Assessment of NASA's Draft 2003 Earth Science Enterprise Strategy: Letter Report

Committee to Review the NASA Earth Science Enterprise Strategic Plan, National Research Council

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EXECUTIVE SUMMARY

Introduction

This report by the Committee to Review the NASA Earth Science Enterprise Strategic Plan responds to a request from the NASA Associate Administrator for Earth Science for a review of the most recent draft of NASA's Earth Science Enterprise (ESE) Strategy, *Understanding and Protecting Our Home Planet* (hereinafter referred to as "the ESE draft document").[1] In writing its report, the committee focused on the five questions posed in the letter of request to the National Research Council's Space Studies Board. The committee believes that the ESE final strategy document must address each of the five questions in a comprehensive and robust manner, in order to both guide the ESE program and communicate its exciting scope and national importance to many crucial audiences. The committee's report focuses primarily on aspects of the ESE draft document that should be improved to better communicate the strengths of and plans for the ESE program.

Principal Findings and Recommendations

Below, the committee summarizes its principal findings and recommendations in connection with each of the five questions. Additional details are included in the body of the report.

1. Does the ESE draft document clearly and compellingly convey the direction of the Enterprise?

The ESE draft document does not clearly and compellingly articulate the Earth Science Enterprise's rationale, scope, relationships, and programmatic approaches. **To transform the ESE draft document and the strategy that it embodies into a coherent and effective plan, the committee recommends that the draft document be revised to address the following issues:**

- Absence of an obvious logical structure, which makes the draft document difficult to read and to interpret.
- Inconsistent levels of detail and a lack of references to other relevant documents.
- Missing elements of a strategic plan, including information on schedules, milestones, and evaluation criteria and approaches. In particular, the ESE draft document should discuss the methodology and the criteria that will be used in establishing relative program priorities.

[1] NASA, 2003, *Understanding and Protecting Our Home Planet: Earth Science Enterprise Strategy,* draft dated April 14, 2003.

It is essential that the ESE outcomes projected in the six science focus areas[2] be realistic and attainable within the resources and time specified, and that they be desirable and practical for partner agencies. **The committee recommends that ESE carefully evaluate each projected outcome for practicality prior to including it in future versions of the draft document. In particular, ESE should evaluate the realizability of its "predictive capabilities enabled by an Earth system modeling capability in 2025." ESE should more clearly delineate the partnerships with other federal agencies that are needed to realize relevant national priorities.** The committee is concerned that the ESE draft document, as submitted, does not clearly state the relevance of NASA's contributions to those of other agencies in light of broader national goals.

2. Does it effectively respond to the NASA Strategic Plan?

The ESE draft document responds effectively to the vision, mission, and goals articulated in the overall NASA Strategic Plan,[3] but not to that plan's implementing strategies. The NASA Strategic Plan links the objectives of each NASA enterprise to NASA's overall goals. This logical structure is not evident in the ESE draft document. **To demonstrate the alignment of the ESE program with the NASA Strategic Plan, the committee recommends that the ESE draft document be revised so that it (1) states explicitly the NASA goals to which ESE contributes and (2) explains how the programs of the ESE contribute to NASA's objectives and goals.**

The committee notes ESE's contribution to the goals under NASA's mission "to inspire the next generation of explorers": ESE's record in training the next generation of researchers is strong and deserves credit. There are, however, no examples of any such accomplishments in the draft document's short section "Earth Science Education," which is also incomplete because it focuses primarily on outreach and K-12 education. **The committee recommends that the ESE draft document describe a vision for a strong partnership between NASA and universities with regard to long-term education needs and the intellectual development of the next generation of Earth system scientists.**

3. Does it describe an endeavor that stands as an important scientific program and makes needed contributions to broader national priorities?

The committee found the range of ESE activities outlined in the draft document to be both potentially exciting and critically necessary for achieving many national and international imperatives. However, the draft document does not make any attempt to persuade the reader that the objectives under ESE's six science focus areas can be achieved given existing and expected knowledge and resources. The draft document does not provide evidence that the applications goals of the specific science focus areas can be realized, nor does it set forth the criteria and processes by which the identified objectives were determined. It lacks descriptions of ESE's approach to setting priorities, assessing progress, and developing and incorporating technology.

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[2] As stated at line 427 of the ESE draft document, the six science focus areas are climate variability, change, and prediction; atmospheric composition; ecosystems and carbon cycle; water and energy cycle; weather; and Earth surface and interior.

[3] NASA, 2003, *National Aeronautics and Space Administration 2003 Strategic Plan,* Report NP-2003-01-298-HQ. Available online at <http://www.nasa.gov/pdf/1968main_strategi.pdf>.

The draft document rationalizes the ESE program almost entirely on the basis of its contributions to applications. The committee finds that the ESE draft document would be improved by an increased emphasis on basic science; inadequate focus on a basic understanding of Earth system science may prove to be a crucial impediment for the timely development of future applications. **The committee recommends that the ESE draft document clearly describe the respective roles of applied and basic science and the appropriate balance between the two.**

The NASA applications strategy should emphasize one of the agency's strengths, which is the provision of objective, scientifically derived environmental information to all parties, inside or outside governments, in a neutral, nonpolitical mode. Although the ESE draft document (lines 814-854) addresses the importance of existing external partnerships, it does not describe how the new partnerships required to achieve the stated objectives will be established. In addition, the ESE draft document does not detail how existing partnerships will be exploited. **The committee recommends that this strategic element be added to the ESE draft document in the section on external partnerships (lines 814-854) and that the text in this section be revised accordingly.**

The ESE Earth science program is far more exciting, and its applications far more important and far ranging, than is conveyed in the draft document. The committee believes that development of the programs presented in the ESE draft document would have benefited from a broader engagement of the external Earth science community. **Prior to the development of ESE's 2006 Strategy, the committee recommends that ESE take new approaches to engaging the Earth science community, modeled perhaps on the outreach and roadmap efforts made by the Office of Space Science in developing its own strategy.**

4. Does it provide appropriate attention to interdisciplinary aspects, integration of technology development, and overall scientific balance?

Earth system science is a complex, highly integrated activity requiring critical interaction among the many agencies and organizations responsible for performing particular elements of the scientific research. ESE recognizes this and has indicated clearly that the Earth "systems" science problem requires a "systems" solution. The committee is concerned that ESE's ability to achieve broad Earth science objectives may be compromised because no single organization is responsible for coordinating the efforts of the many partners. **In light of this concern the committee recommends that ESE describe how it will take the steps necessary to ensure that all important scientific components are identified, and that NASA work with other relevant agencies to ensure that the specific roles of partner organizations are defined and activities properly coordinated.**

The draft document uses an interdisciplinary Earth system science template for its proposed program, but this approach has several deficiencies. **The committee recommends that the ESE draft document be revised to address the following issues:**

- The draft document does not explain the ESE strategy for integration of technology and how technology developments will be strategically coupled to ESE proposed missions.
- The draft document does not give sufficient attention to components of the Earth system, in particular, anthropogenic forcings, which dominate change.

- The "Earth surface and interior" science focus area is not well integrated with the other five science focus areas.
- There is little discussion of ESE's strategy for transforming mission data into scientific information, specifically how space-derived data will be made available for use in laboratory investigations, field programs, theory, and data analysis.

5. What recommendations from recent NRC reports, if any, should be considered in revising the draft?

As detailed in the body of the report, several NRC reports should be consulted in revising the ESE draft document. In addition, the committee finds that in general the draft document does not provide sufficient context through references to either subsidiary or superseding ESE documents and plans. **The committee recommends that the ESE revised document summarize the context and constraints established by the NASA Strategic Plan and that it provide specific references to existing or developing subsidiary ESE documents.** ESE assured the committee that these documents exist but did not make them available to the committee.

In general, the committee strongly believes that the ESE draft document provided to the committee should be viewed as an early draft that is deficient in many respects. It is hoped that, with substantial revisions as recommended, a future more effective ESE strategy document will result.

INTRODUCTION

In response to a letter of request from NASA's Associate Administrator for Earth Science,[4] the National Research Council (NRC) appointed an ad hoc committee[5] to review the draft Earth Science Enterprise Strategy (the ESE draft document).[6] As requested, the committee replied to five questions about the structure and content of the ESE draft document.

In conducting its review, the committee benefited from presentations by Dr. Ghassem Asrar and Mr. Gregory Williams at a May 6 and 7, 2003, meeting at the Beckman Center in Irvine, California. The committee's initial discussions occurred prior to and during that meeting. Given the short schedule for delivery of this report, subsequent discussions were conducted via e-mail or telephone.[7]

NASA's Earth Science Enterprise (ESE) is one of six strategic enterprises organized to implement NASA's mission and goals.[8] The primary mission of ESE is to "understand and protect our home planet" by advancing Earth system science.[9] The ESE science, applications, and educational outreach programs provide an essential foundation for many critical activities and objectives at NASA and elsewhere in the U.S. government, the nation, and the world. The activities include weather and climate prediction by NOAA, health and environmental monitoring by EPA, detecting and monitoring land surface characteristics by USGS, and economic development work by organizations within the government and elsewhere. All of these activities depend on an improved understanding of Earth and its environment. For example, the effects of weather are estimated to directly affect at least 25 percent of the U.S.

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[4] See Appendix A. The formal statement of task for the study is shown in Appendix B.

[5] The members of the Committee to Review the NASA Earth Science Enterprise (ESE) Strategic Plan are listed in Appendix C.

[6] NASA, 2003, *Understanding and Protecting Our Home Planet: Earth Science Enterprise Strategy,* draft dated April 14, 2003. NASA reserves the term "strategic plan" to refer to its overall agency plan; it denotes the strategic high-level plans of its individual NASA enterprises as "strategies." Notwithstanding this distinction in terminology, the committee believes that an effective ESE strategy document must have all the key attributes of a strategic plan.

[7] This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Victor Baker, University of Arizona; Steven Bohlen, Joint Oceanographic Institutions; Robert Corell, Harvard University; John Gille, National Center for Atmospheric Research; Anthony Janetos, Heinz Center; Ralph Milliff, Colorado Research Associates; Michael Prather, University of California at Irvine; and David Sandwell, Scripps Institution of Oceanography. Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Byron Tapley, University of Texas at Austin. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

[8] As listed in Appendix I of the NASA *2003 Strategic Plan*, the other NASA strategic enterprises are Space Science; Biological and Physical Research; Aerospace Technology; Education; and Space Flight.

[9] NASA, 2003, *National Aeronautics and Space Administration 2003 Strategic Plan*. Pp. 12-16 and Appendix I, pp. A-6 and A-7.

economy.[10] Should ESE programs achieve their objectives, there would be a significant and long-term positive impact on many areas of our economy. Therefore, it is essential that ESE's objectives, plans, activities, and approaches be articulated forcefully and persuasively to the government, research, and user communities.

The committee found much that is praiseworthy in the ESE themes, objectives, and programs described in the ESE draft document. However, in its review the committee focused on the draft document's effectiveness in describing ESE activities and instilling recognition of their importance and confidence in their potential for success. The committee agrees with ESE officials that the final version of the draft document should be elegant, unambiguous in its interpretation, and clear in its vision for a program of national significance.

The committee's approach was to directly address the five questions posed in the NASA letter of request. The five questions, along with the committee's interpretation of their intent and scope, follow:

1. *Does the draft Strategic Plan clearly and compellingly convey the direction of the Enterprise?* Does the ESE draft document include the necessary components of a strategic plan and are these components integrated effectively to achieve a coherent plan? In particular, does the ESE draft document satisfy the six critical elements of a strategic plan as identified by the NRC Committee to Review the U.S. Climate Change Science Program Strategic Plan and discussed below?
2. *Does it effectively respond to the NASA Strategic Plan?* Is the ESE program, as described in the draft document, aligned with the vision, mission, and goals in the NASA Strategic Plan and does the ESE approach to achieving its objectives conform to NASA's implementing strategies?
3. *Does it describe an endeavor that stands as an important scientific program and makes needed contributions to broader national priorities?* Are the vision, goals, and objectives as described in the draft ESE document sufficiently ambitious and properly focused?
4. *Does it provide appropriate attention to interdisciplinary aspects, integration of technology development, and overall scientific balance?* Is the plan described by the ESE draft document comprehensive, and are the included topics effectively balanced?
5. *What recommendations from recent NRC reports, if any, should be considered in revising the draft?* Does the ESE draft document contain sufficient reference to documents and plans that could help support or guide the ESE strategy?

The ESE program outlined in the draft document is scientifically and programmatically broad, and its elements are highly integrated and interdependent. The ESE draft document must therefore adequately address each of the above questions;[11] such a plan will be both comprehensive and robust, and will serve as an excellent document for guiding the ESE program and communicating this program to others. The remainder of this report provides a review of the ESE draft document organized around these five questions.

[10] National Research Council, 2003, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations,* National Academies Press, Washington, D.C.
[11] See text of footnote 6.

RESPONSES TO THE FIVE QUESTIONS

1. Does the ESE draft document clearly and compellingly convey the direction of the Enterprise?

At the highest level, the ESE draft document outlines a program to study Earth as a global system, integrating technology-enabled measurements and comprehensive models to yield greatly improved predictive capabilities for climate, weather, and natural hazards. The draft document extends beyond scientific research to include the ESE program's Earth Science Applications theme, which identifies a set of application areas, partner agencies, and activities, including education. The committee finds that the ESE activities are ambitious, exciting, and critically important to the nation. However, the draft document does not clearly or compellingly articulate ESE's rationales, scope, relationships, and programmatic approaches.

Establishing and articulating the draft document's purpose are made difficult by NASA's mandated constraints on format and organization,[12] but doing so is crucial in light of the ambiguities resulting from the subtle differences between a "strategy document" and a "strategic plan." The draft document does not clearly define ESE's aims, nor does it describe its relationship to the higher-level NASA Strategic Plan, or to the lower-level documents that contain important detail on topics that the draft document only summarizes.

The ESE approach to forecasting future needs of the Earth System Science part of its program, including both basic science and activities with eventual operational use, would benefit from greater community involvement.[13] The decadal surveys performed for the Office of Space Science are examples of such community involvement and contributions.[14] The "ten year outcomes" identified as ends for research in each of the science focus areas (see the table starting at line 435 of the draft document), and in supporting documents, would benefit from greater traceability to the scientific and operational communities, including a record of the establishment of the science focus areas and their associated "prediction questions."

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[12] Each of NASA's enterprise strategies exists within a hierarchy of agency documents and plans, all of which support and describe portions of the agency's mission and goals as outlined in the overall NASA *2003 Strategic Plan*. NASA officials informed the committee that all of the enterprise strategies conform to a common organization, format, and terms of reference and that none of the strategies include resource information.

[13] This recommendation is similar to that provided in a 1999 NRC letter report on ESE post-2002 planning, which stated, "The task group recommends that the science plan to underpin the mission set be developed in an open and deliberative process involving the full range of scientific disciplines and a diverse set of potential users. **To ensure a balanced and coherent strategy that will elucidate the key mechanisms thought to underlie global change phenomena, the task group recommends that NASA develop the science plan with the participation of USGCRP agencies and the academic scientific community and in consultation with international partners.** In addition to experts in the various disciplines, NASA should involve scientists who understand the human role and the socioeconomic and health impacts of the designated priority science and applications problems." [Emphasis in original text.] See National Research Council, 1999, "NASA's Plans for Post-2002 Earth Observing Missions," National Academy Press, Washington, D.C., pp. 7-8. The full report may be viewed online at <http://www7.nationalacademies.org/ssb/NASA_Post2000_Earth_ltr.pdf>.

[14] National Research Council, 2003, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics,* National Academies Press, Washington, D.C., and National Research Council, 2003, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, National Academies Press, Washington, D.C.

Organization and Level of Detail in the Draft Document

Committee members found the ESE draft document difficult to understand, both in the context of NASA's plans and as a stand-alone document. These difficulties appear to arise from the lack of explanatory text to guide the reader, an over-reliance on bulleted lists and complex figures at the expense of prose, and inconsistent levels of detail in the different sections of the draft document.

The committee understands that ESE must follow a common outline and chapter headings. Unfortunately, the chapter titles are not intuitive, and they provide little guidance to the reader about the content and the objectives of the text. For example, few readers have a common understanding of the differences and relationships embedded in the chapter titles "Strategic Context and Approach" (Chapter II), "Achieving NASA's Objectives" (Chapter III), and "Strategy Implementation" (Chapter IV). Further, Chapter III (the substantive description of ESE programs, objectives, and desired outcomes) begins, after a single two-line sentence, with an extremely complicated two-page table, followed, after six lines of text, by a complex figure, followed after six more lines of text by a cartoon-like figure in an appreciably different style. The chapter is made up primarily of tables, bullet lists, and schematic (but nonetheless exceedingly complex) figures, with little explanatory text.

The ESE briefing to the committee on May 6 included an extremely effective "pyramid" figure illustrating the relationship of ESE activities to overall NASA activities and defining the terminology used throughout the strategic planning document hierarchy. The briefing also included concise introductions to and summaries of each of the draft document's chapters. These briefing materials could be used to improve the ESE draft document itself.

The draft document's treatment of the ESE program's Earth System Science theme should include a clearer textual description of the six science focus areas and of the overall approaches to be pursued for attaining the objectives. The various roadmap figures in the draft cannot be understood without an accompanying explanatory text. The references to supporting documents must include more detail. Specific examples of how new technologies, improved modeling approaches, or new measurement techniques would be applied in pursuit of the science focus areas would also be helpful. These could convey the excitement and sense of intellectual challenge that are now lacking in the ESE draft document.

Establishing consistent levels of detail would both clarify the intended level of emphasis on particular topics and improve the overall readability of the document. Where appropriate, sidebars or similar formatting techniques could be used to present anecdotal examples or additional detail without detracting from the flow, structure, or logic of the main text.

Realizability of the Draft Document's Projected Outcomes

It is essential that the ESE outcomes projected in the six science focus areas be viewed as realizable and attainable within the resources and time specified, and that they be desirable and practical for partner agencies. For instance, although accurate 10-day forecasts of general global weather patterns might be possible, the committee believes that useful predictions 10 days in advance of severe storms or hurricanes are not likely to be achieved within a decade. Similarly,

in most cases, accurate predictions of volcanic eruptions and earthquake probabilities are not likely within the next decade.[15]

ESE should carefully evaluate each projected outcome for practicality before including it in future versions of the draft document. In particular, ESE should evaluate the realizability of its "predictive capabilities enabled by an Earth system modeling capability in 2025" (line 920 in the draft document) and/or reword this section to suggest that these are hoped-for capabilities, that is, something to strive for and to use as guideposts.

The ESE draft document does not make clear whether the 10-year outcomes for each of the six science focus areas (articulated in the roadmap charts in Section III) should be construed as ESE's description of executable objectives (one of the required elements of a strategic plan identified below). With the exception of the Weather Forecast Duration Improvement activity in Section III, the 10-year outcomes (objectives) in the roadmap charts are qualitative and measurable only in a subjective sense. (In contrast, much more quantitative objectives and predictive capabilities are offered for the year 2025 [lines 920-960], but these visionary capabilities are beyond the current planning horizon, and it is not clear whether they are attainable.) In addition, a clear and concise description of the Earth Science Applications theme is not found until deep into Section III (lines 589 ff.). These top-level summaries within the ESE draft document should (and could) be inspirational rather than a dry list of goals.

Many activities being pursued and planned by ESE are well described in the draft document. Others, however, are not, even though they have the same levels of scientific and technical challenge, utilization potential, and criticality for achieving ESE objectives. In particular, the committee notes that the sheer volume of raw and processed data associated with the planned observing systems (e.g., the Integrated Observing System alluded to at line 960) is much larger than that currently used by Earth science researchers and other potential users. Moreover, ESE has developed flexible and useful data systems serving several broad communities, and it has ongoing programs aimed at revolutionizing the systems of the future. ESE has demonstrated that it has the knowledge of data set characteristics, scientific and application needs, operating methods, and management processes necessary to develop and operate these large-scale data systems. These capabilities surely fall under the rubric "as only NASA can." The committee believes, therefore, that the amount and variety of data that ESE expects to capture, analyze, archive, and distribute should be more prominently featured in the draft document.

Use of Traditional Strategic Plan Elements in the Draft Document

In a recent report,[16] the Committee to Review the U.S. Climate Change Science Program Strategic Plan listed the following elements as being critical to any strategic plan:

- A clear and ambitious guiding vision of the desired outcome;
- A set of unambiguous and executable goals that address the vision and broadly describe what the program is designed to accomplish;

[15] Dennis Mileti, 1999, *Disasters by Design: A Reassessment of Natural Hazards in the United States*, Joseph Henry Press, Washington, D.C.
[16] National Research Council, 2003, *Review of the U.S. Climate Change Science Program Strategic Plan*, National Academies Press, Washington, D.C.

- An assessment of whether existing programs are capable of meeting these goals, thereby identifying required program changes and unmet needs that must be addressed in subsequent implementation planning;
- A clear timetable for accomplishing the goals and criteria for measuring progress;
- A set of explicit prioritization criteria to facilitate program design and resource allocation; and
- A management plan that provides mechanisms for ensuring that the goals are met and for coordinating, integrating, and balancing individual program elements and participating agencies.

The committee finds that the ESE draft document is deficient with regard to several of these elements.

The ESE draft document provides only vague, qualitative timetables for producing the Earth system science outcomes projected between 2003 and 2014. A reader must distill what schedule information exists from an analysis of the roadmap schematics in each of the six science focus areas.[17] The only listed milestones are the 10-year and 2025 deadlines; the document does not provide even approximate dates for completion of intermediate tasks.

The Earth Science Applications component of ESE's program as presented in the draft document lacks roadmaps[18] and thus does not have even schematic timetable information. On the positive side, the program has an explicit benchmarking and assessment component, and it is reasonable to expect that these components might be useful for measuring progress. The 2002 NRC review of the ESE Applications Plan concluded that "the Applications Plan needs to articulate a strategy for translating concepts into more tangible actions."[19] The committee echoes that conclusion.

The draft document does not provide sufficient high-level information on criteria or processes for establishing priorities. This is a critical problem because of the broad scope and ambitious nature of ESE's activities, the evident gap between available resources and the stated objectives,[20] and the reliance on interagency and international partnerships (a laudable approach in the committee's view). Although the first bulleted item (lines 329-332) of the draft document addresses "identifying and prioritizing frontier science questions" as an essential component of the ESE framework, the draft document describes neither the criteria nor the processes for setting relative priorities among the six science focus areas. Similarly, the draft document gives no indication of the relative priorities of the three elements of the ESE's Earth Science Applications theme, nor does it prioritize between the ESE program's Earth System Science and Earth Science Applications themes.

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[17] In their briefing to the committee on May 6, 2003, ESE officials explained that progress assessments and benchmarks for the six science focus areas were defined and described in detail in roadmap documents, which are one level below (i.e., more detailed than and in support of) the strategy document. However, these documents were not explicitly referenced in the draft strategy document.

[18] The committee uses the term "roadmap" in the context of NASA's draft document, that is, as one of the decadal approaches to addressing each of ESE's six focus areas. Therefore the roadmaps can be understood to be supportive components of the ESE draft document.

[19] NRC, 2002, *Review of NASA's Earth Science Enterprise Applications Program Plan,* National Academy Press, Washington, D.C.

[20] The ESE briefing to the committee on May 6 made clear that the present ESE budget is insufficient to achieve all of the identified objectives on the notional (decadal) schedule presented in the draft document.

The ESE draft document touches only briefly on prioritization *processes* in Section IV, "Strategy Implementation." Although an ESE Program Management Council will presumably be the ultimate forum that sets priorities, the document is silent on the composition of the council and the criteria it will apply. What little information is provided (lines 866-873) appears to be specific to space missions and has a strong focus on mission or project initiation. Given the decadal extent of the draft document, re-ranking exercises must be expected in response both to externally imposed perturbations (such as the budget process) and to opportunities and challenges resulting from unanticipated discoveries and new understanding.[21]

The need for prioritization criteria and processes becomes even more urgent in light of ESE's commitment to "align our science priorities with those of major national imperatives," like the U.S. Climate Change Science Program, the U.S. Climate Change Technology Program, the U.S. Weather Research Program, initiatives for a reduction of vulnerability to natural disasters and for homeland security, the National Ocean Partnership Program, and the Study of Environmental Arctic Change (lines 437-443),[22] and in the context of the many different interagency partnerships and collaborations identified as required for achieving ESE objectives. **In light of these deficiencies, the committee recommends that ESE carefully examine the draft document to ensure that it contains all of the elements to successfully and compellingly describe its strategies.**

2. Does the ESE draft document effectively respond to the NASA Strategic Plan?

The draft document embraces and is in many ways responsive to the NASA 2003 Strategic Plan. The draft document states that ESE's role in the NASA vision and mission is "to improve life here" and to "understand and protect our home planet." It also conforms to NASA's overarching principle to engage only in those activities to which NASA can make unique and critical contributions.

However, the draft document is weaker in its discussion of *how* ESE contributes to NASA's goals. For example, the table at line 399 is presented without any explanatory text, which detracts from the central importance and excitement of ESE's contributions. The draft document is also lacking in a substantive discussion of management approaches and processes and thus is unresponsive to NASA's implementing strategy, to "achieve management and institutional excellence comparable to NASA's technical excellence."[23]

The committee strongly endorses NASA's open competition approach, but it is not clear to what extent peer review and open solicitations can be used to manage the complex set of activities and objectives summarized schematically in the roadmaps. Finally, the ESE draft document would be stronger if it summarized the criteria for measuring progress and referred to underlying documents that describe the criteria and processes in greater detail.

The committee notes ESE's contributions to both of the goals under NASA's third mission, "inspire the next generation of explorers," and considers that ESE's record in training

[21] As just one example, many research missions can still provide high-quality measurements after their initial baseline mission ends. Issues related to the decision to continue highly productive science missions beyond their initial lifetimes are discussed in *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations.* They are also the focus of a forthcoming NRC study, *Extending the Effective Lifetimes of Earth Observing Research Missions*, which is scheduled for completion in the spring of 2004.

[22] The draft document provides no indication of the ease or difficulty of these alignments or what actions are needed to ensure their success.

[23] NASA, *2003 Strategic Plan*, p. 10, A1-A2.

the next generation of researchers is strong and deserves credit. But there are no examples of any such accomplishments in the short section "Earth Science Education" (line 690), which is also incomplete because it focuses primarily on outreach and K-12 education and does not describe how ESE will continue to contribute to the development of the next generation of explorers, a stated goal of NASA's agency-wide Education Enterprise. **The committee recommends that the ESE draft document describe a vision for a strong partnership between NASA and universities with regard to long-term education needs and the intellectual development of the next generation of Earth system scientists.**

To demonstrate the alignment of the ESE program with the NASA Strategic Plan, the committee recommends that the ESE draft document clearly state the NASA goals to which ESE contributes and that it link ESE objectives clearly to the agency's goals. Once the NASA goals have been clarified, the specific ESE objectives should be introduced, and the document should make clear how each ESE objective supports the NASA goals. While the six ESE science focus areas on predictive capability appear to be introduced in Section II (lines 231-243), it is not clear how each supports one or more of the four NASA goals that the draft document must support. These six focus areas are the centerpiece of ESE's implementation strategy. Their relevance to NASA's goals should be explicitly and unambiguously stated in Section II. Later, in Section III, additional detail should be provided. Finally, in Section IV, the strategies for pursuing each focus area and their interactions should be described.

The bulleted lists "Earth Observation and Data Management" and "Advanced Technology" (lines 524-588) present a combination of objectives and implementing strategies for ESE programs. Explanatory text describing the intent of the bulleted lists would improve the draft document's readability. In some instances, ESE has developed innovative and successful approaches for achieving the stated aims.[24] Other areas[25] present significant challenges. The draft document would benefit greatly from a more extensive discussion of the past progress and anticipated future challenges associated with each of these implementing strategies.

3. Does the ESE draft document describe an endeavor that stands as an important scientific program and makes needed contributions to broader national priorities?

The ESE draft document describes a program that has two parts, Earth System Science and Earth Science Applications, and that is clearly important both scientifically and in terms of its contribution to broader, societally relevant national priorities. However, because many of ESE's objectives are qualitative their value may be difficult to assess. The draft document would convey a better understanding of future progress if it were to include some descriptive examples of how existing ESE programs have already helped to improve the capability for predicting the effects of Earth system processes. In addition to highlighting the need for new approaches, such

[24] For instance, the first bulleted item (lines 526-527) addresses the need for flexibility and stability in the overall national and international integrated observing system. The successful Earth System Science Pathfinder program allows peer-reviewed selection of timely missions to address high-priority scientific issues to complement more comprehensive (but more costly and longer development time) observatory-class missions.

[25] For example, stability in the observing system (lines 526-527), transition of systematic measurements to operational systems (lines 534-535), and shifting strategic focus from missions to measurements (lines 531-533) are all extremely difficult technical, programmatic, and political aims. *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations* addresses issues associated with transition. With respect to the transition from a missions focus to a measurements focus, the committee notes that the need for essential synergies between different measurements makes the design of successful observing systems challenging.

examples would demonstrate clearly the high level of understanding that ESE has of both its present program and its future objectives.

Both the NASA Strategic Plan and the ESE draft document emphasize activities that directly support applications (primarily predictions of climate, weather, and natural hazards). Indeed, the draft document justifies its programs almost exclusively on the basis of potential societal benefit but says little about the exciting fundamental science that will be necessary to achieve its objectives. The committee believes that effective progress can be made only if fundamental and applied research are balanced appropriately.[26]

Answering specific, societally relevant questions about changes in the Earth system will require investigations of many basic physical, biological, and biogeochemical processes that are not currently understood. Furthermore, understanding how these processes orchestrate the evolution of the Earth system at different time scales is an essential precursor to the development of a scientific framework for the exploration and search for life in the universe—one of the great challenges facing all of science. Progress in this area requires the pursuit of basic knowledge. However, in contrast to some other areas of science, Earth system science has great societal relevance, so it is essential that NASA and the Earth science community pursue parallel and strongly interactive paths, basic and applied, the products of which will add to the body of scientific knowledge and also contribute to the improvement of life on Earth. **Considering the unique relationship between basic and applied research in Earth systems science, the committee recommends that the ESE strategy document clearly describe the respective roles of applied and basic science and the appropriate balance between the two.**

The six science focus areas are important and challenging. However, the reader is left with questions as to how and why these six were selected. A concise summary of the planning processes that resulted in the six science focus areas and the 12 applications focus areas, along with references to supporting lower-level documentation, would strengthen the draft document by demonstrating ESE's expertise at managing planning processes involving input from broad and diverse communities of implementers and stakeholders.

ESE's strategy for accomplishing its applications goals involves partnerships with other government agencies. The committee supports this strategy but believes it to be incomplete. ESE's ambitious goals for predictive capabilities will also require strong and effective collaborations with entities outside government, including universities, nonprofit organizations, and the private sector. Indeed, new paradigms may be required to achieve ESE's objectives, for example, a paradigm that considers partnerships to be only one element of a larger strategy that would also include, for example, the powerful effects of markets as agents for change.

The NASA applications strategy should emphasize one of the agency's strengths, which is the provision of objective, scientifically derived environmental information to all parties, inside or outside governments, in a neutral, nonpolitical mode. Although the ESE draft document (lines 814-854) addresses the importance of existing external partnerships, it does not describe how the new partnerships required to achieve the stated objectives will be established. In addition, the draft document does not detail how existing partnerships will be exploited. **The**

[26] In *Building a Foundation for Sound Environmental Decisions*, the NRC recommended that effective environmental research should have a balance of two kinds of research—*problem-driven research* and *core research.* "Problem-driven research is targeted at understanding and solving particular, identified environmental problems. Core research aims to provide broader, more generic information that will help improve understanding of many problems now and in the future." National Research Council, 1997, *Building a Foundation for Sound Environmental Decisions,* National Academy Press, Washington, D.C., p. 1.

committee recommends that this strategic element be added to the ESE draft document in the section on external partnerships (lines 814-854) and that the text in this section be revised accordingly.

4. Does the ESE draft document provide appropriate attention to interdisciplinary aspects, integration of technology development, and overall scientific balance?

Interdisciplinary Aspects

The draft document emphasizes many interdisciplinary aspects, beginning most importantly with the compelling need to treat Earth as a single system consisting of continents, atmosphere, oceans, ice, and life and extending to the influence of solar variability on Earth in collaboration with NASA's Space Science Enterprise. Each of the identified six science focus areas is, independently, also fundamentally interdisciplinary. Together, the focus areas constitute the physical, biogeochemical Earth system. However, some important elements of global Earth science appear to be excluded from the ESE program (e.g., the population-driven contributions to land cover change), possibly because they are addressed in the programs of other agencies. The ESE draft document should describe how NASA will work with other organizations, public and private, to ensure that the full spectrum of important topics is addressed and should make clear how ESE will use the results of work done by other organizations.

Integration of Technology Elements

The ESE draft document is less successful in addressing the integration of technology development and overall scientific balance. Discussion of technology development is limited to a brief list of strategic elements (lines 570-588), lists of technology requirements needed to support future missions in the focus area roadmaps and the 2025 vision (lines 964-1025), and passing mention of the New Millennium Program for technology flight demonstrations. The draft document could be strengthened by including a discussion of the elements and relative roles of ESE's Earth Science Technology Program and the Aerospace Technology Enterprise's Mission and Sensor Measurements Technology Program in the development of new technologies to support future ESE missions.

Overall Scientific Balance

The committee has pointed out the importance of ensuring an appropriate balance between basic and applied research and notes here several changes that would improve the ESE draft document's scientific balance. The draft document emphasizes missions, measurements, modeling, and prediction, with less attention to the integration of aircraft, laboratory, and field programs. As noted in several places above, although the draft document lists important science questions (lines 1032-1078), it includes very little discussion of how the science will be addressed, how the questions are (or will be) prioritized, and when answers are expected.

The draft document would be improved by a description of how the Earth System Science Pathfinder program will be strategically coupled to ESE's set of defined missions. While such a description might be too detailed for an overview of this kind, including it in the draft document would emphasize the role of technology and hardware in achieving ESE's objectives.

It also would exemplify how NASA will incorporate new concepts rapidly into measurement programs, leading to exciting, cutting-edge programs.

The ESE draft document should demonstrate that important disciplinary science has not been omitted, perhaps by describing each science focus area in more detail. Replacing the bulleted and tabular material between lines 416 and 436 with descriptive text, illustrative of the richness and complexity in each focus area, would be beneficial and more effective. Breadth and inclusiveness are essential in ESE's strategy document, which needs to convey the full range of possible scientific components and interactions.

In the draft document, solid Earth science stands somewhat apart from, and independent of, the other science focus areas. Text describing the solid Earth focus and its connections to the other focus areas would help the reader to understand why Earth must be studied as a system. Connections between seemingly unrelated activities such as the precise measurement of gravitational fields and hydrology/precipitation would help the reader understand the synergies between solid Earth science and the other science focus areas. The importance of ESE's geodetic infrastructural instrumentation, such as its Global Positioning System, Satellite Laser Ranging, and Very Long Baseline Interferometry capabilities, for pursuing such objectives as well as other applications as diverse as monitoring ocean level and atmospheric temperatures and weather forecasting should be emphasized.

It is also important that the description of the science in each focus area reflect the complete range of activities required to perform global Earth science. The existing descriptions do not accomplish this. In particular, the focus area titles (as in the table starting at line 435) are in some cases not well matched to the schematic information included in the roadmaps. Deficiencies identified in the roadmaps for each of the six science focus areas include the following:

- *Climate Variability, Change, and Prediction.* This focus appears to be strongly oriented toward long-term climate change. A more careful balance including science associated with seasonal variability and other time scales would be valuable.
- *Atmospheric Composition.* While ozone-related chemistry is critically important, other topics in chemistry and atmospheric composition science, including such things as aerosols and sulfur dioxide, are also extremely important yet are not described in the ESE draft document.
- *Ecosystems and Carbon Cycle.* While the carbon cycle itself is properly represented as important science, both the role of ecosystems within the carbon cycle and the science of ecosystems external to the carbon cycle (including other biogeochemical cycles) are underrepresented.
- *Water and Energy Cycle.* The emphasis on the global aspects of the water and energy cycle results in insufficient recognition that regional-scale effects are central to many key water and energy issues, including flooding and drought.
- *Weather.* This focus area appears to be complete and balanced.
- *Earth Surface and Interior.* The emphasis on natural hazards, while important, appears to exclude basic understanding of solid Earth physics and processes.

The committee finds that analysis of the measurement data is not emphasized sufficiently to indicate its central importance in ESE's end-to-end strategy. Because the productivity of any particular satellite or satellites depends as much on the readiness of software and data analysis

tools as it does on the readiness of sensor and spacecraft hardware, ESE leadership must "be the advocate for the appropriate balance of investment in data analysis"[27] and should "provide strategic planning and oversight concerning the collection, processing, archiving, and dissemination of data and information collected by NASA's space missions."[28]

Related Program Balance Issues

During the discussion at the May 6, 2003, committee meeting, ESE officials stated that the allocation of funding between universities and NASA centers is based entirely on open competition. The committee believes that this important strategic principle should be explicitly stated in the ESE draft document. The importance of open competition could be included as part of a general discussion of the principles for the overall ESE strategy.

The relative allocation of resources among various activities represents another important aspect of program balance. While detailed budgets are not a necessary part of the ESE document, a discussion of the relative investments in space observations, data analysis and research, applications, and education would be helpful.

The committee is pleased with the frequent references to international collaborations and partnerships but believes it would be appropriate to mention how NASA develops these strategically. For example, ESE might wish to mention NASA's participation in the Integrated Global Observing System Partnership, the Committee on Earth Observing Systems, and other international forums. Strategic considerations include deliberate redundancy, scientific and technical expertise, and cost-effectiveness.

Earth system science is a complex, highly integrated activity requiring critical interaction among the many agencies and organizations responsible for performing particular elements of the scientific research. ESE recognizes this and has indicated clearly that the Earth "systems" science problem requires a "systems" solution. The committee recognizes that systems approaches may not be as amenable to scientific research as they are to engineering development. Nevertheless, many of the concepts inherent in systems engineering, particularly those related to the coordination of multiple and distinct efforts, can be applied to complex scientific research programs as well.

ESE has appropriately recognized that its contribution is in areas within the rubric "as only NASA can" and includes the role of leading or motivating partnerships to accomplish activities that fall at least partly outside the ESE charter. The committee is concerned that ESE's ability to achieve broad Earth science objectives may be compromised because no single organization is responsible for coordinating the efforts of the many partners. **In light of this concern the committee recommends that ESE describe how it will take the steps necessary to ensure that all important scientific components are identified, and that NASA work with other relevant agencies to ensure that the specific roles of partner organizations are defined and activities properly coordinated. The committee believes that it is critical that NASA identify those areas appropriate for NASA leadership, that plans be established to ensure that leadership in other relevant areas has been assigned to and accepted by other organizations, and that mechanisms by which ESE develops or fosters the necessary partnerships be formalized.**

[27] National Research Council, 2002, *Assessment of the Usefulness and Availability of NASA's Earth and Space Science Mission Data*, National Academy Press, Washington, D.C., p. 4.
[28] Ibid.

Finally, the ESE draft document should address data availability. The draft document is silent on ESE's data policy. An inflexible open data access policy could have a significant impact on the range of partnerships ESE is able to develop, while a substantial shift to limitations on data access could impede interdisciplinary use of many data sets. An expanded discussion of the processes and procedures by which data policies are reviewed and are assessed over time would greatly enhance the utility of the ESE strategy document. **The committee recommends that the revised ESE strategy document contain a brief description of ESE data policies and the mechanisms by which they will be regularly reviewed and appropriately revised.**

5. What recommendations from recent NRC reports, if any, should be considered in revising the draft?

The committee's review was guided by several recent NRC reports, including *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations,* 2003; *Review of the U.S. Climate Change Science Program Strategic Plan*, 2003; *Review of NASA's Earth Science Enterprise Applications Program Plan*, 2002; *Review of NASA's Earth Science Enterprise Research Strategy for 2000-2010*, 2000; and "NASA's Plans for Post-2002 Earth Observing Missions," 1999. These reports are cited elsewhere in this report. Below, the committee calls attention to several additional findings and recommendations of these and other reports that ESE may consider as it refines and improves the draft document.

Section III outlines the approach of the ESE Applications Division in working with other federal agencies to enhance nationally important decision support systems. The NRC review of the ESE Applications Program Plan[29] suggested that NASA expand its pool of potential partners, and a recent NRC report on the use of satellite data by local and state governments[30] provides valuable advice on how more widespread and beneficial use of satellite data by state and local governments can be encouraged and achieved. The ESE draft document would benefit from an explanation of why regional, state, and local applications no longer form a part of NASA's approach. Some elaboration of why the particular application areas were chosen rather than others would also improve the document.

Recommendation 5 of the NRC's *Review of NASA's Earth Science Enterprise Research Strategy for 2000-2010*[31] recommends "matrices that map the detailed science questions to measurement parameters, implementation procedures, models, calibration/validation/verification requirements, and potential partners." The ESE draft document should address these issues in order to demonstrate the links between key science questions and the research missions designed to address them. This suggestion responds to a concern raised above by the committee—namely, that the strategic paths to the achievement of goals should be addressed in more detail. Material of this kind would be best included in Section IV.

Finally, the committee recommends that ESE make reference to its earlier strategic plan[32] and describe how the present draft document builds on and continues that strategy,

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[29] National Research Council, 2002, *Review of NASA's Earth Science Enterprise Applications Program Plan,* National Academy Press, Washington, D.C.

[30] National Research Council, 2003, *Using Remote Sensing in State and Local Government: Information for Management and Decision Making,* National Academies Press, Washington, D.C.

[31] National Research Council, 2000, *Review of NASA's Earth Science Enterprise Research Strategy for 2000-2010*, National Academy Press, Washington, D.C.

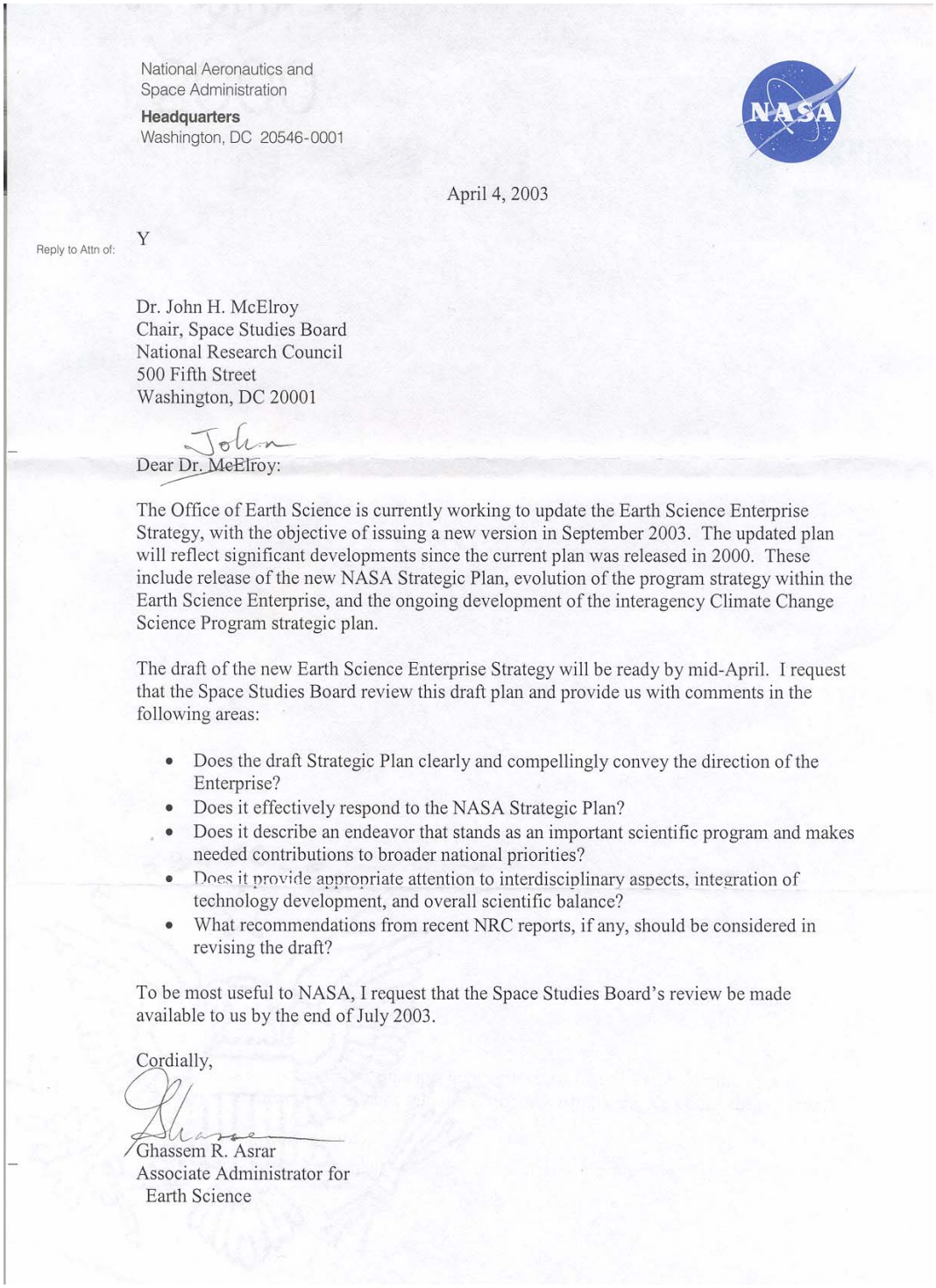
[32] NASA Earth Science Enterprise, "Understanding Our Home Planet, Earth Science Enterprise Strategic Plan," Washington, D.C., 2001. Available online at: <http://www.earth.nasa.gov/visions/stratplan/ese_strategic_plan.pdf>.

here new emphases have been added, what they are, and how they were selected. Non-NRC documents, including internal ESE roadmaps, should also be referenced.[33]

[33] In particular, discussions in the ESE strategy document related to the solid Earth sciences might examine the following:

- *Living on a Restless Planet,* Solid Earth Science Working Group, NASA, 2002. Available online at <http://solidearth.jpl.nasa.gov>.
- EarthScope InSAR. Available online at <http://www.earthscope.org/>.
- *Bathymetry from Space: Oceanography, Geophysics, and Climate*, Geoscience Professional Services, Bethesda, Maryland, June 2003, 24 pp. Available online at <http://www.geo-prose.com/projects/bathy_from_space_rpt.html>.

Appendix A
Letter of Request



National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

April 4, 2003

Reply to Attn of: Y

Dr. John H. McElroy
Chair, Space Studies Board
National Research Council
500 Fifth Street
Washington, DC 20001

Dear Dr. McElroy:

The Office of Earth Science is currently working to update the Earth Science Enterprise Strategy, with the objective of issuing a new version in September 2003. The updated plan will reflect significant developments since the current plan was released in 2000. These include release of the new NASA Strategic Plan, evolution of the program strategy within the Earth Science Enterprise, and the ongoing development of the interagency Climate Change Science Program strategic plan.

The draft of the new Earth Science Enterprise Strategy will be ready by mid-April. I request that the Space Studies Board review this draft plan and provide us with comments in the following areas:

- Does the draft Strategic Plan clearly and compellingly convey the direction of the Enterprise?
- Does it effectively respond to the NASA Strategic Plan?
- Does it describe an endeavor that stands as an important scientific program and makes needed contributions to broader national priorities?
- Does it provide appropriate attention to interdisciplinary aspects, integration of technology development, and overall scientific balance?
- What recommendations from recent NRC reports, if any, should be considered in revising the draft?

To be most useful to NASA, I request that the Space Studies Board's review be made available to us by the end of July 2003.

Cordially,

Ghassem R. Asrar
Associate Administrator for
Earth Science

Appendix B
Statement of Task

February, 2003

Review of the NASA Earth Science Enterprise Strategic Plan

Space Studies Board

Background

NASA has begun to revise and streamline its strategic plan so that the agency's programs are organized under a set of four "mission-driven" strategic enterprises, which are supported by several "enabling capabilities" areas. Earth science constitutes one of the four enterprises.

The Office of Earth Science is currently working to update the Earth Science Enterprise Strategic Plan, with the objective of issuing a new version in September 2003. The updated plan will reflect significant developments since the current plan was released in 2000, especially including the President's Climate Change Research Initiative, NASA's new strategic direction, and evolution of the program strategy inside the Earth Science Enterprise. The strategic plan will constitute one of the principal elements of NASA's response to requirements mandated by the Government Performance and Results Act.

According to NASA, the Earth Science Enterprise strategic plan will be based on a mission statement to "understand and protect our home planet by advancing Earth system science to enable improved prediction of climate, weather, and natural hazards using the vantage point of space." The strategy will be to achieve enterprise goals by integrating research, applications, technology, and education programs. The plan will build on prior SSB reviews of a NASA science plan (in 2000) and an applications program plan (in 2002). NASA now seeks an independent review of the new strategic plan, which will be intended to present an integrated strategy for the program as a whole.

Statement of Task:

The Space Studies Board will organize an independent review of the draft strategic plan for NASA's Earth Science Enterprise. The NASA plan will be evaluated in term's of recent research strategies and other relevant reports of the National Academies and will provide comments in the following areas:

1. Does the draft Strategic Plan clearly and compellingly convey the direction of the Enterprise?
2. Does it effectively respond to the NASA Strategic Plan?
3. Does it describe an endeavor that stands as an important scientific program and makes needed contributions to broader national priorities?
4. Does it provide appropriate attention to interdisciplinary aspects, integration of technology development, and overall scientific balance?

Appendix C
Members of the Committee to Review the NASA Earth Science Enterprise Strategic Plan

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Staff

ARTHUR CHARO, Study Director
RICHARD LESHNER, Research Associate
CLAUDETTE BAYLOR-FLEMING, Senior Program Assistant

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JOHN H. MCELROY, University of Texas at Arlington (retired) C*hair* (through June 30, 2003)
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JOSEPH K. ALEXANDER, Director