. Seeking input from the scientific community via the NRC (in the form of reports such as this one) is one method to achieve this, but not necessarily the only method. The committee hopes that in the future NASA will continue to recognize the importance of such a process.

# 5.4 Science Opportunities Enabled by NASA's Constellation System: Interim Report

A Report of the Ad Hoc Committee on Science Opportunities
Enabled by NASA's Constellation System

## Summary

In 2004 NASA initiated studies of advanced science mission concepts known as the Vision Missions and inspired by a series of NASA roadmap activities conducted in 2003. Also in 2004 NASA began implementation of the first phases of a new space exploration policy, the Vision for Space Exploration. This implementation effort included development of a new human-carrying spacecraft, known as Orion, and two new launch vehicles, the Ares I and Ares V rockets—collectively called the Constellation System. NASA asked the National Research Council (NRC) to evaluate the science opportunities enabled by the Constellation System (see Preface) and to produce an interim report on a short time schedule and a final report by November 2008. The committee notes, however, that the Constellation System and its Orion and Ares vehicles have been justified by NASA and selected in order to enable human exploration beyond low Earth orbit, and not to enable science missions.

This interim report of the Committee on Science Opportunities Enabled by NASA's Constellation System evaluates the 11 Vision Mission studies presented to it and groups them into two categories: those more deserving of future study, and those less deserving of future study. Although its statement of task also refers to Earth science missions, the committee points out that the Vision Missions effort was focused on future astronomy, heliophysics, and planetary exploration and did not include any Earth science studies because, at the time, the NRC was conducting the first Earth science decadal survey, and funding Earth science studies as part of the Vision Missions effort would have interfered with that process. Consequently, no Earth science missions are evaluated in this interim report. However, the committee will evaluate any Earth science mission proposal submitted in response to its request for information issued in March 2008 (see Appendix A).

The committee based its evaluation of the preexisting Vision Missions studies on two criteria: whether the concepts offered the potential for a significant scientific advance, and whether or not the concepts would benefit from the Constellation System. The committee determined that all of the concepts offered the possibility of a significant scientific advance, but it cautions that such an evaluation ultimately must be made by the decadal survey process, and it emphasizes that this interim report's evaluation should not be considered to be an endorsement of the scientific merit of these proposals, which must of course be evaluated relative to other proposals.

The committee determined that seven of these concepts would benefit from the Constellation System, whereas four would not, but it stresses that this conclusion does not reflect an evaluation of the scientific merit of the projects, but rather an assessment of whether or not new capabilities provided by the Constellation System could significantly affect them. Some of the mission concepts, such as the Advanced Compton Telescope, already offer a significant scientific advance and fit easily within the mass and volume constraints of existing launch vehicles. Other mission concepts, such as the Palmer Quest proposal to drill through the Mars polar cap, are not constrained by the launch vehicle, but rather by other technology limitations. The committee evaluated the mission concepts as presented to it, aware nevertheless that proposing a far larger and more ambitious mission with the same science goals might be possible given the capabilities of the Ares V launch vehicle. (Such proposals can be submitted in response to the committee's request for information to be evaluated in its final report.) See Table S.1 for a summary of the Vision Missions, including their cost estimates, technical maturity, and reasons that they might benefit from the Constellation System.

The committee developed several findings and recommendations.

**Finding 1. The greatly increased payload capability promised by Ares V could lead to much more costly science payloads.**

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NOTE: "Summary" reprinted from *Science Opportunities Enabled by NASA's Constellation System: Interim Report*, The National Academies Press, Washington, D.C., 2008, pp. 1-4.

TABLE S.1 Summary of Vision Missions (in Alphabetical Order) Evaluated by the Committee

| Vision Mission | Cost Estimate[a] (billions) | Technical Maturity[b] | Worthy of Further Study as a Constellation Mission? | Notes |
|---|---|---|---|---|
| Advanced Compton Telescope (ACT) | $1 | Medium | No | This mission does not benefit from Constellation. |
| Generation-X (Gen-X) | >$5 | Low | Yes | One Ares V launch of one 16-meter telescope is significantly simpler than the early proposed configurations.<br>Cost estimates are weak. The additional mass capability could significantly reduce mirror development costs. |
| Interstellar Probe | $1-$5 | High—concept, instruments<br>Low—propulsion | Yes | Further study is needed of the benefits of additional launch mass enabled by Ares V, in particular alternative propulsion options. |
| Kilometer-Baseline Far-Infrared/ Submillimeter Interferometer | >$5 | Low | No | The need for Constellation is questionable, except for human servicing. |
| Modern Universe Space Telescope (MUST) | >$5 | High—mission concept, instruments<br>Low—assembly | Yes | Large one-piece, central mirror is possible with Ares V rather than a robotically assembled mirror. |
| Neptune Orbiter with Probes | >$5 | High—mission concept, instruments<br>Low—propulsion and possibly lander | Yes | Ares V could possibly obviate the need for aerocapture and/or nuclear-electric propulsion. |
| Palmer Quest | >$5 | Low | No | This mission does not benefit from Constellation. |
| Single Aperture Far Infrared Mission (SAFIR) | >$5 | Medium—mission concept<br>Low—cooling, detectors | No | This mission does not benefit from Constellation. |
| Solar Polar Imager | $1-$5 | High—mission concept, instruments<br>Low—propulsion | Yes | Consider propulsion options enabled by Ares V. |
| Stellar Imager | $5 | Low | Yes | Could launch larger mirrors (2 meters vs. 1 meter) and a second hub on a single Ares V launch. |
| Titan Explorer | >$5 | Low—requires aerocapture | Yes | Launch on Ares V may enable propulsive capture rather than aerocapture and shorten transit time. |

[a]Cost estimates based on data provided to the committee.
[b]Technical maturity based on data provided to the committee.

**Finding 2. The committee determined that the Ares I capabilities are not sufficiently distinct from those of Atlas V and Delta IV to enable different types or a higher quality of space science missions.**

**Finding 3. The following Vision Mission studies might benefit from the opportunities enabled by the Constellation System and are therefore considered more deserving of future study: Generation-X, Modern Universe Space Telescope, Stellar Imager, Interstellar Probe, Solar Polar Imager, Neptune Orbiter with Probes, and Titan Explorer. The committee did not assess the relative scientific priority of the missions within this group. In the final report, these mission concepts will be compared to additional mission concepts (collected in response to the committee's request for information) that the committee determines to be more deserving of future study, and the committee will produce a consolidated list.**

According to the committee's evaluation criteria, the four mission concepts that it deemed less deserving of future study simply do not appear to benefit highly from use of the Constellation System. The committee concluded that the seven more-deserving mission concepts require greater study of their scientific benefits and the technical benefits enabled by the Constellation System.

**Recommendation 1. NASA should conduct further studies of the scientific benefits as well as the technical benefits to mission execution, such as reduction of mission complexity and risk, enabled by the Constellation System for the following missions: Generation-X, Modern Universe Space Telescope, Stellar Imager, Interstellar Probe, Solar Polar Imager, Neptune Orbiter with Probes, and Titan Explorer.**

The committee accepted the cost estimates provided by the Vision Mission studies themselves or by the study representatives who presented them to the committee. Nevertheless, the committee concluded that these cost estimates are preliminary. The committee is concerned that the costs of these missions will be high, at least for the flagship-class missions, if not substantially higher. Given the fact that NASA has insufficient funding to support more than one flagship-class mission per decade in two science areas (essentially one for astronomy and astrophysics and one for solar system exploration, with the situation for Earth science and heliophysics being slightly more complicated), each of these missions would place substantial strain on the science budget, and the committee therefore emphasizes that close attention to cost issues is required. Since the committee was asked to consider missions that could be flown during the period 2020-2035, very few such large missions could possibly be funded during that period.

**Finding 4. There are uncertainties in the cost estimates associated with the Vision Missions listed above when flown on the Ares V vehicle.**

Although NASA has not yet produced cost estimates for many of the elements of the Constellation System, such as the Ares V launch vehicle, the committee recognized that utilization of the Constellation System, particularly the Ares V, could have a potentially dramatic effect on the costs of these missions. Incorporating the use of an expensive launch vehicle could increase costs. But it could also possibly balance increased costs by simplifying mission design (for instance, by eliminating the requirement for on-orbit assembly or complex deployment mechanisms).

**Recommendation 2. NASA should perform cost analysis for the missions that the committee determined could benefit from the Ares V capability (Generation-X, Modern Universe Space Telescope, Stellar Imager, Interstellar Probe, Solar Polar Imager, Neptune Orbiter with Probes, and Titan Explorer). This analysis should use the Ares V technical capabilities together with appropriate upper stages as a baseline.**

Virtually all of the mission concepts evaluated by the committee are large, complex, and costly. Several are similar to studies currently being undertaken by traditional international partners in space exploration.

**Finding 5. International cooperation could provide access to international scientific expertise and technology useful for these missions, and could reduce costs through provision of foreign instruments and infrastructure.**

The committee was charged with identifying the "benefits of using the Constellation System's unique capabilities relative to alternative implementation approaches." Alternative implementation approaches include technologies that allow the use of smaller launch vehicles (such as in the Evolved Expendable Launch Vehicle class that served as the baseline for the Vision Mission studies). The committee notes that several technology issues are shared by two or more missions. There are benefits to having multiple technology solutions available to achieve objectives, and the committee is concerned that it is risky to rely on only one solution that may never emerge. NASA currently lacks a technology development strategy, a gap identified by the NRC as a shortcoming.[1] The impact of technology on these missions and how it may require, or alleviate the need for, the use of the Constellation System requires further study and will be evaluated by the committee in its final report.

**Finding 6. The committee identified the following technology issues as meriting further attention. Some of these technologies are of a basic, mission-enabling nature; others provide options that can be traded for alternative mission architectures.**

- **Basic enabling technologies**
  —Free-flying constellations
  —Tethered flight
  —Next-generation Deep Space Network
  —Space nuclear reactors
- **Technologies enabling alternatives to Ares V**
  —Aerocapture
  —Solar sails
  —Solar-electric propulsion
  —Nuclear-electric propulsion
  —Robotic assembly and servicing
- **Technologies enhancing Constellation capabilities**
  —Human assembly and servicing

[1] See, for example, National Research Council, *Grading NASA's Solar System Exploration Program: A Midterm Review,* The National Academies Press, Washington, D.C., 2008, pp. 11 and 59-61.

# 5.5 Severe Space Weather Events—Understanding Societal and Economic Impacts: Workshop Report

A Report of the Ad Hoc Planning Committee for the Societal and Economic Impacts of Severe Space Weather Events Workshop

## Summary

### SOCIETAL CONTEXT

Modern society depends heavily on a variety of technologies that are susceptible to the extremes of space weather—severe disturbances of the upper atmosphere and of the near-Earth space environment that are driven by the magnetic activity of the Sun. Strong auroral currents can disrupt and damage modern electric power grids and may contribute to the corrosion of oil and gas pipelines. Magnetic storm-driven ionospheric density disturbances interfere with high-frequency (HF) radio communications and navigation signals from Global Positioning System (GPS) satellites, while polar cap absorption (PCA) events can degrade—and, during severe events, completely black out—HF communications along transpolar aviation routes, requiring aircraft flying these routes to be diverted to lower latitudes. Exposure of spacecraft to energetic particles during solar energetic particle events and radiation belt enhancements can cause temporary operational anomalies, damage critical electronics, degrade solar arrays, and blind optical systems such as imagers and star trackers.

The effects of space weather on modern technological systems are well documented in both the technical literature and popular accounts. Most often cited perhaps is the collapse within 90 seconds of northeastern Canada's Hydro-Quebec power grid during the great geomagnetic storm of March 1989, which left millions of people without electricity for up to 9 hours. This event exemplifies the dramatic impact that extreme space weather can have on a technology upon which modern society in all of its manifold and interconnected activities and functions critically depends.

Nearly two decades have passed since the March 1989 event. During that time, awareness of the risks of extreme space weather has increased among the affected industries, mitigation strategies have been developed, new sources of data have become available (e.g., the upstream solar wind measurements from the Advanced Composition Explorer), new models of the space environment have been created, and a national space weather infrastructure has evolved to provide data, alerts, and forecasts to an increasing number of users.

Now, 20 years later and approaching a new interval of increased solar activity, how well equipped are we to manage the effects of space weather? Have recent technological developments made our critical technologies more or less vulnerable? How well do we understand the broader societal and economic impacts of extreme space weather events? Are our institutions prepared to cope with the effects of a "space weather Katrina," a rare, but according to the historical record, not inconceivable eventuality? On May 22 and 23, 2008, a workshop held in Washington, D.C., under the auspices of the National Research Council brought together representatives of industry, the federal government, and the social science community to explore these and related questions. This report was prepared by members of the ad hoc committee that organized the workshop, and it summarizes the key themes, ideas, and insights that emerged during the 1½ days of presentations and discussions.

### THE IMPACT OF SPACE WEATHER

Modern technological society is characterized by a complex interweave of dependencies and interdependencies among its critical infrastructures. A complete picture of the socioeconomic impact of severe space weather must include both direct, industry-specific effects (such as power outages and spacecraft anomalies) and the collateral effects of space-weather-driven technology failures on dependent infrastructures and services.

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NOTE: "Summary" reprinted from *Severe Space Weather Events—Understanding Societal and Economic Impacts: Workshop Report*, The National Academies Press, Washington, D.C., 2008, pp. 1-5.

### Industry-Specific Space Weather Impacts

The main industries whose operations can be adversely affected by extreme space weather are the electric power, spacecraft, aviation, and GPS-based positioning industries. The March 1989 blackout in Quebec and the forced outages of electric power equipment in the northeastern United States remain the classic example of the impact of a severe space weather event on the electric power industry. Several examples of the impact of space weather on the other industries are cited in the report:

- The outage in January 1994 of two Canadian telecommunications satellites during a period of enhanced energetic electron fluxes at geosynchronous orbit, disrupting communications services nationwide. The first satellite recovered in a few hours; recovery of the second satellite took 6 months and cost $50 million to $70 million.
- The diversion of 26 United Airlines flights to non-polar or less-than-optimum polar routes during several days of disturbed space weather in January 2005. The flights were diverted to avoid the risk of HF radio blackouts during PCA events. The increased flight time and extra landings and takeoffs required by such route changes increase fuel consumption and raise cost, while the delays disrupt connections to other flights.
- Disabling of the Federal Aviation Administration's recently implemented GPS-based Wide Area Augmentation System (WAAS) for 30 hours during the severe space weather events of October-November 2003.

With increasing awareness and understanding of space weather effects on their technologies, industries have responded to the threat of extreme space weather through improved operational procedures and technologies. As just noted, airlines re-route flights scheduled for polar routes during intense solar energetic particle events in order to preserve reliable communications. Alerted to an impending geomagnetic storm by NOAA's Space Weather Prediction Center (SWPC) and monitoring ground currents in real-time, power grid operators take defensive measures to protect the grid against geomagnetically induced currents (GICs). Similarly, under adverse space weather conditions, launch personnel may delay a launch, and satellite operators may postpone certain operations (e.g., thruster firings). For the spacecraft industry, however, the primary approach to mitigating the effects of space weather is to design satellites to operate under extreme environmental conditions to the maximum extent possible within cost and resource constraints. GPS modernization through the addition of two new navigation signals and new codes is expected to help mitigate space weather effects (e.g., ranging errors, fading caused by ionospheric scintillation), although to what degree is not known. These technologies will come on line incrementally over the next 15 years as new GPS satellites become operational. In the meantime, the Federal Aviation Administration will maintain "legacy" non-GPS-based navigation systems as a backup, while other GPS users (e.g., offshore drilling companies) can postpone operations for which precision position knowledge is required until the ionospheric disturbance is over.

### The Collateral Impacts of Space Weather

Because of the interconnectedness of critical infrastructures in modern society, the impacts of severe space weather events can go beyond disruption of existing technical systems and lead to short-term as well as to long-term collateral socioeconomic disruptions. Electric power is modern society's cornerstone technology, the technology on which virtually all other infrastructures and services depend. Although the probability of a wide-area electric power blackout resulting from an extreme space weather event is low, the consequences of such an event could be very high, as its effects would cascade through other, dependent systems. Collateral effects of a longer-term outage would likely include, for example, disruption of the transportation, communication, banking, and finance systems, and government services; the breakdown of the distribution of potable water owing to pump failure; and the loss of perishable foods and medications because of lack of refrigeration. The resulting loss of services for a significant period of time in even one region of the country could affect the entire nation and have international impacts as well.

Extreme space weather events are low-frequency/high-consequence (LF/HC) events and as such present—in terms of their potential broader, collateral impacts—a unique set of problems for public (and private) institutions and governance, different from the problems raised by conventional, expected, and frequently experienced events.

As a consequence, dealing with the collateral impacts of LF/HC events requires different types of budgeting and management capabilities and consequently challenges the basis for conventional policies and risk management strategies, which assume a universe of constant or reliable conditions. Moreover, because systems can quickly become dependent on new technologies in ways that are unknown and unexpected to both developers and users, vulnerabilities in one part of the broader system have a tendency to spread to other parts of the system. Thus, it is difficult to understand, much less to predict, the consequences of future LF/HC events. Sustaining preparedness and planning for such events in future years is equally difficult.

### Future Vulnerabilities

Our knowledge and understanding of the vulnerabilities of modern technological infrastructure to severe space weather and the measures developed to mitigate those vulnerabilities are based largely on experience and knowledge gained during the past 20 or 30 years, during such episodes of severe space weather as the geomagnetic superstorms of March 1989 and October-November 2003. As severe as some of these recent events have been, the historical record reveals that space weather of even greater severity has occurred in the past—e.g., the Carrington event of 1859[1] and the great geomagnetic storm of May 1921—and suggests that such extreme events, though rare, are likely to occur again some time in the future. While the socioeconomic impacts of a future Carrington event are difficult to predict, it is not unreasonable to assume that an event of such magnitude would lead to much deeper and more widespread socioeconomic disruptions than occurred in 1859, when modern electricity-based technology was still in its infancy.

A more quantitative estimate of the potential impact of an unusually large space weather event has been obtained by examining the effects of a storm of the magnitude of the May 1921 superstorm on today's electric power infrastructure. Despite the lessons learned since 1989 and their successful application during the October-November 2003 storms, the nation's electric power grids remain vulnerable to disruption and damage by severe space weather and have become even more so, in terms of both widespread blackouts and permanent equipment damage requiring long restoration times. According to a study by the Metatech Corporation, the occurrence today of an event like the 1921 storm would result in large-scale blackouts affecting more than 130 million people and would expose more than 350 transformers to the risk of permanent damage.

## SPACE WEATHER INFRASTRUCTURE

Space weather services in the United States are provided primarily by NOAA's SWPC and the U.S. Air Force's (USAF's) Weather Agency (AFWA), which work closely together to address the needs of their civilian and military user communities, respectively. The SWPC draws on a variety of data sources, both space- and ground-based, to provide forecasts, watches, warnings, alerts, and summaries as well as operational space weather products to civilian and commercial users. Its primary sources of information about solar activity, upstream solar wind conditions, and the geospace environment are NASA's Advanced Composition Explorer (ACE), NOAA's GOES and POES satellites, magnetometers, and the USAF's solar observing networks. Secondary sources include SOHO and STEREO as well as a number of ground-based facilities. Despite a small and unstable budget (roughly $6 million to $7 million U.S. dollars annually) that limits capabilities, the SWPC has experienced a steady growth in customer base, even during the solar minimum years, when disturbance activity is lower. The focus of the USAF's space weather effort is on providing situational knowledge of the real-time space weather environment and assessments of the impacts of space weather on different Department of Defense missions. The Air Force uses NOAA data combined with data from its own assets such as the Defense Meteorological Satellites Program satellites, the Communications/Navigation Outage Forecasting System, the Solar Electro-Optical Network, the Digital Ionospheric Sounding System, and the GPS network.

NASA is the third major element in the nation's space weather infrastructure. Although NASA's role is scientific rather than operational, NASA science missions such as ACE provide critical space weather information, and NASA's Living with a Star program targets research and technologies that are relevant to operations. NASA-developed products that are candidates for eventual transfer from research to operations include sensor technology and physics-based space weather models that can be transitioned into operational tools for forecasting and situational awareness.

Other key elements of the nation's space weather infrastructure are the solar and space physics research community and the emerging commercial space weather businesses. Of particular importance are the efforts of these sectors in the area of model development.

### Space Weather Forecasting: Capabilities and Limitations

One of the important functions of a nation's space weather infrastructure is to provide reliable long-term forecasts, although the importance of forecasts varies according to industry.[2] With long-term (1- to 3-day) forecasts and minimal false alarms,[3] the various user communities can take actions to mitigate the effects of impending solar disturbances and to minimize their economic impact. Currently, NOAA's SWPC can make probability forecasts of space weather events with varying degrees of success. For example, the SWPC can, with moderate confidence, predict the occurrence probability of a geomagnetic storm or an X-class flare 1 to 3 days in advance, whereas its capability to provide even short-term (less than 1 day) or long-term forecasts of ionospheric disturbances—information important for GPS users—is poor. The SWPC has identified a number of critical steps needed to improve its forecasting capability, enabling it, for example, to provide high-confidence long- and short-term forecasts of geomagnetic storms and ionospheric disturbances. These steps include securing an operational solar wind monitor at L1; transitioning research models (e.g., of coronal mass ejection propagation, the geospace radiation environment, and the coupled magnetosphere/ionosphere/atmosphere system) into operations, and developing precision GPS forecast and correction tools. The requirement for a solar wind monitor at L1 is particularly important because ACE, the SWPC's sole source of real-time upstream solar wind and interplanetary magnetic field data, is well beyond its planned operational life, and provisions to replace it have not been made.

## UNDERSTANDING THE SOCIETAL AND ECONOMIC IMPACTS OF SEVERE SPACE WEATHER

The title of the workshop on which this report is based, "The Societal and Economic Impacts of Severe Space Weather," perhaps promised more than this subsequent report can fully deliver. What emerged from the presentations and discussions at the workshop is that the invited experts understand well the effects of at least moderately severe space weather on specific technologies, and in many cases know what is required to mitigate them, whether enhanced forecasting and monitoring capabilities, new technologies (new GPS signals and codes, new-generation radiation-hardened electronics), or improved operational procedures. Limited information was also provided—and captured in this report—on the costs of space weather-induced outages (e.g., $50 million to $70 million to restore the $290 million Anik E2 to operational status) as well as of non-space-weather-related events that can serve as proxies for disruptions caused by severe space storms (e.g., $4 billion to $10 billion for the power blackout of August 2003), and an estimate of $1 trillion to $2 trillion during the first year alone was given for the societal and economic costs of a "severe geomagnetic storm scenario" with recovery times of 4 to 10 years.

Such cost information is interesting and useful—but as the outcome of the workshop and this report make clear, it is at best only a starting point for the challenge of answering the question implicit in the title: What are the societal and economic impacts of severe space weather? To answer this question quantitatively, multiple variables must be taken into account, including the magnitude, duration, and timing of the event; the nature, severity, and extent of the collateral effects cascading through a society characterized by strong dependencies and interdependencies; the robustness and resilience of the affected infrastructures; the risk management strategies and policies that the public and private sectors have in place; and the capability of the responsible federal, state, and local government agencies to respond to the effects of an extreme space weather event. While this workshop, along with its report, has gathered in one place much of what is currently known or suspected about societal and economic impacts, it has perhaps been most successful in illuminating the scope of the myriad issues involved, and the gaps in knowledge that remain to be explored in greater depth than can be accomplished in a workshop. A quantitative and comprehensive assessment of the societal and economic impacts of severe space weather will be a truly daunting task, and will involve questions that go well beyond the scope of the present report.

## NOTES

1. The Carrington event is by several measures the most severe space weather event on record. It produced several days of spectacular auroral displays, even at unusually low latitudes, and significantly disrupted telegraph services around the

world. It is named after the British astronomer Richard Carrington, who observed the intense white-light flare associated with the subsequent geomagnetic storm.

2. For the spacecraft industry, for example, space weather predictions are less important than knowledge of climatology and especially of the extremes within a climate record.

3. False alarms are disruptive and expensive. Accurate forecasts of a severe magnetic storm would allow power companies to mitigate risk by canceling planned maintenance work, providing additional personnel to deal with adverse effects, and reducing the amount of power transfers between adjacent systems in the grid. However, as was pointed out during the workshop, if the warning proved to be a false alarm and planned maintenance was canceled, the cost of large cranes, huge equipment, and a great deal of material and manpower sitting idle would be very high.

# 5.6 Space Science and the International Traffic in Arms Regulations: Summary of a Workshop

Margaret G. Finarelli, Rapporteur, and Joseph K. Alexander, Rapporteur

## Summary

The United States seeks to protect its security and foreign-policy interests, in part, by actively controlling the export of goods, technologies, and services that are or may be useful for military development in other nations. "Export" is defined not simply as the sending abroad of hardware but also as the communication of related technology and know-how to foreigners in the United States and overseas. The U.S. government mechanism for controlling dual-use items—items in commerce that have potential military use—is the Export Administration Regulations (EAR) administered by the Department of Commerce; items defined in law as defense articles fall under the jurisdiction of the Department of State and the International Traffic in Arms Regulations (ITAR). Because of the potential military implications of the export of defense articles, the ITAR regime imposes much greater burdens (on both the applicant and the government) than does the EAR regime during the process of applying for, and implementing the provisions of, licenses and technical-assistance agreements.

Until the early 1990s export control activity related to all space satellites (commercial and scientific) was handled under ITAR. Between 1992 and 1996 the George H.W. Bush and the Clinton administrations transferred jurisdiction over the licensing of civilian communications satellites to the Commerce Department under EAR. In 1999, however, in response to broad concerns about Chinese attempts to acquire U.S. high technology, the U.S. House of Representatives convened the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China, also known as the Cox Committee. One of the many consequences of the Cox Committee's report[1] was Congress's mandate that jurisdiction over export and licensing of satellites and related equipment and services, irrespective of military utility, be transferred from the Department of Commerce to the State Department and that such equipment and services be covered as defense articles under ITAR. Scientific satellites were explicitly included despite their use for decades in peaceful internationally conducted cooperative scientific research. It is widely recognized that the shift in regulatory regime from EAR to ITAR has had major deleterious effects on international scientific research activities that depend on satellites, spaceflight hardware, and other items that are now controlled by ITAR. Furthermore, contravening U.S. interests in attracting foreign students to U.S. universities, the capture of space technology by ITAR has caused serious problems in the teaching of university space science and engineering classes, virtually all of which include non-U.S. students.

This report is a summary of a September 2007 workshop in which participants from the space research communities and the export-control administration and policy communities came together to discuss problems, effects, and potential solutions regarding the application of ITAR to space science. The principal themes and ideas that emerged from the discussions are summarized below.

### UNINTENDED CONSEQUENCES OF A NET CAST TOO BROADLY

The space science community acknowledges the sensitivity of much hardware and technology related to space activity, but they also argue that controlling "everything that flies in space" casts too broad a net. The current administration has actually recognized the mismatch between the ITAR control regime and the low levels of risk inherent in the bulk of international space science activity. A variety of White House policy statements have been made and regulatory adjustments tried over the years, but the unfortunate net result of such changes has been the introduction of ambiguity and uncertainty. As a result, and because the criminal sanctions for failure to comply with ITAR are personal and great, university officials and researchers tend to err on the side of conservatism in seeking licenses and thus impose on themselves financial, administrative, and time-delay burdens that might not even be necessary.

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NOTE: "Summary" reprinted from *Space Science and the International Traffic in Arms Regulations: Summary of a Workshop*, The National Academies Press, Washington, D.C., 2008, pp. 1-3.

[1]U.S. House of Representatives, *U.S. National Security and Military/Commercial Concerns with the People's Republic of China*, Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China, U.S. Government Printing Office, January 1999.

No one in the policy or political community contends that observed deleterious effects on U.S. leadership in scientific research and on U.S. academic excellence in science and engineering were intended by the use of ITAR as the regulatory regime for scientific-satellite exports. Nonetheless, the unintended consequences continue to plague the space community.

## EFFECTS ON SCIENTIFIC RESEARCH

Science, perhaps more than most fields of endeavor, depends on a full and open discussion and exchange of ideas among researchers who are addressing a given problem. If researchers are constrained by security classification or proprietary interests, communication is necessarily limited. Because most of the results of space science research are placed in the public domain, most space research activity qualifies as "fundamental research," which is excluded from ITAR controls as long as the research is conducted by "accredited institutions of higher learning." However, the bulk of government-sponsored fundamental space research at universities is conducted by consortia, including government research laboratories and private companies, and ITAR requires licensing when persons from other countries are involved—and they usually are. Since the dawn of the space age, other nations have invested in developing their own capabilities and have thereby made themselves desirable partners of the United States. Furthermore, many space-based scientific efforts focus on the science of Earth, and so international collaboration is necessary if global perspectives are to be drawn. The costs and delays imposed by ITAR processing requirements, coupled with other nations' reluctance to be made subject to restrictions derived from U.S. law and regulations, are making the United States less and less desirable as a partner to its foreign collaborators. The implications for continued international collaboration are grave.

## EFFECTS ON ACADEMIC OPERATIONS

Ambiguities about what constitutes fundamental research that can thus be excluded from ITAR controls, about what information can be placed in the public domain, and about what specific kinds of involvement with non-U.S. persons require licensing have led to great uncertainties in the university community about the participation of foreign students and researchers in projects involving potentially controlled hardware or technology. Universities must choose between either going through the burdensome licensing or technical-assistance agreement process to involve their students and researchers from other countries or consciously excluding any non-U.S. nationals from space-related research. The latter approach is injurious to the quality of research and to the educational value inherent in diversity. It is especially damaging when the non-U.S. participants could contribute critical and unique knowledge and skills to a project, as is often the case. According to workshop participants, the same uncertainties are leading some professors to "dumb down" course content rather than risk ITAR violations by discussing their research in the classroom setting. Although they believe that the vitality of education in the U.S. university system depends on its links to state-of-the-art research, many cite fears of breaking the law inadvertently.

## THE OUTLOOK

In the short term, fundamental changes to the law or regulations are unlikely, especially in a political environment in which almost any provisions related to national security are taken as givens and attempts to modify them are viewed as being politically risky, regardless of the potential practical impacts. Over the next year or so, the State Department is committed to incremental improvements in efficiency and to better communication with the space community to clarify and harmonize key definitions and concepts where confusion exists. Similarly, members of the university community are committed to participating actively in that communication to make their actions more effective and to document their problems with ITAR to facilitate favorable change.

Over the long term, however, many believe that a clean-slate approach is needed to fix the fundamental disconnect between ITAR as it is being applied to space science research and the needs of the U.S. space science community as it endeavors to maintain world leadership. The United States has many space-related policy priorities in addition to national security, including space leadership, university excellence, and international partnerships. As emphasized at the workshop, all these national goals need to be considered jointly in the development of a system for controlling the export of space-related hardware and technology that is effective at protecting national security, but that does not inadvertently harm the other policy priorities.

# 5.7 United States Civil Space Policy: Summary of a Workshop

Molly K. Macauley, Rapporteur, and Joseph K. Alexander, Rapporteur

## Summary

What are the principal purposes, goals, and priorities of the U.S. civil space program?[1] This question was the focus of the workshop on civil space policy held November 29-30, 2007, by the Space Studies Board (SSB) and the Aeronautics and Space Engineering Board (ASEB) of the National Research Council (NRC). In addressing this question, invited speakers and panelists and the general discussion from this public workshop explored a series of topics, including the following:

- Key changes and developments in the U.S. civil space program since the new national Vision for Space Exploration[2] (the Vision) was articulated by the executive branch in 2004;
- The fit of space exploration within a broader national and international context;
- Affordability, public interest, and political will to sustain the civil space program;
- Definitions, metrics, and decision criteria for the mix and balance of activities within the program portfolio;
- Roles of government in Earth observations from space; and
- Gaps in capabilities and infrastructure to support the program.

The workshop organizers acknowledged the long-standing problem of reconciling expectations of civil space program accomplishments during the coming decades with the limited public resources available to support these activities. The goal of the workshop was neither to develop definitive solutions nor to reach consensus. Rather, the purpose was to air a range of views and perspectives that would serve to inform broader discussion of such questions by policy makers and the public. This document summarizes the opinions expressed by individual workshop participants and does not necessarily reflect the consensus views of these participants, the SSB, or the workshop planning committee.

By way of background, the SSB and the ASEB had convened a similar workshop in 2003 in the wake of the space shuttle *Columbia* tragedy and the findings of the Columbia Accident Investigation Board. Since the issuance of the report on the 2003 workshop, *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy,*[3] additional developments have taken place to redirect many elements of the civil space program. The Vision for Space Exploration set forth by the executive branch in 2004, the National Aeronautics and Space Administration (NASA) Authorization Act of 2005,[4] and the national space policy presidential directive issued in 2006 have all served to redirect the program. The Vision sets forth a long-term robotic and human exploration program; the NASA Authorization Act of 2005 endorses the Vision and directs the program in several areas with respect to policy, management, and accountability and oversight; and the 2006 presidential directive establishes goals related to U.S. space leadership and the governance of space operations in and through space.

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NOTE: "Summary" reprinted from *United States Civil Space Policy: Summary of a Workshop*, The National Academies Press, Washington, D.C., 2008, pp. 1-5.

[1]Participants at the 2003 workshop considered *civil space* to include all of NASA's human and robotic space programs; NOAA's meteorological and environmental satellite programs; the activities of commercial entities in support of the space programs of NASA, NOAA, and other civilian agencies; and commercial space activities. Military and national security reconnaissance space programs were not included under the rubric of civil space. Participants in the 2007 workshop took the same approach and also considered emerging entrepreneurial efforts such as space tourism to be part of civil commercial space.

[2]National Aeronautics and Space Administration, *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

[3]National Research Council, *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy*, The National Academies Press, Washington, D.C., 2004.

[4]The National Aeronautics and Space Administration Authorization Act of 2005, Public Law 109-155, 109th Congress, U.S. Government Printing Office, Washington, D.C., 2005.

## ROBUSTNESS OF THE CIVIL SPACE PROGRAM

The workshop summarized here thus builds on discussion from the 2003 workshop in light of these developments. A natural starting point was an assessment of the new directions for the U.S. civil space program: How robust or resilient are these new directions to changes in resources available to support the program? How relevant is the program in what many workshop participants see as a rapidly changing international context? Is there public appeal in terms of willingness to embrace the program? Many participants expressed the view that the Vision had not progressed as originally outlined nor as many had expected, due in large part to the failure of the administration and the Congress to seek the required resources. A prominent concern among participants was that although the Vision was to be "pay as you go," shortfalls in the NASA budget had led the agency to reallocate resources toward pursuit of the Vision and away from other activities such as space and Earth science. Speakers argued that continued operational costs of the International Space Station, delayed phaseout of the space shuttle, costs of near-term development of the next-generation space transportation system, and unbudgeted operational costs will all make the Vision increasingly unaffordable. Other participants acknowledged that some of the problems with robustness and program balance are of the space community's own making, in that in many activities, project cost estimates had been unrealistic and subject to significant cost growth. Participants from within and outside the scientific community voiced agreement that the community will need to demonstrate leadership and share responsibility with NASA in controlling science program costs. Speakers expressed concern that NASA's program suffers from a lack of resources, budget realism, and budget stability, thereby making the Vision unaffordable and unsustainable.

The recent report that focused on the space and Earth science issues at this workshop summarized the mood at the workshop as follows:[5]

> Overall, as noted by the participants themselves, the tone of the workshop was surprisingly sober, with frequent expressions of discouragement, disappointment, and apprehension about the future of the U.S. civil space program. During the one and one-half days of discussion, an oft-repeated statement by workshop participants was that the goals of the U.S. civil space program are completely mismatched with the resources provided to accomplish them.

## INTERNATIONAL CONTEXT

In contrast with the 2003 workshop at which international developments were mentioned but did not play a pivotal role in discussion, international collaboration and competition were prominent topics at the 2007 workshop. Speakers summarized their understanding of the capabilities and ambitions of new national space programs in China and India, cited the forming of multinational alliances that exclude the United States or Europe, and pointed out some consequences of the U.S. International Traffic in Arms Regulations (ITAR) as examples of new challenges in balancing cooperation and competition in the U.S. civil space program. For example, speakers questioned whether a goal of cooperation conflicts with the objective in the Vision to support international participation "to further U.S. scientific, security, and economic interests."[6] Some participants suggested that international cooperation could provide a means to share costs, thereby augmenting resources available for the space program, but others noted that collaboration does not always result in reduced costs, particularly if partner roles and responsibilities are unclear. Participants also discussed at length the emergence of China as a major player in space and whether China presents a threat, in which case cooperation may be difficult or even out of the question, or an opportunity for engagement and cooperation, in which case space could gain a new strategic purpose as a vehicle for such cooperation. In any case, discussion highlighted that a decision about how to engage China will not be based solely on space policy, but will depend on much larger geopolitical considerations.

## PUBLIC INTEREST AND SUPPORT

In assessing contemporary public interest in and support for space activities, some participants commented that programs such as the Hubble Space Telescope and the Mars rovers are popular and have a "wow factor"; other

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[5]National Research Council, *Workshop Series on Issues in Space Science and Technology: Summary of Space and Earth Science Issues from the Workshop on U.S. Civil Space Policy,* The National Academies Press, Washington, D.C., 2008, p. 2.

[6]National Aeronautics and Space Administration, *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004, p. iii.

speakers suggested that as long as the NASA budget is not too large, a "wow factor" in space accomplishments becomes less important. Others noted some survey-based evidence[7] that the greatest degree of enthusiasm for human space exploration rests with the Apollo generation (the 45- to 64-year-old age group), with much less support from the generation of youngest voters—the 18- to 24-year-old age group.

## SUSTAINABILITY, RESOURCES, LEADERSHIP, RELEVANCE, AND BALANCE

Subsequent discussion turned to identifying problems in more detail, specifically to addressing a lack of resources, leadership challenges, the relevance and value of the space program, and balance among activities within the program. Speakers cited both internal and external factors that can affect resource requirements. Internal factors include project delays, inadequate contingency funds, pressures for "full employment" at NASA centers, and defensive behavior by program managers and others when resources are scarce. External influences include competition from China and India, the emergence of climate and energy as major global issues, and likely continued federal budget deficits. Another concern was potential congressional opposition to U.S. reliance on Russia during an extended launch hiatus after the retirement of the space shuttle.

The question of leadership figured prominently in workshop discussions. Some participants argued that strong leadership at senior levels of NASA and the government is essential for the success of the space program. In this context, some speakers viewed with considerable urgency the desirability of senior leaders facing up to what was repeatedly described as a program that cannot be executed within the allotted budget. Speakers also reiterated the responsibility of the space community to establish sound cost estimates and to execute programs within realistic budgets.

Why should I care?—suggested by a participant as an appropriate question to be posed by candidates for major national office—served to focus in-depth discussion about a rationale for the civil space program. There were considerable differences in opinion, ranging from historically offered reasons (science, national security, commercial activities, a sense of human destiny and exploration, and national prestige and geopolitics) to a focus on the geopolitical contributions of the space program as perhaps one of the most compelling current-day rationales. But there was less than full agreement as to whether geopolitics meant cooperation or competition as a motivation for space activities. Discussion also addressed but did not reach agreement on whether, and if so to what extent, the civil space program needs to demonstrate practical benefits and value, a "wow" factor, or some mix of both.

Balancing the pursuit of science, human space exploration, aeronautics, and other dimensions of space activities was also a concern among participants. Some speakers cautioned against characterizing the problem as "humans versus robots"; others urged that the focus should be on identifying and exploiting synergies among different parts of NASA, among NASA and other agencies and countries, and between NASA and the private sector. Participants also suggested that assessing balance requires recognition that different constituencies have different objectives—for example, the scientific community measures much of its success in terms of progress toward goals such as those articulated in decadal surveys, whereas the aeronautics community measures progress in terms of responding to commercial and military air transport requirements.

## EARTH OBSERVING PROGRAMS

Workshop discussion also addressed the role of Earth observations. Speakers emphasized that Earth observations necessarily assume even greater importance given evidence of possibly significant changes in climate. But they remained troubled by problems stemming from reorganization of responsibility for and funding of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) and the reduced capability of NPOESS in facilitating necessary climate-related measurements. Discussion also addressed the persistent difficulty between NASA and the National Oceanic and Atmospheric Administration (NOAA) in the "handoff" from use for research purposes to operational use of Earth science infrastructure and information. Speakers argued that differences in these agencies—ranging from culture to objectives—become even sharper when their budgets are declining.

[7] M.L. Dittmar, *Engaging the 18-25 Generation: Educational Outreach, Interactive Technologies, and Space,* Dittmar Associates, Inc., available at http://www.dittmar-associates.com/Publications/Engaging%20the%2018-25%20Generation%20Update~web.pdf.

## CAPABILITIES AND INFRASTRUCTURE

Additional workshop discussion included optimistic comments about future capabilities and infrastructure to support the civil space program if national priorities can be well articulated and sufficient resources made available. For example, both traditional and new companies in aerospace can bring creativity and talent to problem solving when requirements are made clear. Speakers described experiences with bright university students interested in aerospace careers provided students sense that they can have an impact. Speakers further urged that NASA and universities build more effective partnerships to encourage talent and that ITAR restrictions limiting access to good students be remedied. Some participants mentioned institutions where turnover rates among aerospace professionals are very low, even at the present time. Discussion also addressed the attraction of many young people to space activities using contemporary media that create a virtual presence.

## CONCLUDING THEMES

The workshop concluded with the consolidation of discussion topics, which fell into three broad categories: communicating about space exploration; international competition, cooperation, and leadership; and ensuring robustness through new approaches and attitudes. One idea for avoiding the impending programmatic "train wreck" to which many participants referred during the workshop was to "slow down the train" by deferring the first human mission to the Moon; extending the use of the International Space Station in support of research and development for later human exploration; establishing a telepresence on the Moon; creating an environment of institutional stability in NASA's program elements; building globally inclusive working groups on direct missions to Mars, global change, and space science; and defining real, meaningful jobs for humans in space.

# 6
# *Congressional Testimony*

Members of Space Studies Board (SSB) committees may be invited to testify before committees of the U.S. House of Representatives or the U.S. Senate about the findings and recommendations of their reports. During 2007, one hearing was held where members of the SSB family testified to Congress. Their prepared statements are reprinted here (without references, notes, appendices, tables, or figures).

At the March 13, 2008, hearing before the House Committee on Science and Technology's Subcommittee on Space and Aeronautics, Lennard A. Fisk, SSB chair, and Berrien Moore III, SSB member and chair of the Committee on Earth Studies, testified on their perspectives on the state of space science activities at NASA and the fiscal year (FY) 2009 budget. S. Alan Stern, associate administrator for science, NASA, Steven W. Squyres, professor of astronomy, Cornell University, and Jack O. Burns, professor, Center for Astrophysics and Space Astronomy, University of Colorado, also testified. Their prepared statements are available at http://science.house.gov/publications/hearings_markups_details.aspx?NewsID=2119.

# 6.1 NASA'S Space Science Programs: Review of Fiscal 2009 Budget Request and Issues

## STATEMENTS BEFORE THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY SUBCOMMITTEE ON SPACE AND AERONAUTICS

**March 13, 2008**
**Statement of Lennard A. Fisk**
**NRC Space Studies Board**
**National Research Council, The National Academies**

Mr. Chairman, members of the subcommittee, thank you for inviting me here to testify today. My name is Lennard Fisk, and I am the Thomas M. Donahue Distinguished University Professor of Space Science at the University of Michigan. I also served from 1987 to 1993 as the NASA Associate Administrator for Space Science and Applications. I am currently the Chair of the National Research Council's Space Studies Board, although the views I offer today are my own.

In your invitation letter asking me to testify before you today you asked a series of questions that I would like to address now in sequence.

### The State of the Space Science Program

You asked me to comment on whether the space science program is moving in the right direction. I would like to expand this question to read is space science moving in the right direction and are the resources adequate to achieve success.

The budget for the Science Mission Directorate (SMD), and its projected runout, has many, very positive features. There are new starts for seven different missions. Each of the major disciplines—planetary, astrophysics, heliophysics and Earth science—has at least one major new start. Earth science in particular is able to begin making progress in pursuit of the science objectives of its recent NRC decadal survey. There are also increases in the Research & Analysis program, which is vital to the health and the future of space science. The space science community is buoyed by the opportunity to pursue important new science missions and relieved that the unwise decisions of the past have been reversed.

All of these positive features of the SMD program have been accomplished within a fixed budget envelope, which is currently, and for the next few years, growing at only 1% per year. This is a problem. Some of the new starts in the budget come at the expense of other programs that are displaced or deferred. The growth in Earth science is heartening given the importance that society places on deploying NASA's technical prowess to understand global climate change. The growth in Earth science, however, came by taking funds from other science disciplines, all to remain within the fixed budget envelope. Moreover, there is no flexibility in the SMD budget, no robustness. A single major setback in the cost of some mission under development would seriously stress the carefully woven plan of maintaining the vitality of all the different science disciplines.

It needs to be recognized also that NASA's response to the NRC Earth science decadal survey is inadequate if we are serious about understanding global climate change. That decadal survey report pointed out that the Earth science budget has decreased by about $500 million per year since 2000. Restoration of at least this amount of annual funding is required in order that the nation can have a satellite system that adequately provides the sound scientific underpinning for planning for the inevitable climate change that lies before us. However, in the runout of the SMD budget to FY2012 only a total of about $600 million, not $500 million per year, is provided. To be sure, the increased funds for Earth science are all that are available in an overall flat budget. The new funds come from the other science disciplines, and to take more would devastate those constrained, but otherwise healthy programs.

In many ways SMD is a graphic illustration of the dilemmas that face all of NASA—too few resources to accomplish the many tasks that the nation has placed on the agency. Whether it is human space exploration, the use of the Space Station, aeronautics, or science, the funding is not adequate. SMD is doing well with what it has, trying to maintain the vitality of the space and Earth science communities, and to move the program forward with new mission opportunities. However, there is so much more that needs to be done, whether it is a solid start on the Earth science decadal survey recommendations, a vigorous Mars program, a full Living-with-a-Star program, or a vigorous program to understand the astrophysical challenges of dark energy and dark matter. And the budget needs to be robust so that it is actually executable. The funding constraints on all of NASA and on SMD in particular need to be lifted, and the required resources need to be provided so that the nation can have the space program that the nation needs and deserves.

## The State of Heliophysics

You asked me to comment in particular on whether the Heliophysics program is moving in the right direction. Heliophysics is the study of the Sun, the heliosphere (i.e. the region of space created by the solar wind, the outward expansion of the solar atmosphere), the plasma environment of the planets, and the coupling and interactions among these various environments. Research in Heliophysics is essential for understanding the coupling between the Sun and Earth, and for predicting the space environment through which our space assets and eventually our astronauts will fly.

There is good news in this program. As in other disciplines in space science, there is an increase in the Research & Analysis program budget and a new start for the Solar Probe mission. This good news is tempered, as in other disciplines, by the reality that the increase in budget for these elements of the program came at the expense of other planned initiatives, which cannot now be pursued. The budget envelope for Heliophysics is fixed, and in fact has been used, in part, to provide Earth Science with needed funds to make a start on its decadal survey missions. In the case of Solar Probe, then, the required funds have come from the Living-with-a-Star program, which is now unable to pursue, in the near term, either the Sentinel program or missions to the ionosphere.

The new start for Solar Probe should be viewed, then, as a realignment of the scientific priorities. NASA has judged that it is more important to make direct measurements in the region of the solar atmosphere closest to the Sun, than are other priorities such as the study of the ionosphere. This logic is understandable. The inner region of the solar atmosphere is the source of the solar wind and solar energetic particles. It is a region where current instrumentation cannot observe the governing magnetic field and where direct in-situ observations are required to resolve the many mysteries that inhibit our ability to predict the space environment created by the Sun. The Solar Probe mission was endorsed by the 2003 NRC decadal survey for this field. It was considered to be an important, large mission for which funds beyond the planned budget envelope needed to be provided. This has not proven to be feasible, and the required funds have been taken from other planned missions. The science priority, however, of Solar Probe is not in question.

The planned Solar Probe mission is very clever, and solves a number of the concerns associated with previous concepts for Solar Probe. Solar Probe needs to make multiple passes through the solar atmosphere, which is a dynamic, ever changing environment. Only by multiple passes can we avoid confusion that arises from the fact that this is such a dynamic place. The required multiple passes are achievable because the planned Solar Probe mission does not penetrate as close to the Sun as some previous versions of Solar Probes were planned to do. However, the current Solar Probe concept is judged by the scientists who have studied the mission in detail to have a penetration distance that is adequately close to be able to resolve the fundamental processes resulting in the heating of the solar atmosphere and acceleration of energetic particles.

The other important feature of the planned Solar Probe mission is that it is to be undertaken in concert with the European Space Agency Solar Orbiter mission, for which NASA has agreed to provide part of the payload. Solar Orbiter is to be placed in an orbit around 30 solar radii from the Sun, and to achieve an orbit that is inclined to the solar equator. From this vantage point, a capable set of remote sensing instrumentation will make detailed observations of the solar surface and atmosphere, and a capable set of in-situ instruments will observe the solar outputs of plasma and energetic particles in detail.

It should be possible to have Solar Orbiter in place while Solar Probe is doing its penetrations deep into the solar atmosphere, and the combination will be an historic opportunity to once and for all develop a comprehensive, predictive understanding of the basic processes that control the solar atmosphere and its influence on the heliosphere, and on the Earth and other planets. There is, however, an obligation with this combined program that must be met. The instrumentation on both Solar Probe and Solar Orbiter must be comprehensive and complete. The investment in these missions will be large, and the scientific payloads need to be capable of realizing the scientific breakthroughs that this historic opportunity will allow.

### The Status and Health of the Science and Engineering Workforce

You asked for my perspectives on the status and health of the science and engineering workforce as it relates to NASA's space and Earth science plans. I would respond to this question from several different perspectives.

Let me comment first on the NASA workforce. The age distribution of the civil service workforce at the NASA centers is disturbing. It is strongly peaked at age 45-49, with only a small fraction of the workforce under 30, and almost an equal number over 60. There needs, in my judgment, to be a rejuvenation of the NASA workforce. Experience is important, but more current training, particularly in the engineering disciplines, and the enthusiasm, energy, and willingness to explore new concepts that inherently come with youth, are important as well. It will not be easy to rejuvenate the NASA workforce. Fixed budgets, the current age distribution, and the requirement mainly imposed by Congress for 10 healthy NASA centers places severe restrictions on NASA's ability to hire new scientists and engineers.

There is an unfortunate corollary to NASA's inability to rejuvenate its workforce. We want our best young scientists and engineers to aspire to participate in the nation's space program, yet it is widely known that the prospects for jobs at NASA, and thus a major leadership role in the exploration of space, are meager at best.

Next I would comment on the science and engineering workforce outside of NASA. The number of students available to participate in the space program is probably adequate for the simple reason that space requires only a small fraction of the nation's science and engineering workforce. The issue here is the quality of the students, their particular training, and their attitude when they enter the workforce.

There are many capable science and engineering students in this country. The question is why should the best and the brightest aspire to participate in the space program when there are so many other exciting technical challenges that lie before them. The students see a space program that is not a national priority sufficient to receive the funding and support that is necessary for its success. Under these circumstances, only those students who have always aspired to pursue a career in space are likely to enter the field, as opposed to those who have the talents and the capabilities to pursue many different technical disciplines. Thus workforce and priorities for space are linked. If space becomes a national priority, the nation's highly capable technical workforce will respond.

There is also a question of training. It is essential that engineers in particular receive hands-on training with real space projects or space-related hardware. The vast majority of the senior technical workforce currently executing the space and Earth science program had hands-on opportunities earlier in their careers, and they all would say that it was essential for their current success. We should expect no difference for the next generation. It is incumbent upon NASA to provide the universities with the opportunities to offer their students hands-on experience if we are to continue our technical success.

The previous two items are strongly coupled. The experience in most universities is that when students have hands-on research experiences in space engineering as undergraduates they invariably decide to pursue careers in space. If NASA provides universities with the opportunities to offer hands-on experience, not only does the required training occur, but the best and the brightest are recruited into space.

Finally, there is the issue of attitude, particularly among young scientists entering the fields of space and Earth science. Space science is 50 years old this year; Explorer 1, the first space science mission, was launched in 1958. In a science discipline at this age, which is dominated now by scientists who have practiced their disciplines for decades, inevitably there are well established points of view that have been developed, which are resistant to new ideas. It is important that the new scientists entering the field challenge these established points of view, for that is how progress is made in science. And it is incumbent upon NASA, through its Research & Analysis program, to encourage new approaches and new thoughts, so that progress is made and the true answers to the many mysteries of the universe are revealed. Consequently, I strongly support the proposed increase in funding for the Research and Analysis program.

### The State of NASA's Space Weather Program

You asked what is the status of NASA's program to collect data and conduct research on space weather. There are two aspects of this issue that I would like to address: first, the monitoring of space weather that affects Earth, and second, our ability to learn how to predict space weather.

It is important to have a spacecraft at the Sun-Earth L1 point in front of Earth that can provide real-time warning of space weather events that will impact Earth, and also provide information on solar wind conditions for basic research on the response of the Earth's magnetosphere, ionosphere, and atmosphere to space weather events. At present this information is provided by the Advanced Composition Explorer (ACE), which was launched in 1997. It is unwise to rely entirely on ACE and its instrumentation, some of which is showing signs of age. It is possible to put up a relatively inexpensive spacecraft to perform the basic monitoring function. I would add that such a spacecraft may be more appropriately a NOAA rather than a NASA responsibility, since NOAA is to provide operational space weather predictions.

The second issue is our ability to develop a true predictive capability for space weather. It is not sufficient simply to monitor the immediate arrival of a space weather event, or to base predictions on general correlations between events on the Sun and the arrival of space weather disturbances at Earth. Rather, we need to have an adequate understanding of the basic physical processes that govern the acceleration of the solar wind, the release of Coronal Mass Ejections, and the acceleration of energetic particles. With this understanding, we will eventually be able to make detailed observations of the Sun, put that information into comprehensive numerical models, and make real-time predictions of the space weather that will impact the space environment of the entire solar system, and of the Earth in particular.

The pursuit of a detailed understanding of the basic physical processes that govern the solar atmosphere and its extension into space, the response of the space environment of Earth, and the development of comprehensive numerical models is the main purpose of the Heliophysics Division in SMD. It is important that these efforts be encouraged so that a true predictive capability is developed as soon as possible. Missions such as Radiation Belt Storm Probes, which are currently under development, are important for understanding the response of the Earth's magnetosphere to space weather events. Missions such as the upcoming Solar Dynamics Observatory and the proposed Solar Probe and Solar Orbiter, which I discussed earlier, are essential for developing an understanding of the basic mechanisms that heat the solar atmosphere and accelerate energetic particles.

It is also important to make maximum use of the space assets currently in place to study the Sun and the plasma environments that the Sun creates throughout the solar system. There is a flotilla of spacecraft in place known as the Heliophysics Great Observatory. These missions, from the recently launched STEREO missions that observe the Sun and its outputs in 3-dimensions to the venerable Voyager missions probing the distant heliosphere, all are essential to our understanding of the physics that governs the plasma processes in our solar system. It is important to use these missions in a coordinated way, to derive the maximum possible information from them, and in doing so to create the scientific foundation for the predictive models of space weather that we require.

### Issues to Address in the Reauthorization of NASA

You asked for input on the important issues that should be addressed with respect to NASA's space science program as Congress considers its reauthorization of NASA. I would like to take the liberty of answering this question in the broader context of NASA as a whole since I do not believe that the NASA space science program can be considered separately from NASA's overall activities and goals.

We are now four years into implementing the Vision for Space Exploration that was announced by President Bush in January 2004, and it is worth a critical analysis of where we are. So far, with the exception of the initial FY 2005 budget, the Administration has not requested the funds it said were required to execute the Vision. There were underestimates of the costs required to continue to fly the Shuttle and complete the International Space Station. Consequently, NASA has been forced to cannibalize much of the rest of its program to even begin to make progress on the Vision. And it is hard to say that the Vision of returning to the Moon has generated much excitement, or even understanding among the public, particularly among the young who are expected to benefit most from the future that the Vision promises.

We should ask ourselves whether there was a flaw in the Vision for Space Exploration, which we did not recognize at the time. The Vision is all about the future—extending our civilization into space, with the long-term benefits that we expect to accrue for our country. There is, however, little in the Vision that is of immediate concern. So when near-term needs intervene, such as providing funds for the war in Iraq or for Hurricane Katrina, it is NASA that comes up short in funding.

I would encourage you, then, as you consider the reauthorization of NASA, as I would encourage the next Administration, to provide NASA with a role that is not only about the future, but is important in the present. There are several ideas worth discussing:

NASA could use, and serve, a more important geopolitical role. The obvious one is to lead the world in the exploration of space, in a cooperative and facilitating way. NASA then becomes an instrument of our foreign policy through its ability to improve the image and impact of the United States around the world. If that is important to the next Administration then perhaps the resources necessary for NASA to play its proper role in leading the world will be provided.

NASA could use, and serve, a more important role in improving the competitive position of the United States, through the encouragement of technology development, entrepreneurialism, and technical education. This would be a new emphasis for NASA that would encompass more than just human space flight, which is an engineering challenge but which does not often emphasize new technologies. It is the science disciplines of NASA, with their needs for new sensors and electronics and robotic capability that are a better stimulus for technology.

And finally there are the programs in NASA that are of demonstrable immediate importance to the taxpayers—Earth science to provide the scientific basis for understanding global climate change, and aeronautics. In the current implementation of the Vision these programs have been allowed to decline and atrophy, and they deserve strong re-emphasis.

**Berrien Moore III, Ph.D.**
**Executive Director, Climate Central, Inc.**
**Co-Chair, Committee on Earth Studies, NRC Space Studies Board**

Mr. Chairman, Ranking Minority Member, and members of the Committee: thank you for inviting me here to testify today. My name is Berrien Moore III. For the past 20 years, I was Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. Recently, I have assumed the position of Executive Director for a new nonprofit organization, Climate Central, to be located in Princeton NJ and Palo Alto, CA. I appear, today, largely in my capacity as the recent co-chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space, which authored the first "decadal survey" for the Earth Sciences and as the current chair of the National Research Council (NRC)'s Committee on Earth Studies of the Space Studies Board. This said, the views expressed in today's testimony are my own, but I believe they reflect community concerns.

Mr. Chairman, the world faces significant and profound environmental challenges: shortages of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and above all the rapid pace of substantial changes in climate. These changes are not isolated; they interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. Information from NASA and NOAA environmental satellites is critical in addressing these problems, but as a result of significant cuts over several past budget cycles, growth in the cost of accessing space and in development of instruments, and inflation, we find ourselves with a growing mismatch between needs and resources. The fiscal year 2009 budget for NASA begins to redress some of this imbalance, but much more will be needed for many budget cycles to come.

I will now turn to the specific questions included in the letter of 28 February 2008 that I received from the Committee:

1. **Do you believe NASA's space science program, and especially the Earth science program, is moving in the right direction? What, if any, changes would improve the program, and why? Please elaborate on your perspectives.**

Last June, this subcommittee held a hearing, "NASA's Earth Science and Applications Programs: Fiscal Year 2008 Budget Request and Issues." In opening statements, the chair of the subcommittee (Udall) and its now ranking minority member (Feeney) stated that:

> "I called today's hearing for the purpose of examining how well NASA's plans and programs compare to the priorities of the decadal survey, and the extent to which NASA intends to support those priorities in the FY 08 budget and beyond. As numerous witnesses before this Committee have testified, the situation facing NASA's Earth Science program is not good . . . to quote the Decadal Survey, the nation's system of environmental satellites is 'at risk of collapse'"
> —Rep. Mark Udall (D-CO)

"NASA's Earth Sciences program has produced stunning scientific results, often demonstrating, for the first time, measurements and capabilities that have never before been accomplished. I want that record of achievement to continue, and it's also my desire that we build upon the program's success to enable the goals established in the Decadal Survey."
—Rep. Tom Feeney (R-FL)

The subcommittee hearing focused on NASA Earth science programs in general and the recommendations of the recently completed National Research Council decadal survey, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" in particular. The decadal survey outlined near-term actions meant to stem the tide of capability deterioration and continue critical data records, as well as forward-looking recommendations to establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world.

Testifying on behalf of the Decadal Survey steering committee, in which I served as co-chair, Dr. Richard Anthes, President of the University Corporation for Atmospheric Research, outlined the key elements of the recommended program:

- Restoration of certain measurement capabilities to the NPP, NPOESS, and GOESR spacecraft in order to ensure continuity of critical data sets.
- Completion of the existing planned program that was used as a baseline assumption for this survey. This includes (but is not limited to) launch of GPM in or before 2012 and securing a replacement to Landsat 7 data before 2012.
- A prioritized set of 17 missions to be carried out by NOAA and NASA over the next decade. This set of missions provides a sound foundation for Earth science and its associated societal benefits well beyond 2020.
- A technology development program at NASA with funding comparable to and in addition to its basic technology program to make sure the necessary technologies are ready when needed to support mission starts over the coming decade.
- A new "Venture" class of low-cost research and application missions that can establish entirely new research avenues or demonstrate key application-oriented measurements, helping with the development of innovative ideas and technologies. Priority would be given to cost-effective, innovative missions rather than ones with excessive scientific and technological requirements.
- A robust NASA Research and Analysis program, which is necessary to maximize scientific return on NASA investments in Earth science. Because the R&A programs are carried out largely through the Nation's research universities, such programs are also of great importance in supporting and training the next generation of Earth science researchers.
- Suborbital and land-based measurements and socio-demographic studies in order to supplement and complement satellite data.
- A comprehensive information system to meet the challenge of production, distribution, and stewardship of observational data and climate records. To ensure the recommended observations will benefit society, the mission program must be accompanied by efforts to translate raw observational data into useful information through modeling, data assimilation, and research and analysis.

In order to lay the foundation for implementing the full set of recommendations during the next decade, we further recommended these very near-term actions:

First, NASA should commit to and begin to implement its recommended Decadal Missions. Although, the NASA budget for Earth Sciences is not now adequate to implement the survey recommendations (see next question), a useful start can be made with modest resources. The survey's initial seven missions (2010-2013) should begin in 2008; the first four (CLARREO, SMAP, ICESat-II, and DESDynI) should begin intensive Phase A activities and the next three (for the time period 2013-2016—HyspIRI, ASCENDS, and SWOT) should begin pre-Phase A studies. *Increment needed beyond President's Request in FY08: $90 million.*

Second, NASA should increase its suborbital capabilities. NASA's airborne programs have suffered substantial diminution and should be restored. In addition, NASA should lead in exploiting unmanned aerial vehicles (UAV/technology). Both conventional and UAV aircraft are needed for instrument development, and hence risk reduction and technology advancement, and for their direct contribution to Earth observations. *Increment needed beyond President's Request in FY08: $10 million.*

Third, NASA should increase support of its Research and Analysis (R&A) program and in Earth System modeling. Improved information about potential future changes in climate, weather, and other environmental conditions is essential for the benefit and protection of society. This improvement will come from: a) better observations (the recommended missions and enhanced suborbital capabilities); b) more capable models of the Earth System; and c) a vigorous research program to use the observations in models and interpret the results. The R&A program has suffered significant cuts in recent years and these should be reversed. R&A investments are among the most cost-effective as they directly exploit on-going missions, advance knowledge to better define what is needed in the future, and sustain and develop the requisite scientific and engineering workforce. *Increment needed beyond President's Request in FY08: $20 million.*

The President's fiscal year 2009 budget for NASA includes a major new initiative in Earth science and applications, including a plan to provide $910 million over five years (FY2009-2013) that addresses to varying degrees the items above and begins implementation of the decadal survey's nearest-term recommendations. In addition, the budget provides funding to restore the OMPS-L sensor to the NPOESS Preparatory Project (NPP) spacecraft, which is now scheduled for launch in 2010, integrate a spare CERES instrument on NPP, and support instrument development and analyses to identify a suitable satellite platform for hosting the total solar irradiance sensor (TSIS). All of this is very welcome news, but I have several concerns:

- **The Initiative's funding comes at the expense of other NASA science programs:** Approximately two-thirds of the additional $910 million over five years are obtained by drawing from each of the three other science areas in the science mission directorate (SMD). In the planetary portfolio, some $200 million came from the Mars program as a result of delay in a Scout mission procurement. The contribution from the Heliophysics division included changes such as a stretching out in the development of the Solar Probe mission. The Astrophysics division contributions were largely obtained by reducing funding in the out-years of the five-year plan, (2011-2013).

  Earth science requires an ongoing commitment of funding at a higher level than is provided in the FY09 budget run-out and redistribution of resources simply is not a long-term solution to the problem. As noted by members of this committee, NASA has been asked to accomplish too much with too little; what is needed is an increase in the overall top-line budget for NASA, which in turn will allow an increase in NASA's science budget. Absent such an increase, it will not be possible to restore Earth science funding to the needed FY2000 levels (as recommended in the decadal survey) without inflicting great damage to the other science portfolio areas.
- **As illustrated below, the Initiative still falls very short of what is required to implement the Decadal Survey**. Below is an updated version of a graphic that we prepared for the Decadal Survey; it now includes budget profiles from the FY08 and FY09 Presidential budgets (FY08 and FY09). As before, we present the data in FY06 dollars to remove the effects of inflation. It is evident that after an initial rise, funding for Earth science at NASA actually begins to decrease again.
- **The climate record from NPOESS is still very much in danger**. As this committee knows too well, cost and schedule problems triggered a Nunn-McCurdy review of the NPOESS program. Many of the specific capabilities related to better understand, predict, and eventually mitigate the effects of global climate change were lost in the restructured program. The changes to NPP and the decision to find a platform for a new TSIS are welcome news, but, as detailed in a forthcoming NRC report, far from what is needed. Finally, NOAA must have adequate resources to support the development and stewardship of Climate Data Records. This was addressed in both the Interim and Final reports of the decadal survey, and I call it again to the attention of the Committee.

In summary, I am encouraged by the renewed emphasis on Earth science at NASA; however, without additional resources, there is a limit to what management's best intentions can accomplish. The NASA Earth science program is doing what it can with the resources it has been given; it simply has not been given enough to accomplish all that is expected of it, and, more importantly, all that the Nation needs. I address explicitly what further needs to be done in my answer to Question Two below.

**2. What, if any, challenges do you foresee for the future of the NASA Earth science program as presented in the FY 2009 budget request? What are your suggestions for addressing those challenges?**

As I noted in my response to question #1, the FY09 NASA Earth science program request is very good news, but I am concerned about whether the initiative can be sustained and whether it is advisable to fund Earth science at the expense of other NASA science programs. The planned addition of $910 million over five years to the Earth science budget also still leaves a very large shortfall in what is needed to execute the recommendations of the decadal survey (see again the figure above).

The 17 missions recommended by the decadal survey are organized into sets in order to take most advantage of concurrent observations to advance our understanding of Earth as a system—four missions are recommended for launch in the 2010-2013 timeframe. In contrast, the FY09 budget plans for one to launch in 2012 and a second in 2015. A third is slated for 2017. This makes the concurrent observations between missions very difficult. The overall program recommended by the decadal survey is simply not being adequately implemented.

I would like to suggest two challenging and important actions: First, both the Science Mission Directorate and the Earth Sciences Division need a budget plus above the President's request. Congress did this last year, and the result was particularly positive since it served to not only achieve the direct benefits one might expect, but it also encouraged industry to begin to invest anew in technologies relevant to the missions recommended by the decadal survey. For the Earth sciences, the target for this Congressional increase should be a) more rapid implementation of the first four missions and b) a greater technology investment in the missions in the 2013-2016 timeframe—particularly the first two or three missions in the 2013-2016 timeframe. Second, Congress should address the inadequacies in the out-year budget; this could be particularly important as the executive branch of government goes through a transition.

**3. As NASA begins to plan missions recommended in the National Academies Earth science Decadal Survey, what actions do the Decadal Survey and other community input recommend to further the applied use of the data for societal benefits and the transition of research data into operational service? What, if any impediments exist that could constrain progress in this area, and how can they be overcome?**

In the decadal survey report, the steering committee expressed a particular concern with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems. To address societal and research needs, both the quality and the continuity of the measurement record must be assured through the transition of short-term, exploratory capabilities, into sustained observing systems. The elimination of the requirements for climate research-related measurements on NPOESS is only the most recent example of the nation's failure to sustain critical measurements. Therefore, our committee recommended that, *"The Office of Science and Technology Policy (OSTP), in collaboration with the relevant agencies, and in consultation with the scientific community, develop and implement a plan for achieving and sustaining global Earth observations*." In addition, we recommended that the plan recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs.

I am pleased to note that this recommendation is being taken very seriously by the OSTP. It is my understanding that they are developing an overall strategy for Earth observations policy, which will include interagency issues of the kind raised in the decadal survey as well as issues related to the U.S. contribution to a global observing system and GEO.

The issue of an overall national strategy and plan for Earth observation is of central importance, and I return to it below in my answer to the Committee's final question.

Another area that requires attention is the NASA applied sciences program. Last year, the NRC completed a review of this program; at the end of my testimony, I attach a copy the recommendations from that report. These recommendations are entirely consistent with those in the decadal survey; we also noted that the key to meeting societal needs for Earth observation data is to have the potential "users" of these data represented in a substantive way from the earliest stages of mission development, determining priorities, designing products, and evaluating benefits. As noted in my response to question #1, renewed support for the NASA Research and Analysis program is also critical to the success of the applied sciences program.

**4. The Committee on Science and Technology plans to reauthorize NASA this year and in so doing will communicate policy direction to NASA as well as to the next Presidential Administration. What, in your view, are the most important issues with respect to NASA's Earth science programs that Congress should consider in its reauthorization of NASA?**

NASA should consider how to best leverage its Earth science program resources to accomplish both the intended science and societal outcomes as described in the decadal survey. An integrated programmatic approach is required to align efforts towards these common goals. This means coordination of, for example, NASA's technology development investments to ensure needed technologies are ready to support recommended missions. It also will require additional support to applications end users' involvement in mission formulation, and targeted R&A investments to begin work on laying the scientific foundation needed to maximize the value of mission observations. In other words, we need to eliminate the traditional "stove pipe" approach, which often decouples funding priorities between program elements; sustained programmatic attention is required to implement the needed missions in a reasonable timeframe. Yet, as we stressed in the decadal survey, the program must also provide opportunities for entirely new measurements and approaches and so programmatic flexibility must be retained to both accommodate and enable new discoveries.

A key to making more efficient use of scare budget resources is to develop a comprehensive approach to Earth observations from space. As stated above in my response to question 3, the decadal survey committee expressed great concern that the nation's civil space institutions (including NASA, NOAA, and USGS) are not adequately prepared to meet society's rapidly evolving Earth information needs. These institutions have responsibilities that are in many cases mismatched with their authorities and resources: institutional mandates are inconsistent with agency charters, budgets are not well matched to emerging needs, and shared responsibilities are supported inconsistently by mechanisms for cooperation. Further, these are issues whose solutions will require action at high levels of the federal government. It was for these reasons that we recommended development and implementation of a comprehensive plan for achieving and sustaining global Earth observations.

Returning to my opening comments, we know that the planet's environment is changing on all spatial scales including global, and change is rapid, perhaps more rapid than at any time in human history. Further, we know that many of these changes are occurring as a result of human activities. These human-induced changes are over and above the stresses imposed by the natural variability of a dynamic planet and are intersecting with the effects of past and existing patterns of conflict, poverty, disease, and malnutrition.

As I noted, the changes cascade through the Earth's environment in ways that are difficult to understand and often impossible to predict. Therefore, at the least, these human-driven changes in the global environment will require that societies develop a multitude of creative responses, including strategies for mitigation and adaptation. Earth observations are a critical part of developing these responses.

The linked challenges of confronting and coping with global environmental changes, and addressing and securing a sustainable future, are daunting and immediate, but they are not insurmountable. These challenges can be met, but only with a new and even more vigorous approach to observe and understanding our changing planet and with a concomitant commitment by all to alter our actions.

# 7
# *Cumulative Bibliography of SSB Reports: 1958–2008*

The following list presents the reports of the Space Science (later Space Studies) Board (SSB) and its committees by year of publication (which may differ from the report's release date). The Board's major reports have been published by the National Academy Press (as of mid-2002 the National Academies Press) since 1981; prior to this, publication of major reports was carried out by the National Academy of Sciences. Several of the SSB's reports are written in conjunction with other National Research Council Boards, including the Aeronautics and Space Engineering Board (ASEB), the Board on Atmospheric Sciences and Climate (BASC), the Board on Chemical Sciences and Technology (BCST), the Board on Earth Sciences and Resources (BESR), the Board on Life Sciences (BLS), and the Board on Physics and Astronomy (BPA).

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"On Climate Change Research Measurements from NPOESS," letter from SSB chair Claude R. Canizares and Committee on Earth Studies chair Mark Abbott to Ghassem Asrar, associate administrator for NASA's Office of Earth Science, and Robert S. Winokur, NOAA, director of the National Environmental Satellite, Data, and Information Service (May 27)

"Assessment of NASA's Mars Exploration Architecture," letter from SSB chair Claude R. Canizares and Committee on Planetary and Lunar Exploration chair Ronald Greeley to Carl Pilcher, science program director for NASA's Solar System Exploration Division (November 11)

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"On Research Facilities Planning for the International Space Station," letter from SSB chair Claude R. Canizares, Committee on Space Biology and Medicine chair Mary Jane Osborn, and Committee on Microgravity Research former chair Martin E. Glicksman to NASA administrator Daniel S. Goldin (July 8)

"On NASA's Office of Space Science Draft Strategic Plan," letter from SSB chair Claude R. Canizares to Wesley T. Huntress, Jr., associate administrator for NASA's Office of Space Science (August 27)

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"On Internet Access to Astronaut Biomedical Data," letter from SSB chair Claude R. Canizares and Committee on Space Biology and Medicine chair Mary Jane Osborn to Arnauld Nicogossian, acting associate administrator for NASA's Office of Life and Microgravity Sciences and Applications (July 24)

"On Scientific Assessment of NASA's Solar System Exploration Roadmap," letter from SSB chair Claude R. Canizares and Committee on Planetary and Lunar Exploration chair Ronald Greeley to Jurgen H. Rahe, science program director for NASA's Solar System Exploration Division (August 23)

"On the Planned National Space Biomedical Research Institute," letter from SSB chair Claude R. Canizares and Committee on Space Biology and Medicine chair Mary Jane Osborn to Arnauld Nicogossian, acting associate administrator for NASA's Office of Life and Microgravity Sciences and Applications (October 10)

"On NASA Mars Sample-Return Mission Options," letter from SSB chair Claude R. Canizares and Committee on Planetary and Lunar Exploration chair Ronald Greeley to Jurgen H. Rahe, science program director for NASA's Solar System Exploration Division (December 3)

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"On NASA Field Center Science and Scientists," letter from SSB chair Claude R. Canizares to NASA chief scientist France A. Cordova (March 29)

"On a Scientific Assessment for a Third Flight of the Shuttle Radar Laboratory," letter from SSB chair Claude R. Canizares and Committee on Earth Studies chair John H. McElroy to Charles Kennel, associate administrator for NASA's Office of Mission to Planet Earth (April 4)

"On Clarification of Issues in the *Opportunities* Report," letter from SSB chair Claude R. Canizares and Committee on Microgravity Research chair Martin E. Glicksman to Robert Rhome, director of NASA's Microgravity Science and Applications Division (April 19)

"On Peer Review in NASA Life Sciences Programs," letter from SSB chair Claude R. Canizares and Committee on Space Biology and Medicine chair Mary Jane Osborn to Joan Vernikos, director of NASA's Life and Biomedical Sciences and Applications Division (July 26)

"On the Establishment of Science Institutes," letter from SSB chair Claude R. Canizares to NASA chief scientist France A. Cordova (August 11)

"On the International Space Station," letter from SSB Committee on the Space Station chair Thomas Young to Wilbur Trafton, NASA deputy associate administrator for space flight (November 29)

"On 'Concurrence' and the Role of the NASA Chief Scientist," letter from SSB chair Claude R. Canizares and Committee on the Future of Space Science chair John A. Armstrong to NASA chief scientist France A. Cordova (December 12)

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*A Space Physics Paradox*, SSB Committee on Solar and Space Physics with the BASC Committee on Solar-Terrestrial Research

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"On Life and Microgravity Sciences and the Space Station Program," letter from SSB chair Louis J. Lanzerotti, Committee on Space Biology and Medicine chair Fred W. Turek and Committee on Microgravity Research chair William A. Sirignano to NASA administrator Daniel S. Goldin (February 25)

"On the Space Infrared Telescope Facility and the Stratospheric Observatory for Infrared Astronomy," letter from SSB chair Louis J. Lanzerotti to Wesley T. Huntress, Jr., associate administrator for NASA's Office of Space Science (April 21)

"On the Advanced X-ray Astrophysics Facility and Cassini Saturn Probe," letter from SSB chair Claude R. Canizares and former chair Louis J. Lanzerotti to presidential science advisor John Gibbons (July 5)

"On the Utilization of the Space Station," letter from SSB chair Louis J. Lanzerotti, Committee on Space Biology and Medicine chair Fred W. Turek, and Committee on Microgravity Research chair William A. Sirignano to NASA administrator Daniel S. Goldin (July 26)

**1993** *Improving NASA's Technology for Space Science*, SSB and ASEB ad hoc Committee on Space Science Technology Planning

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*Setting Priorities for Space Research: Opportunities and Imperatives*, SSB Task Group on Priorities in Space Research—Phase I

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"On the Solar System Exploration Division's 1991 Strategic Plan," letter from SSB Committee on Planetary and Lunar Exploration chair Larry W. Esposito to Wesley T. Huntress, Jr., director of NASA's Solar System Exploration Division (January 14)

"Letter to the NASA Administrator," letter from SSB chair Louis J. Lanzerotti to NASA administrator Richard H. Truly (March 30)

"On the Advanced X-ray Astrophysics Facility," letter from SSB chair Louis J. Lanzerotti to Lennard A. Fisk, associate administrator for NASA's Office of Space Science and Applications (March 30)

"On the CRAF/Cassini Mission," letter from SSB chair Louis J. Lanzerotti transmitting a report of the Committee on Planetary and Lunar Exploration to Lennard A. Fisk, associate administrator for NASA's Office of Space Science and Applications (March 30)

"On the Space Station Freedom Program," letter from SSB chair Louis J. Lanzerotti to Arnold D. Aldrich, associate administrator for NASA's Office of Space Systems Development (March 30)

"An Interim Report on the Earth Observing System and Data and Information System," letter from SSB Panel to Review EOSDIS Plans chair Charles Zraket and SSB chair Frank Press to Daniel Goldin, NASA administrator (April 9)

"On NOAA Requirements for Polar-Orbiting Environmental Satellites," letter from SSB Committee on Earth Studies chair John H. McElroy to Russell Koffler, assistant deputy administrator for NOAA's National Environmental Satellite, Data, and Information Service (April 30)

"On Continued Operation of the BEVALAC Facility," letter from SSB chair Louis J. Lanzerotti and Committee on Space Biology and Medicine chair Fred W. Turek to Secretary of Energy James D. Watkins and NASA administrator Daniel S. Goldin (August 20)

"On the NASA/SDIO Clementine Moon/Asteroid Mission," letter from SSB chair Louis J. Lanzerotti and Committee on Planetary and Lunar Exploration chair Larry W. Esposito to Simon P. Worden, deputy for technology of the Strategic Defense Initiative Organization, and Wesley T. Huntress, Jr., director of NASA's Solar System Exploration Division (August 21)

"On Robotic Lunar Precursor Missions of the Office of Exploration," letter from SSB chair Louis J. Lanzerotti and Committee on Planetary and Lunar Exploration chair Larry W. Esposito to Michael D. Griffin, associate administrator for NASA's Exploration Division (August 21)

"On the Earth Observing Data and Information System," letter from SSB Panel to Review EOSDIS Plans chair Charles Zraket to Daniel Goldin, NASA administrator (September 30)

"On the Restructured Cassini Mission," letter from SSB chair Louis J. Lanzerotti and Committee on Planetary and Lunar Exploration chair Joseph A. Burns to Lennard A. Fisk, associate administrator for NASA's Office of Space Science and Applications (October 19)

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*Assessment of Programs in Space Biology and Medicine—1991*, SSB Committee on Space Biology and Medicine

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"On the NASA Earth Observing System," letter and attached position from SSB chair Louis J. Lanzerotti to NASA administrator Richard H. Truly (July 10)
"Results of the 103rd SSB meeting," letter from SSB chair Louis Lanzerotti to NASA administrator Richard H. Truly (July 18)
"On Research Uses of LANDSAT," letter from Committee on Earth Studies chair Byron D. Tapley to Shelby Tilford, director of NASA's Earth Science and Applications Division, and Russell Koffler, deputy assistant administrator of NOAA's National Environmental Satellite, Data, and Information Service (September 12)

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"On Principal Issues and Concerns Raised During the Space Studies Board's March 1990 and May 1990 Meetings," letter from SSB chair Louis J. Lanzerotti to NASA administrator Richard H. Truly (June 8)
"On the Scientific Viability of a Restructured CRAF Science Payload," letter from SSB chair Louis J. Lanzerotti and Committee on Planetary and Lunar Exploration chair Larry W. Esposito to Lennard A. Fisk, associate administrator for NASA's Office of Space Science and Applications (August 10)
"On Results of the Space Studies Board Meeting Held on July 31-August 2, 1990," letter from SSB chair Louis J. Lanzerotti to NASA administrator Richard H. Truly (September 28)
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"On the Extended Duration Orbiter Medical Research Program," letter from SSB chair Louis J. Lanzerotti and Committee on Space Biology and Medicine chair L. Dennis Smith to NASA administrator Richard H. Truly (December 20)

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"Recommendation on Planetary Protection Categorization of the Comet Rendezvous-Asteroid Flyby Mission and the Titan-Cassini Mission," letter from SSB Committee on Planetary Biology and Chemical Evolution chair Harold Klein to John D. Rummel, chief of NASA's Planetary Quarantine Program (July 6)
"Assessment of the CRAF and Cassini Science Missions," letter from SSB Committee on Planetary and Lunar Exploration chair Robert O. Pepin to Geoffrey A. Briggs, director of NASA's Solar System Exploration Division (September 1)

**1987** *Long-Lived Space Observatories for Astronomy and Astrophysics*, SSB Committee on Space Astronomy and Astrophysics

*A Strategy for Space Biology and Medical Science for the 1980s and 1990s*, SSB Committee on Space Biology and Medicine

"On Changes to the Explorer Program," letter from SSB Committee on Space Astronomy and Astrophysics chair Blair Savage to Burton Edleson, associate administrator, NASA Office of Space Sciences (January 13)

"On Mixed Launch Fleet Strategy and Policy Option," letter from Space Science Board chair Thomas M. Donahue to Dr. James Fletcher, NASA administrator (February 11)

"Assessment of Planned Scientific Content of the CRAF Mission," letter from SSB Committee on Planetary and Lunar Exploration chair Robert O. Pepin to Geoffrey A. Briggs, director of NASA's Solar System Exploration Division (May 27)

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"On the Decision to Place the High Resolution Solar Observatory Project on Hold," letter from SSB chair Thomas Donahue to Dr. James Fletcher, NASA administrator (September 21)

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"On the Challenger Accident Impact on Space Science," news conference statement by SSB chair Thomas M. Donahue (May 21)

"On the Balance of Shuttle and ELV Launches," letter from SSB chair Thomas M. Donahue to James C. Fletcher, NASA administrator (June 11)

"On the Implementation of CODMAC 1 & 2," letter from SSB Committee on CODMAC chair Christopher T. Russell to Burton Edelson, associate administrator for NASA's Office of Space Science and Applications (October 1)

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"On Categorization of the Mars Orbiter Mission," letter from SSB Committee on Planetary Biology and Chemical Evolution chair Harold P. Klein to Arnauld E. Nicogossian, director of NASA's Life Sciences Division (June 6)

"On the Shuttle Science Payload Program," letter from SSB chair Thomas M. Donahue to Burton Edelson, associate administrator for NASA's Office of Space Science and Applications (June 20)

"On NASA Policy for Planetary Protection," letter from SSB chair Thomas M. Donahue to Burton I. Edelson, associate administrator for NASA's Office of Space Science and Applications (November 22)

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**1972** *Human Factors in Long-Duration Spaceflight*, Space Science Board
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