Review of the National Science Foundation's Division on Atmospheric and Geospace Sciences Draft Goals and Objectives Document

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Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

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

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Although the reviewers listed above have provided constructive comments and suggestions, they were not asked to endorse the views of the committee, nor did they see the final draft of the report before its release. The review of this report was overseen by Thomas H. Vonder Haar, Colorado State University, Fort Collins, appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring panel and the institution.

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July 16, 2014

Dr. Scott G. Borg
Acting Division Director
Atmospheric and Geospace Sciences
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Dear Dr. Borg:

In the summer of 2013, Michael Morgan, Director of the National Science Foundation's (NSF) Division of Atmospheric and Geospace Sciences (AGS), approached the National Research Council's Board on Atmospheric Sciences and Climate (BASC) to ask for a review of an upcoming AGS draft goals and objectives document. These goals and the objectives are for the years 2014–2018. BASC assembled a committee of eight members and charged it with addressing the following questions with respect to the draft document provided on March 7, 2014 (See Appendix A for the committee's complete statement of task [SOT]):

1. Are the goals and objectives clear and appropriate?
2. Are there any content areas missing from the draft that should be present if AGS is to achieve its overall vision and mission?
3. Are there adequate mechanisms for coordinating and integrating issues that involve multiple disciplines and multiple divisions within NSF and other agencies within the atmospheric and geospace sciences enterprise?

AGS also asked the committee to organize a public workshop and engage the atmospheric and geospace sciences community to provide feedback on the draft. The discussion-oriented community workshop was held on March 31-April 1, 2014 at the Keck Center of the National Academies in Washington, DC. More than 45 experts from academia and AGS participated in the 1.5-day workshop. The committee developed the agenda and selected participants who took part in plenary and small group discussions. The workshop was designed to seek specific input on the draft by asking invited workshop participants to share their views in the context of the questions listed above. The majority of participants also wrote "mini reviews" of the document to prepare for the workshop discussions[1]. These mini-reviews and the discussions at the workshop were helpful to the committee in formulating the views expressed in this letter report.

[1] These mini reviews were shared with AGS and are available through the Public Access Records Office.

The committee also considered information gained in discussions with AGS leadership and from the relevant literature when writing this report. The committee had two meetings (including the workshop) to deliberate and review the goals and objectives document (hereafter referred to as "the Document") based on the SOT questions. The committee reviewed the Document as an initial draft and hopes that the suggestions offered here will aid in revisions leading to the final product.

In the review of the Document, it was clear that later sections (pages 21-28), which offer a flavor of program achievements and resources available to the community, are incomplete and only broadly sketched out. It is feasible that this material could be incorporated into the descriptions of the goals as described earlier in the Document (e.g., examples of past activities and progress; key current and near-future investments). However, the purpose of these later sections is not clear because no context or introduction is provided. Furthermore, there is no clear relationship between the goals and these sections. The committee did not review these sections in detail since they do not have any actual or perceived influence on future AGS activities nor are they directly relevant to the three questions in the SOT.

First, this report discusses two key missing pieces from the Document that should be present to help AGS achieve its overall vision and mission [SOT question #2]: (1) clarification of the context and purpose of the Document and; (2) the role of AGS in the context of the national research portfolio. Second, the report makes some observations and recommendations regarding document organization and the definition and articulation of the individual goals. For each goal, the report addresses its appropriateness and identifies missing content [SOT questions #1 and #2]. Finally, the report makes recommendations on how the Document can more clearly articulate collaboration within AGS and NSF, as well as nationally and internationally [SOT question #3].

CONTEXT AND PURPOSE OF THE GOALS AND OBJECTIVES DOCUMENT

As noted by AGS leadership at the workshop, a strategic planning document that sets forth missions, long-term goals, and means to achieve those goals, has not been developed for AGS in decades. They referred to a 2007 NRC report that provided guidance to NSF's Division of Atmospheric Sciences (ATM, the former name of the AGS Division) on its strategy for supporting research to achieve the nation's scientific and education goals in the atmospheric sciences. They highlighted a single conclusion from that report: "…the strategic plan itself will be useful to ATM, but the process of producing it may prove even more valuable, particularly if it is conducted with ample and transparent community engagement." Furthermore, the strategic planning process serves as a mechanism for the community as a whole to participate in an active conversation about the direction of the field and where best to use resources, while remaining sensitive to the societal expectations of that research (NRC,2007).

This committee commends AGS for taking initial steps toward strategic planning, as recommended in the NRC 2007 report, *Strategic Guidance for the National Science Foundation's Support of the Atmospheric Science*, by drafting a goals and objectives document and engaging in a community workshop to discuss it.

It was clear from discussions with AGS that the Document is not intended to be an AGS strategic plan. However, in the committee's view, the revised Document could serve as a first step toward the development of a formal AGS-wide strategic plan while also informing the Directorate of Geosciences

(GEO) Strategic Plan. An AGS strategic document would need to be forward- looking and provide a timeline for accomplishing the goals and a means for assessing progress. It would also help AGS achieve its overall vision and mission. The committee recognizes that undertaking such a task would require a significant investment of human resources and time.

The Document states that the purpose is to provide input to the GEO Strategic Plan. However, AGS also identified several additional disparate purposes at the community workshop: as a communication tool to orient potential and new investigators; as guidance for the new AGS director; as planning guidance to the National Center for Atmosphere Research (NCAR)[2]; as a tool to foster more coordinated thinking across AGS programs; and as a benchmark for assessing near-term AGS activities. It bears noting that there is an apparent mismatch between the timeline for finalizing the Document and some of the intended purposes. For example, the timing of the release of the Document likely will not serve planning purposes outside of NSF, and possibly even outside of AGS, until 2015.

The multiple purposes of the Document should be distinguished in order of priority, as text suitable for one purpose might not be suitable for another. Are the goals intended to reflect the current research portfolio, to predict the future research portfolio, or to guide the future research portfolio? Is the Document's purpose descriptive or evaluative?

It was challenging to review the Document in this context and determine the appropriateness of the goals and identify missing content. Thus, some advice found in this report might be more relevant than other suggestions, depending on which purposes take priority. For example, in the following section, the committee suggests that the Document provide context on the structure of AGS and the various ways it funds research. This context is not essential if the Document will solely be used as input into the GEO strategic plan. However, if the Document will be used to orient new investigators, then this context would add value.

Finally, serving multiple audiences can dilute the impact of the Document. Clearly stating the intended audience and how the Document was created is essential in establishing the context of the remainder of the Document.

AGS IN THE CONTEXT OF THE NATIONAL RESEARCH PORTFOLIO

Discovery-Driven Science at AGS

AGS supports research to add new understanding of the behavior of the Earth's atmosphere and its response to the sun. AGS research focuses on: (1) studies of the physics, chemistry, and dynamics of Earth's upper and lower atmosphere and its space environment; (2) research on climate processes and variations; and 3) studies to understand the natural global cycles of gases and particles in Earth's atmosphere. AGS leadership used the following statements to describe the mission and vision of AGS.[3]

[2] For more information on NCAR, see a later section of this report: *NCAR's Role within AGS*

[3] These are not official Mission or Vision statements.

Mission of AGS

To extend intellectual frontiers in atmospheric and geospace sciences by making responsible investments in fundamental research, technology development, and education that enable discoveries, nurture a vibrant, diverse scientific workforce, and help attain a prosperous and sustainable future.

Vision of AGS

To excel at being the "home" for support of curiosity-driven research in the atmospheric and geospace sciences while also being responsive to community-vetted, national science priorities.

Including the vision of AGS in the introductory section of the Document would help establish the motivation for the goals. Additional background information about the structure of AGS and the various ways in which it funds and supports research and education is also needed, especially if the Document will be used to orient new investigators.

The Document does not provide sufficient context about the range of research supported by AGS and why it is important. AGS is unique among other Federal agencies that support atmospheric research. As articulated in the mission and vision above, AGS is focused on the discoveries that transform our understanding of the atmosphere. Other Federal agencies that support atmospheric research, such as the Department of Energy (DOE), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautic and Space Administration (NASA), are mission-driven, and their research is therefore largely applications oriented (though all fund some basic research in direct support of their missions). A strong AGS is one that continues to focus on new discoveries and knowledge that can be translated to support solutions to a variety of socio-economic problems while also recognizing the leveraging capabilities of the other atmospheric agencies. The committee endorses the recommendation from NRC (2007) that "ATM preserve opportunities for basic research, especially projects that are high risk, potentially transformative, or unlikely to be supported by other government agencies."

The university research portfolio supported by AGS relies almost solely on investigator-driven research. AGS prides itself on the fact that it issues no solicitations for individual and small group investigator projects and conducts few panel reviews, relying instead on the innovative and transformative ideas that come forth from individual or small teams of scientists. This policy is attractive in its reliance on the strength of grassroots ideas to frame and form the AGS program. Nevertheless, decadal surveys, NRC reports, and strategic plans that are undertaken by GEO or other relevant federal and international agencies provide AGS and the PI community a sense of national and international priorities. Setting the context of AGS within these larger efforts could be addressed by discussing the relative importance within AGS of PI proposal driven research versus targeted requests for proposals, and funding for centers and research infrastructure and facilities.

The Document fails to clearly articulate the diverse approaches AGS supports to successfully conduct research in the context of national and international research priorities.

NCAR's Role within AGS

A significant part of AGS's budget is allocated for the Federally Funded Research and Development Center (FFRDC) called the National Center for Atmospheric Research (NCAR). In 1958, an NRC Committee on Meteorology recommended the establishment of a large research center that would work in conjunction with US universities to take on ambitious projects and provide the advanced instruments, observing platforms, computers, and facilities needed to push atmospheric sciences forward (NRC, 1958). This recommendation led to the development of NCAR.

Throughout its history, NCAR has been intimately connected with both university and private sector research activities that utilize the observational facilities and modeling capabilities it has developed and maintained. However, the Document does not adequately present the symbiotic relationship between NCAR and the broader AGS research community. Although NCAR is a significant portion of the AGS portfolio, the Document does not clearly describe how NCAR activities contribute to and are integrated with the AGS goals and objectives. How does AGS view the role of NCAR in a strategically integrated Division? Furthermore, NCAR is currently developing its own 2014-2019 strategic plan.[4] How will the NCAR strategic plan coordinate with the goals and objectives for AGS?

Rather than a simple enumeration of the many contributions made by NCAR, the Document should discuss the strength, breadth, and scalability that AGS gains by virtue of its FFRDC's support of the university and private sector research communities.

DOCUMENT ORGANIZATION AND STRUCTURE

The individual sections of the Document are inconsistently organized with uneven levels of detail. Large differences in length might be appropriate if they correspond to differences in budgets and sizes of research portfolio, but that does not seem to be the case.

Likewise, sections addressing individual draft goals are not written in a consistent style and have different structures and levels of detail. Each goal generally contains several subsections (e.g., Rationale, Implementation, and Future Investments) as well as a descriptive subsection for the goal. The Document is unclear about what information each of these subsections is intended to convey, and the subsectional organization differs from goal to goal. The Implementation subsections are organized in bullet format and other subsections are written in narrative format. All subsections include specific areas for potential investment, with no obvious reason for placing an area in a particular subsection. The Implementation subsections tend to contain a finer level of detail and appear to be intended to describe current activities. The Future Investment subsections describe planned changes of emphasis, while the descriptive subsections seem to contain overviews of the field or descriptions of past NSF investments. There is little mention of coordination mechanisms for each of the goals except for a listing of interagency partners.

The organizational structure of the Document is weak and the presentation of the material is not balanced. It would be improved if the discussion of each goal contained the following:

- **scope, importance, and rationale for the goal**
- **examples of past activities and progress**

[4] http://ncar.ucar.edu/directorate/documents/ncar-strategic-plan-2014-2019

- **key current and near-future investments**
- **anticipated future areas of emphasis**
- **discussion of partners and coordinating mechanisms**

SPECIFIC COMMENTS ON AGS GOALS

In general, goals are broad statements about desired achievements. Objectives are specific supporting achievements that can be accomplished within the plan timeline.

The six main goals that serve as the section headers are not formulated as goals that can be achieved in a four year window, but as research, educational or capability development themes[5] under which multiple goals can be articulated. They reflect activities supported by AGS and the degree to which research priorities arise from the research community rather than simply being dictated by AGS staff.

Some questions that could be asked of more specific goals include:

- Why are the goals relevant to the period 2014-2018? Are these goals different from AGS goals heretofore? Will they change after 2018?
- How is progress toward the goals to be assessed? Are there metrics, or even notional measures of progress? Are all elements of the goals to be met, or just some?
- How is prioritization accomplished within the goals?
- What are the challenges and impediments associated with achieving the goals? How will they be addressed?
- How do the goals evolve as unanticipated discoveries are made during the relevant period 2014-2018?

Given that most AGS investments are proposal-driven, the Document cannot be all encompassing, and does not represent the broad spectrum of research that AGS funds. This fact is not made clear in the Document. Several of the goals use the term "understand" which is ambiguous, and replacing it with more specific wording would reflect the quantitative nature of the science.

The three science goals on climate, atmospheric composition, and sun/earth coupling appear to be linked to specific AGS programs and sections (e.g., the Climate and Large-Scale Dynamics program, the Atmospheric Chemistry program and the Geospace section, respectively). On the other hand, the extreme events and high hazards science goal clearly spans many AGS programs. Workshop presentations and discussions involving AGS staff strongly indicate they had intended all four science goals to cut across large portions of the AGS research portfolio. The Document should emphasize that several AGS (and GEO) programs contribute to each goal. Some common integrative themes related to AGS research in atmosphere and space science emerged from the workshop discussions: couplings between disparate spatial and temporal scales; interconnections across regional and physical boundaries; and utilization and interpretation of large-scale observational and numerical simulation data sets. Furthermore, the last two goals on infrastructure and workforce should link to and complement the science goals.

[5] To be consistent with the document under review, this report still refers to them as "goals".

Expanding the four science goals to reflect their cross cutting integration of major efforts within AGS would reflect a more forward-looking, integrative approach that unifies research activities across the Division.

The following sections are comments about the appropriateness and clarity of each goal put forth in the Document as well as missing content.

Goal: Observe, Understand, and Model Extreme Events and Associated Relevant High Impact Events

This goal clearly engages multiple AGS and other NSF programs. However, its Implementation subsection is very uneven. Some bullets encapsulate large amounts of general research, while others identify very specific items that do not seem to rise to the level of high priorities. Lake-effect snow research is highlighted even though other topics such as tropical cyclones, analysis of data from the Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2), and analysis of cases of hazardous geospace events are not adequately addressed. Other items that appear overly specific to the topic of hazards include gravity waves, the Thermosphere Ionosphere Electrodynamic General Circulation Model (TIE-GCM), and the Cyber Experimentation and Test (CSET). The remaining subsection includes material that other goals break into two subsections. For consistency and as recommended in the previous section, a similar structure and level of detail should be employed here.

The discussion of the goal would be strengthened if it included a definition of extreme events and high impact hazards that encompasses the full spectrum of hazards from the ground through geospace. This includes events that occur on multiple time scales, such as air stagnation/pollution, heat waves, and extreme space weather. Examples of research on hazards could include:

- underlying interdependent physical processes that give rise to such hazards;
- space and time scale interactions such as seasonal prediction of extreme weather, and the study of hazards aggravated by a changing climate;
- human interactions with hazards;
- assessment and communication of risk; and
- understanding of vulnerability, risk, and resilience.

Goal: Advance the State of Knowledge and Understanding of Earth's Climate

This goal is generally appropriate and clear. It provides the right level of detail describing certain facets of implementation, current activities and accomplishments, and future investment. However, the Rationale subsection does not sufficiently articulate the societal benefits of NSF-supported fundamental climate research. Including a more compelling description of the national and international importance of research on climate variability and change would strengthen the Document. For example, the Global Change Research Act of 1990 and the most recent articulation of the goals of the U.S. Global Change Research Program compel NSF to help inform and enable timely decisions on climate change adaptation and mitigation (USGCRP, 2013). The description of this goal is also an opportunity to highlight the impact of climate on society and conversely the impact of human activities on climate.

The goal is particularly well suited for a systems approach. However, in general, climate is discussed in the Document as an isolated atmospheric phenomenon that does not include the ocean, land surface,

sea ice and glacial ice sheets, the geospace environment, and solar radiation, all of which influence climate change. There should also be an acknowledgment of the critical dependence of the climate modeling enterprise on software development, visualization, documentation and maintenance, as well as high-end computational resources.

Although there are several important activities and programs mentioned as examples of AGS investments, there are several aspects of fundamental research on climate that have not been included in the Document. Such research includes:

- the importance of paleoclimate studies, both for providing a better understanding of Earth history and as context for climate variability and change;
- the challenge of measuring and modeling the water cycle;
- the relevance of and potential role that is played by the Arctic in both amplifying global climate change and interacting with weather and climate in the lower latitudes (NRC, 2014; links directly to Polar Programs division of GEO);
- important unresolved climate change questions (e.g., the causes of the current global warming hiatus and whether the probability distribution of climate variables is shifting or changing shape); and
- the seamless nature of weather and climate, including both processes and methods for measuring and modeling that are common to both. The seamless approach has the potential to advance predictability of regional climate variability and change on seasonal to decadal time scales (e.g., Brunet et al., 2010; Hazeleger et al., 2010; NRC, 2010).

Additional missing content in the Document includes:

- Examples of specific processes that are climate-relevant, e.g., formation and dissipation of low-level clouds; interaction of radiatively active species with natural variability; the role of the stratosphere in large-scale atmospheric dynamics; and the influence of biota on atmospheric composition and the impact of chemical and dynamical fluxes on climate.
- How AGS will support interactions of climate scientists with social scientists and societal stakeholders to promote better communications, greater transparency, free and open data access, contributions to national and international assessments, interactions with relevant organizations, and decision support.

Goal: Expand Knowledge of Earth's Atmospheric Composition and Behavior

The Rationale for this goal focuses on aerosols and their effects on climate, and oxidants that determine the lifetimes of greenhouse gases (e.g., methane and hydrohalocarbons). It should include air quality in addition to chemistry-climate connections. The Implementation lacks a coherent framework. It lists several field programs and numerous research sub-topics in a somewhat disorganized manner (e.g., two overlapping subsections on nitrogen) and in more detail than is needed. The Implementation is too long and could be shortened by using selected examples with more of a high level overview. It should follow from the topics called out in the Rationale.

Although several important research areas are discussed, the Document does not articulate key areas of uncertainty. It appropriately considers several key research modes used in atmospheric chemistry, namely field measurement programs, laboratory studies, quantification of fluxes, and elucidation of

transport mechanisms. The Document calls appropriately for analysis of results from recent field programs.

To make this an AGS-wide goal, the title should be revised and the subsequent discussion should be expanded to include investigating the processes that influence the composition of the Earth's atmosphere, including the mesosphere, thermosphere, and geospace.

The discussion of the goal would be strengthened if it included:

- The utility of field data for model evaluation and development, or of models for interpreting field data in a larger context. Models are hardly mentioned in the context of this goal, even though they are used to integrate understanding of the mechanisms affecting atmospheric composition and how it has changed and may change in the future.
- The two-way nature of the interaction between atmospheric composition and climate. There is no mention of chemistry-climate modeling, the interdisciplinary research field that investigates this two-way coupling. For example, the frequency and severity of pollution episodes are affected by climate, and changes in stratospheric ozone affect large-scale circulation (Jacob and Winner, 2009; WMO, 2010).

Goal: Understand the Sun and Geospace Environment as a Coupled System.

The goal is appropriate, however the title should reflect the need to investigate the Sun, geospace, and the atmosphere environments as coupled systems. The description of this goal does an excellent job of integrating the objectives of the Geospace Section. As written, the goal explains how the various programs within the Geospace Section work together to study a complex coupled system. It also has an appropriate level of detail and is a suitable length.

The discussion of the goal would be strengthened if it included a description of how the work of the Geospace Section is coupled to and integrated with the rest of AGS. Currently one bullet in the Implementation focuses on the coupling of the lower atmosphere to the geospace system. The two-way coupling between the lower atmosphere and the near geospace environment as well as the coupling between the Sun and geospace system should be included in the broader descriptions of this goal that appear in the Rationale and Future Investment sections.

Goal: Build a Competent and Diverse Scientific Workforce

This goal represents long-standing and important portions of the AGS portfolio. The educational challenge of ensuring the coming generations of researchers in AGS fields are both highly competent and represent the full range of our nation's diverse population are NSF-wide charges to all research areas supported by the Foundation. US geoscientists have historically been well trained and highly productive; however women and most minorities have not been adequately represented, presenting AGS with a serious challenge.

The Rationale for this goal is clear. The Implementation is mainly focused on existing programs supported by AGS. Overall these are quite comprehensive, and aimed at expanding the workforce to include women and under-represented minorities and advancing the development of researchers at many stages of their careers. Some of the Implementation items require further detail. For example,

"Identify and remedy bottlenecks and 'leaky pipeline' issues" - how does AGS intend to do this? The section on Competent and Diverse Workforce is largely a repetition of the prior Implementation list, and it is not clear what this adds to the Document. Finally, the section on Future Investment is focused mainly on undergraduate education, though it is not articulated why this is the priority for future investment over the other areas of career development.

This goal is quite comprehensive, with a long list of ongoing activities. However, the discussion of the goal would be strengthened if it included:

- An assessment of the effectiveness of the different existing programs including those that were designed to broaden participation by women and under-represented minorities.
- A description of AGS activities and priorities in the context of growing needs for a scientific workforce with capabilities in new model development, new instrument development, the use of large datasets (analysis and visualization), and science communication.

Goal: Provide Research Infrastructure to Advance Understanding

AGS develops, provides and supports, in many cases through its support of NCAR, a great many observational facilities, cyber infrastructure, and computational models. Atmospheric and solar/geospace sciences are global activities requiring major observational platforms and instrumentation, as well as computational software and hardware, well beyond the capacity of individual research groups and even most academic and research institutions.

The research infrastructure goal reads as a list of existing facilities and is not forward looking nor does it provide a sense of priorities. In the current restricted funding environment choices between operational support for existing observational and computational facilities and the development of new facilities are difficult, but vitally important.

The discussion of the goal would be strengthened if it included:

- A description that views the observational and computational facilities as a coherent suite that provides the means of observing the entire sun-geospace-atmosphere system, modeling the coupled system and its component parts on a variety of space and temporal scales, and analyzing both the observations and model outputs. This perspective will allow a clearer view of gaps and duplications and aid in formulating a coherent plan for deciding priorities between maintaining existing infrastructure and developing new facilities.
- An identification of current gaps, and how these may be addressed by AGS activities in upcoming years (e.g., miniaturized sensors, ruggedized sensors, unmanned aerial vehicles, ship- and airborne radars, and an expanded CubeSat program.).
- Plans that more fully and transparently involve the research community in evaluating the existing observational and computational facilities and the potential value of future facilities.

COORDINATION

All of the goals have components that are inherently interdisciplinary and often would require interagency cooperation as well as interdivisional and inter-directorate work within NSF itself. Thus, addressing coordinating and integrating science efforts is central to an effective strategic plan for AGS.

Each goal description (except for the one on workforce) simply lists other agencies that may cooperate with AGS to attain identified goals. Such a list does not give adequate specificity to be actionable in an AGS planning document. The goal to "understand the sun and geospace environment as a coupled system" is the most comprehensive of all the goals in describing coordination mechanisms. It includes a description of the interdisciplinary and interagency aspects of solar-terrestrial research and space weather efforts that will be needed in the future, as described in the 2013-2022 Decadal Survey in Solar and Space Physics (NRC, 2012).

The committee recognizes that AGS and NSF have informal mechanisms for collaboration. AGS staff communicate with one another and are aware of activities in other parts of NSF as well as other agencies relevant to their program. However, it was clear from comments made at the community workshop that there is a perceived lack of transparent mechanisms for properly evaluating interdisciplinary proposals that cross programs within AGS and GEO. As discussed in the workshop, AGS has a policy of taking pains to fairly evaluate interdisciplinary proposals by involving program managers from multiple sections, and possibly outside AGS. However, mechanisms for evaluating and co-funding interdisciplinary proposals within NSF are not clearly articulated in the Document.

The Document would be strengthened if it explicitly identified the mechanisms by which AGS cooperates, collaborates, and integrates among the individual sections at AGS, with other parts of NSF, and with other agencies of the Federal government.

There are four levels of collaboration that should be addressed using Division-wide principles of collaboration: within AGS, within NSF, among Federal agencies, and among nations. First, individual investigators need guidance on how AGS handles interdisciplinary proposals that cut across aspects of the portfolio of research supported within AGS. Second, there are large group projects that may include proposals for a Science and Technology Center, or an Engineering Research Center, or an unsolicited proposal from a large group of investigators. Often, these large group efforts have well-established NSF rules of engagement and a more extensive review process; however, the Document should acknowledge the challenge of large projects that do not necessarily fit into the established categories.

A third level of collaboration involves coordination of efforts between AGS and other federal agencies. An earlier NRC report, *Assessment of Impediments to Interagency Collaboration on Space and Earth Science Missions* (NRC, 2011), provides guidance about such collaborations. Applying the "touchstones" from NRC (2011) could be useful in deciding when AGS should collaborate or more fully cooperate with other agencies. In particular, that report recommends an evaluation of the rationale for collaboration in comparison with separate efforts, the potential for the whole to be greater than the sum of the parts, the unique aspects or level of support that can be gained from the partner agency, and the nuts and bolts of implementing the collaboration. The Document would be strengthened by adding a description on how AGS can work with other divisions, with senior NSF leadership, and with OMB/OSTP to develop a supportable vision of cooperation and collaboration in the national interest.

A fourth level of collaboration involves international programs. There are many such programs whose activities intersect with AGS interests: Future Earth, the Belmont Forum, the Global Earth Observation System of Systems, the World Weather Research Programme, the World Climate Research Programme, other programs of the World Meteorological Organization, the International Geosphere-Biosphere Programme, and the International Council of Scientific Unions. Although international

coordination is also addressed in NRC (2011), the Document should include a summary of principles that guide leveraging international opportunities in a coordinated way.

Interagency and interdivisional collaboration is crucial to future AGS success and clear examples of collaboration modes should be cited for each goal in the Document.

FUTURE DIRECTIONS OF AGS

There are a number of areas where AGS can provide leadership on future integrated research challenges, but where potential roles for AGS are not articulated in the Document. The future challenges not only cut across sections within AGS, but also link with other parts of NSF and other federal agencies. Box 1 includes examples of the cross-cutting and/or high-level issues that might be included in the Document. These examples are illustrative and not intended to be representative of all the research AGS supports. They reflect just a few of the cross-cutting issues that were discussed at the workshop[6].

As noted in NRC 2007, AGS is operating in a research environment that is ever more multi-disciplinary, interagency, and international, making a more strategic approach necessary to manage activities in a way that actively engages the atmospheric sciences community. Since the beginning of basic research programs in atmospheric and geospace science, the science has evolved dramatically from single process studies to the examination of the Sun and Earth as an interconnected system. This has been enabled by enhanced observations and informatics techniques in addition to advances in complex numerical simulations. The goals and objectives document has the potential to reflect a more forward-looking, integrative approach that captures the future research challenges and unifies the Division.

Sincerely,
Susan K. Avery, *Chair*
On behalf of the Committee to Review the NSF AGS Draft Science Goals and Objectives

[6] Other cross-cutting issues that were raised at the workshop are included in the recap which was provided to AGS.

BOX 1
Cross-Cutting Issues

Science at interfaces: It was clear from the workshop discussions that a large number of the science questions facing the community involve multiple components of the Earth-Sun system (e.g. air-sea interaction, exchanges between the land surface and atmosphere, interactions between the atmosphere and the cryosphere, and influences of the Sun on the Earth's atmosphere and surface). The Document does not articulate the role of AGS in ongoing and future research at these critical interfaces. AGS is in a unique position to take a "systems" approach to addressing some of these issues, and the committee encourages AGS to adopt this approach when describing the Division's goals and objectives.

Weather and climate across time and space scales: A recent well documented trend is the recognition that the same processes, observing systems, and modeling methods are relevant to both weather and climate research (e.g., Palmer and Webster, 1995; WCRP, 2005; Hurrell et al., 2009; NRC, 2010; Hoskins, 2013). With its portfolio of community models, and access to a rich observing network that includes both operational and research observing systems, AGS is in a unique position to address the issue of spatial and temporal scale interactions within the atmosphere and geospace. Migrating global models to higher and higher resolution is one approach; another approach is integrating high resolution global models with expertise and infrastructure in regional modeling (NRC, 2012). Examples of the latter approach include the North American Regional Climate Change Assessment Program (NARCCAP)[7] and the Coordinated Regional Climate Downscaling Experiment (CORDEX).[8]

Model hierarchy: NRC 2012 recommends: *To support a national linked hierarchy of models, the United States should nurture a common modeling infrastructure and a shared model development process, allowing modeling groups to efficiently share advances while preserving scientific freedom and creativity by fostering model diversity where needed*. The Document emphasizes the Community Earth System Model (CESM) and the Weather Research and Forecasting (WRF) model, both of which are state-of-the-science models heavily used within the community of AGS researchers, but this emphasis on two models does not fully address the strategy advocated in NRC 2012. The Document presents an opportunity for AGS to address how the community modeling efforts it supports can be broadened and linked with other modeling, data assimilation, informatics, and visualization efforts to nurture the recommended "linked hierarchy." For example, how can the model development efforts better link with those in NOAA and the Navy?

[7] http://www.narccap.ucar.edu/
[8] http://wcrp-cordex.ipsl.jussieu.fr/

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Appendix A
Statement of Task

Review of the National Science Foundation's
Division of Atmospheric and Geospace Sciences
Draft Science Goals and Objectives

Statement of Task

An ad hoc NRC committee will review the draft Division of Atmospheric and Geospace Sciences (AGS) draft science goals and objectives in a two-part process (Phase 1 and 2). The following key questions will be used by the committee, initially (in Phase 1) to organize a public workshop that will feature invited presentations and discussions of the draft goals and objectives and later by the committee itself (in Phase 2):

- Are the goals and objectives clear and appropriate?
- Are there any content areas missing from the draft that should be present if AGS is to achieve its overall vision and mission?
- Are there adequate mechanisms for coordinating and integrating issues that involve multiple disciplines and multiple divisions within NSF and other agencies within the atmospheric and geospace sciences enterprise?

Phase 1 will consist of planning and hosting a public workshop to engage the atmospheric sciences community and others as appropriate to provide feedback on the draft. The workshop will be designed to seek specific input on the draft by asking invited workshop speakers and other participants to share their views in the context of the questions above. In addition to addressing the questions above, the workshop will also include a brief, forward-looking session where participants will discuss "research frontiers" AGS might consider pursuing in light of the goals and objectives that have been identified (and those that have been acknowledged as missing). A recap of workshop will be produced by staff .

In Phase 2, the committee will write a letter report reviewing the AGS draft goals and objectives by addressing the questions above from its own standpoint.

Appendix B
Workshop Agenda and Participant List

Review of the National Science Foundation's
Division of Atmospheric and Geospace Sciences
Draft Science Goals and Objectives

March 31-April 1, 2014

National Academies' Keck Center
Room Keck 100
500 Fifth St., NW
Washington, DC 20001

Workshop Goals

Workshop participants will review and discuss the draft Division of Atmospheric and Geospace Sciences (AGS) draft science goals and objectives. The following key questions will be addressed:

- Are the goals and objectives clear and appropriate?
- Are there any content areas missing from the draft that should be present if AGS is to achieve its overall vision and mission?
- Are there adequate mechanisms for coordinating and integrating issues that involve multiple disciplines and multiple divisions within NSF and other agencies within the atmospheric and geospace sciences enterprise?

The workshop also includes a brief, forward-looking session where participants will discuss "research frontiers" AGS might consider pursuing in light of the goals and objectives that have been identified (and those that have been acknowledged as missing).

Monday, March 31, 2014

OPEN SESSION

9:30AM	Welcoming remarks and introduction	Susan Avery, WHOI
9:45AM	AGS leadership will discuss motivations for the activity and the goals and purpose of the document	Michael Morgan, NSF
10:15AM	AGS addresses questions from committee/participants	Michael Morgan David Verardo Rich Behnke Stephan Nelson
11:00AM	(Q1) Are the goals and objectives clear and appropriate?	

	Provocateur: Jennifer Logan, Harvard University
11:15AM	Discussion
12:15PM	*Lunch*
1:30PM	(Q2) Are there any content areas missing from the draft that should be present if AGS is to achieve its overall vision and mission?
	Provocateur: Amy Clement, University of Miami
1:45PM	Discussion
2:45PM	*Break*
3:15PM	(Q3) Are there adequate mechanisms for coordinating and integrating issues that involve multiple disciplines and multiple divisions within NSF and other agencies within the atmospheric and geospace sciences enterprise?
	Provocateur: Dan Baker, University of Colorado, Boulder
3:30PM	Discussion
4:30PM	General discussion
5:15PM	Begin session on AGS research frontiers: *A forward-looking session where participants will discuss "research frontiers" AGS might consider pursuing in light of the goals and objectives that have been identified (and those that have been acknowledged as missing)*
	Provocateur: James Kinter, COLA
	Summary of research frontiers from *Strategic Guidance for NSF's Support of the Atmospheric Sciences* — Chuck Kolb, Aerodyne Research Inc.
	Summary of research frontiers *from Solar and Space Physics: A Science for a Technological Society* — Dan Baker, University of Colorado, Boulder
6:00PM	*Adjourn for the day*

Tuesday, April 1, 2014

OPEN SESSION

7:30AM	*Breakfast*
8:00AM	Continued discussion on AGS research frontiers
	Provocateur: James Kinter, COLA
10:15AM	*Break*
10:45AM	Continued discussion on Goals and Objectives Document
	Provocateur: John Nielson-Gammon, Texas A&M University

12:00PM	*Lunch*	
1:30PM	Recap of discussion	Susan Avery, WHOI
	Focus on identifying any concerns that remain unresolved	
2:00PM	Workshop Adjourns	

PARTICIPANT LIST

Manda Adams, University of North Carolina at Charlotte

David T. Allen, University of Texas at Austin

Nick Anderson, NSF

Linnea Avallone, NSF

Susan Avery, WHOI*

Daniel N. Baker, University of Colorado at Boulder*

Anjuli Bamzai, NSF

Ana Barros, Duke University

Richard Behnke, NSF

Carol Ann Clayson, WHOI

Amy Clement, University of Miami*

Kim Cobb, Georgia Institute of Technology

Teresa Davies, NSF

Russell Dickerson, University of Maryland

Eric DeWeaver, NSF

Neil Donahue, Carnegie Mellon University

Phil Erikson, MIT Haystack Observatory

Thomas Fahy, Capitol Meteorologics

Sarah Gibson, NCAR

David Green, NOAA

Vanda Grubisic, NCAR

James Hack, ORNL

Gannet Hallar, NSF

Mike Henry, UCAR

Joe Huba, Naval Research Laboratory

W. Jeffrey Hughes, Boston University*

Everette Joseph, University at Albany

James L. Kinter III, Center for Ocean-Land-Atmosphere Studies*

Charles E. Kolb, Aerodyne Research, Inc.*

Gary Lackmann, North Carolina State University

Ruth Lieberman, GATS, Inc.

Michael Liemohn, University of Michigan

Jennifer A. Logan, Harvard University*

Gang Lu, NCAR

Paul Markowski, Penn State University

David McLaughlin, University of Massachusetts

Michael McPhaden, NOAA

Shalini Mohleji, AMS

Michael Morgan, NSF

Rebecca Morss, NCAR

Stephan Nelson, NSF

John W. Nielsen-Gammon, Texas A&M University*

Terry Onsager, NOAA

Robert Palmer, University of Oklahoma

Joyce Penner, University of Michigan

Yvette Richardson, Penn State University

Walter Robinson, North Carolina State University

Ilia Roussev, NSF

Sarah Ruth, NSF

Ross Salawitch, University of Maryland

Tiffany Shaw, Columbia University

Ron Smith, Yale University

Istvan Szunyogh, Texas A&M University

Jeffrey P. Thayer, University of Colorado at Boulder

David Titley, Penn State University

David Verardo, NSF

William Vizuete, University of North Carolina

Mike Wiltberger, NCAR

*denotes a committee member

Appendix C
Committee Biographical Sketches

COMMITTEE TO THE REVIEW THE NSF AGS
DRAFT SCIENCE GOALS AND OBJECTIVES

Dr. Susan K. Avery, Chair
Woods Hole Oceanographic Institution

Dr. Susan K. Avery is the President and Director of the Woods Hole Oceanographic Institution (WHOI). Prior to taking this position she was on the faculty at the University of Colorado, Boulder from 1982-2008. Dr. Avery uses her position and her background in atmospheric research to convey the importance of understanding the Earth as a system connected by ocean, atmosphere, terrestrial, and human interactions. Under her leadership, WHOI is diversifying funding and pursuing more interdisciplinary discovery research as well as problem-oriented research and the application of fundamental research to ocean-related crises. The institution is also developing a wide range of platforms and tools for access to the ocean. Dr. Avery serves on many national and international boards, committees, and program review committees, and is active in professional societies. She 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. Her research interests include atmospheric circulation and precipitation, the development of new radar techniques and instruments for observing the atmosphere, and the role of climate science in decision support.

Dr. Daniel N. Baker (NAE)
University of Colorado, Boulder

Dr. Daniel Baker is Director of the Laboratory for Atmospheric and Space Physics at the University of Colorado-Boulder and is Professor of Astrophysical and Planetary Sciences and Professor of Physics there. He holds the Moog-Broad Reach Chair of Space Sciences at CU. His primary research interest is the study of plasma physical and energetic particle phenomena in planetary magnetospheres and in the Earth's vicinity. He conducts research in space instrument design, space physics data analysis, and magnetospheric modeling. Dr. Baker obtained his Ph.D. degree with James A. Van Allen at the University of Iowa. Following postdoctoral work at the California Institute of Technology with Edward C. Stone, he joined the physics research staff at the Los Alamos National Laboratory, and became Leader of the Space Plasma Physics Group at LANL in 1981. From 1987 to 1994, he was the Chief of the Laboratory for Extraterrestrial Physics at NASA's Goddard Space Flight Center. From 1994 to present he has been at the University of Colorado. Dr. Baker has published over 750 papers in the refereed literature and has edited eight books on topics in space physics. He is a Fellow of the American Geophysical Union, the International Academy of Astronautics, the American Institute of Aeronautics and Astronautics (AIAA), and the American Association for the Advancement of Science (AAAS). He is

an elected member of the National Academy of Engineering. He currently is an investigator on several NASA space missions including the MESSENGER mission to Mercury, the Magnetospheric MultiScale (MMS) mission, and the Radiation Belt Storm Probes (RBSP) mission. He has won numerous awards for his research efforts and for his management activities including recognition by the Institute for Scientific Information as being "Highly Cited" in space science (2002), being awarded the Mindlin Foundation Lectureship at the University of Washington (2003) and being selected as a National Associate of the U.S. National Academies (2004). Dr. Baker was chosen as a 2007 winner of the University of Colorado's Robert L. Stearns Award for outstanding research, service, and teaching. In 2010, he was awarded the University of Colorado's Boulder Faculty Assembly Distinguished Research Lecturer Award. Dr. Baker was the 2010 winner of the American Institute of Aeronautics and Astronautics (AIAA) James A. Van Allen Space Environment Award and Medal. Dr. Baker recently served on several national and international scientific committees including the Chairmanship of the National Research Council Committee on Solar and Space Physics. Dr. Baker served as President of the Space Physics and Aeronomy section of the American Geophysical Union (2002-2004) and he presently serves on advisory panels of the U.S. Air Force and the National Science Foundation. He was a member of the National Research Council's 2003 Decadal Survey Panel for solar and space physics and he was a member of the 2006 Decadal Review of the U.S. National Space Weather Program. Dr. Baker just completed service as chair of the National Academies 2013-2022 Decadal Survey in Solar and Space Physics.

Dr. Amy Clement
University of Miami

Dr. Amy Clement is a Professor and Associate Dean of Graduate Studies at the Rosenstiel School of Marine and Atmospheric Science located at the University of Miami. Her research interests focus on some fundamental questions about the behavior of the climate system. How sensitive is the Earth's climate to external forcing? Is abrupt change a characteristic of the climate? What are the mechanisms of climate change? To address these questions, she uses mathematical models of the climate. These range in complexity from one-dimensional approximations of the climate to global, three-dimensional models (general circulation models—GCMs). Her focus has generally been on the tropical coupled ocean-atmosphere system, and in particular on the El Niño/Southern Oscillation (ENSO). As the largest mode of variability in the modern climate, understanding the whys and hows of past changes in (ENSO) are essential in answering fundamental questions about the behavior of the climate system, and are highly relevant for addressing the problem of how climate may change in the future. Dr. Clement is a Fellow of the American Geophysical Union. Dr. Clement received her Ph.D. in Physical Oceanography from Columbia University.

Dr. W. Jeffrey Hughes
Boston University

Dr. W. Jeffrey Hughes is Professor of Astronomy and Associate Dean of the Graduate School of Arts and Sciences at Boston University. A native of Wales, he received both his B.Sc. and Ph.D. in physics from Imperial College, London. He spent two years as a Hayes-Fulbright Scholar doing post-doctoral research in the U.S., spending a year at both the University of Colorado and the University of California, Los Angeles. He joined the Boston University faculty in 1978, where he was the founding director of the Center for Space Physics. He has served as Astronomy Department chairman, and was director of the Center for Integrated Space Weather Modeling (CISM), an NSF Science and Technology Center. Dr.

Hughes' research focuses on the dynamics of the Earth's magnetosphere and its interactions with the solar wind and the ionosphere.

Dr. James L. Kinter III
Center for Ocean-Land-Atmosphere Studies

Dr. James L. Kinter III is Director of the Center for Ocean-Land-Atmosphere Studies (COLA) where he manages all aspects of basic and applied climate research conducted by the Center. Dr. Kinter's research includes studies of climate predictability on sub-seasonal and longer time scales. Of particular interest in his research are prospects for prediction of El Niño and the extratropical response to tropical sea surface temperature anomalies using high-resolution coupled general circulation models of the Earth's atmosphere, oceans and land surface. Dr. Kinter is a Professor in the Climate Dynamics Ph.D. Program of the College of Science at George Mason University, where he has responsibilities for curriculum development and teaching undergraduate and graduate courses on climate change, as well as advising Ph.D. students. After earning his doctorate in geophysical fluid dynamics at Princeton University in 1984, Dr. Kinter served as a National Research Council Associate at NASA Goddard Space Flight Center, and as a faculty member of the University of Maryland (teaching faculty 1984-1987; research faculty 1987-1993) prior to joining COLA. Dr. Kinter has served on many national review panels for both scientific research programs and supercomputing programs for computational climate modeling.

Dr. Charles E. Kolb (NAE)
Aerodyne Research, Inc.

Dr. Charles E. Kolb (NAE) is President and Chief Executive Officer of Aerodyne Research, Inc. in Billerica, Massachusetts. His principle research interests include atmospheric and environmental chemistry, combustion chemistry, and the chemical physics of rocket and aircraft exhaust plumes. He has served on several National Aeronautics and Space Administration panels dealing with environmental issues as well as on numerous NRC committees and boards dealing with atmospheric chemistry and physics. These include: the Committee on Tropospheric Ozone Formation and Measurement (1989-1991); the Committee on Atmospheric Chemistry; (member 1987-1990, chair, 1990-1993); the Board on Atmospheric Sciences and Climate, 1990-1993 and 1997-2000; the Committee on Strategic Guidance on NSF's Support of Research in the Atmospheric Sciences (2004-2006) and the Committee on the Significance of International Transport of Air Pollutants (chair 2008-2009). Dr. Kolb has also been appointed a National Associate of the National Academies and elected to the National Academy of Engineering. He is a Fellow of the American Physical Society, American Chemical Society, American Geophysical Union, the American Association for the Advancement of Science, and the Optical Society of America. Dr. Kolb graduated from the Massachusetts Institute of Technology with a B.S. in Chemical Physics and from Princeton University with an M.A. and a Ph.D. in Physical Chemistry.

Dr. Jennifer A. Logan
Harvard University

Dr. Jennifer A. Logan was a Senior Research Fellow in the School of Engineering and Applied Sciences at Harvard University until 2013. Her research has used global models and analyses of atmospheric data to improve our understanding of the processes affecting atmospheric composition, and the changes wrought by human activity. Recent work has focused on demonstrating the value of tropospheric observations from the Aura satellite for assessing transport characteristics of meteorological fields used to drive global models. Other research interests include insights gained from hindcasts of atmospheric composition, analysis of ozone trends, and prediction of fires in North America using climate models and the effects of these fires on future air quality. Dr. Logan has coauthored over 120 publications, and she is a Fellow of the American Geophysical Union and the American Association for the Advancement of Science. She is a member of the NOAA Science Advisory Board. Prior NRC service includes membership on the Board on Atmospheric Sciences and Climate, the Committee on Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey, and the Committee on the Role and Scope of Mission-Enabling Activities in NASA's Space and Earth Science Mission. Dr. Logan received her B.Sc. in Chemistry from Edinburgh University and her Ph.D. in Physical Chemistry from the Massachusetts Institute of Technology.

Dr. John Nielsen-Gammon
Texas A&M University

Dr. John Nielsen-Gammon is the Regents Professor and Texas State Climatologist at Texas A&M University. Dr. Nielsen-Gammon's weather-related work involves jet streams, extreme rainfall events, and land and sea breezes. His air quality research includes field forecasting support, numerical simulation, and diagnostic analysis of ozone events in Houston and Dallas for the Texas Air Quality Studies in 2000 and 2005-6. Dr. Nielsen-Gammon has also worked on drought monitoring and forecasting, air pollution climatology, and improvements to the climate data record. Dr. Nielsen-Gammon received a Presidential Faculty Fellow award (now known as PECASE) from the National Science Foundation and the White House in 1996, a Distinguished Achievement Award in Teaching at Texas A&M University from the Association of Former Students in 1996, and was named a Fellow of the American Meteorological Society (AMS) in 2011. He is Past President of the International Commission for Dynamical Meteorology and is past chair of the AMS Board on Higher Education. Dr. Nielsen-Gammon received his Ph.D. from Massachusetts Institute of Technology in 1990.