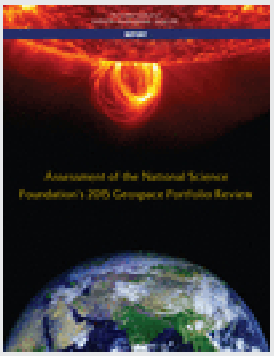


Assessment of the National Science Foundation's 2015 Geospace Portfolio Review

DETAILS

82 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-45483-4 | DOI: 10.17226/24666

CONTRIBUTORS

Committee on Assessment of the National Science Foundation's 2015 Geospace Portfolio Review; Space Studies Board; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine

Assessment of the National Science Foundation's 2015 Geospace Portfolio Review

Committee on Assessment of the National Science Foundation's
2015 Geospace Portfolio Review

Space Studies Board

Division on Engineering and Physical Sciences

A Report of

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This study is based on work supported by Contract AGI-1551518 with the National Science Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-45483-4
International Standard Book Number-10: 0-309-45483-2
Digital Object Identifier: 10.17226/24666

Copies of this publication are available free of charge from

Space Studies Board
National Academies of Sciences, Engineering, and Medicine
500 Fifth Street, NW
Washington, DC 20001

Additional copies of this publication are available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America

Suggested Citation: National Academies of Sciences, Engineering, and Medicine. 2017. *Assessment of the National Science Foundation's 2015 Geospace Portfolio Review*. Washington, DC: The National Academies Press. doi:10.17226/24666.

The National Academies of

SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.national-academies.org**.

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

Reports document the evidence-based consensus of an authoring committee of experts. Reports typically include findings, conclusions, and recommendations based on information gathered by the committee and committee deliberations. Reports are peer reviewed and are approved by the National Academies of Sciences, Engineering, and Medicine.

Proceedings chronicle the presentations and discussions at a workshop, symposium, or other convening event. The statements and opinions contained in proceedings are those of the participants and have not been endorsed by other participants, the planning committee, or the National Academies of Sciences, Engineering, and Medicine.

For information about other products and activities of the National Academies, please visit nationalacademies.org/whatwedo.

COMMITTEE ON ASSESSMENT OF THE NATIONAL SCIENCE FOUNDATION'S 2015 GEOSPACE PORTFOLIO REVIEW

TIMOTHY S. BASTIAN, National Radio Astronomy Observatory, *Chair*
SUSAN K. AVERY, Woods Hole Oceanographic Institution, *Vice Chair*
MARCEL AGÜEROS, Columbia University
PETER M. BANKS, NAE,[1] Visual Communications, Inc., and Liberty Plugins, Inc.
GEORGE GLOECKLER, NAS,[2] University of Maryland
J. TODD HOEKSEMA, Stanford University
JUSTIN C. KASPER, University of Michigan
KRISTINA A. LYNCH, Dartmouth College
TERRANCE G. ONSAGER, National Oceanic and Atmospheric Administration
AARON RIDLEY, University of Michigan
NATHAN A. SCHWADRON, University of New Hampshire
MARIA SPASOJEVIC, Stanford University

Staff

ABIGAIL A. SHEFFER, Program Officer, *Study Director*
ANESIA WILKS, Senior Program Assistant
CHARLES HARRIS, Research Associate (through August 2016)
CHERIE ACHILLES, Lloyd V. Berkner Space Policy Intern
CAROLINE JUANG, Lloyd V. Berkner Space Policy Intern

MICHAEL H. MOLONEY, Director, Space Studies Board and Aeronautics and Space Engineering Board

[1] National Academy of Engineering.
[2] National Academy of Sciences.

SPACE STUDIES BOARD

FIONA HARRISON, NAS, California Institute of Technology, *Chair*
ROBERT D. BRAUN, NAE, University of Colorado, Boulder, *Vice Chair*
DAVID N. SPERGEL, NAS, Princeton University and Center for Computational Astrophysics at the Simons Foundation, *Vice Chair*
JAMES G. ANDERSON, NAS, Harvard University
JEFF M. BINGHAM, Consultant
JAY C. BUCKEY, Geisel School of Medicine at Dartmouth
MARY LYNNE DITTMAR, Dittmar Associates, Inc.
JOSEPH FULLER, JR., Futron Corporation
THOMAS R. GAVIN, California Institute of Technology
NEIL GEHRELS,[1] NAS, NASA Goddard Space Flight Center
SARAH GIBSON, National Center for Atmospheric Research
WESLEY T. HUNTRESS, JR., Carnegie Institution of Washington (retired)
ANTHONY C. JANETOS, Boston University
CHRYSSA KOUVELIOTOU, NAS, George Washington University
DENNIS P. LETTENMAIER, NAE, University of California, Los Angeles
ROSALY M.C. LOPES, Jet Propulsion Laboratory
DAVID J. McCOMAS, Princeton University
LARRY PAXTON, Johns Hopkins University, Applied Physics Laboratory
SAUL PERLMUTTER, NAS, Lawrence Berkeley National Laboratory
ELIOT QUATAERT, University of California, Berkeley
BARBARA SHERWOOD LOLLAR, University of Toronto
HARLAN E. SPENCE, University of New Hampshire
MARK THIEMENS, NAS, University of California, San Diego
MEENAKSHI WADHWA, Arizona State University

Staff

MICHAEL H. MOLONEY, Director
CARMELA J. CHAMBERLAIN, Administrative Coordinator
TANJA PILZAK, Manager, Program Operations
CELESTE A. NAYLOR, Information Management Associate
MARGARET KNEMEYER, Financial Officer
SU LIU, Financial Assistant

[1] Deceased on February 6, 2017.

Preface

The National Science Foundation (NSF) conducted a portfolio review for the facilities, science programs, and other activities of the Geospace Section (GS) of the Directorate for Geosciences' Division of Atmospheric and Geospace Sciences. This review was carried out in 2015 by a 14-member Portfolio Review Committee (PRC), organized by NSF under its Advisory Committee for Geosciences. This review was, in part, a response by NSF to the recommendations highlighted for the geospace scientific community in the 2013 National Research Council (NRC) decadal survey *Solar and Space Physics: A Science for a Technological Society*[1] and the challenge of implementing those recommendations in a highly constrained fiscal environment. The resulting report, *Investments in Critical Capabilities for Geospace Science 2016 to 2025* (hereafter, "ICCGS"), was submitted to the Advisory Committee for Geosciences on February 5, 2016, and was released to the public on April 14, 2016.

NSF asked the Space Studies Board (SSB) of the National Academies of Sciences, Engineering, and Medicine[2] to provide an independent assessment of the portfolio review report. The ad hoc Committee on the Assessment of the National Science Foundation's 2015 Geospace Portfolio Review (hereafter, "the assessment committee" or "the committee"), comprised of members and supported by staff that were fully independent of the PRC, was formed in January 2016 and began its work in April 2016, following the public release of ICCGS. The assessment committee held three face-to-face meetings—May 13-14 and July 18-19, in Washington, D.C., and August 22-23 in Woods Hole, Massachusetts—and biweekly teleconferences. During the May meeting, the committee had discussions with members of the PRC, the Geospace Section Head, and several of the Geospace program directors. At the July meeting, the committee held follow-up discussions with the PRC chair, heard perspectives on the review from the Director of the Division of Atmospheric and Geospace Sciences, and was briefed on the recently released report of the National Academies regarding the science potential for CubeSats, *Achieving Science with CubeSats: Thinking Inside the Box*.[3] The committee also heard from selected members of the geospace science community with experience and perspective relevant to geospace facilities and programs. The objective of the third meeting was to prepare a first draft of this report.

[1] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[2] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in an historical context identifying programs prior to July 1.

[3] National Academies of Sciences, Engineering, and Medicine, 2016, *Achieving Science with CubeSats: Thinking Inside the Box*, The National Academies Press, Washington, D.C.

The assessment of the ICCGS requested by NSF is consistent with the responsibilities of the National Academies and the SSB to review and comment on government agency implementation actions and plans in response to the decadal survey recommendations. The assessment is not meant to second guess the recommendations of the report, or to suggest alternative recommendations, but to assess the process used to establish and prioritize its recommendations and to place them in a broader context. The assessment committee therefore chose not to comment on each of the many findings and recommendations presented in the report. Instead, the committee primarily focused on broader implications raised by the ICCGS recommendations and their implementation. The assessment report discussed some issues regarding large facilities in more detail than other parts of the GS portfolio, because ICCGS's recommended changes to facilities would result in the largest budgetary changes.

The committee would like to thank the members of the PRC for their generous time spent in discussions as the committee sought to understand the processes behind their report. Thanks are also due to the NSF Atmospheric and Geospace Sciences Division Director and the Geospace Section Head and other representatives who were generous both with their time and their insights. Finally, the committee thanks the members of the geospace science community and representatives of geospace facilities for informative discussion and for their responsiveness to requests for information.

The committee notes with great sadness the passing of committee member Dr. Maha Ashour-Abdalla on May 1, 2016, and regrets not having had the pleasure of working with her during the course of this assessment.

Acknowledgment of Reviewers

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

M. Joan Alexander, NorthWest Research Associates,
Daniel Eisenstein, NAS,[1] Harvard-Smithsonian Center for Astrophysics,
Lennard A. Fisk, NAS, University of Michigan,
Jason Jackiewicz, New Mexico State University,
Janet G. Luhmann, University of California, Berkeley,
Jens Oberheide, Clemson University, and
Larry Paxton, Johns Hopkins University, Applied Physics Laboratory.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by Marcia J. Rieke, University of Arizona, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the authoring committee and the institution.

[1] National Academy of Sciences.

Contents

Summary

At the request of the Advisory Committee for Geosciences of the National Science Foundation (NSF), a review of the Geospace Section (GS) of the NSF Division of Atmospheric and Geospace Sciences (AGS) was undertaken in 2015. The Portfolio Review Committee (PRC) was charged with reviewing the portfolio of facilities, research programs, and activities funded by GS and to recommend critical capabilities and the balance of investments needed to enable the science program articulated in the 2013 National Research Council (NRC) decadal survey *Solar and Space Physics: A Science for a Technological Society*[1] (hereafter, "the decadal survey"). The charge given to the PRC is included in Appendix A. The PRC's report *Investments in Critical Capabilities for Geospace Science 2016 to 2025*[2] (hereafter, "ICCGS") was accepted by the Advisory Committee for Geosciences in April 2016.

NSF asked the Space Studies Board of the National Academies of Sciences, Engineering, and Medicine[3] to provide an independent assessment of the ICCGS report. The Committee on the Assessment of the National Science Foundation's 2015 Geospace Portfolio Review (hereafter, "the assessment committee" or "the committee") was charged to assess how well the ICCGS provides a clear set of findings, conclusions, and recommendations for GS that align with the science priorities of the decadal survey, and adequately take into account issues such as the current budget outlook and the science needs of the community. The assessment committee was asked to make recommendations focused on options and considerations for NSF's implementation of the ICCGS recommendations (full statement of task provided in Chapter 1). The ICCGS makes over 100 recommendations (reproduced in Appendix B). The assessment committee does not consider each one individually, and instead considers selected ICCGS recommendations and groups of recommendations within a broader context. A subset of the assessment committee's conclusions and recommendations are presented in this summary.

Geospace science is an integrative and cross-disciplinary enterprise that includes facilities, programs, and activities within NSF as well as other U.S. agencies and international programs. The GS program supports critical components of the solar and space physics program but controls less than 5 percent of the U.S. investment in

[1] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[2] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[3] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in an historical context identifying programs prior to July 1.

the discipline. Consequently, the scope of the decadal survey is much larger than the mandate of GS and provides little specific guidance for individual elements of the GS program. The ICCGS represents a significant effort to meet the challenge of developing specific recommendations that will enable the GS portfolio to address survey priorities and community needs within the given constraints. However, the ICCGS did not, and in some instances could not, fully address all survey priorities (see Chapter 5). The assessment committee's discussion of the process used to develop the ICCGS recommendations, particularly those regarding facilities, is presented in Chapter 4.

> **Conclusion:** The PRC fulfilled its charge within the imposed constraints. The portfolio review process and the resulting report represent a conscientious, thorough, and good-faith effort to review the NSF GS portfolio and make recommendations for portfolio evolution and renewal. (Chapter 4, p. 21)

The ICCGS's boundary conditions included the consideration of the GS portfolio largely in isolation, without a requirement to consider other directly relevant facilities, programs, and activities, such as the National Center for Atmospheric Research and its geospace laboratory, the High Altitude Observatory. An additional development that may affect GS is the National Space Weather Strategy[4] (NSWS) and the Space Weather Action Plan[5] (SWAP), released by the National Science and Technology Council of the Office of Science and Technology Policy in October 2015. The SWAP identifies NSF, in collaboration with other agencies, as responsible for the enhancing "fundamental understanding of space weather and its drivers to develop and continually improve predictive models." [6] Although the PRC demonstrated awareness of relevant activities outside the GS, the assessment committee is concerned that AGS and GS do not currently have their own specific strategic vision and plan or a visible process for developing one. It is important to understand the place GS occupies within the wider geospace sciences landscape and the scientific and societal priorities of the geospace sciences community, such as those embodied in the NSWS and SWAP, as GS strives to meet the challenge of leveraging limited resources to maximize their impact on geospace sciences.

> **Recommendation:** The lack of a strategic plan for the Division of Atmospheric and Geospace Sciences (AGS) and the Geospace Section hinders the ability of the Geospace Section to act fully upon the recommendations given in *Investments in Critical Capabilities for Geospace Science 2016 to 2025*. AGS should develop a strategic vision and a strategic plan that recognizes all components within its portfolio relevant to geospace and interfaces with other programs across other National Science Foundation (NSF) divisions and directorates and across the agency. The plan should be aligned with the 2013 solar and space physics decadal survey, demonstrate awareness of the evolving capabilities outside NSF, and should be regularly updated with close community involvement in response to emerging discoveries, evolving budgets, new imperatives, and developing partnerships. (Chapter 3, p. 17)

A primary task of the PRC was to evaluate the portfolio of GS facilities and research activities to identify adjustments that will better align the portfolio with decadal survey priorities. The ICCGS report provides recommendations formulated to rebalance the program and provide a source of funding to support new programs and initiatives. For the purposes of this assessment, the ICCGS recommended program is grouped into five major sections: actions for current GS facilities, the evolution of facilities programs, competed grants, workforce development and diversity, and partnerships and opportunities (Chapter 5).

A subset of the ICCGS recommendations for current facilities are summarized as follows:

- ICCGS Recommendations 7.6, 7.7, and 9.11 summarized: Reduce annual funding to Arecibo Observatory from $4.1 million to $1.1 million annually. Funding of ancillary instruments for geospace studies should

[4] National Science and Technology Council (NSTC), 2015, *National Space Weather Strategy*, Office of Science and Technology Policy, Washington, D.C., October.
[5] NSTC, 2015, *National Space Weather Action Plan*, Office of Science and Technology Policy, Washington, D.C., October.
[6] Ibid., pp. 22 and 26.

be budgeted and decided in the peer-review process. The costs of running the heating facility at Arecibo should be budgeted as a pay-as-you-go system and decided in a peer-review process.

- ICCGS Recommendations 7.2, 7.3, and 9.11 summarized: Terminate funding for the Sondrestrom Incoherent Scatter Radar (ISR) ($2.5 million annually) when the current continuing contract for its management and operation ends in December 2017, or via ramping down of funds, and allow ancillary instruments to compete for funds through a peer-review process from the core and targeted GS grants programs.
- ICCGS Recommendations 7.18 and 7.19 summarized: The Consortium of Resonance and Rayleigh Lidars (CRRL) as currently organized and directed is not a community facility. Participating members should seek peer-reviewed funding from the core or targeted grants programs. The CRRL technology center should apply for separate funding from the proposed Facilities Innovation and Vitality (I&V) Program.

Both the PRC and the assessment committee recognize that to address decadal survey priorities under a flat-budget scenario, GS funding of facilities or activities must be reduced or, in some cases, eliminated. However, a combination of unknown factors led the assessment committee to two broad concerns regarding the recommended cuts to Arecibo Observatory and Sondrestrom:

Conclusion: Details concerning the actual costs of supporting geospace sciences at Arecibo Observatory and Sondrestrom, including the ISRs and ancillary instrumentation, are not provided in the ICCGS. It is therefore difficult for the assessment committee to understand the nature and extent of capabilities that would remain at the Arecibo and Sondrestrom sites and to evaluate the degree to which the capabilities align with current community science needs. (Chapter 5, p. 25)

Conclusion: The two most significant sources of funds for new facilities and programs within GS result from reducing funding to Arecibo Observatory from $4.1 million to $1.1 million and terminating funding for the Sondrestrom ISR. The ICCGS recommends that these funding changes be complete by 2020. However, management and operations at both sites are inherently complex, introducing a degree of uncertainty regarding the full extent of savings realized by the recommended cuts and of the time required before these funds are available for reallocation. (Chapter 5, p. 25)

The ICCGS redirects the funding currently used to support the CRRL to "strategic grants programs to address DRIVE initiatives recommended by the Decadal Survey."[7] The assessment committee notes that these strategic grants programs appear to lie within the Integrative Geospace Science (IGS) program, which is not the same as the core and targeted grants programs to which the CRRL investigators are recommended to send their proposals. Therefore, pressure on the core and targeted grants programs may increase. Once evaluation criteria have been defined for the ICCGS's recommended new distributed array of small instruments (DASI) Facilities Program (discussed below), programs such as the CRRL could seek funding support there.

Another task of the ICCGS was to recommend the evolution of existing facilities and programs and the creation of new ones to advance geospace science. As part of evolving the GS facilities portfolio, the ICCGS recommends that to largely replace capabilities lost by the termination of the Sondrestrom ISR, GS should investigate joining the European Incoherent Scatter Scientific Association (EISCAT) (ICCGS Recs. 7.2, 7.4, 7.23, and 9.10). The assessment committee considers this to be a sensible approach: leveraging an international partnership to retain certain capabilities and to expand others is consistent with decadal survey guidance regarding international partnerships. However, the time it will take to enter the EISCAT partnership may be longer than assumed by the ICCGS, thereby delaying the availability of funds for new GS initiatives. EISCAT-3D is not yet fully funded, and its management and operations cost are not fully understood. The U.S. contribution to current and future operations and management costs will be an important consideration when entering the partnership.

[7] NRC, 2013, *Solar and Space Physics*, p. 104.

Conclusion: The EISCAT and EISCAT-3D represent an attractive investment that would ensure U.S. access to state-of-the-art ISR instrumentation at a lower cost than is currently the case. However, the time it will take to enter the EISCAT partnership may be longer than assumed by the ICCGS. The U.S. contribution to current and future operations and management costs will be an important consideration when entering the partnership. (Chapter 5, p. 28)

The ICCGS's recommendations also include two new funding lines relevant to instrument development: the Facilities I&V Program and a DASI Facilities Program. The ICCGS recommends using funds freed up by recommendations previously discussed to create the Facilities I&V Program with a budget of $2.7 million annually (ICCGS Rec. 9.14). The Facilities I&V Program would support a number of existing and new activities ranging from major repairs to existing facilities, to development of new instrumentation to an operational capability, to the development of numerical algorithms to improve computational models. The recommended Facilities I&V Program will be at new source of funds for driving innovation; however, the assessment committee notes that the definition of the program line is at present very broad and consideration will need to be given to balancing its constituent parts and to understanding its relationship to the strategic grants programs.

The ICCGS makes a number of recommendations that support the development of DASI-like instrumentation and associated data assimilation. These include the creation of a DASI Facilities Program (ICCGS Recs. 7.4, 7.5, and 9.12) to develop and implement one or more DASI Class 2 facilities. The assessment committee endorses the intent of the recommendations regarding DASIs and DASI-related issues as part of moving GS toward a guiding role in scientifically directing community thought and efforts toward system-level studies of the geospace region. GS support may be needed to propel forward community discussions of DASI projects.

Recommendation: To begin implementation of the *Investments in Critical Capabilities for Geospace Science 2016 to 2025* recommendations to create distributed arrays of small instruments (DASIs) with the goal of starting new Class 2 facilities, the National Science Foundation should support community efforts to establish requirements for future DASI-type sensors and projects—by organizing targeted community workshops, for example—within a wider Geospace Section strategic framework. (Chapter 5, p. 30)

One decadal survey recommendation that the ICCGS could not implement within the challenging constraints is the creation of a midscale funding program to support development of ground-based facilities and experiments that are too small for the NSF Major Research Equipment and Facilities Construction (MREFC) account but too large for the NSF Major Research Instrumentation (MRI) program. The ICCGS estimates that at least $5 million to $6 million per year would be needed for a viable midscale funding line within GS and concludes that it does not fit within the GS budget envelope. The assessment committee agrees with this conclusion. The ICCGS recommends that if funding becomes available from the divestment of facilities or from an increased budget, funding should be directed toward a Midscale Projects Program. As a high-priority recommendation to NSF from two decadal surveys—in astronomy and astrophysics[8] and in solar and space physics[9]—and as 1 of 10 strategic "big ideas" for NSF, the assessment committee believes that the creation of a Midscale Projects Program for geospace facilities requires the investment of new funds outside of the GS budget in a program to which the geospace sciences community will be eligible to apply. Development and implementation will require coordination between the AGS division, the Directorate for Geosciences, and NSF.

Recommendation: The Division of Atmospheric and Geospace Sciences should work with the Directorate for Geosciences and the National Science Foundation to implement the 2013 solar and space physics decadal survey recommendation for a Midscale Projects Program to address midscale priorities. (Chapter 5, p. 28)

[8] NRC, 2010, *New Worlds, New Horizons in Astronomy and Astrophysics*, The National Academies Press, Washington, D.C.
[9] NRC, 2013, *Solar and Space Physics*.

For the competed grants programs, the ICCGS recommends that GS maintain the existing budget share of core grants—at least a third, or not less than $14 million to $15 million annually. The evolutionary component lies within the strategic grants. Specifically, the ICCGS recommends a strategic IGS grants program that includes both a transformed Space Weather Modeling (SWM) program and new Grand Challenge Projects program (ICCGS Recs. 9.3 and 9.4).

Parts of the strategic grants program, CubeSats and the Faculty Development in Space Science (FDSS; a part of the workforce and development programs discussed below), are given lower priority by the ICCGS than the other parts of the strategic grants programs, the core grants programs, and current and new facilities programs (ICCGS Table 9.1, reprinted here as Figure 5.1).

The ICCGS recommends a stricter set of guidelines for CubeSat missions, finding that publication results from the program "are predominantly engineering-oriented and that, on average, basic science productivity is low in comparison to . . . the same financial investment in [other] GS programs."[10] The ICCGS recommends that investment in the CubeSat program be reduced from $1.5 million to $1 million per year to reflect "a focus on mission concept, instrument development, and science exploitation of the data" and a reduced scope of mission development (ICCGS Recs. 6.23-6.26 and 9.6). The ICCGS recommended that GS support two new mission starts per year, as suggested by the decadal survey, only if additional funding is obtained from elsewhere in NSF.

The National Academies recently released the report *Achieving Science with CubeSats: Thinking Inside the Box*,[11] which was not available during the PRC's work, that included a number of findings addressing similar concerns. *Achieving Science* concluded that CubeSats have demonstrated their capability to be a platform for high-value science and recommended that NSF broaden opportunities for participation. The findings of the ICCGS and *Achieving Science* are broadly consistent regarding partnerships and the educational benefit of CubeSat missions. The assessment committee also endorses this approach. However, although the cost of engineering the spacecraft may be reduced by commercially available components, other factors, such as the cost of developing new, innovative instruments and additional support for in-orbit operations, may offset savings. Unless partnerships are established, the assessment committee is concerned that GS CubeSat program will be unduly slowed by the ICCGS's recommendation to reduce the budget by one-third.

> **Recommendation:** The assessment committee endorses the *Investments in Critical Capabilities for Geospace Science 2016 to 2025* recommendation to seek partnerships for CubeSats outside of the National Science Foundation (NSF) Geospace Section. However, mindful of the growing potential of CubeSats to be platforms for science and of the 2013 solar and space physics decadal survey recommendation to augment support for CubeSats, the committee recommends that the NSF Geospace Section carefully consider the impact associated with decreasing funding for the CubeSat program before additional resources through intra-divisional partnerships can be obtained. (Chapter 5, p. 34)

Part of the evolution at GS is the consideration of developing a vibrant and diverse workforce. The ICCGS's main recommendations regarding workforce development were that current GS efforts in these areas should continue. Furthermore, the report emphasized the importance of data collection in assessing the effectiveness of these efforts to increase participation of African Americans, Latino/as, Native Americans, and women in geospace science. These modest, essentially "stay the course," recommendations of the ICCGS stand in contrast with its ambitious Recommendation 4.6, which states, "The GS and the GS community should be in the vanguard of NSF initiatives to promote engagement of women and under-served populations in all aspects of geospace science from school to research proposal writing to leadership in GS activities." The assessment committee agrees that there has been some progress in increasing the participation of women and underrepresented minorities in solar and space physics; however, progress will not continue without substantial effort on the part of GS and the com-

[10] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 69.

[11] National Academies of Sciences, Engineering, and Medicine (NASEM), 2016, *Achieving Science with CubeSats: Thinking Inside the Box*, The National Academies Press, Washington, D.C.

munity. Some suggestions for improving diversity and representation in solar and space physics are included with the following recommendation:

> **Recommendation:** The assessment committee recommends that to realize Recommendation 4.6 of *Investments in Critical Capabilities for Geospace Science 2016 to 2025* fully, the lack of diversity and representation in solar and space physics should be attacked aggressively. The National Science Foundation Geospace Section should identify best practices and provide guidance for new approaches to diversifying geospace. (Chapter 5, p. 36)

As part of guiding the future of GS, the ICCGS discusses internal organization and management issues. To guide the future evolution of the GS portfolio, the ICCGS recommends periodic senior reviews for both the Core and Strategic Grants Programs and for all of the GS facilities. The assessment committee endorses the use of senior reviews as a recognized means of prioritizing existing investments to allow new opportunities and to rebalance and renew the portfolio. The committee is concerned, however, by the recommendation to separate the two sets of reviews, because of the burden placed upon GS administration by two separate semi-decadal reviews.

> **Conclusion:** The assessment committee endorses ICCGS Recommendations 9.8 and 9.15 to conduct periodic senior reviews of the NSF Geospace Section's grants programs and facilities. (Chapter 6, p. 42)

ICCGS recommends a set of improvements to GS management processes that would improve the transparency and efficiency of future reviews and facilitate transitions in GS program management. The assessment committee endorses each of these suggestions.

> **Conclusion:** The suggestions to the NSF GS regarding management processes are excellent and will underpin future senior reviews and allow greater transparency into the decision-making process. (Chapter 6, p. 43)

To conclude this assessment, the ICCGS report represents a comprehensive program for the GS portfolio that is aligned with decadal survey priorities. The exception is funding for a Midscale Projects Program, which cannot be implemented within the budget constraints provided by NSF. The responsibility now passes to NSF to implement the GS portfolio recommended in the ICCGS and to engage with the community in developing a strategic vision and plan that identifies and builds on the strengths of AGS and GS within the broader solar and space physics enterprise.

1

Introduction

1.1 CHARGE TO THE NSF GEOSPACE SECTION PORTFOLIO REVIEW COMMITTEE

At the request of the Advisory Committee for Geosciences of the NSF, a review of the GS of the AGS was undertaken in 2015. The GS PRC was charged with reviewing all facilities, programs, and activities funded by GS, a portfolio of $43.6 million in fiscal year (FY) 2015 dollars. (See the full charge to the PRC in Appendix A.) In brief, the PRC was asked to "recommend the critical capabilities needed over the period from 2016 to 2025 that would enable progress on the science program articulated in the Decadal Survey for Solar and Space Physics"[1] (hereafter, "the decadal survey") and to recommend "a balance of investments in new and in existing facilities, grants programs, and other activities that would optimally implement the survey recommendations. . . ." The PRC was asked to be mindful of the "effects of its recommendations on the future landscape of the U.S. Geospace community" and to ensure that the recommended portfolio is "viable and lead[s] to a vigorous and sustainable future." Such an exercise must proceed with care, considering not only what capabilities were necessary for future success but what "capabilities and activities will be potentially lost in enabling new activities and discontinuing current activities." The PRC's ICCGS report[2] was presented to the Advisory Committee for Geosciences in April 2016.

1.2 CHARGE TO THE NATIONAL ACADEMIES ASSESSMENT COMMITTEE

NSF asked the SSB of the National Academies to provide an independent assessment of the ICCGS report. The statement of task for the Committee on the Assessment of the National Science Foundation's 2015 Geospace Portfolio Review (hereafter, "the assessment committee" or "the committee") is as follows:

> The committee will structure its assessment around how well the PRC report's findings, conclusions, and recommendations:

[1] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[2] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

1. Align with the science issues and priorities highlighted for NSF-GS and the Geospace scientific community in the NRC's Decadal Survey: Solar and Space Physics: A Science for a Technological Society (hereafter called the Survey);

2. Adequately take into account issues such as:
   a. actions already taken by the NSF-GS in response to the Survey priorities;
   b. the current challenging outlook for the U.S. Federal budget—in particular the expected evolution of the NSF-GS budget;
   c. interdisciplinary aspects and the overall scientific balance of all NSF-GS-funded activities;
   d. the alignment of the capabilities of the Geospace Facilities Program with the current science needs of the community—in particular how well the Facilities Program is specifically designed to enhance educational opportunities, diversity, and international participation;
   e. the integration of technology development with the NSF-GS science program, and
   f. the balance of investments between the new and existing facilities, grants programs, and other activities.

3. Provide—considering the value of funded activities in terms of both intellectual merit and broader impacts—a forward-looking focus on the potential of all NSF-GS funded facilities, programs, and activities for delivering the desired science outcomes and capabilities; and

4. Provide a clear set of recommendations on how the NSF-GS should implement the Survey's priorities within the context of the NSF/Geosciences strategic planning process.

> The committee's report will also discuss the general readability and clarity of the PRC's report and in particular its recommendations, as well as offering commentary on other issues relevant to the assessment of the PRC report, as determined by the committee. Any recommendations the committee may make will be focused on options and considerations for NSF's implementation of the PRC recommendations.

In addressing its statement of task, the assessment committee did not evaluate each of the more than 100 specific findings and recommendations made by the ICCGS (reprinted in Appendix B), although some of the ICCGS findings and recommendations are referenced and discussed. Rather, the committee considered the ICCGS recommendations within the broader context of decadal survey priorities, GS portfolio balance, and future needs of the scientific community. The assessment committee was mindful of the limited scope and budget within which the PRC addressed its charge while at the same time considering GS as a component of the larger solar and space physics enterprise, which spans divisions and directorates within NSF, as well as other agencies—NASA, the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy (DOE), and the Department of Defense (DOD). The committee also considered the impact of the NSWS,[3] released by the Office of Science and Technology Policy in October 2015, when the PRC's work was largely complete.

1.3 DECADAL SURVEY PRIORITIES FOR NSF

Science priorities defined by the 2013 decadal survey report *Solar and Space Physics: A Science for a Technological Society* served as the "primary touchstones" for the ICCGS's recommendations. The survey lays out a broad blueprint for the nation's scientific program in solar and space physics for the decade 2013-2022 that will

> . . . improve scientific understanding of the mechanisms that drive the Sun's activity and the fundamental physical processes underlying near-Earth plasma dynamics; determine the physical interactions of Earth's atmospheric layers in the context of the connected Sun-Earth system; and greatly enhance the capability to provide realistic and specific forecasts of Earth's space environment that will better serve the needs of society.[4]

[3] National Science and Technology Council (NSTC), 2015 *National Space Weather Strategy*, Office of Science and Technology Policy, Washington, D.C., October.

[4] NRC, 2013, *Solar and Space Physics*, p. 1.

The decadal survey recommendations are addressed primarily to the NASA Heliophysics Division; to NSF, in both the geosciences and astronomy; and to NOAA and other agencies.[5] The GS program supports critical components of the solar and space physics program, but controls less than 5 percent of the U.S. investment in the discipline. Consequently, the scope of the survey is much larger than the mandate of GS and provides little specific guidance for individual elements of the GS program. Furthermore, the program recommended by the survey was crafted in 2013 with certain assumptions about the funding available to carry out the program. The GS budget has not grown as the survey expected, nor is it anticipated to grow at a rate more than inflation. Except as noted below, the specific implementation of the survey recommendations was left to the agencies.

The decadal survey acknowledges that new and important science can be accomplished with contributions from existing ground- and space-based observing facilities (e.g., the Heliophysics System Observatory; HSO), but it should be recognized that the survey science program focuses primarily on new instrumentation and the science that new observations will enable. The survey's baseline priority for both NASA and NSF is to complete programs in advanced stages of development, while continuing support for key existing program elements of the HSO in the near term. The survey does not judge the value of existing facilities, particularly for long-term studies, nor does it evaluate the contributions of any one facility to the HSO. NASA periodically considers extending the operational lifetime of its various space-based elements with a rigorous process known as the senior review.

The top-priority research recommendation in the decadal survey is the most relevant to GS. It calls for the implementation of the multiagency DRIVE[6] initiative. Directly motivated by the scientific imperatives, DRIVE consists largely of programmatic recommendations to more fully develop and more effectively employ the scientific assets of NSF, NASA, and other agencies. Briefly, the DRIVE recommendation includes the following: (D) diverse observing platforms including microsatellites and midscale ground-based observing systems; (R) adequate funding for operations and data analysis; (I) integration of observations from multiple sources and analysis of data across disciplines; (V) support for concentrated efforts to address major research problems and for the development of new instrument technology; and (E) investment in the education, empowerment, and inspiration of the next generation of space researchers.

As part of the DRIVE initiative, a specific decadal survey recommendation to NSF is to implement a competitively selected midscale project funding line. The survey enumerates several examples of candidate projects that were prioritized by survey panels.[7]

The decadal survey makes a strong case that progress in solar and space physics depends on understanding the system as a whole—that is, the science discipline requires more than independent investigations of a collection of simply interacting physical domains. Hence, cross-cutting science is emphasized, as are Heliophysics Science Centers. The recognition that the coupled system elements must be studied holistically is a guiding principle of the survey,[8] one that demands a balanced approach. In this case, "balance" refers to appropriate investments in facilities and programs that reflect an awareness that scientific investigations transcend traditional subdiscipline boundaries, that measurements are needed in multiple regimes, and that a diverse approach to facilities and programs is required.

The decadal survey has a number of recommendations regarding professional development, education, and training. It is positive about the FDSS program and, furthermore, recommends extending the program to 4-year institutions as well as supporting development of complementary curriculum development. The survey is also positive about the educational opportunities afforded by CubeSats, graduate student and postdoctoral mentoring programs, workshops that focus on professional development skills, and programs that target increasing diversity within the solar and space physics community.

[5] See Tables S.1 and S.2 in NRC, 2013, *Solar and Space Physics*, p. 4.
[6] DRIVE: Diversify, Realize, Integrate, Venture, Educate (see NRC, 2013, *Solar and Space Physics*).
[7] NRC, 2013, *Solar and Space Physics*, pp. 118-119.
[8] Ibid., p. 3.

1.4 ORGANIZATION OF THE REPORT

This assessment of the ICCGS report is organized as follows: Chapter 2 summarizes the "boundary conditions" imposed on the PRC in terms of the scope of the portfolio review and the GS budget guidance. Chapter 3 places the GS portfolio in a broader context of the solar and space science enterprise across AGS and NSF, in other agencies, and the NSWS and the SWAP.[9] Chapter 4 considers the processes used by the PRC to gather information, prioritize facilities, and align their recommendations with survey priorities. Chapter 5 discusses the GS program recommended by ICCGS, and Chapter 6 addresses the clarity and completeness of the ICCGS recommendations as well as the planning and resources needed for their implementation.

[9] NSTC, 2015, *National Space Weather Action Plan*.

2

Portfolio Review Boundary Conditions

The assessment committee was asked to consider how well the ICCGS report[1] took into account actions already taken by GS in response to the priorities of the 2013 solar and space physics decadal survey.[2] However, other than the creation of a Space Weather Research program (SWR) to span and integrate already existing core research areas, GS has not been able to respond effectively to survey priorities, which nearly all require an increased budget to implement. The portfolio review itself is the most responsive action taken so far by the GS to the survey priorities. The PRC recognized that important constraints limited its ability to respond fully to its charge and to judge the alignment of the program against the priorities recommended in the survey. The boundary conditions imposed on the ICCGS response to survey guidance, in terms of scope and budget guidance, are discussed here.

2.1 THE SCOPE OF THE GEOSPACE SECTION PORTFOLIO REVIEW

The GS portfolio is comprised of facilities, core and strategic science grants programs, and professional development programs. In Chapter 7 of the ICCGS,[3] GS facilities were defined as being one of two types: Class 1 and Class 2. A Class 1 facility is defined as a major, complex facility at a single site. Class 1 facilities include ISRs and ancillary capabilities at Arecibo Observatory, Sondrestrom, Jicamarca, Millstone Hill, the Poker Flat ISR (PFISR), and the Resolute Bay ISR (RISR-N). Class 2 facilities are defined as more modest, diverse investments, and these include SuperDARN, AMPERE, SuperMAG,[4] and the Community Coordinated Modeling Center (CCMC). The CRRL is also funded as a facility. The core grants programs are those in aeronomy (AER), magnetospheric physics (MAG), and solar-terrestrial science (STR). The strategic grants programs are Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR), Geospace Environment Modeling (GEM), and the Solar, Heliospheric, and Interplanetary Environment (SHINE). Additional strategic investments are in SWM, CubeSats, and FDSS awards.

---

[1] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[2] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[3] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025,* Chapter 7.

[4] SuperDARN stands for Super Dual Auroral Radar Network. AMPERE stands for Active Magnetosphere and Planetary Electrodynamics Response Experiment. SuperMAG is not an acronym but describes a collaboration of ground-based magnetometers.

These components of the GS portfolio are summarized in Figure 3.1 from the ICCGS report, reproduced here as Figure 2.1a.

The scope of the portfolio review was confined to GS and did not occur within the context of a broader review of an NSF-AGS division portfolio. As summarized by ICCGS Section 8.1.1, the National Center for Atmospheric Research (NCAR) and its geospace laboratory—the High Altitude Observatory (HAO)—are responsible for scientific capabilities and programs that are of direct relevance to the GS portfolio. The NCAR Computational and Information Systems Laboratory (CISL) is also relevant. NCAR falls administratively within a different NSF-AGS facilities section, and it was not included in the GS portfolio review. The PRC was aware of AGS facilities and programs relevant to the GS portfolio, and the PRC interviewed the HAO director. Additional NSF and AGS programs relevant to GS also fell outside the purview of the ICCGS. These included the following:

- NSF-DOE partnership in Basic Plasma Science and Engineering,
- Prediction of and Resilience against Extreme Events (PREEVENTS), and
- Improving Undergraduate STEM Education: Pathways into Geosciences (IUSE: GEOPATHS).

The NSF Faculty Early Career Development Program (CAREER) and the AGS Postdoctoral Research Fellowship Program were both discussed in ICCGS Chapter 4, as were GS FDSS awards. Only the latter fell within the ICCGS purview, however.

Finding: The PRC was charged to consider the NSF GS portfolio largely in isolation, without review of relevant facilities, programs, and activities within the wider AGS portfolio.

2.2 BUDGET GUIDANCE

The total FY2015 GS budget was $43.6 million. Facilities investments accounted for 38 percent of the total; the core grants program for 33 percent (AER, MAG, STR); and strategic grants investments (CEDAR, GEM, SHINE, CubeSats, and SWM) for 28 percent. GS budget trends are summarized in Figure 3.2 of the ICCGS report, reproduced here as Figure 2.1b.

NSF budget guidance for ICCGS was confined to one scenario: a flat budget from 2016-2025, with the only growth being that due to inflation. Hence, any new activities and programs would come at the cost of redirecting, curtailing, or terminating investments in existing facilities, programs, and activities. This was different than the assumption made by the decadal survey.

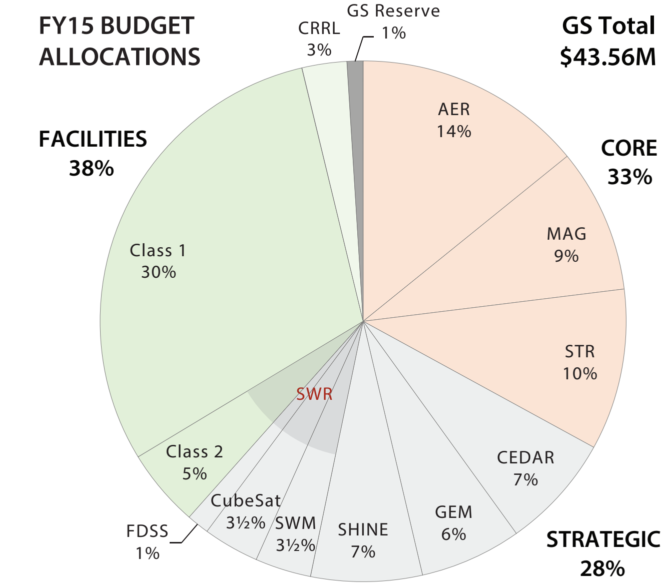
The ICCGS found analysis of the GS budget to be a challenge, stating that "teasing out objective GS budget trends from 1999 forward" was complicated by a number of factors, including the following:

- The addition of new programs and facilities during this time;
- Organizational changes within GS—the implementation of SWR, for example;
- Evolution in the administration of specific programs and facilities; and
- A lack of clarity between research funding and facility operations and management costs.

As the ICCGS commented, these factors conspired to provide "less than optimum transparency"[5] into the GS budget, and knowledge of important background and context for certain budgetary decisions by GS were lost to a significant extent when key GS personnel recently retired. The ICCGS noted three interrelated budgetary trends,[6] summarized here as follows:

[5] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025,* p. 16.
[6] Ibid., Section 3.3.

(a)



(b)

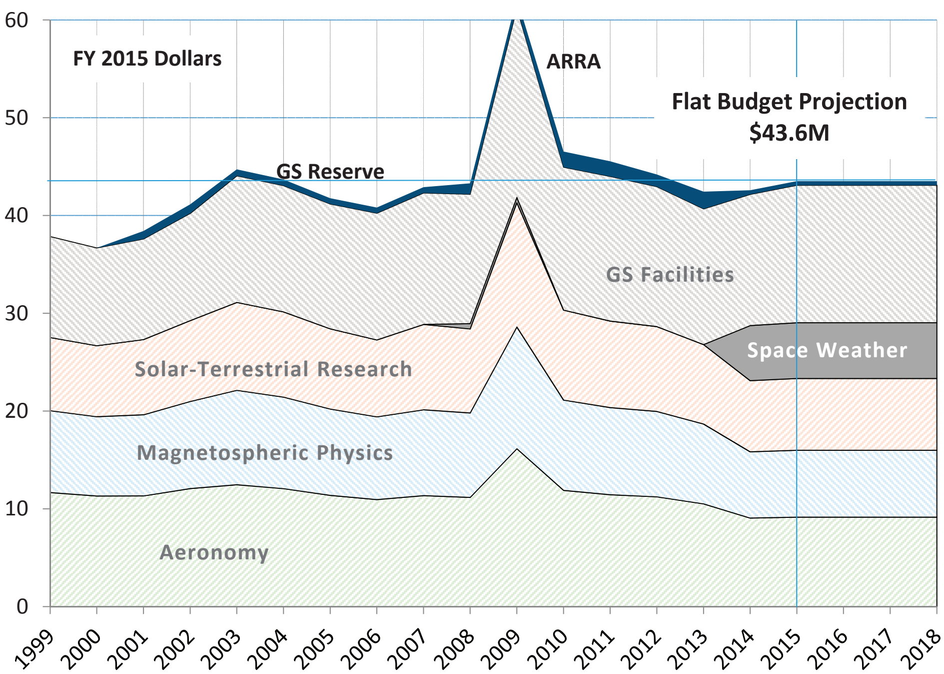


FIGURE 2.1 (a) The GS budget breakdown for FY2015; (b) the GS budget since 1999 and projected through 2018 shown in FY2015 dollars. Note that the three lower color bands in (b) correspond to the three core elements in (a)—that is, solar terrestrial research maps to STR and SHINE; magnetospheric physics maps to MAG plus GEM; and aeronomy maps to AER plus CEDAR. The space weather research program (SWR) was created from the combination of existing program elements as shown in (a). NOTE: Acronyms are defined in Appendix E.
SOURCE: National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf, (a) Figure 3.1, p. 11; (b) Figure 3.2, p. 16.

1. The GS budget has been flat for a decade (FY2015 dollars), discounting the 1-year augmentation of funds due to the American Recovery and Reinvestment Act (ARRA) in 2009. GS added new programs and facilities during this time without terminating existing facilities or programs.
2. Core and targeted grants funding have, as a consequence, been eroding. In past years, funding for grants and for facilities was relatively distinct. With the emergence of Class 2 facilities, which were not in the GS facilities budget, this distinction has been blurred.
3. While there has been a modest increase in the GS facilities budget, it has not kept up with the increase in the number of Class 1 and 2 facilities at a rate sufficient to maintain state-of-the-art technical and scientific capabilities.

The ICCGS notes that these trends are "problematic for achieving leading-edge science in the next decade."[7] This is not a new development, however. The GS is expected to be responsive to the needs and aspirations of the scientific community as well as societal demands with a budget that, if the guidance holds until 2025, will have been flat for more than two decades.

Although the decadal survey identified priorities for NSF and geospace science, it did not specify funding levels needed to address those priorities. ICCGS estimates that being fully responsive to survey priorities would require additional expenditures of $11 million annually (ICCGS Section 3.2). The most significant component of the new expenditures would be implementation of the survey priority for a midscale projects budget line, estimated by the ICCGS to be at least $5 million to $6 million annually (see Section 5.2.1 below). In the absence of any such augmentation, survey priorities must be addressed within the flat budget envelope.

Finding: The ICCGS report estimates that an augmentation of $11 million, or 25 percent, is needed to fully address decadal survey priorities. However, the PRC was asked to respond to its charge under one budget scenario: a flat budget from 2016-2025 with adjustments for inflation.

[7] Ibid., p. 17.

3

The Geospace Section Portfolio in Context

As noted in Section 1.3 of this report, NSF's GS represents a relatively small investment compared to the total U.S. investment made in solar and space physics. Yet it serves an important constituency for scientific discovery in geospace. The ICCGS report[1] emphasizes the transformation of the geosciences community over the past decade with the emerging understanding that geospace is a key component of a complex, coupled system comprised of Earth's upper atmosphere and ionosphere, its magnetosphere and the near-Earth environment, the interplanetary medium, the heliosphere, and the Sun. In considering the GS portfolio, it is therefore important to understand the larger domain in which geospace science is funded and to establish a strategic framework within which geospace science priorities are established.

3.1 STRATEGIC PLANNING

A clear understanding of strategic priorities in the coming decade is necessary to establish the broader landscape on which GS priorities are considered. The assessment committee notes that it would be particularly helpful to have a strategic vision and plan for the AGS and GEO that not only includes GS, but also planning mechanisms for midscale infrastructure, Major Research Instrumentation (MRI) projects, and potential projects for the Major Research Equipment and Facilities Construction (MREFC) account (see Section 3.2, below). The 2013 solar and space physics decadal survey[2] is not very specific regarding smaller elements of GS and does not serve as a strategic plan for GS in terms of providing a focused vision for GS facilities and science. NSF has an agency-wide strategic plan,[3] and among the materials made available to the PRC and to the assessment committee were a 5-year plan for GEO—"Dynamic Earth: GEO Imperatives and Frontiers 2015-2020"[4]—and the 2014 NRC

[1] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[2] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[3] NSF, 2014, *Investing in Science, Engineering, and Education for the Nation's Future: National Science Foundation Strategic Plan for 2014-2018*, https://www.nsf.gov/pubs/2014/nsf14043/nsf14043.pdf.

[4] NSF, "Dynamic Earth: GEO Imperatives & Frontiers 2015-2020," Advisory Committee for Geosciences, https://www.nsf.gov/geo/acgeo/geovision/nsf_acgeo_dynamic-earth-2015-20.pdf, accessed December 19, 2016.

review of the "Division on Atmospheric and Geospace Science Draft Goals and Objectives" document.[5] The AGS goals and objectives document was not intended to constitute a strategic plan, but the NRC review believed that it "could serve as a first step toward the development of a formal AGS-wide strategic plan."[6] It appears that further planning along these lines has been modest, at best. Neither AGS, GS, nor the cross-directorate geospace sciences programs at NSF have presented a vision and a set of strategic goals. The assessment committee notes, however, that since the release of the ICCGS report, GS and NCAR/HAO jointly sponsored a community workshop in May 2016 and released a report[7] to consider a dedicated end-to-end space weather research facility, one that would be of sufficient size and require sufficient resources that it would need to be central to GS and AGS planning.

> **Finding:** GS and AGS do not currently have a clear strategic plan or a visible process for developing one. The portfolio review would have benefitted from a clear strategic vision for an integrated geospace, solar, and space physics program within NSF.

3.2 INTERFACES TO SOLAR AND SPACE PHYSICS IN OTHER PROGRAMS

The GS portfolio exists within the broader context provided by relevant facilities, programs, and activities overseen by other directorates and divisions in NSF as well as those in other agencies, such as NASA, NOAA, DOD, DOE, and international programs. The PRC was fully aware of the broader context (ICCGS Chapter 8), but it was outside their remit to consider it in detail, other than the possible impacts of its recommendations on domestic and international partnerships.

Nevertheless, ICCGS included certain recommendations that encourage GS to be diligent in cultivating and maintaining partnerships across NSF and with other agencies, and to encourage and plan for opportunities that will potentially emerge from community initiatives that exploit the MRI and MREFC budget lines, as well as potential midscale projects (see ICCGS Section 5.2).

While components of the NASA heliophysics program were considered—the CCMC, Collaborative Space Weather Modeling, and Grand Challenge Projects—no attempt was made to anticipate synergies between GS capabilities and the current Magnetospheric Multiscale (MMS) mission and Van Allen Probes, the soon-to-be launched Ionospheric Connection Explorer (ICON) and the Global Observations of the Limb and Disk (GOLD) instrument,[8] as well as the notional MEDICI and DYNAMIC missions recommended by the survey. Consideration of these components of the wider program is needed to understand the full suite of current and planned capabilities in order to optimize programmatic balance.

> **Finding:** Geospace sciences include interfaces to facilities, programs, and activities across NSF, other federal agencies, and foreign agencies. These interfaces evolve over time. They present a challenge because of the need to periodically update the GS portfolio balance as considered within this broader context. They also represent opportunities for partnerships in areas of mutual interest, such as MRI, midscale, and MREFC projects as well as through the CCMC, space weather modeling, and Grand Challenge Projects.

---

[5] NRC, 2014, *Review of the National Science Foundation's Division on Atmospheric and Geospace Sciences Draft Goals and Objectives Document*, The National Academies Press, Washington, D.C.

[6] Ibid., p. 2.

[7] High Altitude Observatory, "Exploring the Geospace Frontier: Quo Vadis?" https://www2.hao.ucar.edu/events/GeospaceFrontier2016. Accessed December 7, 2016.

[8] The NSF Geospace Section sponsored a workshop on September 27-28, 2016, in Boulder, Colorado, titled "Observation and Analysis Opportunities Collaborating with the ICON, GOLD, and COSMIC-2 Missions." COSMIC-2 is the second Constellation Observing System for Meteorology, Ionosphere, and Climate, an international mission to be launched in 2017 (see High Altitude Observatory, "Observation and Analysis Opportunities Collaborating with the ICON and GOLD Missions," https://www2.hao.ucar.edu/geogoldicon, accessed December 1, 2016).

3.3 THE NATIONAL SPACE WEATHER STRATEGY

In October 2015, at about the time work concluded on ICCGS, the National Science and Technology Council of the Office of Science and Technology Policy released the National Space Weather Strategy (NSWS)[9] and the Space Weather Action Plan (SWAP).[10] The NSWS and SWAP were developed in recognition of the increasing need to protect the nation's infrastructure from space weather impacts. The SWAP identifies NSF, in collaboration with other agencies, as being responsible for enhancing "fundamental understanding of space weather and its drivers to develop and continually improve predictive models."[11] In addition to AGS, the Division of Astronomical Sciences (AST), the Division of Polar Programs, the Division of Mathematical Sciences, and the Division of Physics participate in solar and space physics and aeronomy at NSF.

The SWAP also tasks U.S. government agencies with establishing benchmarks for space weather events. An important scientific challenge associated with these benchmarks is to estimate the theoretical maximum level of specific geospace disturbances with consequences on national infrastructure. Furthermore, the SWAP identifies the need to establish baseline, operational observing capabilities. NSF is asked to participate in identifying opportunities to leverage international partnerships to sustain these observations.

These developments, and the potential for new legislation in response to the NSWS and SWAP, have significant implications for the GS portfolio, as well as for the programs of many other agencies. Recognition of the importance of space weather further emphasizes the need to consider geospace science within a system-science context and to understand the underlying science of space weather to address strategic objectives.

Finding: NSF has an important role in supporting national space weather policy that may pose additional challenges to GS in a fiscally constrained environment, but may also present new opportunities for fundamental systems science.

3.4 THE NEED FOR A STRATEGIC VISION

Geospace sciences are fundamentally a complex and interconnected system, the understanding of which represents both a scientific challenge and an urgent need, in order to address the societal requirement of predicting space weather events. It is an integrative and cross-disciplinary enterprise that includes facilities, programs, and activities within NSF as well as other U.S. agencies and international programs. As GS strives to meet the challenge of leveraging limited resources to maximize their impact on geospace sciences, it is important to understand the place GS occupies within the wider geospace sciences landscape and the scientific and societal priorities in geospace sciences, such as the growing national emphasis on space weather understanding and prediction. It is therefore imperative that NSF-AGS and GS develop a strategic vision and plan.

Recommendation: The lack of a strategic plan for the Division of Atmospheric and Geospace Sciences (AGS) and the Geospace Section hinders the ability of the Geospace Section to act fully upon the recommendations given in *Investments in Critical Capabilities for Geospace Science 2016 to 2025*. AGS should develop a strategic vision and a strategic plan that recognizes all components within its portfolio relevant to geospace and interfaces to other programs across other National Science Foundation (NSF) divisions and directorates and across the agency. The plan should be aligned with the 2013 solar and space physics decadal survey, demonstrate awareness of the evolving capabilities outside NSF, and should be regularly updated with close community involvement in response to emerging discoveries, evolving budgets, new imperatives, and developing partnerships.

---

[9] National Science and Technology Council (NSTC), 2015, *National Space Weather Strategy*, Office of Science and Technology Policy, Washington, D.C., October.

[10] NSTC, 2015, *National Space Weather Action Plan*, Office of Science and Technology Policy, Washington, D.C., October.

[11] Ibid., Section 5.5.

4

Assessment of the Portfolio Review Process

The ICCGS report[1] represents a significant effort to meet the challenge of developing recommendations that will enable the GS portfolio to address priorities of the 2013 solar and space physics decadal survey[2] and address community needs within the constraints described in Chapter 2. Since a substantial fraction of GS resources are allocated to facilities, this component of the GS portfolio received particularly close scrutiny in the ICCGS. As part of assessing how well the program recommended by the ICCGS report aligns with survey priorities and with the science needs of the community, the assessment committee examined elements of the ICCGS's review process, particularly the information gathered on which its deliberations were based, and the methodology used to assess critical capabilities needed going forward.[3]

4.1 INFORMATION GATHERED BY THE PORTFOLIO REVIEW COMMITTEE

Information was requested from a wide range of stakeholders in the ICCGS report process. First, requests for information (RFIs) were sent to GS program officers to help the PRC understand all elements of the GS portfolio. There was significant turnover in GS staff; the ICCGS noted that during "the roughly nine months of the review, the PRC interacted with three different Section Heads, two different facility [program managers] PMs, two different AER [aeronomy] PMs, and the three standing PMs for the MAG, STR and SWR programs [magnetospheric physics, solar-terrestrial science, and space weather research]" (ICCGS Section 9.6). This represented an additional challenge to the PRC and to GS.

For facilities, targeted RFIs were sent to the six GS Class 1 facility[4] principal investigators (PIs), to the four GS Class 2 facility PIs, and to the CRRL PI.[5] Facility PIs were then interviewed by telephone.

[1] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[2] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[3] The Portfolio Review Committee's review process, community input, and guiding principles are described in ICCGS Chapter 2 (NSF, 2016); the methodology for establishing critical capabilities is provided in ICCGS Chapter 5 (NSF, 2016).

[4] Definitions of Class 1 and Class 2 facilities are provided in ICCGS Chapter 7.2.3 (NSF, 2016).

[5] The RFIs sent to the facility PIs are reproduced in Appendix C of the ICCGS report.

Cognizant of interfaces to programs and facilities within NSF and external to NSF, the PRC reached out to leadership of several of these programs. Interviews of the NCAR/HAO director, the National Solar Observatory (NSO) director, the EISCAT scientific association director, and the acting head of NSF-GEO Polar Programs (PLR) were conducted.

The PRC solicited information from the wider geospace science community by requesting that input be submitted to an e-mail address that was set up for this purpose. Forty-seven responses were received. Furthermore, town hall meetings were convened at each of the CEDAR, GEM, and SHINE meetings during the summer of 2015 to garner viewpoints of community members.

The assessment committee acknowledges the lengths to which the PRC went to gather information from the relevant stakeholders. The committee had concerns, however, regarding the transparency of the information gathered, particularly that related to GS facilities. The PRC was internal to NSF, not a public advisory committee subject to the terms of the Federal Advisory Committee Act.[6] Public access to data gathered by the PRC was not required, nor was NSF able to make the data generally available to the assessment committee. Other than a short description in ICCGS Section 7.3.1, evidence used by the PRC to determine the comparative productivity and scientific utility of the facilities was not provided explicitly in the ICCGS report or in an appendix. This made it difficult for the assessment committee—and by extension the community—to fully understand the basis for ICCGS findings and recommendations regarding facilities.

In conversations and communications with the PRC chair[7] and other PRC members, the assessment committee learned that a great deal of quantitative data and qualitative information was collected from the facility PIs and NSF, including background information on the technical capabilities of facilities as well as additional facility productivity metrics. Additional targeted information was requested via an RFI sent to each facility or was received as written follow-up in response to phone interviews with facility PIs. NSF provided annual facility reports as well as copies of proposal documents for recent awards. These were reviewed by the PRC for consistency with other information received from facility PIs, GS staff, and community inputs. As a result, the ICCGS had a substantial array of information, data, and metrics upon which to base its evaluation. For facilities, this included the following:

- Hours of operation of the facility per annum in recent years;
- Publications from each facility for at least 5 years;
- Number of facility users and data users;
- Current state of maintenance on all facilities;
- Future science and technology plans for each facility, including some costs;
- Various sources of funding for a facility;
- International agreements with which the facilities were involved; and
- Present and future plans of the facilities in support of the survey.

Finding: The PRC collected substantial amounts of information and data about each GS facility in order to perform its comparative assessment. Little of this information and data were presented in the ICCGS report.

The PRC learned that although each facility routinely collects considerable performance data, the methodology is not consistent between facilities. ICCGS Rec. 7.36 states that GS should develop a standard reporting format that allows facilities to report a common set of annual performance data and metrics to NSF in the same way. The assessment committee endorses this recommendation but cautions that the administration and utilization of data and metrics from facilities and other GS programs may require additional resources and expertise in informatics that is not currently available to GS. See Chapter 6 for further discussion.

[6] General Services Administration, "The Federal Advisory Committee Act," last reviewed April 12, 2016, http://www.gsa.gov/portal/content/100916.

[7] Personal communications via email from William Lotko, Dartmouth College, Portfolio Review Committee chair to Timothy Bastian, committee chair, August 3, 2016.

Conclusion: GS has not had a standard set of performance metrics by which it uniformly evaluates facilities. The assessment committee endorses the ICCGS's recommendation to GS to develop a common set of annual metrics from each facility.

4.2 THE PORTFOLIO REVIEW ALIGNMENT WITH SURVEY PRIORITIES

The ICCGS response to decadal survey priorities in reviewing the GS program was highly constrained by the scope of the review and the budget available. Survey priorities for NSF are summarized in Section 1.3. The ICCGS considered the survey's baseline priority of "completing the current program" as it applied to the existing suite of GS facilities. In considering the recommendations of the DRIVE initiative—in terms of freeing resources and evolving the GS program forward to address future facilities, programs, and activities within the context of systems science—the ICCGS turned to the science goals and science challenges identified in the survey to identify critical capabilities needed.

Chapter 5 of the ICCGS report presents a thorough summary of the survey science program. The key science goals presented in the survey flow down to science challenges identified for atmospheric-ionosphere-magnetosphere interactions, solar wind-magnetosphere-ionosphere interactions, and solar and heliospheric physics.[8] In addition, the overarching objective for Space Weather and Prediction (SWP) is summarized in ICCGS Section 5.4, as are critical capabilities to support the objective. The ICCGS maps survey science challenges and SWP challenges to required capabilities (observational, theory and modeling, and data exploitation) and recommended GS investments—in both current and future GS programs and facilities.[9] The ICCGS also identifies external capabilities and partners of potential interest to GS within NSF-AGS, across NSF, at other U.S. agencies, and internationally. This level of detail goes well beyond the top-level survey recommendations and demonstrates that the ICCGS paid careful attention to the implications of specific survey science goals.

However, while obviously informed by the survey science program, the ICCGS report does not describe how the particular recommended investments provide the capabilities required to address the survey science goals. For example, the report did not assess the contribution of each GS facility to understanding the science goals or explain how the relative facility priorities were established. The ICCGS describes program and facility priorities in ICCGS Chapter 9 (see also ICCGS Table 9.1), but there is no definition of the prioritization process given nor the criteria used to establish the priorities.

Finding: The ICCGS report does not explain how the recommended investments in particular programs and facilities satisfy the required capabilities to address the decadal survey science goals. The process used for establishing the relative priorities between facilities and for program elements is not defined in the report.

4.3 CONCLUSIONS REGARDING THE PORTFOLIO REVIEW PROCESS

The assessment committee has identified two areas of concern regarding the ICCGS process. First, little of the extensive amount of information, data, and metrics gathered from GS facilities is presented in the report. This made it difficult for the assessment committee—and by extension the community—to understand the basis for findings and recommendations made in the ICCGS report. Second, the ICCGS does not explain how the recommended investments in facilities meet the critical capabilities needed to address decadal survey goals and how relative priorities between facilities and for program elements were established. This contributes to a perceived lack of transparency that may undermine the community's confidence in the deliberations that underpinned the recommendations made to GS.

The assessment committee had the benefit of discussing the portfolio review process and the ICCGS report with the PRC chair and members of the PRC during the course of its assessment. The assessment committee is reassured that considerable facility data and metrics were reviewed in a conscientious and comprehensive fashion

---

[8] The survey science goals and challenges are summarized in NSF, 2016, Table 5.1.

[9] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025,* Table 5.2.

and, while alternative recommendations could have emerged from the process, the PRC has fulfilled its charge within the extremely challenging constraints discussed in Chapter 2. The ICCGS did not, and in some instances could not, fully address all survey priorities. These priorities will be identified and discussed in Chapter 5.

Conclusion: The PRC fulfilled its charge within the imposed constraints. The portfolio review process and the resulting report represent a conscientious, thorough, and good-faith effort to review the NSF GS portfolio and make recommendations for portfolio evolution and renewal.

The GS program recommended by the ICCGS is discussed in the Chapter 5. Both the assessment committee and the PRC understand that ICCGS recommendations will have both positive and, in some cases, negative effects on the geospace sciences community. The community must therefore understand the basis for the specific recommendations made by the ICCGS and have confidence in the process that led to them. It falls to GS to reach out to the community to explain the recommended program, explain the basis for the specific recommendations, and to express their confidence in the program as they move forward with its implementation.

Recommendation: The National Science Foundation Geospace Section should reach out to the geospace sciences community to explain the program recommended by *Investments in Critical Capabilities for Geospace Science 2016 to 2025* and its basis and keep the community informed regarding plans to implement the recommended program.

5

The NSF Geospace Section Portfolio Recommended by the ICCGS

The GS scientific program addresses the ambitious and exciting endeavor of advancing the frontiers of understanding of the solar-terrestrial environment. The program is an essential component of the federal support to the upper atmosphere and space physics community, consisting of both curiosity-driven and targeted research. The 2013 solar and space physics decadal survey[1] makes a variety of recommendations to accomplish the program, recommendations, and priorities with which the ICCGS report[2] is well aligned, with some exceptions. For the purposes of this chapter, the recommended program is grouped into five major sections: actions for current GS facilities; the evolution of facilities programs; competed grants—including core, targeted, and strategic programs; workforce development and diversity; and partnerships and opportunities.

5.1 NSF GEOSPACE SECTION FACILITIES: RECOMMENDED ACTIONS

A funding trend identified by the ICCGS is that for at least a decade "GS has added new programs and facilities . . . without terminating existing programs."[3] These relatively new programs include PFISR and RISR-N, CCMC, SuperMAG, SuperDARN, AMPERE, and the CRRL. These additions have caused significant pressure on the GS program and were one of the motivators for the GS portfolio review.

One of the main tasks of the ICCGS was to prioritize facilities and programs in order to free up funds to address decadal survey priorities. The ICCGS therefore formulated a set of recommendations on how to reallocate funding for new programs and initiatives. With the implementation of these recommendations, more than $7 million will be potentially available from the facilities budget to support the development of new instruments, facilities, partnerships, and programs. Both the ICCGS and the assessment committee recognize that these are significant cuts that deeply affect portions of the geospace community. The ICCGS recommendations are summarized in Table 9.1 of the ICCGS report, provided in Figure 5.1.The ICCGS recommendations for GS facilities are summarized and discussed below.

[1] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

[2] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[3] Ibid., p. 16.

		2015	2020	2025	%
Core Grants Program (Priority 1)		2015	2020	2025	%
AER (1)	Core†	6.14	14.4	14.4	Core
MAG (1)		3.88			
STR (1)		4.36			
Core Grant Total		**14.38**	**14.4**	**14.4**	**33%**
Strategic Grants Program (Priorities 1, 2, 3)			Change from 2015 to 2020		
CEDAR (1)	Targeted†	3.09	8.7	6.7	Strategic
GEM (1)		2.63			
SHINE (1)		2.98			
Space Weather (1)	IGS	1.50	1.5	5.0	
Grand Challenge (2)			1.5		
CubeSat (3)		1.50	1.0	1.0	
FDSS (3)		0.60	0.6	0.6	
Strategic Grants Total		**12.30**	**13.3**	**13.3**	**30%**
Class 1/2 Facilities (All priority 1)		2015[a]	2020	2025[b,c]	Facilities
Arecibo [d]	Class 1‡	4.10	1.1	8.4	
PFISR [e]		1.50	1.5		
RISR-N [e]		1.50	1.5		
Sondrestrom		2.50	0.0		
Millstone Hill [f]		2.10	1.9		
Jicamarca		1.35	1.4		
SuperDARN	Class 2‡	0.96	1.0	4.8	
AMPERE		1.02	1.0		
SuperMag		0.15	0.2		
CCMC		0.50	0.5		
CRRL[g]	not a facility	1.20	0.0		
Class 1/2 Facilities Subtotal		***16.88***	***10.1***	***13.2***	
New Facilities Programs (Priorities 1, 2)					
EISCAT (1)	Class 1‡		1.0	b	
Data Systems (1)	Class 2‡		0.5	c	
DASI (1)			1.6		
Innovation & Vitality (2)	Upgrades: Instruments, Facilities		2.4	2.7	
	Upgrades: Community Models		0.3		
New Facilities Programs Subtotal			**5.8**	**2.7**	
Facilities Total		***16.88***	***15.9***	***15.9***	**36%**
Midscale Projects Line [h]	out of budget		$1-6M/year		
GS Reserve		**0.43**	**0.4**	**0.4**	**1%**
Grand Total *		**43.99**	**44.0**	**44.0**	**100%**

NOTES

Priorities: (1) Science Grants Programs; Space Weather; Facilities; EISCAT; Data Systems; DASI. (2) I&V; GC Projects. (3) CubeSats; FDSS

† 2020/25 budget split between core & targeted and between individual programs in core & targeted TBD by proposal pressure

‡ New Class 1/2 facilities may be developed via MRI, Midscale (if created) or MREFC awards; addition may require discontinuation of other facilities

[a] Budget value is 3- or 5-year average based on most recent award, except AO, which is in the last year of a 5-year cooperative agreement

[b] EISCAT/EISCAT-3D membership becomes Class 1 facility by 2025

[c] New DASI/Data Systems projects become Class 2 facilities by 2025

[d] If AO use for GS research cannot be secured for $1.1M, redirect its $1.1M budget to the I&V Program

[e] PFISR+RISR-N budget is $3M; delineated 50/50 here

[f] New data systems line to absorb MH Madrigal budget by 2020

[g] CRRL is not currently operating as a facility (Sec. 7.2); it should seek future funding from core or targeted grants programs

[h] To be funded only with additional future GS funding; if NSF divests from AO, its $1.1M budget should be added to the I&V Line, a portion of which could go to Midscale Projects

* Grand Total exceeds the actual FY 2015 budget of $43.56M because Class 1/2 facilities budgets are 3- and 5-year averages (see note a)

FIGURE 5.1 Summary table of the GS portfolio recommended by the ICCGS. NOTE: Acronyms are defined in Appendix E. SOURCE: National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf, Table 9.1, p. 105.

5.1.1 Class 1 Facilities

The ICCGS establishes a definition for a "community facility" and considers facilities to be of two types: Class 1 and Class 2. A Class 1 facility is defined as "a major, complex facility at a single site. Its investment over time typically reaches many [tens of millions of dollars], requires significant M&O [management and operations] funds and accommodates a variety of complementary instruments at or very near the site. Class 1 facilities might be expected to have a lifetime of 20+ years from first deployment. In the current portfolio, all the ISRs are considered to be Class 1,"[4] and the only Class 1 facilities at present are ISRs. They are as follows: Arecibo Observatory, PFISR, RISR-N, Sondrestrom, Millstone Hill, and Jicamarca. Together, the Class 1 facilities are supported by NSF GS at a level of $13.05 million (FY2015). The ICCGS identifies Class 1 facilities for the largest budget cuts as follows:

- ICCGS Recommendations 7.6, 7.7, and 9.11 summarized: Reduce annual funding to Arecibo Observatory from $4.1 million to $1.1 million annually. Funding of ancillary instruments for geospace studies should be budgeted and decided in the peer-review process. The costs of running the heating facility at Arecibo should be budgeted as a pay-as-you-go system and decided in a peer-review process.
- ICCGS Recommendations 7.2, 7.3, and 9.9 summarized: Terminate funding for the Sondrestrom ISR ($2.5 million annually) when the current continuing contract for its management and operation ends in December 2017, or via ramping down of funds, and allow ancillary instruments to compete for funds through a peer-review process from the core and targeted GS grants programs.

The remaining recommendations concerning Class 1 facilities in ICCGS Section 7 do not involve further significant reductions in funding. These ICCGS recommendations are summarized as follows: funding for RISR-N should be decoupled from funding for any other facility to enhance greater transparency into its costs (ICCGS Rec. 7.8); the optimum location of PFISR for frontier research should be determined through peer review (ICCGS Rec. 7.9); investment in Millstone Hill is required until it can be replaced by a lower cost option, possibly at another location (ICCGS Rec. 7.10), although the assessment committee notes that ICCGS Rec. 9.13 recommends a cut of $0.15 million to Millstone Hill, to be redirected to a Data Systems Program (see Section 5.2.5 below); and the Jicamarca principal investigator should apply to the recommended Facilities I&V funding line (see Section 5.2.3 below) for funding to install needed upgrades (ICCGS Rec. 7.11). Lastly, the ICCGS recommends that "NSF should develop a consistent policy and procedure for supporting the M&O of the ancillary experiments at ISR facility sites" (ICCGS Rec. 7.12).

The assessment committee acknowledges that to address decadal survey priorities under a flat-budget scenario, GS funding of facilities or activities must be reduced, or in some cases, eliminated. However, the committee has two broad concerns regarding the recommended cuts to Class 1 facilities. First, the actual costs of supporting geospace science at Arecibo and Sondrestrom, including both the ISRs and ancillary instrumentation, are not detailed by the ICCGS. It is difficult to understand the nature and extent of capabilities that would remain at the Arecibo and Sondrestrom sites and to evaluate the degree to which the capabilities align with current community science needs. Second, the management and funding arrangements for Arecibo are complex, involving NSF AGS, NSF AST, and NASA funding; whereas Sondrestrom is an NSF-funded facility on foreign soil. Recognizing that a degree of uncertainty is inherent to the time scale on which NSF can implement the ICCGS recommendations for Arecibo and Sondrestrom, the assessment committee is concerned that NSF will not be able to meet the schedule assumed in the ICCGS, a prerequisite for the availability of funds for new programs.

GS's ability to reduce its support to Arecibo is complicated by Arecibo's management and funding structure. Arecibo is owned by NSF and operated via a cooperative agreement by SRI International with the Universities Space Research Association (USRA) and the Universidad Metropolitana. Funding is from GS and NSF AST, with additional funding provided by NASA to USRA for solar system radar studies. Previous reductions in support by AST to Arecibo (from $10.6 million annually in 2006, reducing over time to $4.1 million in 2016) have prompted

[4] Ibid., pp. 74-75.

NSF to consider alternative management arrangements and to conduct an environmental impact review.[5,6] The cooperative agreement for operating Arecibo, slated to expire at the end of FY2016, has been extended to March 31, 2018, and a solicitation for future continued operations of Arecibo is planned.[7] NSF's ongoing considerations for the future of Arecibo may delay the availability of funds for ICCGS's recommended new programs.

The ICCGS recommends terminating funding for the Sondrestrom ISR when its current agreements with NSF expire in December 2017 or via a progressive ramp-down toward 2020, and the costs for performing science with ancillary instruments and their operational costs should be competed through a peer-reviewed process from the core and targeted grants programs (ICCGS Recs. 7.2, 7.3, and 9.9). The ICCGS recommends that GS should develop a consistent policy and procedure for supporting the management and operations (M&O) costs of ancillary experiments at ISR sites and that they should normally be the responsibility of the relevant PI. Implicit in the ICCGS recommendation is the assumption that continuing support of ancillary geospace instrumentation will remain feasible at both Arecibo and Sondrestrom.

The total budget for Sondrestrom is $2.5 million per year. It is unclear how much savings will be gained by termination of only the ISR without additional consideration of the M&O costs of a varying number of ancillary instruments (such as housing of personnel and site maintenance independent of the ISR). The assessment committee notes that continued operation of the Sondrestrom site in general may not be feasible if not enough support is obtained via the grants programs. Moving ancillary instruments to another site would be an additional cost. Similarly, the feasibility of continued operations of ancillary instrumentation at Arecibo is currently unknown.

The combination of unknown factors regarding the futures of Arecibo and Sondrestrom led the assessment committee to draw two conclusions.

> **Conclusion:** Details concerning the actual costs of supporting geospace sciences at Arecibo Observatory and Sondrestrom, including the ISRs and ancillary instrumentation, are not provided in the ICCGS. It is therefore difficult for the assessment committee to understand the nature and extent of capabilities that would remain at the Arecibo and Sondrestrom sites and to evaluate the degree to which the capabilities align with current community science needs.

> **Conclusion:** The two most significant sources of funds for new facilities and programs within GS result from reducing funding to Arecibo Observatory from $4.1 million to $1.1 million and terminating funding for the Sondrestrom ISR. The ICCGS recommends that these funding changes be complete by 2020. However, management and operations at both sites are inherently complex, introducing a degree of uncertainty regarding the full extent of savings realized by the recommended cuts and of the time required before these funds are available for reallocation.

5.1.2 Class 2 Facilities

The ICCGS defines Class 2 facilities as "more modest and diverse investments. They include distributed networks of instruments that are simpler to operate than ISRs . . . , facilities producing value added products from data from other sources . . . , model support for the community . . . , and data management (Madrigal Database, currently funded through the Millstone Hill ISR contract)."[8] The ICCGS includes SuperDARN, AMPERE, SuperMAG, and CCMC as Class 2 facilities. The CRRL is currently funded as a facility, but ICCGS recommends a change in status, as discussed below.

ICCGS recommendations regarding Class 2 facilities are summarized as follows: to continue funding of

---

[5] NSF, 2016, "Environmental Impact Statement for the Arecibo Observatory, Arecibo, Puerto Rico, Draft," October 18, https://www.nsf.gov/mps/ast/env_impact_reviews/arecibo/eis/DEIS.pdf.

[6] The Arecibo environmental impact review examines all options from no action (continued investment at current levels), to various modes of collaboration, to complete deconstruction and site restoration. NSF has not yet made a decision regarding these options.

[7] NSF, 2016, "Dear Colleague Letter: Intent to Release a Solicitation Regarding Future Continued Operations of the Arecibo Observatory," NSF 16-144, September 30, 2016.

[8] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 75.

AMPERE I/II at current levels (ICCGS Rec. 7.13); to continue NSF investment in CCMC at the current level, with a focus on providing scientific expertise and model capabilities that are not supported by NASA (ICCGS Rec. 7.14); to continue funding SuperMAG at the current level (ICCGS Rec. 7.15); to assess whether scientific synergies could be realized "if all GS-sponsored magnetometers were managed as a single array" with the possibility that "such an array could evolve into a Class 2 facility" (ICCGS Rec. 7.16). Regarding SuperDARN, the ICCGS recommends that the U.S. SuperDARN groups determine an optimum balance between local research and community service, as well as optimize the efficiency of M&O (ICCGS Rec. 7.17). These recommendations do not have a significant budgetary impact.

The CRRL, comprised of a network of four LIDARs distributed around the world and a technology center, is currently supported by the GS Upper Atmospheric Facilities program. During their review, "the PRC reached the opinion that CRRL as currently organized and directed is not a community facility as defined in [ICCGS Section 7.2]. Its scientific objectives and its decisions on how different technological capabilities and scientific priorities are pursued are consistent with research activities funded by the GS Core and Targeted Grants Programs rather than the GS Facilities Program."[9] Consequently, ICCGS does not recognize the CRRL as a community facility, and recommends that the "participating members of the CRRL group should seek peer-reviewed funding individually or collectively from the Core or Targeted GS Programs"(ICCGS Rec. 7.18). The associated CRRL technology center "should apply for separate funding from the proposed Innovation and Vitality Program" if it aspires to develop a new GS facility (ICCGS Rec. 7.19).

In contrast to the CRRL, in considering the Low-latitude Ionosphere Sensor Network (LISN), the ICCGS finds that the network has many characteristics of a Class 2 facility and recommends (ICCGS Rec. 7.20) that its M&O and science resources should be funded out of the newly recommended peer-reviewed DASI fund (described in Section 5.2.4 below). The ICCGS does not fully explain why the CRRL is not a community facility while the LISN may be. The CRRL is also characterized as a "DASI-type" network and may therefore be eligible for the DASI Facilities Program according to ICCGS Section 7.4.3.[10] Evaluation criteria for DASI-type instruments or networks have not yet been well defined.

The funding currently used to support the CRRL from the GS facilities program ($1.2 million) would be redirected to "strategic grants programs to address DRIVE initiatives recommended by the Decadal Survey."[11] According to Figure 5.1 (ICCGS Table 9.1), the strategic grants to address DRIVE initiatives appear to be the IGS program that includes Space Weather Modeling and Grand Challenges Projects. This is not the same as the core and targeted grants program to which CRRL investigators are recommended to send their proposals; therefore, pressure on the core and targeted grants programs will increase. An alternative possibility is, like LISN, for the CRRL to apply for support through the DASI Facilities Program, when funding becomes available in 2020, in order to transition to a Class 2 facility, as defined by ICCGS.

Conclusion: The ICCGS recommendation concerning the CRRL, while freeing up resources for the Integrative Geospace Science grant program, may increase the proposal burden on other core and targeted grants programs. Once evaluation criteria have been defined for DASI-type sensors or networks, programs such as the CRRL and LISN could transition to a Class 2 facility by seeking support from the DASI Facilities Program.

5.2 EVOLUTION OF NSF GEOSPACE SECTION FACILITIES

Using resources made available by actions described in Section 5.1, the ICCGS recommends significant new investments in an international partnership (EISCAT) and in two new funding lines relevant to facility renewal, model development/upgrades, and instrument development. These are the Facilities I&V Program, with a stable annual budget of $2.7 million by 2020 (ICCGS Rec. 9.14); and a DASI Facilities Program, with an annual budget of $1.6 million (ICCGS Rec. 9.12). As noted in Section 5.1 above, "DASI" is an acronym for "distributed arrays

[9] Ibid., p. 111.
[10] Ibid., pp. 84-85.
[11] Ibid., pp. 3 and 104.

of small instruments"[12] that has broadened in meaning to instrument concepts that may span a significant range in size, from Class 2 facilities (as in the ICCGS report) up to midscale projects, or even MREFC projects. A modest investment is also recommended for a Data Systems Program. These recommended investments are discussed below along with brief comments on the support of scientific research within facility awards. A potential Midscale Projects Program is also discussed; however, ICCGS was not able to recommend beginning this program within GS's current budget.

5.2.1 Midscale Projects Funding

The recent decadal surveys for astronomy and astrophysics[13] and for solar and space physics[14] both called for an NSF midscale program to support development of ground-based facilities and experiments that are too small for the NSF MREFC account's recently adjusted lower limit of $70 million,[15] but too large for the NSF MRI program's upper limit of $4 million.[16]

The solar and space physics survey's DRIVE initiative emphasized the need for a diverse portfolio of observational platforms, including midscale programs. These address critical gaps in geospace and solar observational capabilities, offer opportunities to integrate new technologies, and offer platforms for innovation in technology, observing techniques, data analysis, and data assimilation. The survey identified several candidate midscale projects—the Frequency Agile Solar Telescope, the Coronal Solar Magnetism Observatory, distributed arrays of ground-based sensors—that cannot be undertaken without a midscale project funding line. Particularly in an era of fixed budgets, such a program is too large for a small section such as GS and would have to be part of a larger division, directorate, or agency initiative.

The ICCGS considers a midscale budget line to address projects in the $4 million to $30 million range,[17] pointing out that at least $5 million to $6 million per year would be needed for a viable midscale funding line within GS (ICCGS Section 3.2). In ICCGS Section 7.7, the ICCGS comments that the "PRC agrees with the [survey] that numerous compelling Midscale projects could address gaps in critical capabilities for geospace and solar science." The ICCGS recommended (ICCGS Recs. 7.33, 7.34, 9.16, 9.17) that if the use of Arecibo Observatory is no longer available to the geospace community due to divestment or insufficient funding for its continued operation, the $1.1 million earmarked by the ICCGS for support of Arecibo Observatory should be redirected to the Facilities I&V Program, some part of which could be used to support a Midscale Projects Program. If future GS budgets exceed the flat budget guidance by more than $1 million, the ICCGS recommends that additional annual funding should be redirected toward the Midscale Projects Program. The assessment committee notes that even if these additional funding sources become available, the total Midscale Projects Program's budget would only enable projects in the lower end of the gap between the MRI and MREFC programs. Not only are the scenarios largely speculative, but even if they were to be realized, the budget may be insufficient for some of the candidate midscale projects identified by the survey.

Survey recommendations are addressed to solar and space physics at NSF, and their implementation requires actions by two divisions, AST and AGS, under two directorates, Mathematical and Physical Sciences (MPS) and GEO, respectively. Furthermore, as a high-priority recommendation to NSF from two decadal surveys, and as 1 of 10 strategic "big ideas" for NSF,[18] the assessment committee believes that the creation of an AGS midscale projects budget line requires the investment of new funds outside of the GS budget in a program to which the geo-

---

[12] NRC, 2006, *Distributed Arrays of Small Instruments for Solar-Terrestrial Research: Report of a Workshop,* The National Academies Press, Washington, D.C.

[13] NRC, 2010, *New Worlds, New Horizons in Astronomy and Astrophysics*, The National Academies Press, Washington, D.C.

[14] NRC, 2013, *Solar and Space Physics*.

[15] NSF, "Important Notice #138: Revision of the Major Research Equipment and Facilities Construction (MREFC) Eligibility Threshhold," www.nsf.gov/pubs/2017/in138/in138.jsp.

[16] *New Worlds, New Horizons* (NRC, 2010) characterizes the range as greater than the MRI cap of $4 million and less than lower limit of $135 million for the MREFC program. An annual funding line of $40 million was recommended.

[17] This is also the budget range for the AST division-wide Midscale Innovations Program.

[18] NSF, "10 Big Ideas for Future NSF Investments," https://www.nsf.gov/about/congress/reports/nsf_big_ideas.pdf, accessed October 20, 2016.

space sciences community will be eligible to apply. The development and implementation of a Midscale Projects Program will require coordination between the AGS division, the GEO directorate, and NSF.

Conclusion: Funding a program for midscale projects currently lies outside the means and ability of the NSF Geospace Section alone.

Recommendation: The Division of Atmospheric and Geospace Sciences should work with the Directorate for Geosciences and the National Science Foundation to implement the 2013 solar and space physics decadal survey recommendation for a Midscale Projects Program to address midscale priorities.

5.2.2 Investment in EISCAT

To replace, in part, capabilities lost by the recommended termination of support for the Sondrestrom ISR—for example, geomagnetic cusp studies at a similar geomagnetic location—the ICCGS recommends (ICCGS Recs. 7.2, 7.4, 7.23, and 9.10) that GS should investigate joining the EISCAT consortium in order for U.S. investigators to access existing EISCAT facilities and the planned EISCAT-3D facility. ICCGS Rec. 7.23 recommends that GS solicit proposals from the U.S. community to form a U.S. EISCAT consortium, to be funded by a block grant. The consortium would initially join EISCAT as an affiliate in order to gain experience with EISCAT before making a 5-year commitment as an associate. The assessment committee considers the recommendations a sensible approach: leveraging an international partnership to retain certain capabilities and to expand others, consistent with survey guidance regarding international partnerships.[19]

Conclusion: The ICCGS has identified an evolution of the ISR program that maintains most of the important capabilities of the existing program and frees up resources for the near-term renewal of existing facilities and for innovation and development of new instrumentation and observations in the next decade.

The assessment committee cautions that assuming "NSF investigators could begin using the EISCAT system soon after the current continuing grant for Sondrestrom" expires (ICCGS Section 9.4) may be overoptimistic for the following reasons:

- The termination of Sondrestrom and investigation into a partnership with EISCAT can proceed in parallel. However, both may take considerable time to accomplish, delaying opportunities enabled by funds that are to be redirected to new programs.
- EISCAT-3D is not, as yet, fully funded, and its management and operations costs are not fully understood. Current and future EISCAT and EISCAT-3D M&O costs and the potential liability of such costs to GS will be important considerations when entering into the partnership.

Conclusion: The EISCAT and EISCAT-3D represent an attractive investment that would ensure U.S. access to state-of-the-art ISR instrumentation at a lower cost than is currently the case. However, the time it will take to enter the EISCAT partnership may be longer than assumed by the ICCGS. The U.S. contribution to current and future operations and management costs will be an important consideration when entering the partnership.

5.2.3 Facility Innovation and Vitality Program

ICCGS Rec. 9.14 recommends the creation of a new Facilities I&V Program (see also ICCGS Recs. 6.2-6.3, 6.19, 7.10, 7.19, and 7.21-7.22) with a steady-state budget of $2.7 million annually. The ICCGS recommends that, given "the diversity of possible applications [to the I&V program], a panel review is recommended so that the broader requirements of the GS community can be represented" (ICCGS Rec. 7.22). The program would com-

[19] NRC, 2013, *Solar and Space Physics*, p. 122.

petitively fund awards through a peer-review proposal process at a cadence of 1 to 3 years. The I&V line would support a number of existing and new activities, including the following:

- Major repairs and renovation of existing facilities,
- Hardware or software development that would enhance the performance of existing facilities,
- Development of new instrumentation to an operational capability,
- Development of numerical algorithms/methodologies to improve computational models, and
- Development of real-time capabilities at facilities.

The recommended Facilities I&V Program will be a source of funds for driving innovation across the GS facilities and modeling portfolio, as well as instrument development and technology integration. However, the assessment committee notes that the definition of the program is at present very broad and consideration will need to be given to balancing its constituent parts via activities such as the ICCGS recommended panel review (ICCGS Rec. 7.22). Its relation to the strategic grants programs, especially space weather modeling and Grand Challenges, needs clarification.

Conclusion: The scope of the Facilities I&V Program, the balance of its constituent elements, and its relationship to the strategic grants program require better definition and focus.

5.2.4 DASI Facilities Program

The DASI concept (ICCGS Section 7.4.3) centers on ground-based and in situ measurements of the atmosphere and ionosphere over a range of costs and scopes and a range of spatial and temporal scales that would work together to provide observational constraints to assimilative modeling tools. This basic idea is critical to the system science approach and the need for DASI-like instrumentation has been recognized for at least a decade. Progress in realizing DASI-like instruments has been slow as a result of several factors: lack of funding opportunities, lack of community experience in forming the necessary partnerships, and inadequate experience in developing the necessary capabilities for "unmanned and energy-efficient operation of distributed instruments."[20] Nevertheless, several DASI-like initiatives have emerged, including CRRL, SuperDARN, and LISN.

The ICCGS made a number of specific recommendations that support the development and implementation of DASI-like instrumentation and associated data assimilation challenges. Recommended actions include the following: support IGS science (ICCGS Rec. 6.2), encourage multidisciplinary efforts and target resources toward them (ICCGS Rec. 6.7), encourage MAG/AER DASI collaborations (ICCGS Rec. 6.11), include a Grand Challenge Project within IGS (ICCGS Rec. 6.21), and create a DASI fund for small instrumentation and related M&O (ICCGS Rec. 7.24), and allow those projects to grow into facilities (ICCGS Rec. 7.25). These lead to ICCGS Rec. 9.12, which calls for a DASI Facilities Program funded at a level of $1.6 million annually. The DASI Facilities Program, as currently conceived, is to be used to "develop and implement one or more Class 2 facilities."

Resources available for DASIs will be limited; therefore, some NSF-led community discussion may be needed to propel the community forward in considering appropriate DASI-type sensors and projects. Community discussion can guide leadership and address DASI planning issues, including the following: defining what needs to be known; determining which sensors can provide that information; deciding which assimilative tools need development; and creating metrics for how well the observations are expected to improve the development of models. These issues as a group collectively form the basis for a traceability matrix for DASI development.

As a new set of DASIs is created, as noted in ICCGS Section 5.1, computational assimilative techniques will need development to make optimal use of the new heterogeneous data sources produced by DASI-like instruments. It is not clear to the assessment committee that the Data Systems Program will be sufficient to address the need for making optimal use of heterogeneous data sources. Other resources that may be helpful toward this development include the Integrative Geospace Science program and targeted grants.

[20] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 84.

The ICCGS suggests metrics for selecting proposals for the DASI Facilities Program, addressing, for instance, capabilities enabling survey priorities, quality of new science, size of user community, quality and range of services to be provided, and leverage from international partners. The ICCGS also states that when DASI facilities become operational and the DASI Facilities Program is fully subscribed, and further DASI facilities cannot be implemented without an increase in the GS budget or defunding one or mode DASI facilities, a "rigorous senior review for DASI programs will be required to determine the future of the DASI program, and future new initiatives in the DASI program."[21]

Conclusion: The assessment committee endorses the intent of the collective ICCGS recommendations regarding DASIs and DASI-related issues, in moving GS toward a guiding role in scientifically directing community thought and efforts toward system-level studies of the geospace region.

Recommendation: To begin implementation of the *Investments in Critical Capabilities for Geospace Science 2016 to 2025* recommendations to create distributed arrays of small instruments (DASIs) with the goal of starting new Class 2 facilities, the National Science Foundation should support community efforts to establish requirements for future DASI-type sensors and projects—by organizing targeted community workshops, for example—within a wider Geospace Section strategic framework.

5.2.5 Data Systems Program

The ICCGS notes that the survey calls for NASA to augment its data systems support for the HSO. The ICCGS also states that GS facilities arguably constitute an "emerging NSF-sponsored Geospace System Observatory (GSO)" (ICCGS Section 9.4) and that NSF should likewise augment its support for GSO data systems. At present the Madrigal system, largely developed by Millstone Hill Observatory, supports the aeronomy community. SuperDARN, SuperMAG, and AMPERE manage their own data; data at other facilities are managed in an ad hoc fashion. The ICCGS concludes that "more effective coordination of these data sets and development of value-added data products would improve their accessibility and utility for geospace science" and recommends (ICCGS Rec. 9.13) that GS fund a Data Systems Program at a level of $0.5 million annually, part of which would come from $150,000 being redirected from the Millstone Hill budget for the Madrigal system. The development and management of the new data system would be awarded through a competitive, peer-reviewed process, and once the system became fully operational, it would transition to a Class 2 facility. However, the assessment committee notes that the scope of the Data Systems Program is not yet defined, and the resources required to implement the program are not well understood. For example, other extant databases might be leveraged to support the initiative in a cost-effective manner. In addition, it is not clear how long-term data records, such as those at Class 1 facilities at Arecibo and Sondrestrom, will be made available through the Data Systems Program.

Finding: The scope of the proposed data system is not well understood at this point, and the resources required are consequently not known.

Conclusion: It is not clear that the proposed budget line is appropriate for the task of supporting a potential Geospace System Observatory.

5.2.6 Evolution of Research Within Facilities

In ICCGS Section 7.5.2, scientific research within facilities awards is discussed. The ICCGS suggests that GS should develop a method for deciding on a case-by-case basis whether to support scientific research at observing facilities and recommends that an upper limit of 10 percent of the facility personnel budget be allocated for scientific research (ICCGS Rec. 7.29).

[21] Ibid., p.110.

In the view of the assessment committee, a 10 percent limit seems arbitrary and may not be sufficient for some facilities to support adequate science operations. The decadal survey makes no specific quantitative recommendation for direct support of scientific work at facilities; however, the *Realize* component of the DRIVE initiative emphasizes that strong support for data analysis is required to make effective use of observations. Operation of observing facilities by those with a direct and active scientific interest helps ensure data quality, calibration, and usability. Competitive selection of facility operators and regular "senior reviews" of facilities overall (ICCGS Rec. 7.30) would ensure that research funds are spent on the most productive science.

Finding: Facility scientists that are active scientific researchers are critical to ensuring data acquired by instruments are of high quality for science usage.

Recommendation: Recommendation 7.29 of *Investments in Critical Capabilities for Geospace Science 2016 to 2025* states that an upper limit of 10 percent be placed on facility personnel budgets allocated for scientific research. The National Science Foundation's Geospace Section should evaluate the support for science operations as a factor in judging how well a given facility enables and supports scientific investigations for its users, not fix the fraction of staff time used for science operations a priori.

5.3 GRANTS PROGRAMS

The competed grants program currently includes the following three core grant programs: AER, MAG, and STR. Targeted grants (CEDAR, GEM, and SHINE), SWM, CubeSats, and FDSS are currently grouped under Strategic Grants, as illustrated in Figure 5.1 (ICCGS Table 9.1).

The GS Grants Program addresses a dual mandate. One goal is to enable curiosity-driven, frontier discoveries of fundamental physical processes, including those enabling systems science. The other goal is to advance integrative and cross-disciplinary science, including the development of coupled Sun-Earth models that can address space weather needs. The first of these mandates is being addressed today through the Core Grants Programs, and to some extent through contributions from the Strategic Grants program. The ICCGS-recommended GS Grants Program detailed below addresses the second mandate by proposing specific portfolio adjustments to advance integrative science and predictive science that underlie space weather applications and cross-disciplinary science. The assessment committee notes that the emphasis on predictive science and space weather is also aligned with the increasing national need to protect critical infrastructure from space weather impacts, as documented in the 2015 NSWS[22] and the SWAP.[23] The action plan identifies NSF, in collaboration with other agencies, as responsible for enhancing the "fundamental understanding of space weather and its drivers to develop and continually improve predictive models."[24]

ICCGS Recs. 9.1 and 9.2 (see also ICCGS Recs. 4.10 and 6.1-6.6) state that GS should maintain the existing budget share of core grants in AER, MAG, and STR—at least a third or not less than $14 million to $15 million annually (ICCGS Figure 9.1, provided in Figure 5.2). AER, MAG, and STR each fund fewer than 10 new awards per year. Also recommended is that GS should use proposal pressure—together with consideration of portfolio balance—to determine the distribution of investments. The ICCGS recommends that GS program managers should be given flexibility in determining allocations between the core and targeted programs; that is, separate budget line items for AER/MAG/STR and for CEDAR/GEM/SHINE should be eliminated by 2020.

The evolutionary component lies within the strategic grants. Specifically, a strategic IGS grants program is recommended that includes both a transformed SWM program and new Grand Challenge Projects.

The survey recommends that NASA and NSF collaborate to create Heliophysics Science Centers as "a mechanism for bringing together critically sized teams of observers, theorists, modelers, and computer scientists

[22] National Science and Technology Council (NSTC), 2015, *National Space Weather Strategy*, Office of Science and Technology Policy, Washington, D.C., October.

[23] NSTC, 2015, *National Space Weather Action Plan*, Office of Science and Technology Policy, Washington, D.C., October.

[24] Ibid., Section 5.5.

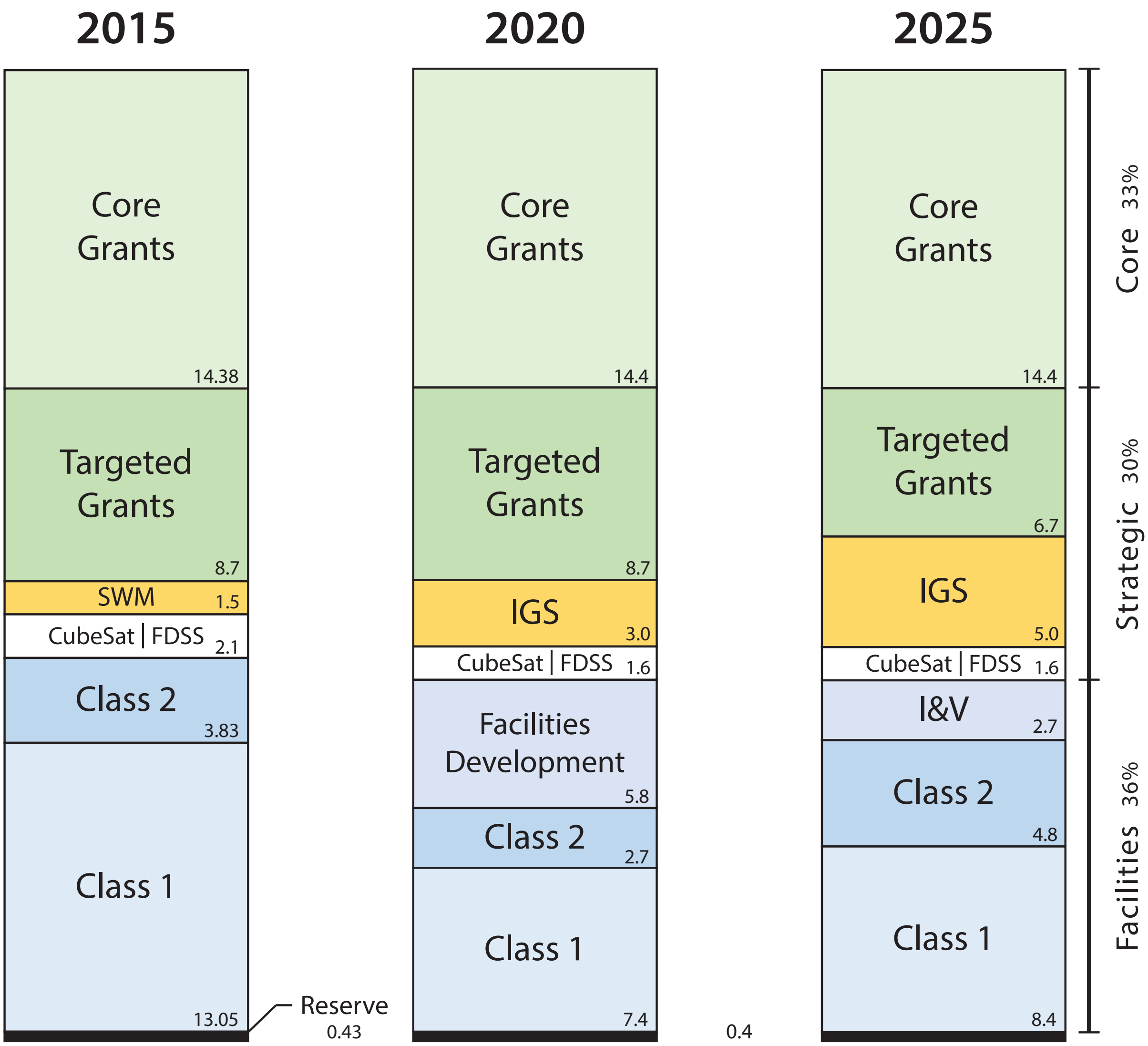


FIGURE 5.2 Relative budgets for Geospace Section program elements and Class 1 and Class 2 facilities itemized in Figure 5.1 for fiscal year 2015 and the recommended distributions for 2020 and 2025. SOURCE: National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf, Figure 9.1, p. 106.

to address the most challenging problems in solar and space physics."[25] The survey recommends that NSF and NASA jointly fund centers for terms up to 6 years at a rate of $1 million to $3 million. Instead, the ICCGS recommends initiating Grand Challenge Projects with a budget of $1.5 million per year by 2020, a new strategic grants program that, together with the current SWM program, would reside under Integrative Geospace Science by 2020 (ICCGS Recs. 9.3 and 9.4). Although Grand Challenge Projects would operate differently than Heliophysics

[25] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Section 5.6.2.

Science Centers, the ICCGS also recommends that NASA and NSF "explore best practices for collaboration on Grand Challenge Projects" (ICCGS Rec. 6.22). The ICCGS comments that the Grand Challenge Projects under IGS is "more consistent with community-driven, collaborative research initiatives emerging from GS targeted grants programs than would be a Heliophysics Science Center model" and that it would also "encourage greater cross-disciplinarity and greater emphasis on integrative and systems science than presently occurs."[26] As recommended by the ICCGS, the IGS portfolio would grow from a total of $3 million per year in 2020 to $5 million per year in 2025 in recognition of the expected evolution of integrative science and by "acquiring IGS projects funded by the Targeted Grants Programs" (ICCGS Rec. 9.4) Although there is no explicit ICCGS recommendation, the assessment committee notes that research on the outer heliosphere is included under "recommended investments" in ICCGS Table 5.1, an example of cross-cutting science cited by the survey.

Finding: Evolution of the strategic and targeted grants programs emphasizes the continuing transition of geospace sciences from distinct strategic areas to an integrative approach to address more optimally geospace science as a complex dynamical system.

The share of the overall GS budget remains stable for the core grants program and increases modestly for strategic grants. However, the assessment committee notes that both components of the grants program potentially will be under increased pressure as a result of recommendations made regarding Sondrestrom, Arecibo, and the CRRL. While the ICCGS recommends termination of the Sondrestrom ISR and a reduction of $3 million to Arecibo, it also recommends that ancillary instruments at Sondrestrom and Arecibo compete for support through the grants program, as discussed in Section 5.1.1. ICCGS made a similar recommendation regarding the CRRL, currently funded out of the facilities budget at a level of $1.2 million, as discussed in Section 5.1.2.

Conclusion: Increased pressures on core and targeted grants may result from competing the operation of ancillary instruments on the Sondrestrom and Arecibo Observatory sites, and the Consortium of Resonance and Rayleigh Lidars.

5.3.1 CubeSats

The survey was enthusiastic about CubeSat missions, highlighting their ability to diversify measurements, to integrate platforms of different sizes, and to make multi-point measurements.[27]As a result, the survey recommended that NSF support at least two new CubeSat missions every year. The technological capabilities of CubeSats have advanced significantly since the survey was published in 2013, and the interest in the platform has also increased greatly.

The ICCGS expressed concern that the science impact per dollar invested by NSF, as measured by science publications, is not as high for CubeSats as it is for individual investigator grants awarded by GS, for example. However, the ICCGS also found that "the NSF CubeSat program has been an educational success and has supported many engineering advances."[28]

ICCGS recommended a stricter set of guidelines for CubeSat missions, with the key selection criterion being the potential impact of the science results (as opposed to the educational or engineering benefits of a mission; ICCGS Recs. 6.23-6.26). The ICCGS recommended that GS support the two new mission starts per year suggested by the survey only if additional funding is obtained from elsewhere within NSF—from the Directorate for Education and Human Resources (EHR) or the Directorate for Engineering (ENG), for example—or from other agencies,[29] and that the GS investment in the CubeSat program be reduced from the current $1.5 million per year

[26] Ibid., p. 107.
[27] NRC, 2013, *Solar and Space Physics*, p. 81.
[28] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 67.
[29] Ibid., Recs. 4.8, 6.27, and 8.9.

to $1 million per year by 2020 (ICCGS Rec. 9.6) to reflect "a focus on mission concept, instrument development, and science exploitation of the data," and a reduced scope of mission development.

While the PRC was conducting its review, the NRC convened a committee to assess the scientific potential of CubeSats. The resulting report, *Achieving Science with CubeSats: Thinking Inside the Box,* was not available during the PRC's work, but included a number of findings that address the PRC's concerns. *Achieving Science* considered the GS CubeSat program as especially successful at innovation, and made the point that "the [GS CubeSat] program is particularly well aligned with the goals and recommendations of the 2013 decadal survey for solar and space physics."[30] The analysis of CubeSat-related publications in *Achieving Science* indicated that although the majority of peer-reviewed publications are engineering papers (74% of the total refereed publications, 2000-2015), the missions are producing increasing numbers of science papers, and solar and space physics papers outnumber all other science disciplines (13% of the total refereed publications, 2000-2015) (Appendix B in *Achieving Science*). Nearly all of the solar and space physics science papers derive from NSF-funded CubeSat projects. Furthermore, *Achieving Science* noted that almost as many NSF missions are planned for 2016-2018 (7 missions, 11 CubeSats) as there have been in the prior 10 years (8 missions, 12 CubeSats). The science returns and resulting publications from these upcoming missions have yet to be realized.

Achieving Science concluded that CubeSats have demonstrated their capability to be a platform for high-value science and recommended that NSF broaden opportunities for participation in CubeSats to disciplines beyond solar and space physics, with these disciplines contributing to the cost of this expanded suite of missions.[31] These additional investments are particularly important because constellation/swarm missions—which are the most promising for understanding, for example, magnetosphere-ionosphere-atmosphere coupling—are not currently available within the current GS program envelope. Also, *Achieving Science* highlighted that the growth of CubeSat programs outside of NSF has not diminished the importance of GS's low-resource, science-and-innovation-driven CubeSat program.[32]

Both ICCGS and *Achieving Science* recommend that GS partner with other disciplines within NSF to enhance the science return from CubeSat missions, and both reports stress the educational value of CubeSats. The assessment committee also endorses this approach. The rapid increase in innovation for and interest in the CubeSat platform has only recently created a market for many standard components to be purchased premade, allowing future CubeSat teams to focus more on instrument development and scientific analysis of returned data and less on repetitive engineering. The potential for high-value science and for the education of scientists via CubeSats is continuing to increase. Therefore, the assessment committee is concerned that unless partnerships are established, the GS CubeSat program will be unduly slowed by the ICCGS's recommendation to reduce the budget by one-third. Even though spacecraft development costs may be lowered by using commercially available components, more funding may be needed to develop new, innovative instruments. With the increase in CubeSat success rates,[33] additional support for the in-orbit operation of missions may also be needed.

Conclusion: The ICCGS and ASC findings regarding GS's CubeSat program are broadly consistent. The assessment committee is concerned, however, that the one-third decrease in the budget for the CubeSat program recommended in the ICCGS report will have an unduly negative effect on the scientific and educational results highlighted by ASC if funding from outside GS cannot be found.

Recommendation: The assessment committee endorses the *Investments in Critical Capabilities for Geospace Science 2016 to 2025* recommendation to seek partnerships for CubeSats outside of the National Science Foundation (NSF) Geospace Section. However, mindful of the growing potential of CubeSats to be platforms

[30] National Academies of Sciences, Engineering, and Medicine (NASEM), 2016, *Achieving Science with CubeSats: Thinking Inside the Box*, The National Academies Press, Washington, D.C.

[31] Ibid., pp. 24-27.

[32] NASEM, 2016, *Achieving Science with CubeSats*.

[33] *Achieving Science* analyzed the success rates of all CubeSat missions and NSF CubeSat missions in particular. For all CubeSats, success rates were 35 percent from 2000 to 2007 and 71 percent from 2008 to 2015. For all NSF CubeSats, the overall success rate is 83 percent (taking into account reflights that occur within the same project). See NASEM, 2016, *Achieving Science,* pp. 21-23.

for science and of the 2013 solar and space physics decadal survey recommendation to augment support for CubeSats, the committee recommends that the NSF Geospace Section carefully consider the impact associated with decreasing funding for the CubeSat program before additional resources through intra-divisional partnerships can be obtained.

5.3.2 Faculty Development in Space Science

The survey gives a strong endorsement to the FDSS program and curriculum development programs and recommends expansion of the program to 4-year institutions of higher education. The ICCGS report does not recommend for or against the expansion that was recommended by the survey but expresses a counterargument for doing so based on "fears that without adequate institutional support for research and relief from the large teaching load typical of four-year colleges, these faculty will have difficulty succeeding,"[34] which is a legitimate concern in the view of the assessment committee. However, ICCGS Rec. 4.1 recommends that FDSS and CAREER programs "should be continued as resources allow," without making a specific statement regarding the expansion.

5.4 WORKFORCE DEVELOPMENT AND DIVERSITY

The ICCGS report's main recommendations regarding workforce development—which includes undergraduate and graduate educational opportunities, professional development at all levels, and workforce diversity—were that current GS efforts in these areas should continue. Furthermore, the ICCGS emphasized the importance of data collection in assessing the effectiveness of these efforts to increase participation of African Americans, Latino/as, Native Americans, and women in geospace science.

At the undergraduate and graduate student levels, the ICCGS explicitly mentions the Center for Integrated Space Weather Modeling and incoherent scatter radar summer schools, student attendance at the GEM, CEDAR, and SHINE summer meetings, and the research experiences for undergraduates (REU) programs in solar and space physics as worthy of continued support (ICCGS Recs. 4.3-4.5). The ICCGS also highlights the educational component of the CubeSat program and recommends that as part of its efforts to obtain broader support for this program, GS should seek to partner with the Directorate for Education and Human Resources. Finally, the ICCGS stated that teacher training, citizen science, and public outreach programs should continue to receive GS support (ICCGS Recs. 4.8-4.9).

For post-graduate scientists, the ICCGS endorsed continued support of the AGS Postdoctoral Research Fellowship and of the FDSS and Faculty Early Career Development (CAREER) programs as resources allow (ICCGS Recs. 4.1 and 4.2). It also encouraged improved tracking of geospace Ph.D. recipients: GS could request that PIs include information about their former graduate students' employment in their final grant reports, for example (ICCGS Rec. 4.7). The ICCGS also recommended that GS should work with NSF to include a "Solar and Space Physics" category in the "Survey of Earned Doctorates" that it administers (ICCGS Rec. 4.10).

The ICCGS examined workforce diversity primarily through the lens of the available data for the gender/ethnicity/race of FDSS and AGS CAREER awardees, and of Colorado REU, Space Weather Research, Education and Development Initiative (SW REDI), and SHINE summer workshop students. Its principal finding is that these programs appear to be doing well at promoting gender and ethnic diversity,[35] but the report urges that "metrics on the diversity of participants should be kept on all such funded programs and reported annually" (ICCGS Rec. 4.5).

These modest, essentially "stay the course," recommendations of the ICCGS stand in contrast with its ambitious Recommendation 4.6, which states, "The GS and the GS community should be in the vanguard of NSF initiatives to promote engagement of women and under-served populations in all aspects of geospace science from school to research proposal writing to leadership in GS activities."

---

[34] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 25.

[35] "The NSF-sponsored REU program and SW REDI program provide undergraduates with opportunities to experience research in the space sciences and to make better informed career decisions. These programs are also doing well in promoting gender and ethnic diversity while training the next generation of researchers." (NSF, 2016, p. 27)

Furthermore, the assessment committee disagrees with the ICCGS finding that programs called out in this report are doing well at promoting diversity (see Appendix C). In addition, the ICCGS's comment that "far more Hispanics and Native Americans are drawn to the biological sciences than the physical sciences, perhaps for cultural reasons and perhaps because these fields are considered less mathematical" is an outdated stereotype.[36]

Achieving and maintaining a diverse workforce in geospace sciences is in the best interest of the profession and is integral to NSF's strategic goals and objectives.[37] The underrepresentation of minorities in solar and space physics and analogous fields must be actively confronted and regarded as a high-priority goal.[38] Lack of diversity in minority role models sends a negative message to young people and may discourage them from pursuing science and engineering careers. Although some progress has been achieved at increasing the participation of women,[39] particularly at the undergraduate and graduate levels, the lack of progress in recruiting and retaining minorities at all levels is concerning and must be addressed.[40]

Recommendation: The assessment committee recommends that to realize Recommendation 4.6 of *Investments in Critical Capabilities for Geospace Science 2016 to 2025* fully, the lack of diversity and representation in solar and space physics should be attacked aggressively. The National Science Foundation Geospace Section should identify best practices and provide guidance for new approaches to diversifying geospace.

Some options to consider for implementation of this recommendation are the following:

1. Evaluating existing NSF programs that focus on increasing diversity (such as those in AST[41] and NCAR[42]) to identify those whose elements are worth importing into GS;
2. Creating a clearinghouse of AGS and GS diversity-related programs and activities by featuring them prominently on the NSF, AGS, and GS websites;
3. Leveraging the recently created NSF-wide INCLUDES initiative[43] to jump-start new GS-specific diversity programming;
4. Supporting increased outreach of the GEM/CEDAR/SHINE communities to national societies focused on diversity in science, technology, engineering, and mathematics (STEM) in general and physics in particular—for example, through attendance at meetings of the National Society of Black Physicists, the National Society of Hispanic Physicists, and the American Physical Society Conferences for Undergraduate Women in Physics; and
5. Encouraging the GEM/CEDAR/SHINE community leadership and organizational teams to develop clear goals for diversity. As competed programs, GEM/CEDAR/SHINE should be required to respond to announcements of opportunity with explicit plans in this regard.

---

[36] University of California Hastings College of the Law, 2014, "Double Jeopardy? Gender Bias Against Women of Color in Science," published online at www.worklifelaw.org, http://www.uchastings.edu/news/articles/2015/01/double-jeopardy-report.pdf.

[37] NRC, 2011, *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*, The National Academies Press, Washington, D.C.; NASEM, 2015, *Innovation, Diversity, and the SBIR/STTR Programs: Summary of a Workshop*, The National Academies Press, Washington, D.C.; NSF, 2014, *Investing in Science, Engineering, and Education for the Nation's Future: National Science Foundation Strategic Plan for 2014-2018,* https://www.nsf.gov/pubs/2014/nsf14043/nsf14043.pdf.

[38] M. Moldwin and C. Morrow, 2016, Research career persistence for solar and space physics PhD, *Space Weather* 14(6):384-390.; American Institute of Physics (AIP), 2013, *Women among Physics and Astronomy Faculty*, College Park, Md., https://www.aip.org/sites/default/files/statistics/faculty/womenfac-pa-10.pdf; AIP, 2014, *African Americans and Hispanics among Physics and Astronomy Faculty*, College Park, Md., https://www.aip.org/sites/default/files/statistics/faculty/africanhisp-fac-pa-12.pdf.

[39] AIP, 2014, *Astronomy Enrollments and Degrees*, College Park, Md., https://www.aip.org/sites/default/files/statistics/undergrad/enrolldegrees-a-12.3.pdf.

[40] AIP, 2014, *Trends in Physics PhDs*, College Park, Md., https://www.aip.org/sites/default/files/statistics/graduate/trendsphds-p-12.2.pdf.

[41] For example, the Partnerships in Astronomy and Astrophysics Research and Education program; NSF, "Partnerships in Astronomy & Astrophysics Research and Education (PAARE)," accessed October 12, 2016, https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501046&org=NSF.

[42] National Center for Atmospheric Research, "Diversity, Education and Outreach," https://ncar.ucar.edu/diversity-education-outreach/diversity-education-and-outreach, accessed October 11, 2016.

[43] NSF, 2016, "Dear Colleague Letter: NSF INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science)," released February 22, 2016, https://www.nsf.gov/pubs/2016/nsf16048/nsf16048.jsp.

5.5 PARTNERSHIPS AND OPPORTUNITIES

The charge to the PRC included the directive to "take into consideration the national and international Geospace Sciences landscape and the consequences of its recommendations for domestic and international partnerships."[44] The domestic and international landscape is broad and a large number of programs and activities relevant to geospace sciences are identified and discussed in ICCGS Chapter 8. These include programs within AGS (see also Section 3.2), the NSF-GEO directorate, cross-directorate programs, foundation-wide programs, and interagency programs (Table 5.1). The ICCGS also discusses investments in international facilities and programs, including the Class 1 ISRs at Jicamarca, Arecibo, and Canada; SuperDARN, and initiatives such as AMPERE, SuperMAG, and Madrigal that harvest data from international sources.

ICCGS recommendations with regard to programs within NSF are to encourage coordination between the NSF-AGS director, GS section head, and the NCAR HAO director (ICCGS Rec. 8.1); for the GS head to coordinate with the Division of Polar Programs director (ICCGS Rec. 8.2); for GS program managers to encourage their PIs to pursue cross-directorate co-funding opportunities such as PREEVENTS (ICCGS Rec. 8.3), with the GS stake to be funded, if possible, from the strategic grants or facilities budget lines; and for GS to coordinate with the heads and program managers in other relevant divisions and directorates (ICCGS Rec. 8.4).

The ICCGS discusses NSF investments in solar facilities, which are at a level of $13 million annually, comparable to the current GS investment in facilities. The NSO facilities portfolio is administered by NSO and funded through AST, with the exception of the Mauna Loa Solar Observatory that is administered by NCAR/HAO. The flagship facility is the Daniel K. Inouye Solar Telescope (DKIST), currently under construction and slated for operations in 2019. Also of great importance is the NSO Integrated Synoptic Program (NISP) under which the Global Oscillations Network Group (GONG) and the Synoptic Optical Long-term Investigations of the Sun (SOLIS) programs are operated. NSF also funds the National Radio Astronomical Observatory (NRAO) which operates the Atacama Large Millimeter/submillimeter Array (ALMA) and the Jansky Very Large Array, both of which have unique solar capabilities but are not solar dedicated.[45] NRAO is also a partner in plans for a next-generation radioheliograph (FASR, the Frequency-Agile Solar Radiotelescope), a not-yet-funded midscale project that was highly ranked by decadal surveys (Section 5.2.1).[46] Hence, current and new facilities for solar observing lie outside the AGS and the GS portfolio. Given the importance of solar observations, including synoptic monitoring, for the geospace sciences, close coordination between AGS and AST is necessary, as emphasized by the survey.

The ICCGS urges GS to encourage and work with PIs applying for and receiving MRI funds and to plan for those projects that may result in requests for M&O support (ICCGS Rec. 8.5). Similarly, the ICCGS notes that concepts for geospace facilities requiring MREFC investments may emerge from the community, and GS should encourage the development of these potentially transformative facility concepts (ICCGS Rec. 8.6) with the caveat that GS plans for how the M&O costs of a facility of this scale would be accommodated (ICCGS Rec. 8.7).

With regard to interagency partnerships, the ICCGS recommends continuing the NSF/DOE partnership in Basic Plasma Science and Engineering (ICCGS Rec. 8.11), the multiagency partnership in CCMC (ICCGS Rec. 8.12), in the NASA/NSF partnership for Collaborative Space Weather Modeling (ICCGS Rec. 8.13), and recommends establishing a new partnership with NASA for Grand Challenge Projects (ICCGS Rec. 8.14). The ICCGS recommends caution regarding legacy instrumentation funded by DOD programs. The assumption of M&O costs by GS for such instruments needs to be considered in the wider context of a senior review process (ICCGS Rec. 8.10).

The potential impacts of ICCGS recommendations, particularly those related to GS facilities, on domestic and international partnerships are not considered by the ICCGS in detail. The closure of the Sondrestrom ISR and the curtailment of funding to Arecibo Observatory represent significant impacts on two facilities, one international and one domestic. The recommendation to explore entry of the United States into the EISCAT Scientific Association represents a new international partnership intended, in part, to mitigate the wider impact of the recommended closure of the Sondrestrom ISR. Given that Arecibo Observatory has been funded through a partnership, and that the ICCGS recommends (ICCGS Recs. 7.5 and 9.11) to curtail the support provided since 2008 by GS, the impact

[44] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 7.
[45] The ICCGS discusses the NRAO Solar Radio Burst Spectrometer at Green Bank, but this instrument has not been operational since 2012.
[46] NRC, 2013, *Solar and Space Physics*, p. 118.

TABLE 5.1 Partnerships and Opportunities for National Science Foundation (NSF) Geospace Identified by *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Chapter 8

Programs within NSF-AGS	Interagency Partnerships
National Center for Atmospheric Research (NCAR) High Altitude Observatory (HAO) AGS Postdoctoral Research Fellowships Program	Department of Defense Air Force Office of Scientific Research Defense University Research Instrumentation Program Department of Energy Partnership in Basic Plasma Science and Engineering NASA NASA/NSF Partnership for Collaborative Space Weather Modeling Community Coordinated Modeling Center (CCMC) Grand Challenges Projects NOAA Space Weather Prediction Center (SWPC) National Center for Environmental Information (NCEI) Global Oscillation Network Group (GONG) NSF Science Technology Center (STC), Center for Integrated Space Weather Modeling (CISM)
Programs within NSF Geosciences	
Division of Polar Programs (PLR) Research in Hazards and Disasters (Hazards SEES) Prediction of and Resilience against Extreme Events (PREEVENTS)	
NSF Cross-Directorate Programs	
Division of Astronomical Sciences National Solar Observatory (NSO) Integrated Synoptic Program (NISP) Daniel K. Inouye Solar Telescope (DKIST) Virtual Solar Observatory National Radio Astronomical Observatory (NRAO) EarthCube	
NSF-wide Programs	International Partnerships
Major Research Instrumentation Program (MRI) Major Research Equipment and Facilities Construction (MREFC) Software Infrastructure for Sustained Innovation (SI2) Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE) EPSCoR Research Infrastructure Improvement Program	Incoherent Scatter Radar at Jicamarca, Peru Resolute Bay Incoherent Scatter Radars in Canada (RISR-N and RISR-R) SuperDARN SuperMAG Madrigal Database (harvests international data) AMPERE (harvests international data) EISCAT and EISCAT 3D

NOTE: AGS, Division of Atmospheric and Geospace Sciences; AMPERE, Active Magnetosphere and Planetary Electrodynamics Response Experiment; EISCAT, European Incoherent Scatter Scientific Association; EPSCoR, Experimental Program to Stimulate Competitive Research; NSF, National Science Foundation.
SOURCE: National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

on the Arecibo Observatory as a whole may be substantial. The ICCGS did not assess, nor was it in a position to assess, the potential impact of its recommendations for Arecibo on the current funding arrangement. Neither did the ICCGS assess what the scientific impact of the loss of the ISR capability at Arecibo would be to the wider geospace community or attempt to make recommendations to mitigate that loss.

Finding: ICCGS recommendations regarding facilities strongly affect two facilities, one international (Sondrestrom) and one domestic (Arecibo). Since Arecibo is funded by a partnership, the recommended action regarding Arecibo may have wider scientific and budgetary impacts.

The assessment committee notes that several other international programs that were not included in the ICCGS can potentially contribute to the GS goals, including the availability of distributed data, model development, and basic and applied research. For example, the International Space Weather Initiative[47] is a United Nations-sponsored

[47] International Space Weather Initiative, http://www.iswi-secretariat.org/, accessed October 11, 2016.

activity that has fostered scientific collaboration and instrument deployment around the globe. Through this program, over 1,000 ground-based instruments have been deployed in dozens of countries.

Similarly, research and modeling efforts are occurring globally. The European Space Agency's Space Situational Awareness program[48] is supporting the development and testing of predictive space weather models and the development of a Virtual Space Weather Modeling Centre.[49] Within the European Union, the Horizon 2020 funding program includes research to advance space weather capabilities.

A new nation-wide project has just begun in Japan, titled the Project for Solar-Terrestrial Environment Prediction.[50] This project is focused on the synergistic development of solar-terrestrial physics research and the next-generation space weather forecasting capabilities. Representatives of this project are actively seeking participation from international collaborators.

Conclusion: A number of international partnership opportunities exist that could be broadly utilized, particularly as the geospace science focus evolves to having a larger emphasis on system science and the development of predictive capabilities.

Recommendation: Assessing all possible international partnerships was beyond the charge given to the Portfolio Review Committee. However, when considering the implementation of the portfolio recommended by *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, the National Science Foundation (NSF) Geospace Section should continue to maintain an awareness of and explore opportunities to leverage measurements available from international programs. The potential value of these observations for fundamental research, for the development of system and data assimilative models, and for the improvement of predictive capabilities should be considered as an integral component of the broader NSF observing program.

---

[48] European Space Agency, "Space Situational Awareness," http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness, accessed October 11, 2016.

[49] European Space Agency, "Virtual Space Weather Modelling Centre," last update March 3, 2016, https://esa-vswmc.eu/.

[50] Institute for Space-Earth Environmental Research (ISEE) Nagoya University, "Project for Solar-Terrestrial Environment Prediction," http://www.pstep.jp/?lang=en, accessed October 11, 2016.

6

Implementation Planning

The assessment committee was tasked with considering whether the ICCGS report[1] provides "a clear set of recommendations on how GS should implement the [2013 solar and space physics decadal] survey's[2] priorities within the context of the NSF/Geosciences strategic planning process." The committee pointed out in Section 3.1 that the NSF AGS and GS do not currently have a strategic plan or a visible strategic planning process and recommended that a strategic framework be developed within which to assess and prioritize the GS portfolio and related programs and initiatives in future years.

The ICCGS report detailed more than 100 recommendations that together address survey priorities. In this chapter, the assessment committee briefly addresses the clarity and completeness of the ICCGS recommendations and the planning and resources needed for their implementation.

6.1 CLARITY AND COMPLETENESS OF ICCGS RECOMMENDATIONS

As part of its statement of task, the assessment committee was asked to discuss the general readability and clarity of the PRC's report and in particular its recommendations (see Section 1.2). The ICCGS report is logically organized, comprehensive, and readable, with one notable exception: the large number of findings (121) and recommendations (113) reduced the clarity of the report. Recommendations did not always follow from prior findings, and many recommendations were themselves underpinned by several other recommendations. Some recommendations can be distilled into a single recommendation (e.g., ICCGS Recs. 4.1-4.4). Other recommendations are aspirational rather than actionable (e.g., ICCGS Rec. 4.6, discussed in Section 5.4). The assessment committee recognizes that the large number of recommendations reflects, to some extent, a high degree of granularity of the GS portfolio. The assessment committee is less concerned with the readability of the ICCGS report than with the actionability of the recommendations made. The number of recommendations is comprehensive but perhaps daunting when GS staff resources are limited.

[1] National Science Foundation (NSF), 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[2] National Research Council (NRC), 2013, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, Washington, D.C.

The large number of ICCGS findings and recommendations notwithstanding, ICCGS Chapter 9 distills many of the findings and recommendations detailed in ICCGS Chapters 4, 6, 7, and 8 into 17 specific recommendations for the GS portfolio (ICCGS Recs. 9.1-9.17). Collectively, the recommendations made in ICCGS Chapter 9 and the broad priorities given therein constitute the implementation plan for GS facilities and grants programs. The balance of GS investments in the ICCGS-recommended portfolio roughly maintains the current budget percentages among core grants, strategic grants, and facilities (33%, 28%, and 38%, respectively, in FY2015), but shifts 2 percent from facilities funding into strategic grants programs to address survey DRIVE priorities.[3]

The ICCGS prioritizes the recommended program in terms of first, second, and third priority, in the event that the GS budget is more pessimistic than the flat budget the PRC assumed. These are as follows:

- Priority 1: The AER, MAG, and STR core grants programs; the CEDAR, GEM, SHINE, and SWM strategic grants programs; Class 1 and 2 facilities; the EISCAT partnership; the DASI Facilities Program; and the Data Systems Program.
- Priority 2: Grand Challenge Projects and the Facilities I&V Program.
- Priority 3: CubeSat program and FDSS.

A Midscale Projects Program is considered by the ICCGS to be out of budget and is therefore not prioritized.

The assessment committee regards ICCGS Recs. 9.1-9.15 as actionable under the priorities given. Taken together with recommendations on workforce development and diversity in ICCGS Chapter 4 and partnerships in ICCGS Chapter 8, ICCGS presents a complete, balanced, and actionable program.

The ICCGS recommendations regarding investment in a new Midscale Projects Program (ICCGS Recs. 9.16 and 9.17) are contingent on additional changes to the geospace facilities landscape (such as the closure of Arecibo Observatory) or future increases in the GS budget and are not actionable at this time. As discussed in Section 5.2.1, the assessment committee concludes that the creation of a Midscale Projects Program lies outside the means or ability of GS to implement. Funds outside GS are required to develop a Midscale Projects Program within AGS for which the geospace sciences community is eligible to apply.

In further considering the completeness of the ICCGS report, the assessment committee was tasked with addressing whether the recommended program adequately takes into account "the integration of technology development with the NSF-GS science program."[4] The charge to the PRC does not discuss the integration of technology development with the GS science program, although it is part of the survey's DRIVE initiative, as detailed in ICCGS Table 6.1. Technology development is briefly discussed in ICCGS Rec. 6.3 (that "AER/MAG/STR grants research also should continue to serve as a technology incubator") and in connection with CubeSats (ICCGS Rec. 6.25: that "NSF GS should provide an annual, tabulated set of detailed metrics, documenting the accomplishments and challenges of the program in terms of training, research, technology development, and contributions to geospace science and/or space weather forecasting"). Appropriate technology development could be included as a component in future announcements of opportunity for the DASI Facilities Program or the Facilities I&V Program.

6.2 PORTFOLIO EVOLUTION AND RENEWAL

There is broad agreement that GS needs to renew and rebalance its portfolio continuously by investing in new instrument development; ensuring the continuing scientific productivity of existing facilities; tuning its core, targeted, and strategic grants programs to address community science imperatives and modeling needs; supporting workforce development and diversity; and being alert to partnerships that leverage resources to enhance GS activities. A GS and AGS strategic plan is needed to provide the framework within which GS establishes priorities (Section 3.3). Periodic reviews are needed to address portfolio balance and evolution within the strategic framework.

[3] NSF, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, p. 104.

[4] See the Portfolio Review Committee's charge, reprinted in Appendix A.

6.2.1 Senior Reviews

The ICCGS recognizes the need for a regular review process of the GS portfolio. ICCGS Rec. 9.8 (see also ICCGS Section 6.7 and ICCGS Recs. 6.4-6.6 and 6.29-6.30) recommends a senior review of the GS Core and Strategic Grants Programs. The objectives of the grants programs senior review are twofold: (1) to "review and balance of investments in core and strategic grants programs in light of the budget and research environment at the time of the review, [as well as] evaluate the programs' effectiveness in achieving Section and Decadal Survey science goals and, . . . recommend adjustments in the direction and balance of the grants programs . . ."; and (2) to "facilitate transparency in GS investments in its grants programs by evaluating progress of the Section in implementing recommendations of the decadal portfolio review. . . ." (ICCGS, p. 71).

ICCGS Rec. 9.15 (see also ICCGS Section 7.8 and ICCGS Recs. 7.29-7.32 and 7.35-7.36) recommends a senior review of all GS facilities. The objectives of the facilities senior review are to (1) "reconcile the GS facilities budget with the costs required to provide adequate M&O for all GS facilities and to maintain the state-of-the-art in facilities instrumentation and capabilities" and (2) "to review and rank each facility's capabilities (i) to enable, as a standalone instrument or system, transformative scientific discoveries, and (ii) to contribute to integrative scientific understanding as a complementary element in NSF's distributed capabilities for observing geospace as a system" (ICCGS, p. 89). The ICCGS recognizes that such a review "may require closure or divestment of some facilities to accommodate the innovative capabilities provided by new facilities or augmented facilities."

In agreement with ICCGS, the assessment committee endorses the use of senior reviews as a recognized means of prioritizing existing investments to allow investment in new opportunities and to rebalance and renew the portfolio. The ICCGS makes a number of suggestions on how the senior reviews could be most effective based on their experience with the GS portfolio review and suggests criteria for reviewing major scientific initiatives (ICCGS Section 7.8). The ICCGS concludes with Rec. 7.36, which recommends that "NSF GS should develop a common set of annual metrics from each facility, which can be collected year-on-year to provide the underpinning of the next Senior Review." As concluded in Section 4.1, the assessment committee agrees with the ICCGS's recommendation but cautions that the administration of uniform data and metrics may require additional resources.

Two concerns have arisen regarding the senior review process proposed by the ICCGS. First, the assessment committee questions the need for two senior reviews, one for the Core and Strategic Grants Programs and another for GS facilities. Separate senior reviews may lead to "myopic reviews . . . rather than a holistic portfolio review," as recognized in ICCGS Section 6.7. The administration of two reviews may add considerable burden to an already over-extended GS staff. The ICCGS favors two reviews because each senior review has a different scope and metrics, and the members of the review committees could be optimized for each review. The assessment committee suggests that a possible approach for a combined review may be to form subcommittees optimized to review each of the major components of the GS portfolio (e.g., grants, facilities, workforce and diversity, partnerships) and then reconcile subcommittee recommendations jointly.

A second concern of the assessment committee is the frequency with which senior reviews occur. The ICCGS recommends semi-decadal reviews. Again, this may place administrative burden on the GS staff, especially if GS elects to conduct separate senior reviews for grants and facilities. GS will have to consider the number of senior reviews that it can realistically perform with current resources and what additional resources would be needed to perform more frequent senior reviews.

Conclusion: The assessment committee endorses ICCGS Recommendations 9.8 and 9.15 to conduct periodic senior reviews of the NSF Geospace Section's grants programs and facilities.

Conclusion: The assessment committee questions the need for two separate senior reviews, one for the Core and Strategic Grants Programs and another for GS facilities. The committee is also concerned about the burden placed upon GS administration by two separate semi-decadal reviews and concluded that a single unified review is preferable.

6.2.2 Management Processes

ICCGS Section 9.6 discusses organization and management issues internal to GS. In particular, the report recommends reforms to organizational processes that would improve the transparency and efficiency of future reviews (e.g., portfolio reviews and senior reviews) based on ICCGS experiences with the portfolio review process. The suggested improvements would also facilitate transitions in GS program management by inevitable turnover of personnel. The ICCGS makes recommendations in ICCGS Section 9.6 but does not enumerate them as such. The bulleted list of recommendations may be summarized as follows: GS should (1) develop "accurate, complete, and transparently understandable data metrics . . . for all grants in the various programs of the Section," including both "historical data and data for the current fiscal year" in order to assist with understanding trends and vitality of these programs; (2) consider making a set of these metrics publicly available on a GS webpage; (3) separate fully funded GS research proposals from special categories of awards (conference awards, MRI and co-funded projects, AGS postdocs, NSF/DOE awards); (4) "track, maintain, and publish data on workforce issues" for awards in each program; (5) track M&O costs in grants and facility awards; (6) "establish guidelines for determining the impacts of encumbering program resources M&O of new facilities before committing future budget to them"; and (7) communicate the "outcomes, rationale, and impacts of decisions" made in response to senior reviews and other advisory bodies. The assessment committee endorses each of these suggestions. In addition, the committee reiterates its strong support for ICCGS Rec. 7.36 for GS to "develop a common set of annual metrics from each facility." The assessment committee is aware that to develop, collect, maintain, and exploit data and metrics from GS facilities, grants, and other programs requires resources in informatics that GS may not currently possess.

As noted in Section 6.1, the assessment committee recognizes that the large number of ICCGS recommendations to some extent reflects the high degree of granularity of the GS portfolio. To the suggestions made in ICCGS Rec. 9.6, the committee would add the suggestion that GS consider reducing administrative burden through a consolidation and reduction of program elements where it makes sense to do so.

Conclusion: The suggestions to NSF GS regarding management processes are excellent and will underpin future senior reviews and allow greater transparency into the decision-making process.

To conclude this assessment, the PRC met its charge in the face of challenging constraints. The ICCGS report presents a comprehensive program for the GS portfolio that is aligned with survey priorities. The exception is funding for a midscale projects program which, for reasons discussed in Section 5.2.1, cannot be implemented within the budget guidance provided to the PRC by NSF. The recommended program nevertheless enables investments in new programs, instrument development, and facilities and defines a framework for ensuring program renewal and balance going forward through a more uniform set of metrics for evaluating existing programs and facilities and through periodic senior reviews. The ICCGS also provides a number of suggestions regarding GS processes that will support and streamline GS management function. The responsibility now passes to NSF AGS and GEO to implement the GS portfolio recommended in the ICCGS and to engage with the community in developing a strategic vision and plan that identifies and builds on the strengths of AGS and GS within the broader solar and space physics enterprise, identifies partnerships within the NSF and external to NSF, and leverages opportunities from the NSWS[5] and SWAP[6] initiatives.

[5] National Science and Technology Council (NSTC), 2015, *National Space Weather Strategy*, Office of Science and Technology Policy, Washington, D.C., October.

[6] NSTC, 2015, *National Space Weather Action Plan*, Office of Science and Technology Policy, Washington, D.C., October.

Appendixes

A

Charge to the Portfolio Review Committee

CONTEXT

This review is motivated in part by priorities highlighted for the Geospace scientific community in the National Research Council's (NRC) Decadal Survey: *Solar and Space Physics: A Science for a Technological Society* (hereafter called the *Survey*) and by the current challenging outlook for the U.S. Federal budget.

The review is designed to examine the balance across the entire portfolio of activities supported by NSF's Geospace Section (GS) within the Division of Atmospheric and Geospace Sciences (AGS). The primary goal of this review, and of any resulting adjustments of the GS portfolio, is to ensure that investments in the GS science disciplines and respective facilities are properly aligned, both now and in the future, with the needs and priorities of the Geospace scientific community, in part as articulated in the Survey.

The following boundary conditions will be adopted for the review:

- All of the GS-funded activities should be considered together with the *Survey* recommendations: Core Programs of Aeronomy, Magnetospheric Physics, and Solar Terrestrial Research, focused programs CEDAR, GEM, and SHINE, elements of the new Space Weather Research & Instrumentation Program (CubeSats, space weather modeling, and other multi-user, space weather-related activities), components of the Geospace Facilities Program, such as the Incoherent Scatter Radar, Lidar Consortium, SuperDARN HF radars, and those activities specifically designed to enhance educational opportunities, diversity, and international participation.
- The review should be forward-looking focusing on the potential of all funded facilities, programs, and activities for delivering the desired science outcomes and capabilities (while taking into account respective past performances) and considering the value of funded activities in terms of both intellectual merit and broader impacts.
- The review should assume budget scenarios (to be provided by GS) to encompass the period from 2016 through 2025, and consider the costs of (i) continuing the existing observing capabilities and science-funded programs, as well as of (ii) new facilities and programs, including those recommended in the *Survey* and others the Review Committee may wish to introduce.
- The Committee's deliberations should take into consideration the national and international Geospace Sciences landscape and the consequences of its recommendations for domestic and international partnerships.

THE CHARGE

The committee is asked to construct its recommendations around two themes:

1. Recommend the *critical capabilities* needed over the period from 2016 to 2025 that would enable progress on the science program articulated in Chapter 1 of the *Survey*. These recommendations should encompass not only observational capabilities, but also theoretical, computational, and laboratory capabilities, as well as capabilities in research support, workforce, and education.
2. Recommend the *balance of investments* in the new and in existing facilities, grants programs, and other activities that would optimally implement the *Survey* recommendations and achieve the goals of the Geospace Section as articulated in the *AGS Draft Goals and Objectives Document* (including Academies/BASC Review, 2014) and the GEO/Advisory Committee Document "*Dynamic Earth: GEO Imperatives & Frontiers 2015-2020*" (NSF, 2014). These recommendations may include closure or divestment of some facilities, as well as termination of programs and other activities, and/or new investments enabled as a result. The overall portfolio must fit within the budgetary constraints provided to the Committee.

It is important that the Portfolio Review Committee considers not only what new activities need to be introduced or accomplished, but also what activities and capabilities will be potentially lost in enabling these new activities and discontinuing current activities.

The elements of the recommended portfolio should be prioritized in sufficient detail to enable GS to make subsequent appropriate adjustments in response to variations in Federal and non-Federal funding.

The committee should consider the effects of its recommendations on the future landscape of the U.S. Geospace community. The recommended portfolio and any changes should be viable and lead to a vigorous and sustainable future. In particular, the Committee is asked to examine how the recommended portfolio supports and develops a workforce with the requisite abilities and diversity to exploit the recommended research and education investments.

The committee will be a sub-committee of the Directorate for Geosciences Advisory Committee (AC/GEO). The Committee is asked to provide its recommendations by September 2015 for presentation to the AC/GEO, so NSF can consider them in formulating the FY 2017 Budget Request.

PORTFOLIO REVIEW TIMELINE

The timeline for this review is based on the desire for its results to inform on the input into the Fiscal Year 2017 budget process, and it is constrained by the needs to be initiated and reported to the GEO/Advisory Committee that meets in April/May and October/November each year.

B

Recommendations from *Investments in Critical Capabilities for Geospace Science 2016 to 2025*

This appendix contains recommendations reproduced verbatim from the 2016 Portfolio Review Committee report *Investments in Critical Capabilities in Geospace Science 2016-2025*[1] for the convenience of the reader. These are not recommendations of the assessment committee. Acronyms are defined in Appendix E.

CAPABILITIES FOR A VITAL PROFESSION

Recommendation 4.1. The FDSS and CAREER programs should be continued as resources allow.

Recommendation 4.2. The AGS Postdoctoral Research Fellowship should be continued as resources allow. All such funded programs should keep metrics on the diversity of the participants and report them annually.

Recommendation 4.3. The CISM summer school and the ISR summer school should be continued, periodically assessed and competed for renewal. Metrics on the diversity of the student participants should be kept and reported annually.

Recommendation 4.4. GS support for graduate and advanced undergraduate students to attend the GEM, CEDAR and SHINE summer workshops should be continued as resources allow. Metrics on the diversity of the student participants receiving support should be kept for each workshop and reported annually.

Recommendation 4.5. NSF support for REU programs in solar and space physics should be encouraged. The SW REDI program should be continued as resources allow. Metrics on the diversity of participants should be kept on all such funded programs and reported annually.

Recommendation 4.6. The GS and the GS community should be in the vanguard of NSF initiatives to promote engagement of women and under-served populations in all aspects of geospace science from school to research proposal writing to leadership in GS activities.

[1] National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

Recommendation 4.7. Where possible, the first employment step of geospace PhD students should be tracked to determine and demonstrate how the skilled workforce is being utilized. This information could be entered in a data-information box in the final grant report.

Recommendation 4.8. The GS should continue its CubeSat program at the funding level recommended in Sections 6.6 and 9.3. Given the educational and engineering successes of the CubeSat program, the GS should cultivate partnerships with the NSF Engineering and Education Directorates to broaden NSF investment in CubeSat programs and expand their reach across NSF.

Recommendation 4.9. Continue modest investments in projects and programs that involve teacher research and citizen science and inform public interest in geospace and solar science.

Recommendation 4.10. The GS should work with the NSF office that maintains "Survey of Earned Doctorates" to implement immediately the category "Solar and Space Physics" (or another name to be determined) into the Survey.

GS CORE AND STRATEGIC GRANTS PROGRAMS

Recommendation 6.1. A collective budget for core programs should be apportioned among AER, MAG and STR according to proposal pressure (number and quality) without fixed budgets for each discipline. Similar principles should be applied to the targeted programs.

Recommendation 6.2. The PRC recommends that GS continue support of multi-scale physics-based and data-assimilation models with an emphasis on integrated science and the coupling of models. Opportunities for model development and implementation can come from core and targeted research as well as the Space Weather and GCP programs, the CCMC, and the recommended Innovations & Vitality line (Section 7.4).

Recommendation 6.3. AER/MAG/STR grants research also should continue to serve as a technology incubator, funding modest-scale projects in experimental instrument development with a focus on new scientific capabilities. As these development efforts mature, their funding source should transition from the core programs to programs such as the recommended Innovation and Vitality (Section 7.4.1) and DASI (Section 7.4.3) programs and the CubeSat program. The GS should also encourage instrument development projects to seek funding through the NSF-wide MRI and MREFC programs when appropriate (Section 8.1).

Recommendation 6.4. The PRC recommends that GS maintain its Core Research Program as a Priority 1 effort, with a collective budget for all three programs not less than the current level. The core programs should conduct innovative data analysis and exploitation, theory, modeling, development and application of new instrumentation, measurement techniques and laboratory experiments aligned with the core goals of each program, as articulated in following subsections.

Recommendation 6.5. The GS should continue to encourage the geospace science community to participate in leveraged, targeted research programs, but caution is advised when the leveraged funding is derived from GS core research programs. In committing core grants funds to these targeted opportunities, GS PMs should guard against scope creep over time that tends to diminish un-solicited core funds available for competition.

Recommendation 6.6. The GS should continue to support the three targeted research programs and their summer workshops (as also recommended in Section 4.8) and evaluate their continuing alignment with GS goals at semi-decadal intervals using a Senior Review process (Section 6.7).

Recommendation 6.7. The GS should encourage multidisciplinary research that bridges the traditional program areas within the Section, in particular, across the three targeted grants programs. Over the next decade and as appropriate projects emerge, a portion of the current budget for targeted grants programs should migrate into the Integrative Geospace Science grants programs (Section 6.5). (See Chapter 9 regarding provisional budget recommendations.)

Recommendation 6.8. The GS should evaluate the utility of proposal deadlines in its targeted grants programs and determine whether proposal deadlines may be stimulating an artificial inflation in proposal submissions for the limited funding available in the targeted programs, resulting in lower proposal success rates as suggested in an experiment undertaken by the Division of Earth Sciences. If proposal deadlines do result in inflated numbers of proposal submissions, then the GS should charge its Committees of Visitors to evaluate the merit of retaining proposal deadlines in its targeted programs.

Recommendation 6.9. The GS should encourage and fund AER research projects, in collaboration with the MAG community, for early development of DASI concepts for diagnosing upper atmospheric, ionospheric and magnetospheric processes, as well as the development of self-consistently coupled physics-based models. As the DASI concepts mature, their funding source should migrate to the GS Facilities program (Section 7.4.3).

Recommendation 6.10. The CEDAR grants program should continue to support community-defined "Grand Challenge Workshops", preferably jointly with the GEM Grants program.

Recommendation 6.11. The GS should encourage and fund MAG research projects, in collaboration with the AER community, for early development of DASI concepts for diagnosing upper atmospheric, ionospheric and magnetospheric processes. As the concepts mature, their funding source should migrate to the GS Facilities program.

Recommendation 6.12. The GEM grants program should continue to support community-defined research challenges and, when appropriate, "Grand Challenge Workshops" jointly with the CEDAR Grants program.

Recommendation 6.13. STR grants programs should continue to support analyses of important synoptic and high-resolution observations derived from observatories operated external to GS.

Recommendation 6.14. The STR program manager should continue to meet regularly with managers of the various ground-based telescopes in order to coordinate priorities and improve communication. Such efforts must continue in order to minimize any unintended consequences of altering the priorities of data collection at these facilities.

Recommendation 6.15. To reap the full potential of DKIST, the AST and AGS Divisions should explore modes of collaboration that best support science from this new facility.

Recommendation 6.16. The PRC recommends the establishment of a distinct funding line for basic space weather research that supports improved capabilities in space weather specification and forecasting, and sustain a robust space weather and climatology program that invests in "predictive space weather science" and activities that "optimize the use of research to address national needs."

Recommendation 6.17. The PRC generally endorses a continuation of the current NASA/NSF Collaborative Modeling under Space Weather. However, well in advance of each new request for proposals to this program, the GS PM for SWR should determine if the NASA call for proposals on Strategic Capabilities continues to be aligned with GS program goals for SWR. If the alignment is consistent with GS program goals, then continuation at appropriate funding levels should be sustained. Additionally, over time, funds in this line should be made available for other strategic space weather focused capabilities.

Recommendation 6.18. The PRC recommends that GS maintain its support to CCMC as a Priority 1 effort in the Facilities Program in order to continue and enhance efforts in Integrative Geospace Science.

Recommendation 6.19. The PRC recommends that GS use the proposed Innovation and Vitality Program (Section 7.4.1) to open funding paths for scientifically viable space weather observations and platforms that could serve demonstrated real-time IGS monitoring needs.

Recommendation 6.20. The PRC endorses NSF's critical role in contributing to national efforts for coordinated space-weather preparedness, and recommends that the GS section pursue opportunities for collaboration between agencies which can be used to further NSF goals to "innovate for society," as well as Decadal goals related to DRIVE.

Recommendation 6.21. The Integrative Geospace Science program should also be the home of a new Grand Challenge Projects program.

Recommendation 6.22. The PRC recommends that NASA/NSF explore best practices for collaboration on Grand Challenge Projects, perhaps along the lines of the aforementioned NASA/NSF Collaborative Modeling under Space Weather. The broadening of these collaborative efforts embraces the holistic scope of the Decadal Survey.

Recommendation 6.23. The CubeSat program should include additional design reviews and oversight aimed at achieving mission success and be evaluated for impact and effectiveness in order to justify the investment. This oversight should be implemented in a way that does not undermine the high-risk high-payoff benefits of CubeSat projects.

Recommendation 6.24. CubeSat missions should contribute their data to a science data center or other curated archive.

Recommendation 6.25. NSF GS should provide an annual, tabulated set of detailed metrics, documenting the accomplishments and challenges of the program in terms of training, research, technology development, and contributions to geospace science and/or space weather forecasting.

Recommendation 6.26. In this budget-constrained environment GS should continue to invest in the CubeSat program with an enhanced focus on science/strategic instrument development and less focus on the satellite bus and system development and strive for greater scientific value from this investment. GS should also continue its collaborative and partnering efforts with NASA, DoD, and international partners and investigate partnering opportunities with industry.

Recommendation 6.27. It is the PRC's view that additional collaboration with other Directorates and NSF Offices, whose activities align with education, engineering and multidisciplinary efforts (e.g., NSF Office of Emerging Frontiers and Multidisciplinary Activities) are needed for the GS initiative in CubeSats to continue as a vibrant cross-Foundation effort and to allow the GS section to augment NSF's CubeSat program to support "two new starts per year," as recommended by the Decadal Survey. Short of such whole-of-Foundation support for this frontier effort, the PRC must recommend a rebalancing of the GS CubeSat effort to focus on science and with perhaps fewer missions than envisioned by the Decadal Survey.

Recommendation 6.28. Beyond a level of M&O support by the GS Facilities Program to be described in Chapter 7, proposals for research activities associated with facilities should be peer reviewed separately from facilities proposals and evaluated against the same scientific standards as any competitive research proposal conducting the same research with data from the facility.

Recommendation 6.29. The GS should charge a senior review committee to conduct an interim, semi-decadal review of the GS Core and Strategic Grants Programs. A separate senior review of the GS Facilities Program is also recommended, as described in Chapter 7.

Recommendation 6.30. Administration and decisions on the structure of the Senior Review process should reside with the GS Head and Program PMs.

GS FACILITIES AND INFRASTRUCTURE

Recommendation 7.1. A facility should exhibit the following functions:

1. Serve a community of users well beyond a single PI or small group of investigators, i.e., at least national but may be international;
2. Be operated in such a way as to ensure responsiveness to the needs of the research community to sustain international-class scientific productivity; thus each facility is expected to have both an advisory group and a user forum, with membership not selected by facility management;
3. Operate for more than one award cycle and typically substantially longer if warranted by the Senior Review process (see Section 7.8);
4. Make all data openly available and accessible in a timely fashion according to a published data distribution and dissemination plan;
5. Develop and deliver an effective long-term plan to maintain the facility at an international cutting-edge level;
6. Carry out a limited amount of science funded from the Maintenance and Operations (M&O) contract (see Section 7.5.2);
7. Support the deployment and operations of co-located instruments with the full costs covered by each co-located instrument Principal Investigator;
8. Deliver substantial education, outreach, and diversity programs; and
9. Provide cost-effective operations.

Recommendation 7.2. The ISR facility at Sondrestrom should be terminated, and science performed at Sondrestrom should be covered by participation, after peer review, in EISCAT and EISCAT-Svalbard for cusp studies.

Recommendation 7.3. Ancillary instrumentation for geoscience studies and their operational costs at Sondrestrom should be budgeted and decided by a peer-review process from the Core or Targeted GS programs.

Recommendation 7.4. The GS should investigate costs and contractual arrangements for U.S. investigators' access to the existing EISCAT facilities and, more importantly, to the planned EISCAT 3D facility (See section 7.4.2 for further details).

Recommendation 7.5. The GS should reduce its M&O support for the Arecibo ISR to $1.1M/year; i.e., to a proportional *pro rata* level approximately commensurate with the fractional NSF GS proposal pressure and usage for frontier research.

Recommendation 7.6. Ancillary instrumentation (including the extensive optics instrumentation) for geoscience studies and their operational costs at Arecibo should all be budgeted and decided in the peer-review process.

Recommendation 7.7. Costs of running the HF heater at Arecibo should be budgeted as a pay-as-you-go system, and decided in the peer-review process.

Recommendation 7.8. Funding for RISR-N should be decoupled from the funding for any other facility in order to have accurate cost analysis available.

Recommendation 7.9. The future location and use of the PFISR radar for research should be determined by peer review by the time the EISCAT-3D begins operations. Peer review should determine the value proposition for continuing to use the radar's capabilities at its current site or if they might be better used for new, frontier research if the radar were to be installed at another location.

Recommendation 7.10. Investment is required to extend the lifetime of Millstone Hill until such time as it may be replaced by a lower cost option, and/or at another location.

Recommendation 7.11. The JRO PI should apply to the recommended, competitive Innovation and Vitality Program (Section 7.4.1) for support to install needed upgrades to bring the ISR system up to modern radio science standards.

Recommendation 7.12. NSF should develop a consistent policy and procedure for supporting the M&O of the ancillary experiments at ISR facility sites. Normally the M&O costs should be the responsibility of each ancillary instrument PI.

Recommendation 7.13. AMPERE I/II should continue to be funded at the current levels.

Recommendation 7.14. NSF involvement in CCMC should continue at the present level and its funding focus should be on the provision of scientific expertise and model capabilities not supported by NASA, e.g. ITM and atmosphere-ionosphere-thermosphere coupling.

Recommendation 7.15. SuperMAG should continue to be funded at the current level.

Recommendation 7.16. The GS should assess if the era may now exist wherein greater scientific synergies and optimization of operations could be obtained if all GS-sponsored magnetometers were managed as a single array. Such an array could thus evolve into a Class 2 facility (see Section 7.4.3 for more details on DASI).

Recommendation 7.17. The U.S. SuperDARN groups should determine an optimal equilibrium between local research and community service, and optimize the efficiency of their M&O.

Recommendation 7.18. The participating members of the CRRL group should seek peer-reviewed funding individually or collectively from the Core or Targeted GS programs.

Recommendation 7.19. If the CTC aspires to develop innovative instrument capabilities and concepts for a new GS facility, e.g., an Observatory for Atmosphere Space Interaction Studies (OASIS), it should apply for separate funding from the proposed Innovation and Vitality Program (see Section 7.4.1).

Recommendation 7.20. The M&O and science resources for LISN should be funded via peer review under the recommended "DASI" line as outlined in Section 7.4.3.

Recommendation 7.21. A central fund to support innovation and vitality for GS facilities should be established. It is envisaged that this fund would support several different activities. These should include, but not be limited to:

- Major repairs and renovation of an existing facility.
- Funding for developing software and/or hardware that will significantly improve the performance of currently-funded Class 1 and 2 facilities.
- The development of new instrumentation, probably already designed and developed from research funds, into a capability where it could operate as a facility; this could include operation of a prototype.
- The development of numerical algorithms and methodologies (independent of science objectives) to improve the efficacy and accuracy of computational models for community use.
- The development of facilities—including models, data provision and measurement capabilities—to make them operational in real time, if a compelling scientific need for real-time capabilities becomes evident.

Recommendation 7.22. Funds from the proposed Innovation and Vitality Program should be competed every 1-2 years depending on the level of funding available. It is expected that some awards might extend over 1-3 years. Given the diversity of the possible applications, a panel review is recommended so that the broader requirements of the GS community can be represented.

Recommendation 7.23. The GS should solicit proposals from the US GS community to form a US EISCAT consortium that would be funded by a block grant from NSF, initially to join EISCAT as Affiliate and eventually as an Associate. The initial Affiliate status would allow the consortium to gain experience with EISCAT before making a five-year commitment as an Associate and to develop a deeper understanding of EISCAT system capabilities when EISCAT-3D becomes operational. Upon attaining Associate status, the consortium should be tasked with (1) transfer of the EISCAT annual membership fee to EISCAT-3D and (2) development and administration of a proposal and panel review process for the selection of US EISCAT users. The consortium should develop procedures for cost-effective grant administration that minimizes the encumbered overhead expenses of multiple member institutions.

Recommendation 7.24. The GS should create a “DASI” fund with two purposes: (i) to develop and build new “small” instrumentation suitable for deployment in a DASI network and (ii) to provide M&O funds to maintain the network once created.

Recommendation 7.25. The initial opportunity for awards, to be evaluated by an ad hoc review panel, should provide funding of sufficient duration that the DASI projects can be evaluated in conjunction with the other Class 1 and Class 2 facilities by the proposed Senior Review Panel (Section 7.5) at its first meeting.

Unnumbered Recommendation, Section 7.4.4. NSF should create a separate competitive fund for the further development of data management and data visualisation from many sources, including new value-added data products. This funding should include the further development and operation of the Madrigal database, thus separating it from the Millstone Hill ISR M&O funding for greater transparency.

Recommendation 7.26. All facilities should have a formal and active users/advisory group, appointed by NSF and chaired by an independent person to support NSF and the PI in deciding priorities.

Recommendation 7.27. Each facility PI should provide an annual report to NSF that should include a 3-year development plan, prioritised and budgeted for the facility.

Recommendation 7.28. All annual reports should be open to the GS community, except for sections that are commercially sensitive or involve individual personnel issues.

Recommendation 7.29. NSF should develop clear procedures for deciding whether to award science research funding within a facility contract, and the level of that funding, which normally should not exceed 10% of the personnel costs.

Recommendation 7.30. The semi-decadal Senior Review of facilities should evaluate the quality of the science undertaken with the M&O funding.

Recommendation 7.31. NSF should identify both the ongoing M&O costs and their funding source(s) before awarding the grant.

Recommendation 7.32. For instruments funded from external sources, the Senior Review panel (Section 7.8) should be tasked to determine whether facility funding is appropriate.

Recommendation 7.33. If use of the Arecibo Observatory is no longer available to GS researchers, e.g., due to divestment or insufficient funding for its continuing operation, and the GS budget remains at or above the flat funding level assumed for the Portfolio Review, then the recommended annual funding of $1.1M for Arecibo should be redirected to the Innovations and Vitality Program described in Section 7.4. Depending on community consensus and the recommendations from the facilities Senior Review recommended in Section 7.8, a significant portion of this augmented I&V annual budget might be directed to funding for a new Midscale project.

Recommendation 7.34. If future GS budgets exceed the flat-budget assumption of this review by $1M per year or greater, then the additional annual funding should be directed to a Midscale Projects Program.

Recommendation 7.35. To prevent scope creep in future facilities without adequate budget to support the additional M&O costs, a periodic "Senior Review" of all GS facilities should be conducted, at least every 5 years. This review should include established facilities i.e. all Class 1 and Class 2 facilities. Nascent "facilities" that may be on a trajectory for facility status but either are not yet operating as a facility, as defined in Section 7.2, or have not yet been fully developed, e.g., as part of an MRI, MREFC, a possible new Mid-Scale Projects line, or other initiative, should also be included in the Senior Review if their transition to facility class is expected to occur before the next Senior Review. Ideally, all facility proposals (including those for new facilities) should eventually be synchronized on a 5-year renewal for the envisioned Senior Review process.

Recommendation 7.36. NSF GS should develop a common set of annual metrics from each facility which can be collected year-on-year to provide an underpinning of the next Senior Review. These metrics could include science outputs both from facility staff and external users, annual expenditure (capital and resource), data downloads and usage, and key technical developments (hardware and software).

PARTNERSHIPS AND OPPORTUNITIES

Recommendation 8.1. The AGS Director and GS Head should continue to coordinate with the Director of HAO to facilitate alignment of HAO science goals with GS science goals.

Recommendation 8.2. The GS Head should continue to coordinate with the GEO-PLR AAGS Program Director to facilitate alignment of AAGS science goals with GS science goals.

Recommendation 8.3. GS PMs should continue to encourage GS investigators to pursue co-funding from the PREEVENTS and similar future programs of the Geoscience Directorate. Whenever possible co-funding these types of targeted programs from the GS budget should be derived from GS Strategic Grants or Facilities programs rather than the GS Core Grants program.

Recommendation 8.4. GS PMs should continue to encourage GS investigators to pursue co-funding from the EarthCube program for Data Systems, Products and Management. If co-funding from the GS is desirable or required to secure external EarthCube funding, whenever possible the co-funding should be derived from the newly recommended GS Facilities Program for Data Systems, Products and Management (Sec. 7.4.4).

Recommendation 8.5. The GS should continue to encourage and work with PIs applying for and receiving MRI funds to develop innovative new instrumentation for use in geospace science research. Consistent with the finding and recommendation of Section 7.6, when additional funds will be requested from the GS for future M&O costs for the MRI, the funding source(s) and space in the GS Facilities budget should be planned well in advance of taking-on the new facilities' costs. Alternatively, PIs should be encouraged to explore non-NSF sources of funding for future M&O costs.

Recommendation 8.6. Concepts appropriate for MREFC investment in geospace science have recently emerged in GS community forums (e.g., at the conference on Measurement Techniques in Solar and Space Physics held in Boulder in April, 2015 and at recent CEDAR and GEM workshops). The GS should encourage development of transformative facility concepts appropriate for MREFC investment by co-sponsoring community workshops to advance innovative new concepts.

Recommendation 8.7. Planning for a possible future MREFC investment should include budget scenarios for how M&O would be accommodated for a new facility of this scale, including possible sun-setting of one or more existing GS facilities.

Unnumbered Recommendation, Section 8.1.4. If and when NSF central funding for INSPIRE projects phases-out, the GS should continue to use its own internal and well-established processes to fund high-quality projects that cross the disciplinary boundaries of its core grants programs and seek appropriate partners external to GS for projects that cross section, division or directorate boundaries.

Recommendation 8.8. GS PMs should encourage eligible PIs to pursue EPSCoR opportunities to leverage funding for appropriate geospace research and educational projects.

Recommendation 8.9. In line with the findings and recommendations of Section 6.6 regarding the future of the GS CubeSat program, the GS should explore possible partnerships across NSF (and with DoD, NASA, industry, international partners) for augmenting the scientific impact of investments in the GS CubeSat program.

Recommendation 8.10. The GS should carefully review the impact on its facilities and grants programs of assuming M&O costs for legacy DoD instrumentation. When doing so is well-aligned with DS and Section science goals, continuing use of such equipment may bring significant added value to GS programs with no up-front costs for investment in the instrument development. The GS should use the recommended Senior Review processes (Section 6.7 and 7.7) to determine the overall value of assuming M&O costs for legacy DoD equipment.

Recommendation 8.11. The GS should continue to participate in the NSF/DOE Partnership and co-fund research projects that address DS Key Science Goal 4.

Recommendation 8.12. The GS should continue to co-fund CCMC at the current level as recommended in Section 6.5.1).

Recommendation 8.13. The GS should continue the NASA/NSF Partnership for Collaborative Space Weather Modeling in the current modus operandi and as long as it continues to advance space weather research goals for the GS (as recommended in Section 6.5.2).

Recommendation 8.14. The GS should explore a new partnership with NASA to create a co-funded Grand Challenge Research program (as recommended in Section 6.5.2).

Recommendation 8.15. The GS should continue its collaboration with NOAA's SWPC through resource and information sharing in ways that are consistent with each agency's respective goals in advancing basic and applied knowledge of space weather and capabilities for predicting its effects.

Recommendation 8.16. The GS should continue to sponsor highly-rated proposals to develop, deploy and operate new instruments, instrument networks and data acquisition, especially when GS resources for the project are leveraged through international partnerships.

Recommendation 8.17. The GS should continue to provide funding for international workshops.

RECOMMENDED GS PORTFOLIO

Recommendation 9.1. The GS should maintain the existing budget share for the *Core Grants Program* in Aeronomy, Magnetospheric Physics and Solar-Terrestrial Research within the assumed inflation-adjusted 2015 level (or greater) for the next decade. It should use proposal pressure in concert with portfolio balance to determine an optimum distribution of investments across the three programs. The PRC recognizes that the budget allocation between core and targeted grants programs (CEDAR, GEM, SHINE) may vary from year to year depending on the number and quality of proposals submitted to the various grants programs. GS program managers should continue to have the flexibility to adjust these budget lines in response to proposal pressure, but they should strive to maintain a minimum budget for the core program. A good balance for the portfolio would be at least $^{1}/_{3}$ of the GS budget for the core grants programs and not less than $14-15M per year should the overall budget decline.

Recommendation 9.2. GS program managers should allow proposal pressure to play a role in determining the relative budget allocations among the core grants programs in *AER*, *MAG* and *STR* and among the targeted grants programs *CEDAR*, *GEM* and *SHINE*.

Recommendation 9.3. The GS should initiate a new strategic grants program, *Grand Challenge Projects,* initially with a budget of $1.5M per year by 2020.

Recommendation 9.4. The budget for *Integrative Geospace Science*, including *Space Weather Modeling* and *Grand Challenge Projects,* should grow from $3M per year in 2020 to $5M per year by 2025 by acquiring IGS projects funded by the *Targeted Grants Programs*.

Recommendation 9.5. With the assumption that future research in core and targeted grants programs will entail an increasing number of collaborative projects devoted to integrative and cross-disciplinary geospace science, the GS should migrate future funding for such projects into strategic grants programs for *Space Weather* research and *Grand Challenge Projects*. As these projects migrate from either core or targeted grants programs into Space Weather Research or Grand Challenge Projects grants, the core grants program budget should remain approximately constant (or grow if future budgets are more optimistic than flat) while the budget for targeted grants program decreases.

Recommendation 9.6. GS should continue its *CubeSat Program* with a focus on mission concept, instrument development and science exploitation of the data while partnering with other entities with engineering experience in the development of CubeSat buses. The PRC recommends an annual budget of $1M for the reduced scope of GS CubeSat mission development.

Recommendation 9.7. GS should continue to support the *FDSS* program with an annual budget of $0.6M (cf. Section 4.2).

Recommendation 9.8. The GS should implement a semi-decadal Senior Review of its Core and Strategic Grants Programs, as described in Section 6.7.

Recommendation 9.9. The GS should terminate funding for the *Sondrestrom ISR* facility when the current continuing grant for its management and operation ends (December 2017). Ancillary instrumentation for geospace studies and their operational costs at Sondrestrom should be budgeted and decided by a peer-review process from the Core or Targeted GS programs.

Recommendation 9.10. The GS should investigate costs and contractual arrangements for U.S. investigators' access to the existing *EISCAT* facilities and to the planned *EISCAT-3D* facility. If no barriers to system use and data access arise, NSF investigators could begin using the EISCAT system soon after the current continuing grant for Sondrestrom M&O expires.

Recommendation 9.11. The GS should reduce its M&O support for the *Arecibo Observatory (AO)* to $1.1M when the current agreement expires in September 2016, i.e., to a proportional *pro rata* level approximately commensurate with its fractional NSF GS proposal pressure and usage for frontier research.

Recommendation 9.12. The GS should create a new *DASI Facilities Program* with a $1.6M annual budget. This fund should be used initially to develop and implement one or more DASI Class 2 facilities with concept selection determined by peer review. For a fully operational DASI to transition to a Class 2 facility, it must satisfy the criteria for a community facility as defined in Section 7.2.

Recommendation 9.13. The GS should fund a new *Data Systems Program* for data exploitation with an annual budget of $0.5M, of which $0.15M should be redirected from the current Millstone Hill Observatory budget for the Madrigal system. Selection of a proposal(s) for development and management of the new system should be determined by peer review. Once the system becomes fully operational, it should become a Class 2 facility, with competitive renewals determined by peer review.

Recommendation 9.14. The GS should fund a *Facilities Innovation and Vitality (I&V) Program* with an annual budget reaching a steady-state value of $2.7M by 2020. Allocation of I&V Program funds should be decided using a peer-review proposal process to determine improvements of greatest value in any given year for instrument, facility and/or community model upgrades. The budget scenario in Table 9.1 provides notional budgetary guidance on an approximate, average partition of the fund between instrument and facility upgrades and model upgrades.

Recommendation 9.15. Going forward the GS should strive to maintain a balanced portfolio of cutting-edge facilities and should periodically evaluate the performance and budget of each facility against Decadal Survey and Geospace Section science goals using the Facilities Senior Review process described in Section 7.8.

Recommendation 9.16. If use of the Arecibo Observatory is no longer available to GS researchers, e.g., due to divestment or insufficient funding for its continuing operation, and the GS budget remains at or above the flat funding level assumed for the Portfolio Review, then the recommended annual funding of $1.1M for Arecibo should be redirected to the Innovations and Vitality Program described in Section 7.4. Depending on community consensus and the recommendations from the Facilities Senior Review recommended above, a significant portion of this augmented I&V annual budget might be applied to investment in a new *Midscale Project Program*.

Recommendation 9.17. If future GS budgets exceed the flat-budget assumption of this review by $1M per year or greater, then the additional annual funding should be directed to a *Midscale Projects Program*.

C

Additional Information on Diversity Among Physics and Astronomy Students

As pointed out by the 2016 Portfolio Review Committee report *Investments in Critical Capabilities for Geospace Science 2016 to 2025*[1] (hereafter, "ICCGS"), there are few data available on diversity that is specific to solar and space physics. However, data are available for physics and astronomy, fields that overlap with solar and space physics.

The Research Experiences for Undergraduates (REU) Program in Solar and Space Physics at the University of Colorado, Boulder, which the ICCGS report cites, shows that 4 percent of the participants from 2007-2015 were Latino/as and 5 percent were African Americans (ICCGS Table 4.7). Although there are little data specific to solar and space physics, these REU data meet or exceed the representative percentages of Latino/a and African American groups graduating with a bachelor degree in physics[2] and astronomy.[3] However, as shown in Table C.1, the total number of Latino/as achieving bachelor's degrees in these fields has been significantly increasing, a growth that is not reflected in the diversity of REU participants from 2007-2015 (Table C.1). The number of Latino/a physics Ph.D.'s has increased nearly 300 percent over the last decade, with 8-12 awarded each year from 1997-2004 to an average of 32 awarded in both 2011 and 2012. The data for African American physics Ph.D.'s are not so positive. The number has stayed relatively constant with an average of 10-20 earned each year from 1997 to 2012.[4]

For women, the data on SHINE workshop students supported by the National Science Foundation from 2006-2009 show that only 31 percent were women, and that the absolute number per year has essentially stayed the same since 2007 (ICCGS Table 4.9), suggesting that progress toward equal representation has stalled.

[1] National Science Foundation, 2016, *Investments in Critical Capabilities for Geospace Science 2016 to 2025*, Geospace Section of the Division of Atmospheric and Geospace Science, February 5, https://www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf.

[2] American Institute of Physics (AIP), 2015, *African American Participation among Bachelor's in Physical Sciences and Engineering*, College Park, Md., https://www.aip.org/sites/default/files/statistics/minorities/africanamer-pse-13.1.pdf.

[3] AIP, 2014, *Hispanic Participation among Bachelor's in Physical Sciences and Engineering*, College Park, Md., http://files.eric.ed.gov/fulltext/ED550396.pdf.

[4] AIP, 2014, *Trends in Physics PhDs*, College Park, Md., https://www.aip.org/sites/default/files/statistics/graduate/trendsphds-p-12.2.pdf.

TABLE C.1 Numbers of Bachelor's Degree Recipients for Latinos(as) and African Americans in Physics and Astronomy

		2002[a]		2012[a]		**Δ 2002 to 2012**[a]	
		#	%	#	%	#	%
Total Bachelor's Degree Recipients	Latino/a	95,492	7.3	176,699	9.8	81,207	85.0
	Total	1,308,970		1,810,647		501,677	38.3
Physical Sciences	Latino/a	997	5.4	1,774	6.5	777	78.0
	Total	18,559		27,282		8,723	47.0
Physics	Latino/a	165	4.1	342	5.5	177	107.0
	Total	4,011		6,177		2,166	54.0
Astronomy	Latino/a	12	3.7	21	4.7	9	75.0
	Total	327		448		121	37.0
		2003[b]		2013[b]		**Δ 2003 to 2013**[b]	
		#	%	#	%	#	%
Total Bachelor's Degree Recipients	Af. Am.	120,175	8.4	168,981	9.1	48,806	40.6
	Total	1,423,725		1,865,429		441,704	31.0
Physical Sciences	Af. Am.	982	5.3	1,365	4.8	383	39.0
	Total	18,601		28,459		9,858	53.0
Physics	Af. Am.	151	3.6	153	2.3	2	1.0
	Total	4,256		6,725		2,469	58.0
Astronomy	Af. Am.	5	1.6	5	1.2	0	0.0
	Total	311		413		102	33.0

NOTE: Af. Am., African American.
[a] American Institute of Physics, 2014, *Hispanic Participation among Bachelor's in Physical Sciences and Engineering*, College Park, Md., http://files.eric.ed.gov/fulltext/ED550396.pdf.
[b] American Institute of Physics, 2015, *African American Participation among Bachelor's in Physical Sciences and Engineering*, College Park, Md., https://www.aip.org/sites/default/files/statistics/minorities/africanamer-pse-13.1.pdf.

D

Committee and Staff Biographical Information

TIMOTHY S. BASTIAN, *Chair,* is assistant director and head of the Science Support and Research department at the National Radio Astronomy Observatory, where he has been an astronomer since 1990. He is also an adjunct faculty member in the Astronomy Department at the University of Virginia. Dr. Bastian's research interests include solar and stellar radiophysics; planetary/exoplanetary radio emission; radio propagation phenomena as probes of the solar wind; radio interferometry; and the physics of flares and coronal mass ejections. He is currently the principal investigator on the ALMA Development Study to implement solar observing modes with ALMA. He serves as chair of the AAS Publications Board, and is a member of the NASA Living With a Star Steering Committee. Dr. Bastian previously served as scientific editor of the *Astrophysical Journal*. He earned his Ph.D. in astrophysics from the University of Colorado. For the National Academies of Sciences, Enginering, and Medicine, Dr. Bastian served on the Panel on Solar and Heliospheric Physics for the Decadal Strategy for Solar and Space Physics (Heliophysics), and he is currently a member of the Committee on Solar and Space Physics.

SUSAN K. AVERY, *Vice Chair,* is the former president and director of the Woods Hole Oceanographic Institution, having served in the position from 2008-2015. Avery was on the faculty of the University of Colorado, Boulder, from 1982 to 2008, most recently holding the academic rank of professor of electrical and computer engineering. Her research interests include studies of atmospheric circulation and precipitation, climate variability and water resources, and the development of new radar techniques and instruments for remote sensing. She also has a keen interest in scientific literacy and the role of science in public policy. She is the author or co-author of more than 80 peer-reviewed articles. A fellow of CIRES since 1982, Dr. Avery became its director in 1994. In that role, she facilitated new interdisciplinary research efforts spanning the geosciences and including the social and biological sciences. She spearheaded a reorganization of the institute and helped establish a thriving K-12 outreach program and a Center for Science and Technology Policy Research. She also worked with NOAA and the Climate Change Science Program to help formulate a national strategic science plan for climate research. She currently serves on the Committee to Advise the U.S. Global Change Research Program. Dr. Avery is a fellow of the Institute of Electrical and Electronics Engineers, the American Association for the Advancement of Science, and of the American Meteorological Society, for which she also served as president. She is a past chair of the board of trustees of the University Corporation for Atmospheric Research. She holds a master's in physics and a doctorate in atmospheric science from the University of Illinois. Recently she served on the Committee on a Survey of the

Active Scientific Use of the Radio Spectrum and as the chair of the Committee on the Review of the NSF's Division on Atmospheric and Geospace Sciences Draft Science Goals and Objectives.

MARCEL AGÜEROS is an assistant professor of astronomy at Columbia University. His research uses new data sets and technologies to address classic questions in stellar astrophysics. Dr. Agüeros's current focus is on combining large-scale, time-domain photometric surveys, spectroscopic campaigns, and X-ray observations to place observational constraints on the evolution of low-mass stars, and in particular to explore the relationship between a star's age, its angular-momentum content, and its magnetic activity. Previously, Dr. Agüeros was a National Science Foundation (NSF) Astronomy and Astrophysics post-doctoral fellow in Columbia's Astrophysics Laboratory. He received a NSF Faculty Early Career Development (CAREER) award in 2013 and a Presidential Early Career Award for Scientists and Engineers (PECASE) in 2016. Dr. Agüeros also directs the Bridge to the Ph.D. in the Natural Sciences Program, which is increasing the number of underrepresented minorities moving into STEM graduate programs. In 2008, the National Society of Black Physicists awarded him a Certificate of Excellence "in recognition of distinguished personal initiative on diversity in astronomy." Dr. Agüeros served on the NSF Astronomy Division's Portfolio Review Committee in 2011-2012. He earned his Ph.D. in astronomy from the University of Washington in 2006.

PETER M. BANKS assists the development of early-stage technology companies and is currently a member of the Board of Directors of Visual Communications, Inc. and Liberty Plugins, Inc. Dr. Banks provides expertise and advice for challenges facing young companies relative to their development plans, personnel, technologies, intellectual properties, financial needs, and fundraising. He is also active in the Academies, having served on the Reports Review Committee and as a senior advisor to the president of the National Academy of Sciences. Previously, Dr. Banks was a Partner in Red Planet Capital of Palo Alto, California. This venture capital investment firm was funded by NASA and provided the agency and employees with access to emergent high-technology developments of Silicon Valley and other technology-rich areas. During this period, Dr. Banks was a trustee and chair of the board of trustees of the Universities Space Research Organization, located in Greenbelt, Maryland. Prior to the above activities and over two decades, Dr. Banks was a director of two public companies (Tecumseh Products and X-Rite Corporation) and partner of XR Ventures, Inc., of Grand Rapids, Michigan. In the 1990s, Dr. Banks was dean of engineering and professor in the Atmospheres, Oceans and Space Science Department at the University of Michigan, then CEO of the Environmental Research Institute of Michigan, Ann Arbor. Dr. Banks' scientific expertise lies in the areas of space science, Earth remote sensing, climate change science, ionospheric physics, computer systems, and environmental science. He is a member of the National Academy of Engineering (NAE) and an affiliate of the National Academy of Sciences (NAS). He has received the Appleton Prize of the Royal Society (London), is a fellow of the American Geophysical Union (AGU), is a recipient of the AGU's Nicolet Award, and is a recipient of the Distinguished Public Service Award from NASA (for activities relating to the definition of scientific needs of the International Space Station). He has published over 200 articles in scientific literature. Dr. Banks received M.S.E.E. and Ph.D. (physics) degrees from Stanford and Pennsylvania State University, respectively. His university experience includes faculty appointments at the University of California, San Diego, Utah State University, Stanford University, and the University of Michigan. He has served on many National Academies activities, including the Committee on Assessment of NASA Laboratory Capabilities, the Report Review Committee, and the Committee on Space-Based Additive Manufacturing of Space Hardware.

GEORGE GLOECKLER is a distinguished university professor, emeritus, of the University of Maryland and research professor in the Climate and Space Sciences and Engineering Department at the University of Michigan. Dr. Gloeckler's research focuses on space plasma physics, particularly the properties of the local interstellar medium, such as its magnetic field, density and composition of its gas, and its interaction with the solar system. He is known for developing a new experimental measurement technique allowing observations of interstellar pickup ions and for pioneering discoveries and the invention of instruments carried on satellites and deep space probes, including the two Voyagers, Ulysses, and Cassini. Elected to the NAS in 1997, Dr. Gloeckler is also a fellow of the AGU and the American Physical Society and the recipient of the COSPAR Space Science Award. He earned his Ph.D. in physics from the University of Chicago. Dr. Gloeckler's most recent National Academies service was as a member of the Panel on Solar and Heliospheric Physics for the Decadal Strategy for Solar and Space Physics (Heliophysics). He currently serves on the Committee on Solar and Space Physics.

J. TODD HOEKSEMA is a senior research scientist in the W.W. Hansen Experimental Physics Laboratory at Stanford University. His primary scientific interests include the physics of the Sun and the interplanetary medium, the large-scale solar and coronal magnetic fields, solar velocity fields and rotation, helioseismology, solar-terrestrial relations, and education and public outreach. His professional experience includes research administration, system and scientific programming, and the design, construction, and operation of instruments to measure solar magnetic and velocity fields from both ground and space. He is co-investigator and magnetic team lead for the Helioseismic and Magnetic Imager (HMI) on NASA's Solar Dynamics Observatory and was instrument scientist for the Michelson Doppler Imager on the Solar and Heliospheric Observatory. He directs the Wilcox Solar Observatory at Stanford, with which he has been associated for more than three 11-year sunspot cycles. Dr. Hoeksema has chaired the Solar Physics Division of the American Astronomical Society (AAS) and the Solar Observatory Council of the Association of Universities for Research in Astronomy (AURA). He is currently the Secretary of the Solar and Heliophysics (SH) subsection of the Space Physics and Aeronomy (SPA) Section of the American Geophysical Union (AGU). He has served on the Heliophysics subcommittee of the NASA Advisory Council Science Committee. In 2004, NASA recognized Dr. Hoeksema's leadership in developing the roadmap for "Heliophysics" by awarding him NASA's Distinguished Public Service Medal. Dr. Hoeksema earned his B.A. from Calvin College and Ph.D. from Stanford University in applied physics. Dr. Hoeksema was a member of the Committee on Survey of Surveys: Lessons Learned from the Decadal Survey Process, the steering committee for the Decadal Strategy for Solar and Space Physics (Heliophysics), and the Astro2010 Panel on Optical and Infrared Astronomy from the Ground. He currently serves as co-chair of the Committee on Solar and Space Physics.

JUSTIN C. KASPER is an associate professor in the Climate and Space Sciences and Engineering Department in the University of Michigan's College of Engineering. Prior to his recent appointment at the University of Michigan, Dr. Kasper was an astrophysicist in the Solar and Stellar X-Ray Group in the High Energy Astrophysics Division of the Harvard-Smithsonian Center for Astrophysics and a Lecturer in the Department of Astronomy at Harvard University. Dr. Kasper has worked on the development, construction, and analysis of instrumentation for the in situ and remote measurement of particles and fields, including space-based plasma probes and particle telescopes such as the Faraday Cups on Wind, and ground-based radio telescopes including the Murchison Widefield Array (MWA). His major results concern heating, instabilities, and helium in the solar corona and solar wind, and the impact of space weather on society. He is currently the principal investigator (PI), SWEAP Investigation, Solar Probe Plus; instrument lead, Faraday Cup, Deep Space Climate Observatory; co-investigator, FIELDS, Solar Probe Plus; instrument lead, Solar Wind Experiment Faraday Cup, Wind spacecraft; co-investigator, Cosmic Ray Telescope for the Effects of Radiation, LRO; and PI of NASA and NSF grants to conduct investigations into the fundamental physics of solar corona and solar wind, including heating, instabilities, composition, shocks, magnetic reconnection, and radio emission. Dr. Kasper received his Ph.D. in physics from Massachusetts Institute of Technology. He was a member of the U.S. organizing and instrumentation committees for the 2007 International Heliophysical Year and the project scientist for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), on the Lunar Reconnaissance Orbiter. Dr. Kasper served on the steering committee for the Decadal Strategy for Solar and Space Physics and was the committee's liaison to, and member of, the decadal survey's Panel on Solar and Heliospheric Physics. He currently serves on the Committee on Solar and Space Physics.

KRISTINA A. LYNCH is a professor of physics in the Department of Physics and Astronomy at Dartmouth College. At Dartmouth, Dr. Lynch has led the design, manufacturing, testing, and launch of a number of NASA auroral sounding rocket payloads. Her research interests include instruments that measure ionospheric plasma particles and fields, the plasma physics of the lower thermal ionosphere, laboratory plasma physics used to develop space instrumentation, and developing and analyzing space mission architectures for low-resource ionospheric multipoint missions. Previously, Dr. Lynch was on the research faculty of the University of New Hampshire, in the Department of Physics and the Institute for Earth Oceans and Space. She is a recipient of an NSF Career Award.

She earned her Ph.D. in physics from the University of New Hampshire. She has served on several National Academies activities, including the Panel on Atmosphere-Ionosphere-Magnetosphere Interactions for the Decadal Strategy for Solar and Space Physics (Heliophysics), the Committee on Heliophysics Performance Assessment, the Committee on Solar and Space Physics, and the Committee on Plasma 2010: An Assessment of and Outlook for Plasma and Fusion Science.

TERRANCE G. ONSAGER is a physicist with the NOAA Space Weather Prediction Center. His research includes solar wind-magnetosphere coupling, modeling the signatures of magnetic reconnection at Earth's magnetopause and in the magnetotail, and the dynamics of the electron radiation belts. His recent efforts include coordinating the capabilities and priorities of international space weather organizations to improve global space weather services and working to bridge the gap between research and operations. Currently he is the director of the International Space Environment Service. He serves as co-chair of the World Meteorological Organization Inter-Programme Coordination Team on Space Weather. He received a Ph.D. in physics from the University of Washington with a focus on shock waves in collisionless plasma, using Earth's bow shock as a natural laboratory. Dr. Onsager has previously served as a member of the Committee on the Assessment of the Role of Solar and Space Physics in NASA's Space Exploration Initiative and a member of the Panel on Education and Society, and he is currently a member of the Committee on Solar and Space Physics.

AARON RIDLEY is a professor in the Department of Climate and Space Science and Engineering at the University of Michigan (UM). He previously served as a research scientist at the Southwest Research Institute. His research interests include modeling of the near-Earth space environment, ground-based instrumentation, and small satellites. Dr. Ridley currently has an active program for Fabry-Perot Interferometers in North America. He has been PI of three CubeSats, including CADRE and two CubeSats for the European QB50 mission, each of which will measure the state of the upper atmosphere. Dr. Ridley has received the UM's College of Engineering Monroe-Brown Foundation Education Excellence Award, the NASA Group Achievement Award, the UM's College of Engineering Outstanding Research Scientist Award, and the Most Cited Paper (2005-2010) for the *Journal of Atmospheric and Solar-Terrestrial Research*. He earned a B.S. from Eastern Michigan University, and a M.S. and Ph.D. in atmospheric and space science from the University of Michigan. He currently serves on the Committee on Solar and Space Physics.

NATHAN A. SCHWADRON is a professor at the University of New Hampshire's (UNH) Institute for the Study of Earth, Oceans, and Space and in UNH Department of Physics in the Space Science Center. He also serves as the PI for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on the LRO mission and the PI for the Dose Spectra from Energetic particles and Neutrons (DoSEN) instrument. He serves as the science operations lead for the Interstellar Boundary Explorer Mission, and the science operations lead on Solar Probe Plus (SPP) Integrated Science Investigation of the Sun. Dr. Schwadron is the PI for NASA/NSF/LWS Strategic Capability Earth-Moon-Mars Radiation Environment Module (EMMREM) and is the co-lead of the NSF/FESD Sun-2-Ice project that studies particle acceleration and radiation interactions from the Sun through the Earth system. Dr. Schwadron is the NASA/NSF/LWS strategic capability lead of the recently selected Chromosphere-Solar-Wind and Energetic Particle Acceleration (C-SWEPA) Model. Dr. Schwadron's previous experience includes positions as an associate professor of astronomy at Boston University; senior research scientist, principal scientist, and staff scientist at the Southwest Research Institute; assistant research scientist at the University of Michigan; senior research scientist at the International Space Science Institute in Bern, Switzerland; and postdoctoral scholar at the University of Michigan's Atmospheric, Oceanic and Space Science Department. Dr. Schwadron's research interests include heliospheric phenomena related to the solar wind, the heliospheric magnetic field, pickup ions, cometary X-rays, energetic particles, cosmic rays, energetic neutral atoms, space weather and radiation hazards and effects. He received a B.A. with honors in physics from Oberlin College and a Ph.D. in physics from the University of Michigan. Dr. Schwadron served as a member of the National Academies Panel on Solar and Heliospheric Physics for the Committee for a Decadal Strategy for Solar and Space Physics (Heliophysics) and the Committee on Priorities for Space Science Enabled by Nuclear Power and Propulsion: A Vision for Beyond 2015. He currently serves on the Committee on Solar and Space Physics.

MARIA SPASOJEVIC is a senior research scientist at Stanford University in the Department of Electrical Engineering. Her research focuses on global aspects of space weather including the dynamics of the plasma populations in the Earth's inner magnetosphere (plasmasphere, ring current, and radiation belts), the generation of plasma waves, and the interaction of these waves with ions and electrons over a wide range of energy. She has served on the NSF's Geospace Environment Modeling steering committee as a student representative and as a member and was leader for the focus group on Plasmasphere-Magnetosphere Interactions. She served as Magnetospheric Physics representative for the AGU's Outstanding Student Paper Award organizing committee and as community representative on the Management Operations Working Group for the Geospace Sciences cluster of NASA's Heliophysics division. Dr. Spasojevic earned her B.S. in electrical engineering from Worcester Polytechnic Institute and her M.S. and Ph.D. in electrical engineering from Stanford University.

STAFF

ABIGAIL A. SHEFFER, *Study Director*, is a program officer for the Space Studies Board (SSB) of the National Academies. In fall 2009, Dr. Sheffer served as a Christine Mirzayan Science and Technology Policy Graduate Fellow for the National Academies and then joined the SSB. Since coming to the National Academies, she has been the staff officer and study director on a variety of activities such as the Committee on Solar and Space Physics, *Achieving Science With CubeSats: Thinking Inside the Box*, *Sharing the Adventure with the Student: Exploring the Intersections of NASA Space Science and Education—A Workshop Summary*, *Landsat and Beyond—Sustaining and Enhancing the Nation's Land Imaging Program,* and *The Effects of Solar Variability on Earth's Climate: A Workshop Report*. Dr. Sheffer has been an assisting staff officer on several other reports, including *Pathways to Exploration—Rationales and Approaches for a U.S. Program of Human Space Exploration* and *Solar and Space Physics: A Science for a Technological Society*. Dr. Sheffer earned her Ph.D. in planetary science from the University of Arizona and A.B. in geosciences from Princeton University.

ANESIA WILKS is a senior program assistant. Ms. Wilks began working at the National Academies in the conference management office and later transferred to the Division on Engineering and Physical Sciences, where she began working on administrative roles for different projects. She is currently working on the Committee on Propulsion and Energy Systems to Reduce Commercial Aviation Carbon Emissions and the Space Technology Industry-Government-University Roundtable, among various other projects. Ms. Wilks has a B.A. in psychology, magna cum laude, from Trinity University in Washington, D.C.

CHARLES HARRIS was a research associate for the SSB and the Aeronautics and Space Engineering Board (ASEB) until August 2016. He graduated from the University of North Carolina, Chapel Hill, in 2014 with a double major in public policy and communication studies, and a minor in astronomy. He has served as an intern with NASA's Space Technology Mission Directorate at NASA Headquarters and with the Committee on Science, Space, and Technology in the U.S. House of Representatives. He has also worked as a junior associate with an independent policy firm focused on providing clients in the commercial space sector with government relations services and strategic consulting.

CHERIE ACHILLES was a Lloyd V. Berkner Space Policy Intern with the SSB. Dr. Achilles is a Ph.D. student studying geosciences at the University of Arizona. Her research focuses on Martian surface materials, specifically the crystalline and amorphous phases comprising rocks and sediments analyzed by the Mars Science Laboratory (MSL) rover. Prior to entering graduate school, Dr. Achilles received a B.Sc. in molecular and cellular biology and in microbiology from the University of Arizona. From 2005-2008, she was a member of the engineering and operations team for the Surface Stereo Imager on the Phoenix Mars Lander. Following the Phoenix mission, Dr. Achilles joined the Astromaterials and Research Exploration Science group at NASA Johnson Space Center (JSC). While at JSC, she was involved in several Mars-related research projects and became a member the MSL Science Team working with the CheMin instrument. In addition to her involvement with the Mars research group, she contributed to the analysis of interplanetary dust particles as well as the sampling and analysis of hypervelocity impact structures from space hardware (e.g., space shuttle, the International Space Station). Dr. Achilles left JSC in 2013 to pursue her Ph.D. but continues her involvement in CheMin operations and research while at Arizona.

CAROLINE JUANG was a Lloyd V. Berkner Space Policy Intern with the SSB for summer 2016. Ms. Juang is studying Earth and planetary sciences with a minor in environmental science and public policy at Harvard University. She is most interested in climate, energy, space, and their intersections with public policy. In the past, Ms. Juang has interned with NASA Goddard Space Flight Center, the Smithsonian National Air and Space Museum, and the Joint U.S.-China Collaboration on Clean Energy. Most recently she interned at Harvard Forest, where she curated a mobile-friendly, online virtual tour for their newest recreational trail that includes both historical knowledge and ongoing research in the forest.

MICHAEL H. MOLONEY is the director for Space and Aeronautics at the SSB and the Aeronautics and Space Engineering Board (ASEB) of the National Academies. Since joining the ASEB/SSB Dr. Moloney has overseen the production of more than 60 reports; including five decadal surveys—in astronomy and astrophysics, Earth science and applications from space, planetary science, microgravity sciences, and solar and space physics—prioritizations of NASA space technology roadmaps, a major report on the rational for and future direction of the U.S. human spaceflight program, as well as reports on issues such as NASA's Strategic Direction, lessons learned from the decadal survey processes, the science promise of CubeSats, the challenge of orbital debris, the future of NASA's astronaut corps, NASA's aeronautical flight research program, and national research agendas for autonomy and low-carbon propulsion in civil aviation. Since joining the Academies in 2001, Dr. Moloney has also served as a study director at the National Materials Advisory Board, the Board on Physics and Astronomy (BPA), the Board on Manufacturing and Engineering Design, and the Center for Economic, Governance, and International Studies. Dr. Moloney has served as study director or senior staff for a series of reports on subject matters as varied as quantum physics, nanotechnology, cosmology, the operation of the nation's helium reserve, new anti-counterfeiting technologies for currency, corrosion science, and nuclear fusion. Before joining the SSB and ASEB in 2010, Dr. Moloney was associate director of the BPA and study director for the 2010 decadal survey for astronomy and astrophysics (New Worlds New Horizons in Astronomy and Astrophysics). In addition to his professional experience at the Academies, Dr. Moloney has more than 7 years' experience as a foreign-service officer for the Irish government—including serving at the Irish Embassy in Washington and the Irish Mission to the United Nations in New York. A physicist, Dr. Moloney did his Ph.D. work at Trinity College Dublin in Ireland. He received his undergraduate degree in experimental physics at University College Dublin, where he was awarded the Nevin Medal for Physics. Dr. Moloney is a corresponding member of the International Academy of Astronautics and a Senior Member of the American Institute of Aeronautics and Astronautics. He is also a recipient of a distinguished service award from the National Academies of Sciences, Engineering and Medicine.

E

Acronyms

AAGS	American Association for Geodetic Surveying
AC	advisory committee
AER	Aeronomy Program
AGS	Division of Atmospheric and Geospace Sciences
ALMA	Atacama Large Millimeter/submillimeter Array
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AO	Arecibo Observatory
APS	American Physical Society
ARRA	American Recovery and Reinvestment Act
AST	Division of Astronomical Sciences
CAREER	Faculty Early Career Development program
CCMC	Consortium of Resonance and Rayleigh LIDARS
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CISL	Computational and Information Systems Lab
CRRL	Consortium of Resonance and Rayleigh Lidars
DASI	distributed arrays of small instruments
DKIST	Daniel K. Inouye Solar Telescope
DOD	Department of Defense
DOE	Department of Energy
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DYNAMIC	Dynamical Neutral Atmosphere-Ionosphere Coupling
EHR	Directorate for Education and Human Resources
EISCAT	European Incoherent Scatter Scientific Association
ENG	Directorate for Engineering
EPSCoR	Experimental Program to Stimulate Competitive Research

FDSS	Faculty Development in Space Science
GEM	Geospace Environment Modeling
GEO	Directorate for Geosciences
GOLD	Global Observations of the Limb and Disk
GONG	Global Oscillations Network Group
GS	Geospace Section
GSO	Geospace System Observatory
HAO	High Altitude Observatory
HF	high frequency
HSO	Heliophysics System Observatory
I&V	Innovation and Vitality
ICCGS	Investments in Critical Capabilities for Geospace Science 2016 to 2025
ICON	Ionospheric Connection Explorer
IGS	Integrative Geospace Science
INCLUDES	Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science
INSPIRE	Integrated NSF Support Promoting Interdisciplinary Research and Education
ISR	incoherent scatter radar
IUSE	Improving Undergraduate STEM Education
JRO	Jicamarca Radio Observatory
LIDAR	light detection and ranging
LISN	Low-latitude Ionospheric Sensor Network
M&O	management and operations
MAG	Magnetospheric Physics Program
MEDICI	Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation
MMS	Magnetospheric Multiscale
MPS	Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
MRI	Major Research Instrumentation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NISP	NSO Integrated Synoptic Program
NOAA	National Oceanic and Atmospheric Association
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NSF	National Science Foundation
NSO	National Solar Observatory
NSWS	National Space Weather Strategy
OASIS	Observatory for Atmosphere Space Interaction Studies
PFISR	Poker Flat incoherent scatter radar
PI	principal investigator

PLR	Polar Program
PM	program manager
PRC	Portfolio Review Committee
PREEVENTS	Prediction of and Resilience against Extreme Events
REDI	Research, Education and Development Initiative
REU	Research Experiences for Undergraduates
RFI	request for information
RISR-N	Resolute Bay incoherent scatter radar
SEES	Science, Engineering, and Education for Sustainability
SHINE	Solar, Heliospheric, and Interplanetary Environment
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SSB	Space Studies Board
STEM	science, technology, engineering, and mathematics
STR	Solar Terrestrial Program
SuperDARN	Super Dual Auroral Radar Network
SW REDI	Space Weather Research, Education and Development Initiative
SWAP	Space Weather Action Plan
SWM	space weather modeling
SWP	Space Weather and Prediction
SWR	space weather research
USRA	Universities Space Research Association