Review of the Organization and Management of Research in NOAA

A Report to the NOAA Science Advisory Board

by

The Research Review Team

Berrien Moore III, Chair
University of New Hampshire

Richard D. Rosen
NOAA Office of Oceanic and Atmospheric Research

Andrew A. Rosenberg
University of New Hampshire

Richard W. Spinrad
NOAA National Ocean Service

Warren M. Washington
National Center for Atmospheric Research

Richard D. West
Consortium for Oceanographic Research and Education

August 6, 2004

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Science Advisory Board
Executive Director's Office
Silver Spring, MD 20910

August 6, 2004

Conrad L. Lautenbacher, Jr., VADM US Navy (Ret.)
Under Secretary of Commerce for Oceans and Atmosphere
National Oceanic and Atmospheric Administration
Herbert C. Hoover Building, Room 5128
14th & Constitution Avenue, NW
Washington, DC 20030

Dear Admiral Lautenbacher:

The National Oceanic and Atmospheric Administration (NOAA) Science Advisory Board is pleased to convey to you the "Review of the Organization and Management of Research in NOAA" by the NOAA Research Review Team (RRT), a working group of the Science Advisory Board (SAB). The Report represents the results of extensive consultation with clients of NOAA science products and NOAA staff, analysis and synthesis of results of the consultations, and review by diverse experts and stakeholders. It includes eleven recommendations which, collectively, address key shortcomings that were found in the way that research in NOAA has been managed in the past. The report also addresses directly the charge to the SAB with regard to the location of research in NOAA and the linkage of the Office of Oceanic and Atmospheric Research to other components of NOAA. Subject to the discussion below, the SAB endorses the recommendations in the report.

The SAB notes that many of the problems highlighted and addressed in the RRT Report have been identified in past reviews of NOAA science and operations, including many recommendations from the SAB itself. Recurring issues are the lack of a comprehensive Science Plan for NOAA research over the near, medium, and long term; the uneven, often weak integration of science activities across (and sometimes within) line offices; and the absence of structures and processes which ensure timely and effective transition of NOAA efforts from research to operations.

The SAB also feels it is important to acknowledge that a number of important initiatives have already been taken that have potential to address these issues. We particularly note the charge already given to the NOAA Research Council for 5-year and 20-year Science Plans, the implementation of matrix management across line offices for all NOAA projects, and the establishment of the PPBES to coordinate planning, budgeting, and accounting. These initiatives are important steps that have already been taken by NOAA to address issues prompting the RRT recommendations.

If all three initiatives achieve their objectives, the result will be a NOAA with many of the characteristics envisioned in the RRT Report. The message should be conveyed clearly to the Administration and to the Congress that changes in NOAA are underway, with strong support from your office, NOAA managers, and the SAB. The SAB stresses

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Science Advisory Board
Executive Director's Office
Silver Spring, MD 20910

that many of the changes needed in NOAA science are fundamentally cultural. NOAA critics must understand that change in NOAA culture is more important than merely making changes in organizational structure, although changes in NOAA organization will be made whenever they are necessary to move forward. For example, we strongly endorse the recommendation to create an Associate Administrator for Research.

It is also important that all parties interested in NOAA understand that long-term, visionary research for discovery will always be a crucial part of NOAA science, as the "seed-corn" from which the crop of continually improved application of research to operational problems can be harvested. This consideration compels the Board to express a cautionary note regarding the recommendations of the report. The report properly emphasizes the need for NOAA research to have a strong focus on supporting operations. However, NOAA research has responsibilities that extend beyond improving the delivery of products and services. NOAA research must also be undertaken to ensure that United States (U.S.) government policy is well founded in science. The research conducted in NOAA laboratories, that ultimately underpinned the Montreal Protocol, is an historical example of this end-to-end process. Today, basic research to understand the Earth's climate system and to characterize anthropogenic effects on that system is vitally important to framing the nation's contributions to the IPCC. In addition, the U.S. federal government has entered into a large number of bilateral and multiple-government agreements. In many of these, NOAA has an assigned role to play. Some of these require research and development activities that have little apparent connection to applications in the U.S., e.g., drought monitoring and prediction in the Sahel of Africa. Thus it is important that as its research is better focused on supporting operations, NOAA management must also ensure that sufficient capability is retained to meet non-operational R&D needs.

The SAB stresses that the implementation of the initiatives cited above may not remedy or mitigate the long-standing challenges in the management of NOAA Science. The SAB is well aware that institutional cultures are very difficult to change, and many critics of NOAA have the perception that NOAA's research culture is particularly unwilling to change. We look forward to working with you and your officers to bring about these changes, and to build a strong, effective, and respected NOAA.

Respectfully,

Leonard J. Pietrafesa, PhD
Chair, NOAA SAB

TABLE OF CONTENTS

Preface

The National Oceanic and Atmospheric Administration (NOAA) was created to serve a national need to better protect life and property from natural hazards, to better understand the total environment, and to explore and develop ways we can wisely use our marine resources. To meet these goals NOAA needs research to develop products and services that protect life and property, to promote sustainable economic growth, to provide information services relating to the total environment, and to foster stewardship of marine and other Earth system resources.

The FY 2004 House and Senate Appropriations Committee Reports contain language that challenged explicitly the organization of research in NOAA's primary research office and implicitly raised the issue of how should research best serve NOAA and the nation.

In response to these Congressional concerns, NOAA asked its Science Advisory Board (SAB) to establish a Research Review Team with the broad task of providing findings and recommendations for NOAA to use to enhance its research organization and connection to operational activities.

In this Report, we have sought to do this by establishing operational and organizational principles for guiding research, by providing findings and recommendations to enhance NOAA's research organization and connectivity to operational activities, and by answering the specific Charge of the SAB. The Research Review Team believes that our report should give guidance and direction for NOAA, but it is for the agency to determine the detailed steps and actions needed to take that new direction for research within the agency.

NOAA serves the American public, the nation, and the world with the highest possible distinction as a trusted information agency. Significant portions of the research enterprise are internationally recognized as world-class, and the work is of extraordinary value to the country.

However, to meet the new and increasingly complex demands and challenges, including those posed by the Climate Change Science Program, the Global Earth Observing System of Systems, and the preliminary report of the U.S. Commission on Ocean Policy, NOAA must embrace changes in its operational procedures and organizational structure; these changes are in the best interests of NOAA, its research enterprise, and our country. We see evidence that changes for the better are beginning to take hold in NOAA, and we urge the agency to continue down this path, using this Report as a helpful guide.

In change there is opportunity.

I. Introduction

On October 3, 1970, the National Oceanic and Atmospheric Administration (NOAA) was created and incorporated into the Department of Commerce (DoC) to serve a national need "...for better protection of life and property from natural hazards...for a better understanding of the total environment...[and] for exploration and development leading to the intelligent use of our marine resources." Research is essential to NOAA's development of products and services that protect life and property and promote sustainable economic growth. A focal point for NOAA research is the Office of Oceanic and Atmospheric Research (OAR), one of six NOAA line offices.

The FY 2004 House and Senate Appropriations Committee Reports contain language specific to NOAA research in OAR, and this language is included by reference in the Conference Report accompanying the Consolidated Appropriations Bill. The House Report accompanying the FY 2004 Commerce, Justice, State, and Judiciary, and related Agencies Appropriations Bill directs NOAA to develop a laboratory consolidation plan: "In recognition of current resource limitations the Committee is forced to operate within, the Committee directs NOAA to review the continued requirements for twelve separate laboratories, six of which are located in Boulder, Colorado. The Committee directs NOAA to submit a laboratory consolidation plan to the Committee by March 15, 2004." The Senate Report accompanying the FY 2004 Appropriations Commerce, Justice, State, and Judiciary, and related Agencies Appropriations Bill states, in part: "NOAA is directed to report to the Committee on Appropriations on the costs and benefits of breaking OAR up into its constituent parts and distributing those parts as desirable to the other line offices. The report should specifically address how the newly configured research sector will directly assist line offices in developing timely solutions to problems confronting NOAA now and in the next 5 years."

In response to these Congressional directives, NOAA asked its Science Advisory Board (SAB) to establish a Research Review Team (Appendix 1) to address five primary issues:

- Does the research conducted by the Office of Oceanic and Atmospheric Research provide effective support and vision for NOAA by enabling it to improve products and services, and to introduce new products and services through the transfer of technology and the development and application of scientific understanding?
- Is OAR adequately linked to NOAA's operational line offices- National Weather Service (NWS), National Environmental Satellite Data and Information Service (NESDIS), National Marine Fisheries Service (NMFS) and National Ocean Service (NOS)- and are the research programs relevant to the needs of these organizations? If so, what are the benefits? If not, what changes would the Review Team recommend? Is it adequately connected to the Program Planning and Integration Office?
- How do the management structure and processes of OAR compare to those of other agencies managing research? Based on that analysis, should OAR be dissolved into its constituent components and distributed across NOAA, should it be left as is, or should NOAA consolidate all of its research activities into a single organization?

- Focusing specifically on the OAR labs, would consolidation of the labs yield a more effective scientific program? If so, what would the Team recommend?
- Would lab consolidation yield a more efficient structure, by reducing administrative overhead and infrastructure/manpower? If so, what would the Team recommend?

The broad task to the NOAA Research Review Team is to conduct a review of OAR "for the purpose of improving the effectiveness and efficiency of its research enterprise. The review will provide findings and recommendations that will be used by NOAA to enhance its research organization and connectivity to operational activities."[1] Additionally, the Review Team's recommendations are intended to assist NOAA in responding to the Senate and House language. It was in that spirit that the Review Team prepared and released on January 29, 2004, *A Preliminary Report*; this document subsumes that *Preliminary Report*. More broadly, the Review Team believes that to respond logically to the Charge of the SAB that it is essential that we consider the research enterprise at NOAA and not just focus upon OAR. In honoring this expanded perspective, we also acknowledge that in the time available we have not been able to focus as much attention on many of the specific issues in the other line organizations; however, we are making recommendations that go beyond just OAR and pertain to NOAA science and research structure as a whole. In this regard, we hope that this Report contributes to the wider ongoing discussion about the management and organization and role of science and research.

We also have taken into consideration three items that directly impact the research program of NOAA: the Climate Change Science Program, the Global Earth Observing System of Systems framework, and the recently released Preliminary Report of the U.S. Commission on Ocean Policy.

The Climate Change Science Program (CCSP) Strategic Plan, prepared by 13 federal agencies as a multi-agency collaboration, addresses global climate variability and change. The CCSP incorporates the near-term deliverables of the Administration's Climate Change Research Initiative, and the long-term breadth of the U.S. Global Change Research Program authorized by the Global Change Research Act of 1990. NOAA is the lead or co-lead for 19 of the 21 CCSP deliverables. CCSP identified goals to address how climate variability and change will affect the environment and our way of life and to assess how we can use this knowledge to protect the environment and provide a better living standard for all:

1. Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.
2. Improve quantification of the forces bringing about changes in the Earth's climate and related systems.
3. Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.

---

[1] Letter from Vice Admiral Conrad C. Lautenbacher, NOAA Administrator, to Dr. Leonard J. Pietrafesa, chair NOAA Science Advisory Board, October 6, 2003

4. Understand the sensitivity and adaptability of different natural and managed ecosystems to climate and related global changes.
5. Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

The CCSP goals must be an integral part of the climate portion of the NOAA Research Vision and Plan. Moreover, they will take many years to accomplish as NOAA works collaboratively with its federal partners. Concurrently, NOAA recently established a matrix management system to improve coordination and efficiently use resources for programs, such as climate, that span two or more NOAA line offices. The matrix management approach to climate ensures that there will be a focused program that fulfils NOAA’s commitments to the implementation of the CCSP.

Global Earth Observing System of Systems (GEOSS) will develop a pioneering global architecture that will provide new observational capabilities which, combined with subsequent modeling and assessment studies, will over the next decade revolutionize the understanding of how Earth works to advance informed decision making on national, regional, and local levels. NOAA plays a critical role in constructing the GEOSS international initiative, and consequently, NOAA's research enterprise must be advanced in conjunction with developments in Earth observations. In particular, the goal of GEOSS to take the "pulse of the planet" will require integration not only across observing systems but also across the research enterprise that will both formulate the needs for these measurements and use them to advance understanding and prediction. Observations of the evolving physical, chemical, and biological state of Earth will place new demands on the organization of NOAA research (for example, in the development of advanced data assimilation techniques) so that NOAA can take proper advantage of GEOSS. Traditional disciplinary research will not suffice, and NOAA will need to ensure that its research efforts have the required breadth and co-ordination to match GEOSS.

The U.S. Commission on Ocean Policy preliminary report contains several recommendations that are of critical importance to the future direction for NOAA’s research. Relevant priority recommendations from the Commission’s Preliminary Report (Appendix II) include:

1. Congress should pass an organic act for NOAA, codifying its mission, functions, and structure, consistent with the principles of ecosystem-based management and with NOAA’s primary functions of assessment, prediction, and operations; resource management; and research and education;
2. The federal budget for ocean-related research should double over the next five years;
3. Expand specific programs within NOAA that directly relate to the research enterprise; and
4. NOAA should assume a leadership role for the Integrated Ocean Observing System.

The Commission’s recommendation to double the federal research budget for ocean-related science adds urgency and emphasis to the Review Team’s call for a comprehensive research plan for NOAA and a senior management team to manage this research enterprise. Of critical importance as the federal science budget grows is NOAA’s responsibility to properly integrate intramural and extramural research to maximize this investment. We discuss the intramural and extramural research in NOAA in subsequent sections of this report.

The creation of an organic act must include the clear recognition of NOAA as a science-based agency with a corporate view of the research program. The Ocean Policy Commission recommendation for restructuring along functional lines is also supported by the Review Team. The Review Team proposes several means of integrating the research activities across line offices as the first stage of a possible restructuring process. Our principles for the research organization (Section II) offer a guide for future restructuring efforts. The expansion of programs such as ocean exploration, ocean mapping, aquaculture, preventing the spread of invasive species, and oceans and human health, and the leadership of an integrated ocean observing program should be considered as critical building blocks for the future development of NOAA's ocean-related research program. In addition, the Commission's recommended consolidation of currently fragmented programs across all federal agencies, including NOAA, will challenge the agency to ensure that the science and research support for these activities can be maintained within NOAA and its external partners. Examples include: habitat protection and restoration, protected area management, and marine mammal and protected species programs.

It is the Review Team's view that research in NOAA, and particularly the role of OAR, is a vital cornerstone of NOAA's mission that includes research-to-customer interactions. On topics that range from ozone depletion, air quality and weather prediction, and climate variability and change to global water resources, coastal dynamics and ecosystems management, NOAA has served the American public, the nation, and the world with the highest possible distinction as a *trusted* information agency. Significant portions of the research enterprise are internationally recognized as world-class, and the work is of extraordinary value to the country. It is the hope of this Research Review Team that in addressing its assigned tasks, we are challenging NOAA constructively to do even more to enhance its research enterprise.

The Findings and Recommendations in this Report are based on examining substantial amounts of data and various reports, as well as extensive internal NOAA interviews, including: focused and repeated discussions with the OAR Laboratory Directors; meetings with Assistant Administrators of NOAA's line offices, Goal Team leads, and other senior NOAA staff; meetings with senior managers (past and present) of other governmental agencies and large private sector, research-based companies; wide-ranging discussions with representatives of NOAA's external community (including Joint Institutes); and discussions with the SAB (Appendix III).

We sought collaborating comments and data for our findings, but these findings are the product of both analysis and synthesis, and they are, of necessity, partly subjective. In making recommendations, our approach was to compare specific recommendations to the guiding principles and to remind ourselves of the physician's oath of "First, do no harm"; we have tried to honor this. We have consciously sought to provide latitude as appropriate in our recommendations, but this latitude does not include the *status quo*. We believe that it is appropriate to identify options and constructive opportunities for change, from which NOAA leadership can select the most appropriate solutions. We do believe that there are changes needed, and these changes are in the best interests of NOAA, its research enterprise, and our country.

The Research Review Team expresses its appreciation to the many individuals who contributed their energy, time, and wisdom to this enterprise; we are particularly grateful to the NOAA employees, who willingly and openly shared their thoughts with us. Throughout this study we have enjoyed and benefited from the support of the NOAA leadership at all levels, and for this support we express our appreciation. Finally, the team is particularly grateful to Ms. Mary Anne Whitcomb and Ms. Tracey McCray for service beyond the call of duty.

II. Principles

NOAA is a science-based agency with regulatory, operational, and information service responsibilities. To fulfill these responsibilities, it is essential that NOAA maintain a vigorous and forward-looking research enterprise. Given the vital importance of research to the agency, it is perhaps not surprising to discover that research has spread across NOAA; there are 29 somewhat heterogeneous NOAA Laboratories and Centers and 18 Joint Institutes associated with research in NOAA (Appendix IV). Because such complexity can work to the disadvantage of NOAA's mission, the Review Team believes there needs to be a set of principles to guide recommendations focused upon ensuring research excellence, to invigorate the program to transfer research into operations and information services, to ensure that the best research is the basis for scientific advice for regulatory responsibilities, and enhance NOAA's information services. The following principles are consistent with the successful research programs in support of operational requirements that we reviewed outside of NOAA (Appendix III).

Operational Principles for Guiding Research Focus

Value and Quality

- A sustained research program is essential for a science-based agency with long-term operational responsibilities.
- Research in support of the organization's mission should cover a spectrum of temporal frames: for example, short-term time frame (<2 years), mid-term time frame (2-5 years), and long-term time frame (>5 years). A Research Plan with milestones is necessary to ensure continuity across this spectrum.
- A culture of risk tolerance commensurate with a robust investment in long-term research with potentially high programmatic payoff must be established and maintained. A quantifiable and consistent level of resources must be dedicated to research that may not have a near-term operational application but provides the cutting-edge solutions for the future.
- Extramural research is essential to a science-based agency to broaden and deepen the scientific enterprise on which it depends while maintaining cost effectiveness and flexibility.
- The research program must be an open, merit-based process that brings together intramural and extramural efforts to contribute to problem solving. Extramural partners must be full participants in the program. The infrastructure supporting extramural research, including the administration of grants and contracts, needs to encourage and facilitate their participation in contributing toward the research objectives of the agency.
- Trust in and respect for the integrity of the research planning process is essential. The resulting budget should be simple, transparent, and provide maximum flexibility for budget planning and execution. Fragmentation of the budget into a large number of line items is an impediment to continuity and flexibility in the research program.

Relevance and Focus

- Research priorities must be consistent with the overall mission and goals of the organization, and the strategy for ensuring that consistency must be explicit. These priorities must be formally expressed in an enterprise-wide Research Plan. This plan should explicitly consider whether particular efforts should be developed within the agency and/or extramurally.
- Research responsibilities include identification, in collaboration with operational lines, of relevant operational requirements, including regulatory responsibilities, and efficient transition of research into operations and information products. This responsibility includes ensuring that the scientific advice for resource management and regulation is of the highest quality and uses the most current research.
- Research planning and investment must be agency-wide. This research investment must be reviewed and verified by the agency periodically to make sure that the research supports the mission. This process should sustain research, ensure transition from research to operations, and identify research that is no longer applicable to the mission.
- In-house scientific expertise must be fostered, over the long-term, in those recognized areas where a science-based agency has a major mission-related responsibility. Those areas should be defined by the core mission foci of the agency, including emerging aspects of these missions. A science-based agency must be able to lead national and international research and assessment efforts through intramural and extramural programs.
- To the extent possible, budgeting and funding streams for the research program must guarantee continuity with flexibility. Both intramural science and research and extramural programs are necessarily multi-year efforts, and multi-year funding must be planned for with reasonable certainty, including both base funds and project funds. Budgeting should be based on the research plan as far as possible.

It is important to ensure that the research programs respond directly to the other mission activities. For developmental and longer-term objectives, it is important to ensure that the ability to undertake higher risk research that may not have a near-term application is not compromised by immediate operational needs. Similarly, it is imperative that the products of NOAA’s research, be they operational advancements or expanded information services, reach the user. These Operational Principles are necessary to make certain these capabilities thrive across the spectrum of research, but they are not sufficient; there must be a corresponding set of Organizational Principles.

Organizational Principles for Guiding Research Location and Management

- The overall research enterprise should be viewed as a corporate program. Explicit linkages between research efforts across organizational lines must be forged and maintained for the agency and the nation to obtain the full benefit from research.
- There must be a single point of accountability for all science and research and this must be at the highest levels of the organization. This must be a primary responsibility, not a collateral duty.
- Formal mechanisms that clearly define responsibilities for transitioning research into operations and information services, including the commitment of resources, must be agreed to and understood throughout the agency.
- Organization must follow function as specified in the organization's strategic plan; therefore, if the transition of research into scientific advice, operations, services, and information is to be successful, then this function must be reflected clearly in the organization and in its processes.
- Dedicated resources for research that is focused on mid- to longer-term mission needs are essential. Locating these resources for intramural and extramural research in a research line can ensure these needs are not subsumed by shorter-term operational demands.
- Research that addresses near-term improvements to current operational capabilities should be formally aligned, with the operational activity organizationally and/or through explicit operating agreements.
- Scientific advice including that needed to meet operational resource management requirements should be formally aligned to the corporate research program to ensure that policy is based on the best available science.
- The structure of the organization should foster not only intra-agency but also inter-agency collaboration in the research enterprise.

These principles are consistent with the need of moving NOAA from an amalgamation of separate line offices to becoming an integrated organization—in business terms, NOAA needs to move from being a "holding company" to becoming a "corporation." We note that in most successful technologically advanced governmental agencies, corporations, and research universities, the research function reports to the "front office," budget structure formally recognizes a spectrum of research, and for corporations and agencies, there is almost always a corporate plan for research. Universities may not have a formal research plan, but generally, there are stated research priorities in their strategic plans.

For example, the budget structure within the Department of Defense (DoD) formalizes management of research across a gradient of operational maturity (e.g., its 6.1 – 6.7 structure Appendix V), and importantly, this structure and process codifies roles and responsibilities in the transition of research to operations, including transition criteria during formal research progress reviews. The DOD 7-level system can be modified to meet more appropriately the needs of NOAA, but at the least, the DoD rules and criteria for transitioning from research dollars to operational dollars offer an additional example and perhaps a useful framework. In this same vein, in 1995 the National Aeronautics and Space Administration (NASA) initially proposed Technology Readiness Levels (TRLs; Appendix V.A), and the US DoD adopted TRLs in June 2001 where they are now mandated for all major acquisition programs. Again, the use of TRLs could prove particularly helpful in the transition of research to specific operational products. From a slightly broader perspective and one that complements the Operational and Organizational Principles set forth above, Dr. Mal O'Neill, Chief Technical Officer, Lockheed-Martin Corporation, presented the following set of guiding principles:

- Customer pull must be accommodated early;
- R & D staff must advocate technology transition and focus on customer mission success;
- Observing Best Practices and Lessons Learned will optimize R&D investments;
- Large, diverse organizations must horizontally integrate R&D and leverage external R&D; and
- Like other corporate functions, R&D must have an accountable focal point.

Finally, while plans and processes are important, people are vital. Science and research after all are uniquely human endeavors. Leadership in scientific research is particularly difficult: herding butterflies is one analogy; a hockey referee is another. But whatever science leadership is, it is clear that it is important. Effective senior leadership at the top scientific level is essential if an agency-wide research endeavor is to be successful. Scientific distinction only comes when the leaders are people whom other scientists want to follow. At the research laboratory level, this implies that genuine leadership is, almost always, by outstanding scientists; this is central to laboratory leadership and integral to the success of any research institution. Fortunately, it is demonstrably possible to find within NOAA outstanding scientists who have the genuine scientific respect of their staff, and who also can and are willing to manage. This has implications for our subsequent recommendations.

III. Findings and Recommendations

Our strategy for establishing findings and making recommendations was to conduct extensive discussions (Appendix III) and to examine a wide variety of quantitative data. These data are available at http://review.oar.noaa.gov/.

In establishing Findings and in making Recommendations, the Review Team notes that our recommendations are not exhaustive. We focused our attention on the most important areas for change. We suggest directions that NOAA should take to improve an already distinguished research enterprise. Our recommendations should be viewed as a guide to NOAA management and researchers on ways to improve their programs. The Review Team sought to strike a balance in the level of detail of our recommendations. We leave implementation to NOAA, but hope these findings and recommendations give strategic direction.

Research Plan and NOAA's Mission

Finding: The NOAA Strategic Plan is a valuable guide for the future of the agency that identifies six crosscutting priorities that are essential for NOAA to meet its mission responsibilities. One of these priorities is *Sound, State-of-the-Art Research*. A core activity is NOAA's recently instituted Planning, Programming, Budgeting, and Execution System (PPBES), which could help in developing timely solutions to problems facing NOAA now and in the next five years. It is important that sufficient resources be devoted to the ongoing development and maintenance of the PPBES system. We find, however, that there is neither a research strategy nor a research plan to support the Strategic Plan. We also find that this lack contributes significantly to a severe *communication problem* between NOAA (and particularly OAR) and Congress, the Office of Management and Budget, and the external community. It also contributes to an internal communication problem regarding research priorities and objectives and linkages between the line offices or even within a line office. The absence of a longer-term research vision will undermine NOAA's future operational and informational services capabilities.

Recommendation: NOAA should develop a Vision for Research that supports the Strategic Plan. The Vision and Strategic Plan should extend outward to 20 years. The Research Vision should provide broad guidance and directions. NOAA should also develop a NOAA-wide Research Plan that provides explicit guidance including specific programmatic actions, performance measures, and milestones for implementing the Research Vision. The initial Research Plan should be based upon the direction of the current Strategic Plan and the initial Research Vision, and it should be the basis for developing goal-specific plans. Importantly, as a "corporate" research plan it should not be a collection of the plans for each line office, but rather a coherent integrated vision for NOAA's research efforts as an entity.

The Plan should clearly articulate the research goals, projects, and required capabilities for the next 5 years in a phased approach. Potential outcomes and payoffs, which link the research enterprise to the broad NOAA mission, should also be articulated. It should provide a blueprint that would indicate how the laboratories, Joint Institutes, Cooperative Institutes, Joint Centers and the broad extramural community are going to deliver on the Research Plan.

Consequently, the Research Plan should be developed in close consultation with the external community; however, the initial version will need to be fast-tracked so that it can help shape the FY 05 budgetary actions. Given that this Plan must be evolutionary in nature, there will be the opportunity for a greater role for the external community in shaping subsequent versions of both the Strategic Plan and the Research Plan. We are pleased that following our Recommendation in our Preliminary Report, NOAA has produced an initial Draft 5-year Research Plan, and we also applaud NOAA for charging its Research Council to prepare a 20-year Vision for Research. Subsequent versions of the Research Plan and Vision will require commitment not only from NOAA scientists but also NOAA's research partners.

In this regard, the Research Plan as it evolves must also build upon the appropriate National Research Council reports and consider international research plans. NOAA has already demonstrated sensitivity to and support of important international research initiatives including:

- Global Energy and Water Cycle Experiment (http://www.gewex.org);
- Joint Global Ocean Flux Study (http://www.uib.no/jgofs/jgofs.html);
- World Ocean Circulation Experiment (http://woce.nodc.noaa.gov); and
- Global Ocean Ecosystem Dynamics (http://www.pml.ac.uk/globec/main.htm).

To implement, monitor, and update the plan, the PPBES system needs to be fully used with appropriate support on an ongoing basis. Finally, review of the NOAA Research Plan is essential, both internally and externally, both nationally and internationally, and through periodic assessments of the Plan.

Research Organization within NOAA

Finding: NOAA needs a stronger and more coherent research management structure to execute a NOAA-wide Research Plan. The NOAA Research Council can play a vital role in defining NOAA's research mission. The role of the OAR Assistant Administrator, as its Chair of the Council, could provide senior management important control over the needed Research Vision and associated Research Plan. We recognize that the terms of reference for the Research Council state that the purpose of the Council is to provide "corporate oversight" and its mission is "to ensure that all NOAA research programs are consistent with the NOAA Mission, and NOAA Strategic Plan" Among the Council's roles and responsibilities are to "establish criteria and develop processes for reviews of all research and development programs…" and to "ensure appropriate mechanisms are in place to facilitate transfer of information and transition of research to operational use." We further recognize that the Council structure has been designed by NOAA to provide corporate-wide oversight, for a number of its activities, e.g., Research Council, Observations Council, and Ocean Council. The Councils are still growing into their roles, and we concur that their presence attests to NOAA's recognition of the need for a corporate perspective.

Despite the Council's roles and responsibilities, we believe that there needs to be higher-level budgetary and programmatic oversight for all research in NOAA. Furthermore, there is ample evidence that NOAA as a whole has suffered from not having a clear and forceful research voice. Creating a senior leadership position that would allow articulation of the research goals and objectives across NOAA would be a step toward finding the needed voice for research.

Recommendation: NOAA should establish the position of Associate Administrator for Research reporting directly to the NOAA Administrator and who would have budget authority for research across NOAA. The Associate Administrator for Research would oversee the transition of research to operations and would also serve as a primary point of contact for NOAA's external research relationships, nationally and internationally. This "front office" position in charge of NOAA-wide research should be a career appointment position of a distinguished scientist with broad knowledge of and appreciation for the research throughout NOAA. This recommendation is consistent with both the Operational and the Organizational Principles established in Section II; moreover, it was repeatedly recommended to us during the extensive interview process.

We recommend two formal bodies to manage NOAA's research enterprise. The first is a Research Board, chaired by the Associate Administrator for Research; the second is a Research Council, chaired by the Assistant Administrator for OAR.

The NOAA Research Board should be a standing committee of the NOAA Executive Council. Senior NOAA management should determine the membership. One possible scenario for membership of the Research Board would be the NOAA Assistant Administrators. The Research Board would be responsible for execution of the NOAA Research Vision and Plan and for timely progress in meeting research milestones. The Research Board would conduct regular formal reviews of all of NOAA's research and would determine and monitor the overall NOAA research program including ensuring the steady transition of research advances to operational products and the requirements and delivery of informational services. The Associate Administrator for Research (and Chair of the Research Board) would exercise budget authority over research in NOAA, and thereby the Chair would be charged with achieving the appropriate balance and direction of research and development across the line offices. Finally, the Associate Administrator will need to help streamline the communication on research matters among NOAA, the Department of Commerce, and the Office of Management and Budget (OMB).

In each of the Line Offices there should be a senior manager for the research program reporting directly to the Assistant Administrator. These senior managers form the Research Council. This Council would be an implementing and information gathering arm of the Research Board (i.e., would serve as a working group).

Transitioning NOAA Research to Operations and Providing Information Services

Finding: The transition of research to operations occurs at many levels and through many channels, and within NOAA there have been numerous successful transfers of research into operations and the provision of information services:

- **Modernization of the National Weather Service**: NOAA researchers developed the Next Generation Weather Radar (NEXRAD) in the 1980s and the Advanced Weather Information Processing System (AWIPS) in the 1990s. These technologies are the backbone of today's weather service. The recently deployed Open Radar Product Generator builds on these capabilities and is expected to continue improvements in weather forecasting.
- **ENSO forecasting and seasonal outlooks:** Much of NOAA's El Niño/Southern Oscillation (ENSO) forecasting effort has been transferred, or is in the process of being transferred, from a research mode to NWS operations. The Tropical Atmosphere-Ocean buoy array is among the research assets being moved into an operational line.
- **Tsunami Hazard Mitigation:** Advanced computer models, inundation maps, deepwater buoys, and an expanded seismic network are all products of the NOAA National Tsunami Hazard Mitigation Program, which was transferred from research to operations in 2004.
- **Week Two Climate Outlook:** Experimental, improved 8-to-14-day temperature and precipitation forecast products developed by OAR will be adopted by NWS as a starting point for its operational forecasts.
- **Hurricane Tracking Model:** This model, developed by OAR, is the primary tool for providing NWS guidance to emergency managers in states affected by hurricanes.
- **The Intergovernmental Panel on Climate Change:** In each of the three previous IPCC Assessments, work by OAR scientists has been cited numerous times, reflecting the critical research on climate change performed in the NOAA laboratories. The Chair of Working Group I for the 2007 IPCC Assessment is an OAR scientist.
- **Coastal Change Analysis Program:** This program works to transition emergent capabilities in remote sensing and geographic information systems into land resources information and decision support tools for our nation's coastal managers.
- **Fisheries Oceanography:** NOAA scientists provide important, new information on ecosystem dynamics to assist in developing regional fisheries management policies. In April 2004, NOAA research on issues related to by-catch in the Hawaiian long line fishery contributed to the fishery being reopened after a two-year closure by Federal courts.

While the above examples show successful transfers of research to operational lines and the provision of information services (see Appendix VI for additional examples), the transition of research to operations must be significantly strengthened. Greater success could be realized if NOAA had an agency-wide plan to guide the transition of its research investment into its operational mission. We are pleased to see that the recently developed draft 5-year Research Plan addresses this transition challenge. The Review Team notes the development of a Science and Technology Infusion Plan within the NWS, and we find that this could be a valuable model for a NOAA-wide effort that could contribute significantly to guiding the transition of research to operations and information services.

NOAA must address the proper agency balance between research push and operations pull for research investment. Because the various line offices within NOAA address mission needs from a different approach and timescale, this balance must be addressed and managed by agency leadership. The push-pull tension between research and service is inherent to the enterprise. For example, in fisheries new research on multi-species interactions or on the description of uncertainty has led to changes in the form of scientific advice for management both internationally and nationally. This is an example of research "push"; whereas, much of the recent social and economic science being applied to fisheries has been done because of "pull" from the management side. Likewise, the operational use of advanced weather radar systems is the result of pioneering steps taken by the "push" research community. Improvements in NWS weather information processing systems, on the other hand, came about through management's "pull" for computer systems with better data integration capabilities.
We must point out that it is not a simple matter of one-way flows of knowledge from science to operations. The operations/management side must be a full partner with the R&D side. The operations side of NOAA must see its success as depending, in part, on NOAA's ability to support successful and effective research, which will elucidate new concepts and new questions to support new operations, information products, and management policies.

We believe the transition process can be enhanced through creative use of test-beds, product validation experiments and prototypes, and planned and funded user evaluations. These are just a few of the activities that should be part of an effort to enhance the transition to operations and services, but all will require explicit and not *ad hoc* funding. We call attention again to guidelines for research and development from Lockheed Martin (see Section II).

Recommendation: The recommended Research Plan should address directly the transition of research to operational products and the provision of services. The Research Council and recommended Board should assure that this aspect of the Plan is well executed. The Research Plan should make clear that both research and operations activities share management, programmatic, and fiscal responsibilities for transition.

The lack of an appreciation for the role of "push-pull" in research and the inefficiencies in the transition of research to operations and information products are tied to inadequacies in NOAA's budget structure and program planning and integration. The Associate Administrator in collaboration with the Assistant Administrators must ensure that there is a vigorous and articulated pull from operations and information services products. NOAA's research entities are instrumental in maintaining a healthy research push. The push-pull balance and research to operations and information products should be topics that are addressed on an agency-wide basis through the Research Board and Council. There should be a continuing formal process for evaluating these elements of an agency-wide research investment. In Section II, we noted the DoD 6.1-6.7 system, the NASA Technical Readiness Level, and the guiding principles presented by Dr. O'Neill as existing systems that have proven useful in guiding research to operational products and ensuring clear delineation of roles and responsibilities.

In each of the mission line offices there should be a structure at the senior management level to manage the research enterprise and the transition of research products to operations and the provision of information services. In particular, OAR should establish an entity responsible for overseeing the development and evaluation of its research programs, including the degree to which its research is successfully transferred to operations and services. In OAR, this office, reporting directly to the OAR Assistant Administrator, should work closely with the individual responsible for Laboratory and Joint Institutes (a position that would follow a subsequent recommendation). It should also work with OAR's extramural grants programs to ensure a successful pursuit of both a quality research program and one that is appropriately focused on operations and information services.

Research Location within NOAA

Finding: NOAA conducts research in all operational line offices as well as OAR. Some of the research programs have a long history (pre-dating the creation of NOAA in some cases), and aspects of the current distribution are a reflection of this history. There is no formal process or criteria for structuring the NOAA-wide research organization, nor is there a clearly articulated process for determining, on an ongoing basis, where different types of research will be located in the larger organization. Although a corporate sense of "One NOAA" is emerging, the organizational structure of research in NOAA is not fully consistent with the general Organizational Principles described in Section II. However, as noted in our Finding regarding the **Research Plan and NOAA's Mission**, we are encouraged by NOAA's constructive effort to produce a draft Research Plan in a very timely manner.

We find that there is a requirement for long-term research, and it must be identified and managed agency-wide. This investment for the future may not have an immediate application or meet the short-term demands of the agency's programs, but it is crucial for the long-term health of NOAA's mission. This is one of the central roles for OAR and, as such, it is an appropriate entity within the larger NOAA organization to manage the longer-term research investment.

We also find that there is a difference between operational responsibilities and regulatory responsibilities. In general, operations mean regular ongoing activities like weather forecasts using a set of standardized model outputs, and here, the Review Team is concerned that day-to-day operational demands could re-focus the research effort to shorter term ends or eliminate it altogether if the research effort were located primarily within the operational line. Consequently, we believe it is appropriate to separate the purely operational activities from the mid- to longer-term research effort (but retaining appropriate linkages). In mission areas like fisheries, coastal zone management, or more generally ecosystem-based management, NOAA must provide the best advice on which to base management and regulatory decisions. This scientific advice (e.g. fisheries stock assessment) is best based on work in a research environment. Locating this work offers different challenges. NOAA must exercise caution to ensure that the research program is not unduly influenced by regulatory responsibilities, but at same time, it is essential to ensure that the best science is available and responsive to policy and management needs including the regulatory process.

Building the linkages between research, scientific advice, and management will continue to challenge NOAA. Maintaining the research program within NOS and NMFS with appropriate safeguards for the higher-risk, more basic research efforts can do this. It can also be accomplished by having the research in a separate organizational structure with clear and unambiguous responsibility to meet management and regulatory needs. The Review Team notes that the former approach facilitates the provision of scientific advice for management, but the latter approach may provide a more integrated research effort and enhance extramural involvement. In this regard, we note that the Ocean Commission's preliminary report recommends NOAA's structure be aligned according to its primary functions of assessment, prediction, and operations; management; and research and education.

Recommendation: Consistent with the organizational principles given in Section II and the concepts associated with research and scientific advice as identified in the Findings, NOAA should develop a clear set of criteria for determining where research programs are located within NOAA. These criteria should be applied to new programs immediately, and over the next two years, the Research Board should apply these criteria in a review of the organizational location of the existing research activities and identify opportunities for possible migration.

We recommend retaining and strengthening a line office with the predominant mission of research, i.e., OAR. There must be a stronger commitment generally to long-term, visionary research for all of NOAA areas of responsibility. The NOAA Research Plan must identify the importance of long-term research and its relationship to short- to mid-term research. If not addressed at the agency level, essential long-term, high-risk research (and its potential payoff) will disappear under the pressure of near-term operational requirements. Without long-term research, the science-based operational missions will eventually become untenable. At the same time, it is essential that the "culture" of the research line be such that the research is not isolated from the overall mission and other activities of the organization. Researchers must be responsive to the overall vision and mission of the agency including the operational and regulatory missions. They must be connected to the scientific enterprise as a whole including the scientific advisory functions and the users of science within NOAA as a whole. In this vein, we note that the research being conducted in NMFS and NOS could migrate to OAR, *but only* if the scientific advice associated with ecosystem-based regulatory responsibilities went with the research role. Such a change will involve changing the culture in the research organization to accommodate the need for timely advice for policy and regulation.

The U.S. Commission on Ocean Policy identifies the need for ecosystem-based management and emphasizes that policy must be grounded in an understanding of ecosystems. In establishing this as a "foundation" concept, the Commission added: "Ecosystem-based management will also require a deeper understanding of biological, physical, chemical and socioeconomic processes and interactions."[2] A challenge is to enhance ecosystem resilience through management. The

[2] U.S. Commission on Ocean Policy Preliminary Report, p. 305

time scales of the processes, their complexity and nonlinear interactions, and our overall uncertainty (not just science) make this challenge daunting, almost intractable. Consequently, an adaptive management approach that is both integrated and inclusive will be required. Moreover, the adaptation mechanism involves in part continuing monitoring and analysis. In a sense, this ties together the Integrated Ocean Observing System and ecosystem-based management themes of the Ocean Commission Report. The ultimate decision-making system needs to be flexible to incorporate such new knowledge. Such a strategy is characterized by continuous monitoring and science that is informed by specific management and policy questions coupled with a set of evolving management and policy protocols as our knowledge and understanding improves. Moreover, adaptive management requires an integrated and inclusive forum for dialog between all parties affected by the state of our oceans.

To address this daunting challenge, NOAA should establish an external Task Team to evaluate and strengthen the structure and function of ecosystem research in, and sponsored by, NMFS, NOS, and OAR. For example, efforts at the Great Lakes Environmental Research Laboratory dealing with invasive species might be more effectively aligned with related interests in NMFS and NOS elsewhere in the country. Also, the Atlantic Oceanographic and Meteorological Laboratory and the Pacific Marine Environmental Laboratory could work with the (nearly co-located) NMFS and NOS laboratories even more aggressively to forge coordinated NOAA-wide programs in their regions. Already, the NMFS organization into regional fisheries Science Centers is a useful model for interaction and management of laboratories within regions. In each of the fisheries Science Centers there are several laboratories, each with a specific focus area, but they are managed and administered collectively through the Center. This model could, also, be an effective means of integrating the science and research efforts across the line offices. The Task Team should consider opportunities for enhancing functional and thematic alignment of research activities within NOAA utilizing, where appropriate, the geographic alignment of the laboratories within NOAA.

Extramural Research in NOAA

Finding: Extramural research is critical to accomplishing NOAA's mission. NOAA benefits from extramural research in many ways, including:

- World class expertise not found in NOAA laboratories;
- Connectivity with planning and conduct of global science;
- Means to leverage external funding sources;
- Facilitate multi-institution cooperation;
- Access to vast and unique research facilities; and
- Access to graduate and undergraduate students.

Academic scientists also benefit from working with NOAA, in part, by learning to make their research more directly relevant to management and policy. It is an important two-way street. Examples of success stories from the extramural research programs are included in Appendix

VII. We note that these and other successes are, unfortunately, not well recognized by Congress or the OMB. During its many visits, interviews and discussions with those interested in the NOAA budget process, the Review Team found a lack of understanding for the necessity of extramural research in support of the NOAA mission. For all the reasons above, NOAA and the budget process must recognize and efficiently use extramural research.

NOAA has, however, not managed this external research component with the proper awareness of its role in the NOAA mission. NOAA cannot accomplish its goals without the extramural community, specifically the universities and institutions that represent the broad range of expertise and resources across the physical, biological, and social sciences. Moreover, there is the important issue of maintaining a scientific and technologically competent workforce in NOAA and that workforce is another "product" of the external research community.

NOAA has not articulated, agency-wide, the role of extramural research, nor provided Congress and OMB sufficient explanation for the importance of its external partners. A consequence of such a situation seems to be reflected in the President's FY 2005 budget request for NOAA in which more than half of the proposed reductions in the NOAA climate program are slated for the extramural research community, via reductions to the Office of Global Programs (OGP). Over the fifteen year investment in NOAA's Climate and Global Change Program, managed by OGP, significant advances in climate sciences and services have been made through close collaboration with the external climate community, both in the development of interagency and international science plans and in the implementation of such plans through the solicitation and award of extramural grants. We note that OGP has made a small but significant investment in extramural social science research that is particularly vital for the NOAA Climate Goal and the nation's Climate Change Science Program. We further note that there are important recommendations for strengthening of social science research in the recent extensive report, "Social Science Research Within NOAA: Review and Recommendations," prepared for the NOAA Science Advisory Board by the Social Science Review Panel.

External research capabilities efficiently broaden NOAA's expertise and capabilities, and yet the granting process is also inconsistent and fragmented. We have received reports that there are too many Announcements of Opportunity for too little money. In addition, the recent change in the structure of appropriations regarding the temporal frame for monies may be disruptive to the current procedures. Timely administration of the grants and contracts is a vital dimension to maintaining robust external research capabilities. There are examples where extramural organizations received their annual NOAA funding in the last few weeks of the fiscal year, making partnering with NOAA quite difficult.

The Review Team notes the proposed relocation of the U.S. Weather Research Program (USWRP) from OAR to the NWS, with the intent of better addressing the transition of weather research into operations. While the transition process is a leading issue for the Review Team, we suggest other organizational approaches to manage such transitions. Moreover, the NOAA USWRP ought also to support extramural research with longer-term objectives aimed at the delivery of future weather services and products. We believe that this vital aspect of the USWRP will be more effectively sustained in the research line office.

Recommendation: The importance of extramural research requires documentation and articulation to the DoC, to OMB, and to Congress. The role of extramural research should be clearly delineated in NOAA's Research Vision and Plan. It should also be an integral part of NOAA's budget presentation to Commerce, OMB and the Hill.

NOAA must use best business practices in its support of extramural research. Extramural research is a critical component of NOAA's business model. Through engagement of the extramural research community, NOAA can effect a more efficient means of identifying its research priorities and addressing the most critical scientific problems. This will entail a continuous involvement by the extramural community in the agency's Planning, Programming, Budgeting and Execution System, as appropriate. For example, the Announcement of Opportunity structure (size, foci, and process) should be reviewed to more effectively employ NOAA's scarce research dollars and involve more comprehensively *all* of NOAA's Line Offices. NOAA must develop a robust mechanism to engage the extramural research community early during the planning process, through the exploitation of research planning conferences and symposia similar to those conducted by the National Science Foundation and the Office of Naval Research. NOAA must develop a more consistent process for extramural researchers to interact with the agency. A single application process, consistent review procedures, and more consistent timing for extramural grant fund availability, as well as a more rapid grants disposition process would be extremely helpful.

NOAA should formalize the involvement of the extramural community in the assessment and evaluation of the Agency's overall research activity. Also, it is important that during difficult budget periods that NOAA not disproportionably target the extramural research for budget cuts. The Science Advisory Board of NOAA can provide an important leadership role in the assessment of NOAA's extramural research activities.

Cooperative Research in NOAA

Finding: The NOAA cooperative research institutions (including Joint Institutes, Cooperative Institutes, and Joint Centers) have been productive partners with the NOAA research programs for many years. Cooperative research programs, unlike extramural research supported in response to specific announcements of opportunity, involve long-term partnerships between NOAA and other parties. They provide the mechanism for a unique set of partnerships that help leverage the research that NOAA needs to fulfill its mission in serving the Nation's needs.

The Joint Institutes vary in their specific research foci, structure within the university, service responsibilities, and financial scope. All are established through cooperative agreements rather than grants or contracts. Through the cooperative agreements they can conduct research with all line offices within NOAA and are regarded as providing research over the broad scope of the NOAA mission. The larger OAR Joint Institutes have clear interactions with co-located OAR research laboratories and have established vigorous research collaborations between scientists in the laboratories and those in the university. Smaller institutes and institutes not co-located with a laboratory often serve different research communities and research programs within NOAA and emphasize different outreach or service activities.

There is a formal process within the federal government by which Space Grant, Land Grant, and Sea Grant institutions are established (and reviewed). The National Science Foundation has a process for Long Term Ecological Research and Centers of Excellence. There is no clear statement on guidelines for the creation of a NOAA Joint Institute; they can be established on an ad-hoc basis and sometimes they are created by Congressional action.

Recommendation: NOAA should establish a process by which Joint Institutes and other cooperative arrangements with extramural partners are established and maintained. This process should include approach-specific criteria, including:

- Demonstrated track record of working with NOAA scientists on research projects;
- Demonstrated commitment (in terms of resources and facilities) and track record to a long-term collaborative research environment/culture;
- Nationally recognized expertise within the appropriate disciplines needed to conduct the collaborative/interdisciplinary research;
- Unique capabilities in a mission-critical area of research for NOAA;
- Established programs of excellence that support graduate education in the appropriate disciplines; and
- Well-developed business plan including fiscal and human resource management as well as strategic planning and accountability.

The guidelines should also define the review process, the renewal process, and sunset clauses.

Reimbursable Research in NOAA

Finding: In some cases, the historical legacy that we mentioned in an earlier Finding (**Research Location in NOAA**) governs not only the laboratory location but also its funding strategy. The Environmental Technology Laboratory (ETL) in Boulder had historical expertise in remote sensing technologies. The NOAA-specific interest in these technologies has waxed and waned over the years. This led to an aggressive marketing of the laboratory expertise to other government agencies, which in turn led to ETL becoming heavily dependent on non-NOAA funding (i.e., reimbursable funding from other government agencies). This, in itself, is not all bad; however, in the ETL case the laboratory became significantly "in debt" in the late 1990s. Subsequently, ETL was restructured and is now moving into a stronger financial situation. The Air Resources Laboratory, also for historical reasons, is very dependent on reimbursable funding primarily from the Department of Energy (DoE) and the Environmental Protection Agency (EPA). Again, we find that while reimbursable funding has some benefits to NOAA and the government, there are several concerns, and senior management must carefully watch the pattern. The dependence of ETL and ARL on external resources is not unique within NOAA (although the extent of such support is higher here than at most other labs in the agency); levels of reimbursable support vary among all line offices. The issue, however, is that the labs lack any clear corporate guidance regarding solicitation or receipt of such external support.

In sum, we find that reimbursable work to fund laboratory budgets has, at times, conflicted with providing research support for NOAA mission priorities. Some of these arrangements have led to serious budget issues and to problematic mission foci in some laboratories (to other agency work rather than NOAA work).

Recommendation: We strongly recommend that NOAA review its policies and procedures for the management of reimbursable funding and that NOAA develop and implement clear guidelines to better manage this complex issue. Reimbursable funds should only be used to support NOAA research activities when that research relates directly to NOAA's mission. Reimbursables should not be used as a means of "artificially" maintaining programs and workforce. Those programs that are on a reimbursable basis but only loosely related to mission should be restructured to meet NOAA's mission, or considered for transfer to the appropriate supporting agency as soon as practicable.

Research Organization within OAR

Finding: The directors of the OAR Laboratories and the Joint Institutes have substantial independence in setting the research agendas for their laboratories and institutes. While there are some positive aspects of this independence, it is obvious to the Review Team that there has not been sufficiently strong leadership and processes in OAR to ensure that all of the OAR laboratory activities are well focused and integrated into NOAA's mission. These research activities should have a dynamic and successful transition into the operations or provide important informational services to NOAA customers. We have also found insufficient definition of focus and scope of research activities across the laboratories within OAR.

Recommendation: Within OAR, each laboratory should have a clearly defined mission statement setting forth priorities that are clearly linked to the NOAA Strategic Plan, Research Vision, and Research Plan. This mission statement for each OAR lab could also be used as a prototype for the other NOAA laboratories and serve as a basis for periodically reviewing the relevance of every laboratory's activities to NOAA's mission.

There should be a single authority for OAR laboratory programs and Joint Institutes who would have budgetary authority over the OAR laboratories and Joint Institutes, and who would report directly to the OAR Assistant Administrator (AA). This "Director of OAR Labs and Joint Institutes" would also help establish partnerships, as appropriate, with other agencies and universities working closely with the AA of OAR and the Associate Administrator for Research. Most importantly, this headquarters leadership team will also seek to strengthen and renew partnerships across NOAA.

Research Organization within OAR Boulder Laboratories

Finding: The accomplishments of the Boulder laboratories have contributed significantly to advancing NOAA's mission (See Appendix VIII). Mostly, the laboratories have been foresighted and forceful in pursuing NOAA related science. Successful examples include: the research foundation of the forthcoming production of operational air quality forecasts dates back to studies of natural sources of atmospheric acidity begun decades ago; the modernization of NWS through the introduction of its Advanced Weather Information and Processing System resulted from research and development activities begun years earlier in Boulder; and the important monitoring and understanding of many atmospheric chemical components, including landmark work on the Antarctic ozone hole.

Although there are six OAR laboratories in Boulder, the Review Team did not include the Space Environment Center (SEC) in its recommendations since SEC is proposed to be transferred to the NWS in FY 2005. Frankly, the system was in too much flux for an effective recommendation. Nevertheless, we did find that SEC is a solid scientific center with an operational forecasting capability. We also found that it was not able to adequately support its important research mission nor could it support adequately its operational mission. We are concerned that moving the SEC to the NWS will only address the latter finding, namely a necessary enhancement of its operational capability. This concern is consistent with those expressed earlier in our Finding and Recommendation regarding "**Research Location within NOAA**."

The unifying themes of the other five Boulder laboratories are: the scientific focus is continental to global with the capabilities to work locally and regionally; the focus is the monitoring and understanding the processes of the chemistry, physics, and dynamics of the atmosphere; and improving predictive capabilities is at the center of the laboratory activities. We believe that the potential benefits from consolidating these five OAR Boulder laboratories are improved quality of research planning and execution; more efficient use of infrastructure resources and funding; and increased opportunities for multi-disciplinary collaboration. In sum, consolidation would greatly facilitate the continued development of an internationally recognized center of excellence. This Center would focus on achieving and synthesizing critically important long-term measurements of the atmosphere to improve understanding and thereby to realize new predictive capabilities. This potential benefit clearly outweighs the near-term, challenging demands and difficulties that such consolidation will impose.

Finally, we find the understandable concerns about security at all government installations may well prove to be detrimental to the essential scientific enterprise. This is particularly true at the NOAA laboratories in Boulder where security measures are restricting the spirit and actuality of openness so critical to the vitality of scientific dialogue. This is important given the strength and breadth of the Boulder scientific community.

Recommendation: The review team recommends that there be a laboratory consolidation of the five OAR laboratories in Boulder into a single Center[3]. The consolidation should seek even better coordination across NOAA and OAR; it should further increase the responsiveness of

[3] The Review Team does not propose any name for this center.

research to NOAA's operational and information service needs; and it should enhance the visibility of NOAA's collective scientific effort in Boulder. Whatever plan of consolidation is agreed upon, we also strongly recommend that Boulder laboratory leadership continue to make effective technology transfer to the operational parts of NOAA a high priority.

We do not recommend a specific path for this consolidation, but rather there is a set of options that should be explored, refined, and decided upon by OAR and NOAA leadership working closely with the Boulder laboratories management. The consolidation should be structured around clear, easily understood functional capabilities. Guiding these decisions should be a recognition that the scientific and technological activities in Boulder fall into discrete functional categories. One such grouping, for example, is systems development, chemical and dynamical process studies, and atmospheric composition monitoring. Another is systems development, atmospheric composition monitoring, atmospheric dynamics, and atmospheric chemistry. Other possibilities exist, however, that link the chemical monitoring and process studies functions, while maintaining a distinct dynamical studies activity. Further, an organization linked to product types, such as information services, monitoring, operational measurement system development, and operational software system development, could be an alternate construct. Our point is that synergies currently exist among the five OAR Boulder laboratories that can be strengthened by a considered realignment and consolidation of the management structure focused on mission-critical research functions. Acute care must be given not to weaken existing strengths based upon natural synergies, appropriate sizes, and shared commitments.

Whatever is developed must address the means to attain the benefits of improved quality of research planning and execution, more effective use of infrastructure resources, increased opportunities for multi-disciplinary collaboration, and what and how to realize a shared vision.

Key to the success of a renowned Boulder Center will be the appointment of a scientific leader for the entire OAR Boulder enterprise. Recruiting and retaining the best scientists in OAR, and maintaining the highest quality research by them, will only occur if they continue to be led by distinguished scientists who have demonstrated leadership and management skills. This recognition is central to an effective implementation of this recommendation.

Senior management, in Boulder, in OAR, and in NOAA should consider options for consolidation and work towards implementing the most viable one with deliberate speed. It will be important to involve the relevant Joint Institutes (CIRES and CIRA) in such considerations, because of the impact on these important components of the potential Boulder Center.

Research Organization within the Air Resources Laboratory

Finding: The Air Resources Laboratory (ARL) is the most managerially complex laboratory within OAR (see Appendix IX). It serves the nation well, but the complexity of the organization may limit its long-term effectiveness and ability to identify with NOAA's mission. It is important to note that NOAA is an interconnected part of the federal research program, and care should be exercised that this important government capability not be lost. This is important since ARL contains expertise that is important to national research responsibility, interests, and capability.

Recommendation: ARL should be better aligned with the NOAA mission and the emerging needs of Homeland Security. There must be greater NOAA oversight of its direction and its relationships. All significant inter-agency activities should be subject to an MOU similar to that with the Environmental Protection Agency regarding the ARL air quality and air-surface modeling activities in Research Triangle Park, N.C. As we discussed in "**Research Location in NOAA**," we recommend that that NOAA and OAR review their policies and procedures for the management of reimbursable funding with an objective of developing a set of clear guidelines.

There should be a core capability analysis conducted to determine areas of most effective mission alignment and to identify opportunities for improved organizational coordination. This is particularly important given the increasing importance of air quality forecasting and the reality of Homeland Security placing greater importance on predicting atmospheric dispersion.

If the analysis demonstrates that there could be gains in efficiency, enhancements in synergy, elimination of duplication of efforts, and increased organizational and financial transparency, then the functions of ARL should be realigned, consolidated with other entities, or eliminated. We believe that the service to the nation and the coherence of the budget would be improved by this analysis. In particular, the valuable services of ARL would actually, in the end, be enhanced. We acknowledge that any transition would be difficult and challenging, so that it would need to be paced by clear parameters and needs. Finally if the core capability analysis of ARL proves useful, then NOAA should consider applying a similar analysis to those other research components of the organization that are supported substantially by reimbursable funding.

Continuing Oversight of NOAA Research

Finding: There have been previous external reviews conducted that recommended changes in how NOAA defined and conducted research; we found little change as a result of these reviews and recommendations. The fact that Congress directed very specific actions with regard to NOAA research in the FY 2004 appropriations bills also indicates that NOAA has not instituted the necessary changes that Congress deems necessary. We also heard similar concerns from OMB.

Recommendation: To ensure that NOAA takes appropriate action, the Review Team believes that an External Committee should be established to review this report and previous relevant reviews and to report directly to the NOAA Administrator on progress in reforming the research enterprise in NOAA.

As indicated at the outset of this Section, the Review Team recognizes that these Findings and Recommendations, while far-reaching, do not cover the full spectrum of NOAA research issues. Nevertheless, the issues and suggested actions addressed here recognize fundamental opportunities for dramatic improvement to the NOAA research enterprise.

IV. Responding to the Charge

We now turn to answering the Charge of NOAA's Science Advisory Board (SAB). As stated in the Introduction, in response to FY 2004 Congressional directives, NOAA asked its Science Advisory Board to establish a Research Review Team to address five primary issues. We have sought to establish the context for change by setting forth Operational and Organizational Principles (Section II) and a set of Findings and Recommendations (Section III). Within this context, we now respond explicitly to the Charge from the SAB. We note, however, that our responses to the Charge must be viewed in the environment set in Sections II and III.

- *Does the research conducted by the Office of Oceanic and Atmospheric Research provide effective support and vision for NOAA by enabling it to improve products and services, and to introduce new products and services through the transfer of technology and the development and application of scientific understanding?*

  The research conducted and supported by OAR provides the scientific basis for the agency's future products and services. Despite numerous examples of successfully transferring this research into operations, there is a need to give substantially more emphasis and structure to this process. OAR research is clearly more closely linked to NWS operational activities than to the other lines such as NOS and NMFS. Better linkage and development are needed for OAR's research to be fully leveraged for the NOAA mission.

  The transfer of research into operations must be addressed on an agency-wide basis through the Research Council and Board, and there must be a continuing formal process for evaluating the effectiveness of the transition process. There are two important components of this process. The first is the need for highest-level oversight and budgetary control of NOAA's corporate research portfolio. Additionally, each of the line offices should institute a formal structure at the senior management level to address this process. OAR, in particular, should establish an entity reporting directly to the OAR Assistant Administrator that oversees the development and evaluation of its intramural and extramural research programs, including the degree to which this research is successfully transferred to operations and services. This position must coordinate with the position of over-seeing the lab structure in OAR to ensure efficient use of all research resources available to OAR.

  The introduction of NOAA matrix management and a new Research Plan will require close management of research to ensure the academic and private research communities are integral partners in this investment.

- *Is OAR adequately linked to NOAA's other line offices (National Weather Service, National Environmental Satellite Data and Information Service, National Marine Fisheries Service, National Ocean Service) and are the research programs relevant to the needs of these organizations? If so, what are the benefits? If not, what changes would the Team recommend? Is it adequately connected to the Program Planning and Integration Office?*
  There are good examples of linkages between the NOAA line offices that result in collaborative research programs across lines, a clear connection of research to operational

needs, and the transition of research products to operational products. Appendix VI contains a set of example success stories that document that the OAR research programs have demonstrated relevance and benefits to the needs of the other line offices. However, these linkages are most often developed on an *ad hoc* basis resulting from connections between individual researchers or programs rather than organizational imperatives.

The benefits of linkages between OAR and other NOAA lines are large and crucial to NOAA's mission as a science-based agency. The interactions must be formalized organizationally, encouraged for both the research and operations, and recognized fully by NOAA corporately. The developing NOAA Research Plan recognizes the connections of the research efforts across the agency, and NOAA's new mission goal matrix structure (overseen by the PPI office) and PPBES tool are designed so that programs develop an "end-to-end" perspective, from OAR research to the delivery of products and services. The matrix structure establishes an important means of engaging both the research (OAR and other) programs with the operational programs in the development of plans, budgets, and performance metrics.

The Review Team recommendation for better using the functional and/or regional location and co-location of NOAA laboratories, possibly using a regional center model, will also help improve the connections between line office efforts. In this vein, we recommend that NOAA should establish an external Task Team to evaluate the structure and function of ecosystem research in the NMFS, NOS, and OAR laboratories, with an eye for further rationalization.

- *How do the management structure and processes of OAR compare to those of other agencies managing research? Based on that analysis, should OAR be dissolved into its constituent components and distributed across NOAA, should it be left as is, or should NOAA consolidate all of its research activities into a single organization?*

Neither NOAA nor OAR has the management structure or process to manage a large research enterprise that we observed in other science-based organization. We reviewed two large federal agencies with significant research budgets (DoD and NIH; we also had discussions with people knowledgeable about DoE and NASA), two very large commercial enterprises (Lockheed Martin and General Motors), and the general model used at research universities. The lack of a research plan in NOAA and thus the lack of corresponding direction for conduct of research in OAR encourage the labs to determine their own destiny. There is no formal process to ensure the research investment in OAR meets the needs of the NOAA mission. It appears to us in most successful research enterprises, there is one person responsible for that mission, and there is formal guidance [research plan] that guides all that expend resources for that mission. There are also mechanisms in place to formally review the research investment and ensure it supports of the operational mission of the parent organization. Also, for all science based operational agencies or companies we reviewed, there were organizational and operational mechanisms that provided funding stability for a research program with a longer-term focus. With the development of a NOAA research plan and data obtained during this research review, NOAA OAR can quickly implement changes necessary to manage a successful research program for NOAA.

Regarding the issue of migrating all of NOAA research to the line offices, this is not a wise course of action. The changes that we recommend in management and structure are more appropriate to the issues facing OAR and NOAA. Our conclusion not to recommend the dissolution of OAR into its constituent components and distributed across NOAA was based upon extensive interviews and discussions. The discussion with Robert Frosch was particularly beneficial since he had written an important, relevant paper (Appendix X) that addressed the issue of where research should be located within an organization, and therefore it is directly relevant to the question: "…should OAR be dissolved into its constituent components and distributed across NOAA, should it be left as is, or should NOAA consolidate all of its research activities into a single organization?" With regards to dissolving OAR into its constituent components and distributing them across NOAA, his conclusions are set forth in a particularly apt metaphor:

> "Having been in the R&D business for some time, I keep my eye on the spring styles in R&D and try to decide whether I think they are hot stuff or not. The current fad seems to be: 'Let's breakup all that central R&D, which does something or other but we don't know what, and put it out in the divisions. If we can't pull it all out, then let the divisions buy what they need instead of letting those people in the ivory tower do all that stuff we don't understand. We must have relevance now, with everything results-oriented, and small improvements the big thing.'
>
> I listen to all this (I've heard it before) and it reminds me of someone investing in a farm who insists upon saying, 'Don't ask me to buy any seed, please don't bother me with investing in planting, I don't want to be around when you're cultivating, and I don't care about irrigation. But when you get to the harvest, call me, and I'll be there to help you out.'
>
> We know what happens to that farmer. That farmer—or that investor—ends up with no crop and no harvest. I have a feeling that in a few years we shall discover that the farm that was going to be planted, seeded, irrigated, and produce a good harvest, will for some reason be producing no fruit or stunted fruit."

The major challenge for NOAA is connecting the pieces of its research program and ensuring research is linked to the broader science needs of the agency. As we have indicated in the recommendations, this is best done by strengthening organizational processes, clarifying shared responsibilities regarding transition of research, and establishing a higher level of corporate oversight, all consistent with fundamental principles for structuring and operating a research organization. The wholesale dissolution of OAR and distribution of its resources and talent to the other lines would splinter rather than more tightly connect the science and research enterprise. There is undoubtedly a need to improve the linkage of research to operations and change the culture of OAR to value and support this linkage.[4] However, breaking OAR apart and distributing the parts to the other line offices would be a mistake.

Regarding the question, "Should NOAA consolidate all of its research activities into a single organization?" we do not have a sufficiently clear sense of direction to make a definitive recommendation. We do, however, have a clear sense of the scope of realistic and reasonable possibilities, which range from the current distribution of research across the lines to migrating increasing proportions of research from the operational lines to OAR. This migration must include a defined, clear, and unambiguous responsibility to meet management and regulatory needs. In this regards, we believe that a focused thematic study would likely prove to be useful, and as such, we recommend (as noted above and in Section III) establishment of an external Task Team to evaluate and strengthen the structure and function of ecosystem research in, and sponsored by, NMFS, NOS, and OAR.

- *Focusing specifically on the OAR labs, would consolidation of the labs yield a more effective scientific program? If so, what would the Team recommend?*

  The OAR Laboratories are, as are all NOAA laboratories, centers, and Joint Institutes, an important and integral part of NOAA's scientific program. In the opinion of the Review Team, there is an opportunity to increase the effectiveness of the five OAR laboratories in Boulder through consolidation. Specific findings and recommendations for a Boulder consolidation are contained in "**Research Organization within OAR Boulder Laboratories.**"

  We believe that forming a Boulder Center would open the possibility of not only more effective management but also strengthening the ability of scientists within each lab to interact with colleagues in other labs (at Boulder or elsewhere). The Boulder laboratory scientists are engaged in some important collaborative research within the laboratories and with other organizations, which needs to be fostered to the maximum extent possible. With increased connectivity to a broader set of NOAA laboratories, there would, undoubtedly, follow an enhanced effectiveness in meeting a broader set of NOAA needs (e.g., applying breakthroughs in weather and air quality forecasting to a more diverse set of NOAA modeling efforts). Moreover, having the ability and the responsibility to act as a unit will allow the Boulder leadership to confront even more effectively the significant Earth system challenges. And, acting as a unified team, the Boulder Center would be positioned to become an even stronger world-class institution for atmospheric research.

- *Would lab consolidation yield a more efficient structure, by reducing administrative overhead and infrastructure/manpower? If so, what would the Team recommend? Strong fiscal constraints for the foreseeable future mean that the Congress, the Office of Management and Budget, and NOAA leadership must seek ways to prioritize more effectively research activities.*

---

[4] We note that Bob Frosch's paper also suggests that one way to improve the connectedness of research to operations is to move people from research labs to the operating side ("synthetic alumni"). NOAA might consider a similar activity.

The areas offering the greatest potential for possible efficiencies involve functions at a consolidated Boulder Center. One aspect of such efficiencies is described above (in terms of increased attention to a broader set of NOAA-wide issues, for which a consolidated Boulder complex may provide new opportunities). Specifically, there may be efficiencies from the consolidation from five Financial Management Centers to one; centralizing certain functions such as management/clearance of Memoranda of Agreement (MOA) and Memoranda of Understanding (MOU), personnel and training, safety and security, and some procurement actions. Having one staff expert in some of these subject matter areas could be more efficient than the current situation where each laboratory maintains its own expertise. Some efforts such as time and attendance and travel are proportional to the size of the staff being served and would likely remain the same. We note that progress has already been made through the executive management system in information technology. Some additional efficiency may be expected by consolidation into one IT security plan and standardized hardware and software; this issue will need further study to consider the impact on scientific operations. It is unlikely that there will be substantial financial savings from a consolidation but, if any, it should be re-invested in the NOAA research enterprise.

It is important to note, however, that the recommendations of the panel include increased responsibilities (generally associated with program planning and integration) concomitant with a Boulder laboratory consolidation. Consequently, while there could be efficiencies gleaned by reducing some potentially redundant administrative responsibilities, there should be a need for increased investment in professional support for strategic planning and program assessment. Before any final determinations of efficiencies can be made there must be a more detailed study of functions to be performed and a preliminary identification of people to do these functions at various levels in the organization (including OAR HQ). The Review Team also notes that such a study must be done in close coordination with NOAA's ongoing assessment of efficiencies in its system of administrative support, since some of the administrative functions addressed above may be handled differently NOAA-wide in the future.

In closing Section III on Findings and Recommendations we noted that we are seeking to give suggestions on direction that NOAA should take to improve an already well-respected research program. It is in that same spirit that we respond to the specificity of the charge. We believe that there is a path of constructive change that will lead to a stronger and better organized and better supported research enterprise that is even more responsive to NOAA's mission. If changes are not adopted, then NOAA will remain a collection of weakly linked research enterprises without a strong centralized focus supporting NOAA's mission. However, we believe that this Report provides NOAA the opportunity to change and serve the nation better.

V. Closing Comments

In closing, there are three themes that we want to revisit so that they might be seen afresh in the context of the overall Report.

The Value of Research. The Review Team recognizes and appreciates that the language in the Senate report speaks only about the need for research to assist "line offices in developing timely solutions to problems confronting NOAA now and in the next 5 years." Meeting the near-term, unmet operational needs of NOAA must be a high priority. However, producing significant advances in weather and environmental forecasting, providing well-reasoned prognostic climate information, and anticipating and meeting the information service needs for commerce and transportation and ecosystem management require that NOAA address an array of increasingly complex scientific issues as well as deal with ever more complex organizational elements. This reality is unavoidable, and it must be wisely balanced against pressing very near-term operational needs. We note also that there is a danger that in focusing research exclusively on operational needs of various services, climate-relevant research needs might go unmet. We acknowledge that the matrix Goal alignment should help limit this risk, but the relationship between NOAA's Goal teams and its line offices is still in a formative stage, so that we cannot be assured on this point.

We strongly believe that a guiding mid-to-long-term view is essential for cost effective research management - it is essential to the future of NOAA. It is the longer-term view of OAR that creates the foundation needed to supply the products of the future. For example, NOAA's climate research (on both climate variability and change) started about 30 years ago. Greatly enhanced operational benefits of climate change research still lie 10-20 years in the future, and for seasonal forecasting, 5-10 years will still be needed to reach the maturity comparable to that for numerical weather prediction. The Review Team firmly supports the tenet that long-term purposeful research is a required dimension in NOAA's overall research program. The Review Team is likewise aware of the need for near-term operational products and information services. Unfortunately, as discussed in Section III, the Review Team found that NOAA does not have an agency–wide research plan or research management structure, let alone a blueprint or formal process to guide the transition of its research investment into its operational mission. Filling this void is essential and creating a "front office" research management structure and authoritative process are fundamental for success. As we stated in Section III, we are pleased that following our Recommendation in our initial Report of January 29, 2004 that NOAA has produced an initial Draft 5-year Research Plan, and we also applaud NOAA for charging its Research Council to prepare a 20-year Vision for Research.

The Organizational Location of Research in NOAA. We believe that there are programmatic migration steps that need to take place both within OAR and NOAA; we have tried to provide explicit guidance in this area. The issues are, however, complex. There are important products and services that do not have a clear operational line office home (e.g., climate-relevant observations) or a singular line home (e.g., ecosystems research supporting both fisheries operations and coastal zone management activities). Consequently, if these elements are migrated to a line office, then there is a danger that these critically important activities might be compromised. In addition, the near-term pressure inherent in the operational line offices raises serious questions about their viability as appropriate homes for developing the operational products of the future. In a similar vein, a vital and important part of research at NOAA is the development and delivery of products and information services. Hence, there are observations and research products that are produced routinely (e.g., measurements of greenhouse gas concentrations for climate studies) but are not routine—namely the quality of the observations and the sensitivity required to monitor and constantly upgrade them requires a research environment. Also, if NOAA is to continue to attract "the best and the brightest" scientists, a viable, vibrant, and visible research enterprise must be sustained. Finally, we are aware that physical proximity between research and operations is often an important catalyst for successful transitions.

It seems to us that the broader aspects of the issue of "what is where, and why" might be addressed subsequently in the context of expected developments nationally and internationally. The recommendations in the preliminary report U.S. Commission on Ocean Policy are specific regarding the important role that NOAA has in serving this nation and recommends strengthening the organization to ensure meeting the recommendations of the report to Congress and the President. The Aldridge Commission on Space Exploration has recommended fundamental changes in the way NASA conducts and plans its Earth science missions, which will have a significant impact on NOAA. The emerging initiatives of the Earth Observations Summit process may well raise important issues that will challenge current organizational structures for both research and observations.

It appears that an even broader study is needed that looks across government, at the issue of "what is where, and why" regarding the monitoring and understanding of our planet. This study might be phased focusing first on NASA and NOAA. The National Research Council/National Academy of Science might undertake such a study focused on new partnerships, including multi-agency partnerships, and new missions leading to even greater effectiveness and scientific return.

The Way Forward. The Research Review Team dedicated many hours interviewing NOAA personnel and reviewing documents that apply to research in NOAA. We also spent several hours with members of the external scientific community and with Congressional staff and examiners at the Office of Management and Budget on current issues relative to NOAA's research enterprise and related agency issues. Almost without exception, from field lab personnel to researchers, lab directors and front office personnel, NOAA employees acknowledge that procedures and structure must change for NOAA to perform its public mission with the support of Congress, the Administration, external partners, and the entire NOAA team. And just as NOAA was formed by a recommendation of the Stratton Commission 35 years ago to help the nation better manage our relationship with Earth; the recently released preliminary report of the U.S. Commission on Ocean Policy again places NOAA in the spotlight. The Administration has designated NOAA as the lead U.S. agency for the Global Earth Observing System of Systems and NOAA has a lead role in the nation's Climate Change Science Program. To respond to the challenges attendant with these roles, the nation needs and deserves a robust, forward-looking federal agency focused on understanding and predicting changes in the environment of our planet.

It took NOAA's Sea Grant Program nearly 30 years to evolve from a collection of good but somewhat random research programs into a coherent group of relevant and coordinated research programs. In part this transition came about by identifying local, regional and national problems at each Sea Grant institution and developing research programs that address these through short-, medium-, and long-term efforts. The primary catalysts were first a strong National Sea Grant Review Panel that insisted each Sea Grant Institution develop a strategic research plan coupled with a program of reviewing the results of each institution on a four-year basis. The second was strong program management to implement the Review Panel's recommendations. This can be viewed as a path finding activity for NOAA research as a whole.

In this Report, we have focused upon evolutionary changes that will lead to a stronger and more effective NOAA. This will be good for the country and the planet. We have also considered and debated more radical changes such as dissolving the lines and restructuring NOAA along simpler dimensions such as: Observations, Services, Regulation, and Research. This more revolutionary change merits further consideration.

NOAA has a distinguished record of accomplishment in performing and supporting oceanic and atmospheric research and in providing needed products and services. To meet the new demands and challenges, including those posed by the Climate Change Science Program, the Global Earth Observing System of Systems, and the U.S. Commission on Ocean Policy report, NOAA must embrace changes in its operational procedures as well as organizational structure and culture. We see evidence that changes for the better are beginning to take hold in NOAA, and we urge the agency to continue down this path, using this Report as a helpful guide.

Appendix I

Request to Establish NOAA Research Review Team and Terms of Reference for Team

Dr. Len Pietrafesa
Interim Chair, NOAA Science Advisory Board
Director of External Affairs
College of Physical & Mathematical Sciences
North Carolina State University
Box 8201, 118 Cox
Raleigh, NC 27695-8201

Dear Dr. Pietrafesa:

I request the NOAA Science Advisory Board (SAB) conduct a review of NOAA Research for the purpose of improving the effectiveness and efficiency of its research enterprise. The review will provide findings and recommendations that will be used by NOAA to enhance its research organization and connectivity to operational activities. Specific instructions to the review panel, hereafter referred to as the NOAA Research Review Team, or Review Team, are contained in the enclosed Terms of Reference, A Strategy to Respond to Congressional Language Pertaining to the NOAA Office of Oceanic and Atmospheric Research.

I propose an Ad Hoc Working Group of the SAB, consisting of five members, and which will be disbanded after the review. I request your concurrence on the suggested panel members. These are distinguished individuals who represent a diverse range of expertise and perspectives on the organization, structure and management of research. Three of the members are past or future members of the SAB. I further propose that the panel be chaired by Dr. Moore.

We have contacted Dr. Berrien Moore III, Dr. Richard D. Rosen, Dr. Richard W. Spinrad, Dr. Warren Washington, and RADM Richard West and they are willing and able to serve on the Review Team. I would like your thoughts on all these potential panelists.

Berrien Moore III
Dr. Moore is a Professor of Systems Research and has been the Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire since 1987. Actively involved on panels and committees at the National Academy of Science, he ended his Chairmanship of the National Academy's Committee on Global Change Research in 1999.with the publication of <u>Global Environmental Change: Research Pathways for the Next Decade</u> From January 1998 through January 2003, Professor Moore served as Chair of the overarching Scientific Committee of the International Geosphere-Biosphere Programme (IGBP) and also served as a lead author within the Intergovernmental Panel on Climate Change's (IPCC) Third

Assessment Report. In July 2001 he chaired the Global Change Open Science Conference in Amsterdam and is one of the four architects of the Amsterdam Declaration on Global Change. Professor Moore is the author of numerous scholarly publications on the carbon cycle and related topics and over the years has been called upon by the United States Congress to give testimony on the results of research regarding the carbon cycle and global climate change.

Warren Washington
Dr. Washington is an internationally recognized expert in atmospheric science and climate research specializing in computer modeling of the Earth's climate and has published more than 100 papers in professional journals. He is a senior scientist and head of the Climate Change Research Section in the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR) and is the current Chair of the National Science Board. In 1999 he was elected by the Woods Hole Oceanographic Institution Board of Trustees as a member of the corporation for a three-year term; he was appointed by the U. S. Secretary of Energy to the DOE Biological and Environmental Research Advisory Committee (BERAC) and the Advanced Scientific Computing Advisory Committee; and in February of 2002 he was elected to the National Academy of Engineering. Also in 2002, he was appointed to the Science Advisory Panel of the U.S. Commission on Ocean Policy and the National Academies of Science Coordinating Committee on Global Change

Richard Rosen
Dr. Richard Rosen is the incoming Assistant Administrator for Oceanic and Atmospheric Research at the National Oceanic and Atmospheric Administration. He previously served as Vice President and Chief Scientist of the Research and Development Division of Atmospheric and Environmental Research, Inc. Dr. Rosen is a Senior Lecturer at M.I.T. and past President of the American Meteorological Society. He has published over 60 scientific papers on many different aspects of large-scale atmospheric behavior.

Richard Spinrad
Dr. Spinrad is the Assistant Administrator of the National Ocean Service. Before joining NOAA, he served as Technical Director in the Office of the Oceanographer of the Navy where he served as the senior civilian technical advisor to the Navy's meteorological and oceanographic command (METOC). Dr. Spinrad had previously served as Executive Director for Research and Education at the Consortium for Oceanographic Research and Education (CORE). He has worked as a research scientist and is the past President of Sea Tech, Inc., a major manufacturer of oceanographic sensors. Dr. Spinrad received a Ph.D. in marine geology from Oregon State University. He has published more than 50 technical articles and is the editor of one textbook and several special issues of marine-oriented journals. He served as Editor-in-Chief of Oceanography magazine and has been an elected member of the Council of The Oceanography Society. Dr. Spinrad also served on the faculty of the U.S. Naval Academy and George Mason University.

Richard West
Rear Admiral West is President of the Consortium for Oceanographic Research and Education (CORE). Before joining CORE, RADM West served as Oceanographer and Navigator of the

Navy. He held a variety of ship and shore commands during his naval service including Commanding Officer of the Surface Warfare Officers School. RADM West graduated from the University of Rochester, receiving his commission through the ROTC program. He holds Master's degrees in management and national security.

NOAA Research headquarters staff will work with you and the SAB as needed to plan and conduct the review. Administrative and technical support for the review will be provided by Mary Anne Whitcomb at (301) 713-2454, extension 173. Please contact Michael Uhart at (301) 713-9121, extension 159, for any issues regarding the SAB.

Sincerely,

VADM Lautenbacher

Enclosure

cc: (w/enclosure) J. Kelly
S. Rayder
L. Koch
M. Uhart

Addendum: Biographical Information:

Andrew Rosenberg
Dr. Andrew Rosenberg is a Professor in the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire where, prior to April 2004, he was dean of the College of Life Sciences and Agriculture. Prior to assuming the dean’s position in June 2000, he was the deputy director of the National Marine Fisheries Service (NMFS) in the National Oceanic and Atmospheric Administration. He was also the northeast regional administrator for NMFS for four years. He has served as the U.S. representative to international organizations including the Food and Agriculture Organization of the United Nations and the Northwest Atlantic Fisheries Organization. With his expertise in marine biology and living marine resource conservation, he has earned recognition from such diverse organizations as the U.S. Coast Guard and the World Wildlife Fund.

STRATEGY TO RESPOND TO CONGRESSIONAL LANGUAGE PERTAINING TO THE NOAA OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH

1. Purpose: The 2003 House and Senate Appropriations Subcommittee Reports have language pertaining to the Office of Oceanic and Atmospheric Research (NOAA Research). The 2003 House Appropriations Commerce Justice State (CJS) Subcommittee Report has requested that NOAA develop a laboratory consolidation plan. The report accompanying the House CJS Appropriations Subcommittee mark states: "In recognition of current resource limitations the Committee is forced to operate within, the Committee directs NOAA to review the continued requirements for twelve separate laboratories, six of which are located in Boulder, Colorado. The Committee directs NOAA to submit a laboratory consolidation plan to the Committee by March 15, 2004." The Senate report language states: "NOAA is directed to report to the Committee on Appropriations on the costs and benefits of breaking OAR up into its constituent parts and distributing those parts as desirable to the other line offices. The report should specifically address how the newly configured research sector will directly assist line offices in developing timely solutions to problems confronting NOAA now and in the next 5 years."

2. Review Team: NOAA will appoint a Blue Ribbon Review Team, under the auspices of the Science Advisory Board (SAB), to conduct the review. The confirmed team members are: Dr. Berrien Moore III (UNH), Chair, Dr. Richard D. Rosen (AER, Inc), Dr. Richard W. Spinrad (NOS AA - NOAA), Dr. Warren Washington (NCAR), RADM Richard West (CORE).

   Addendum: Additional Team Member added
   At the January 6, 2004 meeting of the NOAA Science Advisory Board, a motion was passed which stated "SAB requests the addition to the RRT of the NOAA's Assistant Administrator for Fisheries (or his designee)."The NOAA Assistant Administrator for Fisheries provided a prioritized list of RRT nominees to the Chair of the SAB, from which the Chair selected Dr. Andrew A. Rosenberg, Dean of the College of Life Sciences and Agriculture at the University of New Hampshire, for an ex-officio membership.

3. Review Team Support: Background information will be compiled including line office administrative costs, data for each lab on staffing, costs, facilities, and programs. Program data will include information such as: description of programs, requirements for programs and users of program results, performance measures and relationship to similar programs in other laboratories or in NOAA. Relevant material from earlier studies of laboratories, results from the program baseline assessments that will be completed this fall, laboratory reviews, and other existing data will also be assembled. NOAA will also provide information on the costs of integrating the constituent parts of NOAA Research to the appropriate line offices. Mary Anne Whitcomb is the lead NOAA contact person providing support for the Review Team.
4. Charge to the Review Team: Using the information provided above, and any additional information garnered by the Review Team, please address the following questions:

4.1 NOAA is a science-based agency with operational responsibilities. Does the research conducted in the Office of Oceanic and Atmospheric Research (NOAA Research) provide effective support and vision for NOAA by enabling (i) the improvement of products and services, and (ii) the introduction of new products and services through the transfer of technology and the development and application of scientific understanding?

4.2 Is NOAA Research adequately linked to NOAA's service organizations (i.e., NWS, NESDIS, NMFS, NOS, etc.) and are the research programs relevant to the needs of these organizations? If so, what are the benefits? If not, what changes would you recommend?

4.3 How does the management structure and processes of NOAA Research compare to those of other agencies managing research? Based on that analysis, should NOAA Research be dissolved into its constituent components and distributed across NOAA, should it be left as is, or should NOAA consolidate all of its research activities in a single organization?

4.4 Focusing specifically on the NOAA Research labs, would consolidation of the labs yield a more effective scientific program? If so, what would you recommend?

4.5 Would consolidation of labs yield a more efficient structure, by reducing administrative overhead and infrastructure/manpower? If so, what would you recommend?

5. Timing: The consolidation plan is due to the Appropriations Committee on March 15, 2004. The report is due to the Commerce Department February 2, 2004. The Review Team should provide its draft report, including findings and recommendations, to the SAB by mid-December. A copy of the draft report will also be provided to NOAA for technical review. The SAB will meet early January to consider the draft report and deliver its Final Report to NOAA by mid-January to allow NOAA leadership time to develop its final consolidation plan by February 2.

Costs: NOAA Research will pay for all the costs associated with the development of this plan.

Appendix II

Selected Recommendations
from the
Preliminary Report (Governors Draft)
of
The U.S. Commission on Ocean Policy

Recommendation 7–1. Congress should pass an organic act that codifies the establishment and missions of the National Oceanic and Atmospheric Administration (NOAA). The act should ensure that NOAA's structure is consistent with the principles of ecosystem-based management and with its three primary functions: assessment, prediction, and operations; resource management; and research and education.

Recommendation 17–4. The National Invasive Species Council and the Aquatic Nuisance Species Task Force, working with other appropriate entities, should establish a national plan for early detection of invasive species and a system for prompt notification and rapid response. Congress should provide adequate funding to support the development and implementation of this national plan.

Recommendation 25–1. Congress should double the federal ocean and coastal research budget over the next five years, from the 2004 level of approximately $650 million to $1.3 billion per year. A portion of these new funds should be used to support research directed by the regional information collection programs, enlarge the National Sea Grant College Program, and support other high priority research areas described throughout this report.

Recommendation 25–4. Congress should support a greatly expanded national ocean exploration program. The National Oceanic and Atmospheric Administration and the National Science Foundation should be designated as the lead agencies, with additional involvement from the U.S. Geological Survey and the U.S. Navy's Office of Naval Research. Public outreach and education should be integral components of the program.

Recommendation 26–9. Congress should fund the Integrated Ocean Observing System (IOOS) as a line item in the National Oceanic and Atmospheric Administration (NOAA) budget, to be spent subject to National Ocean Council direction and approval. IOOS funds should be appropriated without fiscal year limitation. NOAA should develop a streamlined process for distributing IOOS funds to other federal and nonfederal partners.

Appendix III
Meetings Held By NOAA Research Review Team
September 26, 2003 – May 25, 2004

September 26, 2003 -Washington D.C.

- Conrad C. Lautenbacher Jr. - Vice Admiral, U.S. Navy (Ret.), Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator

October 7, 2003 - Silver Spring, Maryland

Informal meeting and discussions with OAR's Laboratory and Headquarters Staffs.

October 22-23, 2003 - Silver Spring, Maryland

Individual meetings with:

- Louisa Koch - Deputy Assistant Administrator, Oceanic and Atmospheric Research
- Daniel L. Albritton - Director, Aeronomy Laboratory
- Bruce B. Hicks - Director, Air Resources Laboratory
- Peter B. Ortner - Acting Director, Atlantic Oceanographic & Meteorological Laboratory
- Randall Dole - Director, Climate Diagnostic Center
- David J. Hofmann - Director, Climate Monitoring & Diagnostics Laboratory
- William D. Neff - Director, Environmental Technology Laboratory
- Alexander E. MacDonald - Director, Forecast Systems Laboratory
- Ants Leetmaa - Director, Geophysical Fluid Dynamics Laboratory
- Stephen B. Brandt - Director, Great Lakes Environmental Research Laboratory
- James F. Kimpel - Director, National Severe Storms Laboratory
- Eddie N. Bernard - Director, Pacific Marine Environmental Laboratory
- Kenneth A. Mooney- Deputy Director, Office of Global Programs
- Ronald C. Baird - Director, National Sea Grant College Program
- Greg W. Withee - Assistant Administrator, National Environmental Satellite Data & Information Service
- John E. Jones - Acting Assistant Administrator, National Weather Service
- Michael P. Sissenwine - Director, Northeast Fisheries Science Center, National Marine Fisheries Service
- Donald Scavia - Senior Scientist, National Ocean Service
- Mary Glackin - Assistant Administrator, Program Planning and Integration

November 4, 2003 - Rosslyn, Virginia

Science Advisory Board Meeting - Public Meeting

Science Advisory Board Members

- Leonard J. Pietrafesa - Interim Chair, Director of External Affairs, College of Physical and Mathematical Sciences, North Carolina State University
- Vera Alexander - Dean School of Fisheries and Ocean Sciences, University of Alaska
- David Blaskovich - Sales and Marketing Executive, Weather and Environmental Markets, IBM Corporation
- Otis Brown - Dean, Rosenstiel School of Marine and Atmospheric Science University of Miami
- Peter M. Douglas - Executive Director, California Coastal Commission
- Susan Hanna - Professor, Oregon State University
- Arthur E. Maxwell - Professor Emeritus, University of Texas
- Jake Rice - Canadian Stock Assessment Secretariat, Fisheries and Oceans Canada
- John T. Snow - Dean, College of Geosciences, University of Oklahoma
- Denise Stephenson-Hawk - Chairman, The Stephenson Group

NOAA Senior Staff in Attendance

- Conrad Lautenbacher Jr. - Vice Admiral, U.S. Navy (Ret.), Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
- James R. Mahoney - Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, NOAA
- John J. Kelly Jr. - Deputy Under Secretary, NOAA

November 25, 2003 - Washington, D.C.

- Ronald D. McPherson - Executive Director, American Meteorological Society (AMS)
- John Orcutt - President-Elect, American Geophysical Union (AGU)
- Peter Folger - Outreach/Government Affairs, American Geophysical Union (AGU)

November 25, 2003 - Washington, D.C.

- James R. Mahoney - Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, NOAA

December 4, 2003 - Washington, D.C.

- Erin Wuchte - Budget Examiner for NOAA Atmospheric programs
- John Webb - Department of Commerce, Budget Office
- Everett Whiteley - NOAA, Budget Office

December 4, 2003 - Washington, D.C.

Telephone call with Thomas Kitsos - Executive Director, Ocean Commission

December 5, 2003 - Washington, D.C.

- Carolyn Thoroughgood - Chairing the Board of Consortium for Oceanographic Research and Education (CORE)
- Mark R. Abbott - Dean, College of Oceanic Atmospheric Sciences, Oregon State University
- Penelope D. Dalton - Vice President and Technical Director, CORE

December 5, 2003 - Washington, D.C.

- Conrad C. Lautenbacher Jr. - Vice Admiral, U.S. Navy (Ret.), Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
- Leonard J. Pietrafesa - Interim Chair, Science Advisory Board, Director of External Affairs, College of Physical and Mathematical Sciences, North Carolina State University

December 5, 2003 - Washington, D.C.

- Peter Bell - Chairman Sea Grant Review Panel, Retired Executive Vice President for Technology, St. Gobain Corporation
- Robert Stickney - Sea Grant Association, Director of Texas Sea Grant Program
- Ronald C. Baird - Director, National Sea Grant College Program

December 5, 2003 - Washington, D.C.

- James D. Baker - former NOAA Administrator

December 10, 2003 - San Francisco, California

American Geophysical Union (AGU) Fall Meeting - Informal Public Comment Session. Nineteen people attended the session.

December 16, 2003 - Washington, D.C

Meeting with House and Senate Appropriations staff

- Kevin Linskey
- David Pomerantz
- Amy Carroll
- Jean Fruci

January 6, 2004 - Washington D.C.

Science Advisory Board - Public Meeting

Science Advisory Board Members

- Leonard J. Pietrafesa - Chair, Director of External Affairs, College of Physical and Mathematical Sciences, North Carolina State University

- Vera Alexander - Dean School of Fisheries and Ocean Sciences, University of Alaska
- David Blaskovich - Sales and Marketing Executive, Weather and Environmental Markets, IBM Corporation
- Otis Brown - Dean, Rosenstiel School of Marine and Atmospheric Science University of Miami
- Peter M. Douglas - Executive Director, California Coastal Commission
- Susan Hanna - Professor, Oregon State University
- Arthur E. Maxwell - Professor Emeritus, University of Texas
- Jake Rice - Canadian Stock Assessment Secretariat, Fisheries and Oceans Canada
- John T. Snow - Dean, College of Geosciences, University of Oklahoma
- Denise Stephenson-Hawk - Chairman, The Stephenson Group

NOAA Senior Staff in Attendance

- Conrad Lautenbacher Jr. - Vice Admiral, U.S. Navy (Ret.), Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
- John J. Kelly Jr. - Deputy Under Secretary, NOAA
- John E. Jones - Acting Assistant Administrator for National Weather Service
- Rick Rosen - Assistant Administrator for NOAA Research
- Greg Withee - Assistant Administrator for National Environmental Satellite Data and Information Service
- Rick Spinrad - Assistant Administrator for National Ocean Service
- William Hogarth - Assistant Administrator for National Marine Fisheries Service
- Mary Glackin - Assistant Administrator, Program Planning and Integration

January 14, 2004 - Seattle, Washington

Special session held at the annual meeting of the American Meteorological Society. One hundred and twenty-nine people attended this meeting.

January 23, 2004 - Washington, D.C.

- Scott Gudes - Senate Appropriations Staff

January 28, 2004 - Silver Spring, Maryland

Teleconference with Joint Institute Directors list:

- Mike Wallace - JISAO, Seattle, Washington
- Susan Avery - CIRES, Boulder, Colorado
- Bob Weller - CICOR, Woods Hole, Massachusetts
- Tom Vonder Haar - CIRA, Fort Collins, Colorado

February 3, 2004 - Washington, D.C.

- Christine Kojac - House Appropriations, Majority staff
- Annmarie Goldsmith - Department of Commerce
- Christine Maloy-Jacobs - NOAA

February 3, 2004 - Washington, D.C.

- John J. Kelly Jr. - Deputy Under Secretary, NOAA

Meeting with Assistant Administrators:

- Greg W. Withee - Assistant Administrator, National Environmental Satellite Data & Information Service
- John E. Jones - Acting Assistant Administrator, National Weather Service
- William Hogarth - Assistant Administrator for National Marine Fisheries Service
- Mary Glackin - Assistant Administrator, Program Planning and Integration

February 26 - 27, 2004 - Silver Spring, Maryland

Group and Individual meetings with:

- Daniel L. Albritton - Director, Aeronomy Laboratory
- Bruce B. Hicks - Director, Air Resources Laboratory
- Peter B. Ortner - Acting Director, Atlantic Oceanographic & Meteorological Laboratory
- Randall Dole - Director, Climate Diagnostic Center
- David J. Hofmann - Director, Climate Monitoring & Diagnostics Laboratory
- William D. Neff - Director, Environmental Technology Laboratory

- Alexander E. MacDonald - Director, Forecast Systems Laboratory
- Ants Leetmaa - Director, Geophysical Fluid Dynamics Laboratory
- Stephen B. Brandt - Director, Great Lakes Environmental Research Laboratory
- James F. Kimpel - Director, National Severe Storms Laboratory
- Eddie N. Bernard - Director, Pacific Marine Environmental Laboratory
- Ernest G. Hildner - Director, Space Environment Center

February 26, 2004 - Silver Spring, Maryland

Group meeting with Assistant Administrators or designees

- Stan Wilson - National Environmental Satellite Data & Information Service
- Jamie Hawkins - National Ocean Service
- General David L. Johnson - Assistant Administrator, National Weather Service
- Michael P. Sissenwine - Director, Northeast Fisheries Science Center, National Marine Fisheries Service
- Mary Glackin - Assistant Administrator, NOAA Program Planning and Integration

February 26, 2004 - Washington, D.C.

Group meeting at the Office of Management and Budget

- Erin Wuchte and Emily Woglom - Budget Examiners
- Christine Maloy-Jacobs - NOAA

February 26, 2004 - Washington, D.C.

Group meeting with NOAA Goal Team Leaders

- Chet Koblinsky - Climate
- Jack Hayes - Weather and Water
- Mike Sissenwine - Ecosystems
- Charlie Challstrom - Commerce and Transportation

March 11-12, 2004 – Boulder, Colorado

Extensive meetings and discussions with the Council of Boulder Laboratory Directors, laboratory scientists, and employees working in the David Skaggs Research Center plus with Susan Avery, Director of CIRES (Joint Institute)

March 17, 2004 - Rosslyn, Virginia

Science Advisory Board Meeting - Public Meeting

Science Advisory Board Members

- Leonard J. Pietrafesa - Chair, Director of External Affairs, College of Physical and Mathematical Sciences, North Carolina State University
- Vera Alexander - Dean School of Fisheries and Ocean Sciences, University of Alaska
- David Blaskovich - Sales and Marketing Executive, Weather and Environmental Markets, IBM Corporation
- Peter M. Douglas - Executive Director, California Coastal Commission
- Susan Hanna - Professor, Oregon State University
- Arthur E. Maxwell - Professor Emeritus, University of Texas
- Jake Rice - Canadian Stock Assessment Secretariat, Fisheries and Oceans, Canada
- John T. Snow - Dean, College of Geosciences, University of Oklahoma
- Denise Stephenson-Hawk - Chairman, The Stephenson Group

NOAA Senior Staff in Attendance

- Tim Keeney - Deputy Assistant Secretary of Commerce for Oceans and Atmosphere
- John J. Kelly Jr. - Deputy Under Secretary, NOAA

March 17, 2004 - Rosslyn, Virginia

- Bruce B. Hicks - Director, Air Resources Laboratory
- Richard Artz - Deputy Director, Air Resources Laboratory

April 6, 2004 - Washington D.C.

- Floyd Des Champs and Margaret Spring – Senate, Commerce, Science and Transportation Committee Staff
- Eric Webster, Amy Carroll and Jean Fruci -House Science Committee Staff

April 14, 2004 - Washington D.C.

Follow-up Teleconference with Joint Institute Directors from the January 28, 2003 call

April 14, 2004 - Washington D.C.

- Bob Frosch - Senior Research Fellow, Belfer Center for Science and International Affairs, John F. Kennedy School of Government

April 16, 2004 - Washington D.C.

- Dr. Mal O'Neill - Vice President and Chief Technical Officer, Lockheed Martin Corporation

April 16, 2004 - Washington, D.C.

- Conrad C. Lautenbacher Jr. - Vice Admiral, U.S. Navy (Ret.), Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator
- James R. Mahoney - Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, NOAA
- John J. Kelly Jr. - Deputy Under Secretary, NOAA

April 16, 2004 - Bethesda, Maryland

- Richard Wyatt - National Institutes of Health (NIH)
- Anthony Demsey - National Institutes of Health (NIH)

May 18, 2004 - Washington, D.C.

- James R. Mahoney - Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, NOAA
- John J. Kelly Jr. - Deputy Under Secretary, NOAA
- Scott Rayder - NOAA Chief of Staff

May 18, 2004 - Washington, D.C.

- Otto Wolfe - DoC Chief Financial Officer and Asst Secretary for Administration

May 18, 2004 - Washington, D.C.

Meeting with House and Senate Appropriations staff

- Michael Ringler
- David Pomerantz
- Scott Gudes

May 24, 2004 – Washington, D.C.

Meeting with House Science Committee Staff

- Eric Webster
- Amy Carroll
- Stan Sloss (Rep. Udall's staff)

May 25, 2004 – Washington, D.C.

Meeting with Senate, Commerce, Science and Transportation Committee Staff

- Margaret Spring
- Danielle Renart

July 13 2004 – Rosslyn, Virginia

Science Advisory Board – Public Meeting

Science Advisory Board Members

- Leonard J. Pietrafesa - Chair, Director of External Affairs, College of Physical and
- Mathematical Sciences, North Carolina State University
- Vera Alexander Dean, School of Fisheries and Ocean Sciences, University of Alaska
- David Blaskovich - Sales and Marketing Executive, Weather and Environmental
- Markets, IBM Corporation
- Otis Brown - Dean, Rosenstiel School of Marine and Atmospheric Science University of
- Miami
- Jake Rice - Canadian Stock Assessment Secretariat, Fisheries and Oceans Canada
- John T. Snow - Dean, College of Geosciences, University of Oklahoma
- Denise Stephenson-Hawk - Chairman, The Stephenson Group

NOAA Senior Staff in Attendance

- James R. Mahoney - Assistant Secretary of Commerce for Oceans and Atmosphere and Deputy Administrator, NOAA

Appendix IV
NOAA Laboratories and Joint Institutes

NMFS LABORATORIES
- Alaska Fisheries Science Center - 2 Field Stations
- Northeast Fisheries Science Center - 4 Field Stations
- Northwest Fisheries Science Center - 5 Field Stations
- Southeast Fisheries Science Center - 4 Field Stations
- Southwest Fisheries Science Center - 2 Field Stations
- Pacific Islands Fisheries Science Center - 1 Facility

NMFS JOINT INSTITUTES

None

NESDIS LABORATORIES
- Center for Satellite Applications and Research

NESDIS JOINT INSTITUTES
- Cooperative Institute for Climate Studies
- Cooperative Institute for Oceanographic Satellite Studies
- Cooperative Institute for Meteorological Satellite Studies

NOS LABORATORIES
- Center for Coastal Fisheries and Habitat Research (including Beaufort, NC and Kasitsna Bay, AK)
- Center for Coastal Monitoring and Assessment
- Center for Sponsored Coastal Ocean Research
- Center for Coastal Environmental Health and Biomolecular Research
- Hollings Marine Laboratory
- Oxford Cooperative Laboratory
- Coast Survey Development Laboratory

NOS JOINT INSTITUTES
- Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)
- Joint Hydrographic Center

NWS LABORATORIES
- Environmental Modeling Center
- Meteorological Development Laboratory
- Office of Hydrologic Development

NWS JOINT INSTITUTES

None

OAR LABORATORIES
- Aeronomy Laboratory
- Air Resources Laboratory
- Atlantic Oceanographic and Meteorological Laboratory
- Climate Diagnostics Center
- Climate Monitoring and Diagnostics Laboratory
- Environmental Technology Laboratory
- Forecast Systems Laboratory
- Geophysical Fluid Dynamics Laboratory
- Great Lakes Environmental Research Laboratory
- National Severe Storms Laboratory
- Pacific Marine Environmental Laboratory
- Space Environment Center

OAR JOINT INSTITUTES
- Cooperative Institute for Arctic Research (CIFAR)
- Joint Institute for Marine Observations (JIMO)
- Cooperative Institute for Research in the Atmosphere (CIRA)(co-sponsored with NESDIS)
- Cooperative Institute for Research in Environmental Sciences (CIRES)
- Cooperative Institute for Marine and Atmospheric Studies (CIMAS)
- Joint Institute for Marine and Atmospheric Research (JIMAR)
- Cooperative Institute for Climate and Ocean Research (CICOR)
- Cooperative Institute for Limnology and Ecosystems (CILER)
- Cooperative Institute for Atmospheric Sciences and Terrestrial - Applications (CIASTA)
- Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)
- Joint Institute for the Study of the Atmosphere and Ocean (JISAO)
- Cooperative Institute for Climate Sciences (CICS)
- Cooperative Institute for Climate Applications and Research (CICAR)

Note: In April 2004, the NOAA Line Offices provided this updated list of laboratories and Joint institutes.
The Laboratories now total 29 and the Joint institutes total 18.

Appendix V
DoD Financial Management 6.1-6.7 System

Budget Activity	Title	Brief Description
6.1	**Basic Research**	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind
6.2	**Applied Research**	Systematic study to understand the means to meet a recognized and specific national security requirement
6.3	**Advanced Technology Development**	Development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment
6.4	**Advanced Component Development and Prototypes**	Efforts necessary to evaluate integrated technologies, representative modes or prototype systems in a high fidelity and realistic operating environment
6.5	**System Development and Demonstration**	Engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production
6.6	**Research, Development, Testing and Evaluation Management Support**	Efforts to sustain and/or modernize installations or operations
6.7	**Operational System Development**	Development efforts to upgrade systems that have been fielded or received approval for full rate production and anticipate production funding in the current or subsequent fiscal year.

Source for this table is DoD Financial Management Regulation (DoD 7000.14-R, Volume 2B, Chapter 5), June 2002 (http://www.dod.mil/comptroller/fmr/)

Appendix V.A
Technical Readiness Level

Technical Readiness Level (TRL)	Description
1. Basic principles and broad vision of the system observed and reported.	The most general discussion of the system, i.e., the lowest level of resolution in system analysis. It corresponds to the lowest level of technology readiness. The results of this level of analysis are usually presented as paper studies of a system's basic properties. Correspondingly, it is also the lowest level of software readiness. Basic research begins to be translated into applied research and development.
2. Conceptual design of a system and/or technology and its application formulated.	Beginning of the system's refinement: resolution grows. Key engineering solutions are proposed, innovations are introduced, key resource limits are chosen. Practical applications are invented and tested. Applications are partially tested, partially hypothesized, and there may be no exhaustive proof or reliable analysis to support the assumptions and visions of the developing team.
3. Thorough theoretical and experimental critical analysis of system's function; detailed characteristic proof of concept.	More detail is addressed. Active research and development are initiated. Theoretical studies are conducted in the laboratory targeting physical and/or computational (simulation) validation of analytical predictions for separate sub-systems of the system. Those sub-systems are being scrutinized that are innovative and have not been integrated. Similar active research and development is initiated for the software subsystems. The number of resolution levels must be properly chosen. The programs are written that can validate theoretical predictions for separate software subsystems. Algorithms are tested in laboratory environment or in simulation.
4. Component and/or breadboard validation is conducted in the laboratory environment.	All basic subsystems and components are integrated to establish that they will work together. This usually includes ad hoc sub-systems integration. This includes integration of software components are integrated to determine how they will work together. They are relatively primitive with regard to efficiency and reliability compared to the eventual system. System Software architecture development initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. At this point, we are able to check the matching between computational parameters of the algorithms and programs on one hand and the parameters of other components (sensors, actuators) on the other.
5. Component and/or breadboard validation in more realistic relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements: it includes "high fidelity" ("high resolution") laboratory integration of software components. Configuration control is initiated. Verification, Validation, and Accreditation (VV&A) initiated. At this point, we have an opportunity to check whether the state-space is tessellated properly, whether the parameters of sampling, or parameters of randomization are proper ones.

Technical Readiness Level (TRL)	Description
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. This stage represents a major step up in software-demonstrated readiness. Software support structure is in development. VV&A is in process. At this stage we check the value of parameters such as carrying frequencies, bandwidths, etc.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major growth in resolution comparatively with TRL 6, requires demonstration of an actual system prototype in an operational environment such. Examples include testing the prototype in a test bed aircraft. Software support structure is in place. Software releases are in distinct versions. Frequency and severity of Software deficiency reports do not significantly degrade functionality or performance. VV&A completed.
8. Actual system completed and qualified through test and demonstration.	The system has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of the system development. Examples include developmental test and evaluation of the system in its intended application to determine if it meets design specifications. Software has been demonstrated to work in its final form and under expected conditions. In most cases, this TRL represents the end of system development. Examples include test and evaluation of the Software in its intended system to determine if it meets design specifications. Software deficiencies are rapidly resolved through support infrastructure.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions. Actual application of the Software in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last debugging aspects of the system development. The system is used under operational mission conditions. Software releases are production versions and configuration controlled.

Appendix VI

Office of Oceanic and Atmospheric Research—Success Stories

TRANSITION OF RESEARCH TO OPERATIONS

Foundation for the National Weather Service Modernization: For the past 30 years, OAR has provided the scientific and technological foundation for major technological infusions supporting the largest modernization effort in the history of the National Weather Service (NWS). In the 1970s, OAR recognized the potential for Doppler radar to improve the detection and warning of severe weather, which led to the development and deployment of the Next Generation Weather Radar program (NEXRAD). This resulted in the creation of a critically important national network of Doppler radars. Another major component underpinning the modernization of the NWS was the research and development carried out in OAR laboratories and Joint Institutes which led to the delivery of the Advanced Weather Interactive Processing System (AWIPS). This system revolutionized the delivery and use of weather information at forecast offices across the nation. These improvements have all been successfully transferred to the NWS.

Testing of the Warning Decision Support System in the 1990s has led to improvements in AWIPS software and warning applications. The recently deployed Open Radar Product Generator (ORPG) builds on these capabilities, and is expected to continue improvements. The ORPG is the part of NEXRAD that processes raw data gathered by radar, performs data quality checks, creates radar images and products for display, and sends those products to display systems such as AWIPS used by NOAA's NWS. OAR is also looking to advance lead time significantly beyond 2007 levels for tornadoes and improve flood warning capability, by working with the NWS to upgrade the existing WSR-88D (NEXRAD) radar network to a dual polarization radar network.

Building on the Success and Systems of the NWS Modernization: OAR's efforts in support of Phased Array Radar development are looked to as the best candidate to underpin the next generation of radar advancements; the advancements are designed to help future forecasters provide earlier warnings for tornadoes and other types of severe and hazardous weather. This new, state-of-the-art radar was unveiled in 2003 at NOAA's National Severe Storm Laboratory (NSSL) in Norman, Oklahoma, thereby establishing the National Weather Radar Testbed. This testbed provides the meteorological research community with the first full-time phased array radar facility.

Advancements Lead to More Timely Tornado Warnings: The lead-time for NWS tornado warnings in 1987 was three minutes. OAR investments in new radar and software technologies helped deliver tornado warning lead times of 13 minutes in 2003. These advances were extremely helpful during the Midwest tornado outbreak from May 4-10 2003. With approximately 400 tornadoes reported during this period, the NWS was able to issue tornado warnings with an average lead-time of 18 minutes.

Improvements in Hurricane Track Forecasts: NOAA and the Joint Institutes have made continuous improvements in hurricane track forecasts. $2.5B in damage costs is saved annually, on average, because of more accurate hurricane watches and warnings. OAR provides core modeling advances in support of NWS hurricane predictions. Numerous improvements made by OAR have led to a 20 percent improvement in track forecasts. NOAA and Joint Institute scientists were instrumental in developing observational advances (e.g., dropwindsonde) necessary to obtain detailed measurements of low-level hurricane eyewall winds. The data collected during these missions improved the one- and two-day model track forecasts by an average of 13 percent, and longer-range forecasts by up to 32 percent. Some evidence suggests that the aircraft-dropwindsonde data have an even larger positive impact on track forecasts for strong or rapidly intensifying storms. Improvements in tracking hurricanes have been demonstrated in the past year; the accuracy of the 2003 Hurricane Isabel forecast, and the skill at forecasting hurricanes in the entire 2003 season, is a true NOAA accomplishment. In 2003, verification of Isabel was much better than the 10-year average. The average 48-hour track error for Isabel was only 60 nautical miles (nm); and the 5-day forecast was as reliable as the 3-day forecasts provided for similar hurricanes 15 years ago. The recent advancements in hurricane forecasting are a result of better partnerships between researchers and forecasters, better use of observations in models, and improved model physics.

Science Supports New Ozone Forecasts: NOAA and the Environmental Protection Agency signed an agreement to deliver air quality forecasts to the Nation. The transfer of this information to the NWS is now completing the first stages; the NWS will begin providing 24-hour ozone forecasts in New England in the fall of 2004. OAR science is the foundation of these forecasts and will contribute to the future development of nationwide ozone and fine particle forecasts. Ongoing OAR activities in research-grade air pollution observations, intensive field studies to understand photochemical processes in the atmosphere, and diagnostic and predictive modeling make the development and implementation of operational air pollution forecasts possible.

Tsunami Hazard Mitigation: Advanced computer models, tsunami inundation maps, tsunami detection buoys, an expanded seismic network, evacuation signs, educational videos, and mitigation plans are all products of the NOAA National Tsunami Hazard Mitigation Program. The five-state/three- federal agency program was created in 1996 after a small local tsunami was generated in northern California that raised concerns about the tsunami threat to the west coast. To reduce the 75 percent false alarm rate of tsunami warnings, a breakthrough technology, to detect tsunamis in the deep ocean in real-time, was developed. Six deep-water tsunami detection buoys are now deployed in earthquake-prone areas off Alaska, the U.S. west coast, and Chile. The $10 million investment in this new tsunami warning capability is already paying big dividends; tsunami data received in November 2003 following a magnitude 7.5 Alaskan earthquake convinced officials in Hawaii that the tsunami was not destructive, leading to the quick cancellation of the warning. The timely cancellation averted a false alarm evacuation that saved Hawaii an estimated $68 million. The tsunami program was successfully transferred to the NWS in 2003. The tsunami detection network will consist of 20 deep-water buoys when it is completed in 2011.

Transportation on the Great Lakes: NOAA researchers are expected to decrease error in their six-month Great Lakes level forecasts by 1 cm by 2007. The shipping industry is highly sensitive to small changes in lake levels. A two-centimeter error in a forecast can translate into a loss of $1.5 million for one ship carrying cement over the course of one year. With the incorporation of real-time water level measurements, precipitation (Doppler radar derived), air temperature, wind speed, cloud cover, and humidity, the models developed by NOAA scientists provide improved forecasting over traditional water level forecasting models. These forecasts are operationally used at the U.S. Army Corps of Engineers, the New York Power Authority, and several universities. In addition to the shipping industry, hydropower plants use the forecasts extensively to plan their peaking and ponding operations.

Understanding Our Global Climate System to Improve Short-Term Climate Prediction: Using a combination of numerical modeling and data from its El Niño observing system, NOAA successfully monitored the largest El Niño event on record in 1997/8 and predicted its evolution in the tropical Pacific several months in advance. This allowed for the successful prediction of the subsequent shift to a La Niña cold phase, resulting in major changes to U.S. weather patterns during the winter of 1997-8. Predictions such as these had their genesis in the coupled (ocean/atmosphere) global climate models developed by OAR Laboratories and Joint Institutes, recognized as world leaders in modeling the complex physical processes that govern the behavior of the atmosphere and oceans. Through the generation of large ensemble data sets that are based upon historical data, NOAA and Joint Institute researchers have also been able to better assess the affects of El Niño climate events on regions outside of the tropics, where the El Niño signal has been more difficult to track. Since 1997-8, OAR has reached new heights in increasing the skill of NWS operational seasonal forecasts. These improvements are being made through better understanding of the physics of variability and through better predictions using numerical models. OAR plans to systematically introduce model outputs from five models into NWS operations over the next five years. In addition, OAR’s experimental sub-seasonal forecast products for 8-14 day temperature and precipitation and tropical Pacific rainfall variability will be implemented in an operational framework by NWS before October 2004.

Regional Ecological Observing System Data Supports Management Responsibilities: OAR laboratories on both coasts and in the Great Lakes have collected physical and biological ocean and lake parameters in the Gulf of Alaska/Bering Sea, Florida Bay/Florida Keys and Great Lakes regions for more than 20 years. These observations are incorporated into fisheries forecasts, protected species management models, models to predict lake levels, tsunami preparation, and to gauge the success of coastal habitat restoration efforts. One such program, initiated in the North Pacific Ocean in 1984, produced its first annual recruitment forecast for walleyed Pollock in 1992. Pollock is the largest component of the lucrative Alaskan groundfish industry, which comprises 47 percent of the entire U.S. fish catch by weight. The forecasts for the Gulf of Alaska population are provided to the National Marine Fisheries Service as part of the input used by the North Pacific Fisheries Management Council to set the total allowable catch..

Space Environment Center: OAR provided the foundation for the development of the Space Environment Center (SEC), which provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. SEC's Space Weather Operations Center is jointly operated by NOAA and the U.S. Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment. The center will be transferred to the NWS in FY 2005.

RESEARCH PROVIDING INFORMATION SERVICES

Acid Precipitation: Ongoing air quality assessments based on field studies and diagnostic modeling provides crucial scientific information to support decisions of policy makers. In the 1980s and 1990s, NOAA scientists made major contributions to the National Acid Precipitation Assessment Program's scientific assessments of the causes of acidic deposition, providing a firm scientific foundation for the acid rain control provisions of the 1990 Clean Air Act Amendments.

Air Quality Management: NOAA's air quality research provides scientific input into the development of scientifically effective management strategies. Discoveries NOAA made in 2000 allowed the State of Texas to develop a less onerous pollution control strategy that protects public health while projecting to save the state more than $9B and 64,000 jobs by 2010.

Homeland Security: Building on capabilities delivered over several decades (starting with volcano dispersion plume simulations), OAR scientists created UrbaNet, a dedicated turbulence measuring system deployed in Washington, D.C., New York City, and Las Vegas, providing decision makers with specialized forecasting of atmospheric dispersion in the event of a terrorist attack.

Discovery of the Underlying Causes of Our Depleted Ozone Layer: Conclusive evidence of stratospheric ozone depletion over Antarctica was gathered in the mid-1980s. Subsequent National Ozone Expeditions to Antarctica in 1986-1987 were led by an OAR scientist and confirmed that depletion of the ozone layer is caused by human-produced chlorofluorocarbons interacting with polar stratospheric clouds. These discoveries led to the strengthening of major international agreements, such as the Montreal Protocol, to phase-out the wide use of these compounds. Recent scientific assessments have led to an accelerated schedule of phase-outs, new caps on other ozone depletors, and trade limits on ozone-depleting chemicals. NOAA has led the preparation of the state-of-the-science assessments for the United Nations, and an OAR scientist serves as Scientific Advisor to the Montreal Protocol.

OAR has been pivotal in understanding and describing the atmospheric processes that caused the unexpected occurrence of the Antarctic ozone hole and, more recently, the linkages between the ozone hole and climate in the Antarctic region. OAR scientists published the first and a subsequent series of award-winning papers documenting and dissecting the rise, turnover, and decline of ozone-depleting gases in the atmosphere. These publications were based upon the unique, long-term measurements made globally by OAR and Joint Institutes and underscore the significance of human activities in the rise, and now decline, of these gases in the atmosphere.

Almost since the study of the thinning ozone layer began, OAR scientists have been the reliable source of information about the ozone-layer friendliness and climate friendliness of substitute chemical compounds that industry proposes for a variety of societal uses such as refrigeration, air conditioning, electronics manufacture, and fire protection. These scientists carried out laboratory and modeling evaluations of more than a dozen substances and gained OAR the reputation among industries and governments as the main source for information.

Explaining and Predicting Impacts of Global Carbon Dioxide Increases: A four-station Baseline Observatory network operated by OAR has provided the world with a continuous record of the increase in global atmospheric carbon dioxide (CO_2) over the past 40 years. These observations, combined with samples collected globally through a cooperative flask-sampling network at about 50 sites, contribute to about 85 percent of a global atmospheric CO_2 database compiled by OAR. The database serves as a world-renowned source of CO_2 data for climate modeling. In 1990, OAR scientists used the global network data to show that there was a large, previously unknown, amount of CO_2 being taken up by the terrestrial biosphere (trees, plants, soils) in the Northern Hemisphere. This discovery of major "free sequestration" of carbon by the biosphere provided impetus for the current North American Carbon Program (NACP), an interagency/university research program designed to study carbon sources and sinks in North America and surrounding ocean basins. As a part of this program, OAR is building a network of aircraft and tall tower CO_2 monitoring stations across North America to determine the interannual variability of U.S. and North American carbon uptake.

OAR has also made dramatic strides in understanding how the land and oceans buffer anthropogenic emissions of CO_2 to the atmosphere. The first database inventory of anthropogenic CO_2 in the ocean was compiled by OAR scientists, documenting that the oceans alone have absorbed 29% of the excess CO_2 produced by human activity since the start of the industrial revolution. The annual oceanic uptake of CO_2 represents a $4B annual carbon sequestration "service."

NOAA researchers have also contributed to the first climatology of surface ocean CO_2 levels through measurements from NOAA research ships. Through targeted studies, NOAA researchers have improved calculations of CO_2 fluxes between the atmosphere and the ocean. The resulting "maps" are used in models and as a baseline for CO_2 flux anomalies resulting from phenomena such as El Niño. The monthly climatologies have been one of the most important contributions to oceanic and atmospheric carbon cycle studies in the last decade.

We should also note (as indicated in Appendix VII), that the US academic research community has played a central role in advancing our knowledge of the carbon cycle beginning with Charles Keeling's seminal record of the increase in atmospheric carbon dioxide over the last 50 years, the extension of that record back in time through ice cores, and forward through models. We should also point out that the academic community performed a vital function in formulating, initiating, and maintaining the early programs in CO_2 measurements and the TOGA-TAO array. The North American Carbon Plan represents the best in university and government partnerships.

Intergovernmental Panel on Climate Change and OAR Citations: OAR continues to provide scientific understanding to inform the policy-making process in the global climate change arena as noted in the proceedings of the Intergovernmental Panel on Climate Change (IPCC). Citations in these critical assessments are a key gauge of the value of research. For each of the three completed IPPC Assessments, OAR boasts the following increasing numbers of citations of its scientists: 67 (1990), 131 (1995) and 295 (2001). An OAR senior scientist is the Chair of Working Group 1 for the 2007 IPCC Assessment. OAR contributions in carbon cycle research, greenhouse gas monitoring, aerosols characterization, radiative forcing understanding, and a coupled atmosphere, land, ice, and ocean model will all be used in the forthcoming 2007 IPCC Report.

A Measure of the High Impact of OAR Scientists in the Geosciences: OAR scientists are prominent in the listing of "The World's Most Influential Researchers" in the geosciences over the period 1981-1999, compiled by ISI Thompson Scientific by tracking citations of publications in the international scientific literature. Of the ten NOAA scientists on the list of most highly cited, nine are from OAR. Researchers on the list are considered to have formed or changed the course of research on a subject. The result provides a measure of OAR's very high impact in the geosciences.

Appendix VII
Extramural Research Success Stories

Climate Outlooks and Predictions: The extramural research community and Joint Institutes helped form the concept and methodology for seasonal-to-annual climate prediction with research on El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), coupled atmosphere-ocean modeling, and statistical methods for data analysis. NOAA's Office of Global Programs (OGP) Tropical Ocean Global Atmosphere (TOGA) fieldwork, a major coordinated observational campaign, paved the way for ENSO climate predictions. This research took a decade to mature to forecasts that are now regular operational products from the Climate Prediction Center (CPC) within NOAA's National Centers for Environmental Prediction (NCEP). Similar work is now under way on other climate patterns that will eventually improve our ability to provide accurate climate outlooks on longer time scales. The ENSO forecast likely is the single most important event that launched NOAA into predictive climate services.

Climate Services: The Cooperative Institute for Research in Environmental Sciences (CIRES) and Joint Institute for the Study of the Atmosphere and Ocean (JISAO) as well as three other university locations, have extensive contacts with managers responsible for water resources management, flood control, power generation, fisheries, forest resources, agriculture, and wildland fire. These managers are all potential users of seasonal to decadal climate forecasts and outlooks. By talking to these individuals, it is learned what kinds of climate services might benefit various sectors of the economy and how climate information can be tailored. Specific products that have been developed include new hydrometeorology forecasting tools, snowmelt products, new climate division analyses, improved fire-management decision models, and crop outlooks.

Multi-institutional Programs: The development of a center of excellence in meteorological radar engineering and radar meteorology in Norman, OK is the result of collaboration between NOAA's National Severe Storms Laboratory, four different units within the University of Oklahoma, and the private sector. The hinge for this collaboration is the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), the NOAA Joint Institute that links NOAA with the university. Central to the effort is the adaptation of the SPY-1 Phased Array Radar of the U.S. Navy for meteorological applications. NSSL provides the scientific and engineering leadership for this initiative, with strong support from CIMMS scientists and engineers who team the NSSL federal employees. Faculty members from the OU schools of Meteorology and Electrical and Computer Engineering also contribute. Both schools are adding five new faculty members to strengthen the effort. The State of Oklahoma is fully funding these new positions at a time of constrained state budgets. The private sector is an additional partner, including Lockheed Martin and Basic Commerce and Industries (BCI). Lockheed Martin supports the OU School of Electrical and Computer Engineering to nurture its radar-engineering program. Complementing the SPY-1 initiative is the development of low-powered short-range radars by the new National Science Foundation Engineering Research Center (CASA) in which the OU Center for the Analysis and Prediction of Storms is a major partner. These small-scale radars will work with the scans of the SPY-1 radar and contribute to more local severe-weather warnings.

Hawaiian Long-Line Fishery*:* On April 1, 2004, the Hawaiian long-line fishery was reopened after a two-year closure by the Federal courts. The fishery was closed because of concerns about incidental catch (by-catch) of protected species, especially sea turtles. The Joint Institute for Marine and Atmospheric Research (JIMAR) participated in collaborative research with the Pacific Islands Fisheries Science Center and provided funding through JIMAR's Pelagic Fisheries Research Program to a suite of national and international researchers to address issues related to by-catch. Direct outcomes of these efforts have included development of the design of hooks and techniques of setting lines that contributed to the reopening of the fishery.

Hurricane Intensity Forecasting: The exchange of heat and momentum at the air-sea interface plays a critical role in hurricane development. Work at Cooperative Institute for Marine and Atmospheric Studies (CIMAS), in cooperation with NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) uses radar altimeter data to estimate oceanic heat content coupled with the seasonal climatology in the Atlantic Ocean Basin. These are used daily to make intensity forecasts using the Statistical Hurricane Intensity Prediction Scheme (SHIPS) model at the National Hurricane Center. This has led to improved intensity forecasts by more than 5 percent. These oceanic heat content data are now a key element in the data stream for hurricane forecasts. Research in this area was begun under a program supported by Office of Naval Research (ONR). After various field programs validated the procedure, the research was assumed under NOAA support through CIMAS.

Ocean Observations: Woods Hole Oceanographic Institution (WHOI) and Scripps Institution of Oceanography (SIO) have been central players in the development of new technologies for sustained ocean observations and in their deployment as parts of NOAA's Climate Observation Program. Contributions by these and other partnering research institutions have put the Climate Observation Program at the forefront of using such technology to observe, understand, and better predict the evolving state of the global ocean and its role in climate variability. Key technologies and sampling modes developed and deployed by SIO and WHOI include: profiling floats for the global Argo array, surface drifters for the Global Drifter Network, moored observations in the water column, flux reference sites on the sea surface, and Volunteer Observing Ship programs including high resolution XBT networks and improved marine meteorological observations. The institutions also provide enabling technology and participation in repeat deep ocean CTD/hydrographic transects. Moreover, NOAA-funded research at these institutions includes ocean data assimilation, demonstrating a valuable application of the observing system and the bottom-to-top integration of instrumentation development, observations, and synthesis. The Cooperative Institute for Climate and Ocean Research (CICOR) at WHOI, and the Joint Institute for Marine Observations (JIMO) at SIO make institutional research facilities and capabilities available to NOAA, including a number of ships with global range to supplement the capacity of the NOAA fleet. With these contributions, it is now becoming possible for the first time to observe the essential roles of the ocean in the climate system - the oceanic transport and storage and the air-sea exchange of heat, freshwater, and momentum on global space-scales and on seasonal, interannual, and decadal time-scales.

Land Dynamics and Biogeochemistry: Extramural research has the lead in developing the physical as well as biological components of a new land model for Geophysical Fluid Dynamics Laboratory (GFDL) Earth system model including vegetation and hydrology, with ongoing work to add nutrient cycling in agricultural areas and forests. Research includes the impact of land surface processes on climate prediction on time scales from months to centuries, the dynamics and simulation of drought, changes in the sizes of terrestrial carbon sources and sinks, changes in the distribution of biomes, effects of vegetation and land use change on the hydrologic cycle, and effects on human activities; air quality impacts of changes in biogenic volatile organic compounds (BVOC) emissions and their influence on surface ozone.

Chemistry, Radiation, and Climate: Graduate students led the way in developing an improved representation of aerosols in Geophysical Fluid Dynamics Laboratory's (GFDL) new Earth system model and understanding of their role in climate, including representations of the role of indirect forcing; studies of hygroscopic and optical properties of organic carbon; studies of the effects of volcanic aerosols on tropospheric climate and the Arctic Oscillation; analyses of water vapor feedback effects; analyses of cloud microphysics-radiation interactions; studies of the climate sensitivity due to trace gases versus aerosols; and theoretical studies guided by observations on the effects of aerosol plumes on cloud properties highlighting the importance of size distribution and chemical composition in the effects of aerosols on climate.

Education and Training: Under the Joint Institute Program, Sea Grant, National Undersea Research Program (NURP), and Ocean Explorer programs, there is a long term and highly successful program of training post-doctoral students, graduate students, and undergraduate students. Many of these former students now play major roles as faculty members and researchers around the world, including many in NOAA and other national laboratories. These training programs provide opportunities for hundreds of young scientists annually to engage in NOAA-focused research and often provide the means to work across disciplines or provide the mechanism for transitioning research into information or operational services.

NOAA's Educational Partnership Program with Minority Serving Institutions provides financial assistance to minority-serving academic institutions to support collaborative research and training of students in NOAA-related sciences through competitive processes. The goal is to increase the number of students who are trained and graduate in sciences directly related to NOAA's mission. It also seeks to increase collaborative research efforts between NOAA scientists and researchers at Minority Serving Institutions, as defined by the Department of Education. Since 2001, 19 students have been hired as full-time NOAA employees, and more than 300 students have received training in programs supported by the Educational Partnership Program.

Investment in Marine Aquaculture: Through its investments in off-shore aquaculture in such areas as Hawaii, Florida/Puerto Rico, New Hampshire, the Gulf of Mexico, and the mid-Atlantic, NOAA Sea Grant hopes to establish an environmentally sustainable, profitable offshore aquaculture industry in the United States and the Caribbean. In addition to creating a major source of global food production, investments by NOAA in marine aquaculture help alleviate stress on natural stocks, create jobs, and address the U.S. trade deficit. For example, the University of Hawaii Sea Grant College Program has been instrumental in the development of a strong aquaculture enterprise in the Hawaiian Islands. There are currently 126 farms valued at $25.2 million dollars, translating into about 630 jobs.

Life-Saving Products from the Sea: Biotechnological research conducted by NOAA Research-supported scientists has revealed candidates for new drugs and treatments from the sea that can be used in the fight against a wide range of human ailments, including cancer and AIDS. In addition to revolutionizing modern scientific theory about the origin and sustenance of life, the discovery of undersea hydrothermal vents and seeps in the 1980s has fueled the hope that sources of badly-needed new antibiotics lay in oceanic microbial communities just off our coasts. Sea Grant scientists and researchers from NURP's National Institute for Undersea Science and Technology have discovered and described more than 1,000 compounds. One compound, a set of peptides (called halovirs), was recently discovered in a marine-derived fungus and found to suppress replication of the herpes virus in marine mammal cells. Another compound, bryostatin 1, is expected to be approved for treating esophageal cancer. Sustained support of these scientific efforts from NOAA Research and others means that these new drugs may become available within the decade.

Discovery: NOAA's 2003 Ocean Exploration Ring of Fire expedition in the Western Pacific Ocean mapped more than 36,000 kilometers of seafloor and surveyed more than 50 submarine volcanoes, discovering that 10 of them had active hydrothermal systems. One of their main objectives was to characterize the biology and chemistry of the hydrothermal systems. The hydrothermal systems of submarine volcanoes along island arcs are relatively unexplored. Preliminary work at a few sea-floor sites and analyses of samples indicate that island arc hydrothermal systems are probably very different in character (e.g., morphology, eruptive style, chemical composition) from those found along the mid-ocean ridge. This expedition is one of the first comprehensive investigations of this type of submarine volcanic environment.

Innovation: NOAA's Undersea Research Program (NURP) provides scientists with the ability to live and work for up to 10 days at 60 feet beneath the ocean's surface in the world's only undersea laboratory, *NOAA's Aquarius*. The *Aquarius* is owned by NOAA and operated by the NURP Center at the University of North Carolina at Wilmington, one of six university-based NURP Centers, each of which supports competitive scientific proposals that target coastal and ocean resource science and management issues. *NOAA's Aquarius*, located in the Florida Keys National Marine Sanctuary, is a national asset that supports scientists in their efforts to better understand coral reef ecosystems. Science achievements from *NOAA's Aquarius* include research related to the damaging effects of ultraviolet light on coral reefs, geological studies that use fossil reefs to better understand the significance of present-day changes in coral reefs, research that is rewriting the book on how corals feed, water quality studies that evaluate sources of pollution, and long-term studies of reefs to help distinguish between changes caused by natural system variability and humans.

Invasive Species Control: Sea Grant universities conducted an aquatic invasive species (AIS) survey in the Great Lakes to assess and improve the effectiveness of AIS boater education by Sea Grant and collaborating agencies and organizations. The survey was developed to measure boater attitudes and behavior in five freshwater and marine states. This is the first time a study has compared the efficacy of AIS boater awareness programs in different regions of the U.S. The survey demonstrated that investment in AIS public education can significantly change boater behavior to prevent and slow the spread of AIS. This finding has helped many states, provinces and task forces to justify expending limited resources for AIS boater education, because results show a return on this investment. The survey also identified the best methods to reach boaters and change their behavior. Outcomes of the study were presented at 16 conferences, workshops and meetings reaching 893 policy makers, resource managers, researchers and educators in five states. Additional are already planning to adapt the survey for their use. Working from the existing survey will save roughly 70 percent of the overall survey costs for the sponsoring organization.

Coastal Health and Water Quality: Using radioisotope data, Sea Grant researchers have found concentrations of DDT and PCBs in a Southern California water column that are 100 to 1,000-fold higher than the current limiting concentrations for effluents set by the State Water Resources Control Board. Their methods have been adopted by the Southern California Coastal Water Research Project and the Department of Earth Sciences at USC, resulting in approximately 155 person hours saved per month (equivalent to one full-time employee). Sea Grant researchers are also working on better ways to study the protozoans *Giardia* and *Cryptosporidium,* which sicken thousands of people, some fatally. The researchers are studying the pathogens in water, using laser traps and a fluorescent oxidation-reduction (redox) dye that enables them to visualize the respiration of the cysts. This new technique, which improves upon current technologies, is capable of trapping cells or particles at certain depth in an aquatic environment, thus allowing researchers to perform observations in real time under natural conditions. A commercial laboratory, Waterborne, Inc. (New Orleans, LA) has tested the method for potential commercial use and marketing.

Appendix VIII
OAR Boulder Laboratories

FY 2003 Funding and Staffing

Laboratory Name	Total Funding ($ in Millions)	Staffing Demographics Federal	Contractors	JI/others	Total Staffing
Aeronomy Laboratory	$14.5	40.6	0.5	59.3	100.4
Climate Diagnostics Center	$5.7	14.0	0.0	42.0	56.0
Climate Monitoring & Diagnostics Lab.	$14.3	51.0	4.0	42.0	97.0
Environmental Technology Laboratory	$15.6	55.0	16.8	35.3	107.1
Forecast Systems Laboratory	$28.1	88.0	57.0	58.0	203.0
Space Environmental Center 1/	$7.9	46.0	0.0	12.0	58.0
BOULDER TOTALS	$86.1	294.6	78.3	248.6	621.5

1/ The Space Environmental Center is proposed to be transferred to the National Weather Service in the FY 2005 President's Budget.

AERONOMY LABORATORY

Mission

The mission of the Aeronomy Laboratory (AL) is to improve the understanding of the chemical, dynamical and radiative processes of the Earth's atmosphere that are needed to improve NOAA's capability to predict its behavior. The chemical, dynamical, and radiative processes of the atmosphere are the mechanisms of atmospheric change. As such, their identification and characterization are a fundamental necessity for building better models for predicting the behavior of regional and global phenomena, which is at the heart of NOAA's mission.

- The Aeronomy Laboratory currently focuses on understanding the atmospheric processes important to model predictions of changes in climate, regional air quality, and the stratospheric ozone layer.
- In this user information context, Aeronomy Lab scientists conduct investigations of the atmospheric process under controlled conditions in the laboratory, carry out field measurements in a variety of environments, and use diagnostic models for analyses and interpretations.
- The Aeronomy Laboratory also assesses the current state of scientific understanding and interacts with those who use this information both within NOAA and elsewhere.

Brief History

The Aeronomy Laboratory was formed in 1965. Over AL's nearly 40-year history, its research has evolved to meet a sequence of most-pressing national needs for scientific understanding of atmospheric chemistry and related air motions. It initially focused on the chemistry and motions of the upper atmosphere's ionosphere, in response to the Nation's need for scientific information that would enable advances in radio communications and matters of national security. In the 1970s, the Aeronomy Laboratory's research shifted to the chemistry of the lower layers of the atmosphere as the national environmental issues of stratospheric ozone depletion and acidic deposition emerged. Over the recent decade, AL's research foci have included the chemical processes that control the characteristics of greenhouse gases and aerosols in the lower atmosphere and that control surface-level ozone pollution episodes.

CLIMATE DIAGNOSTICS CENTER

Mission

The mission of the Climate Diagnostics Center (CDC) is to develop national capabilities to analyze, interpret, and forecast important climate variations on time scales ranging from a few weeks to centuries. To achieve its mission, CDC develops and applies a wide range of research methods, particularly emphasizing state-of-the-art diagnostic techniques, to elucidate fundamental processes governing climate phenomena such as droughts, floods, and the El Niño/Southern Oscillation, and to identify the causes of longer-term (decadal to centennial) climate variations. CDC also performs extensive intercomparisons of observational and climate model data, an activity vital to improving current research and prediction models.

The development of improved climate assessments and predictions enhances the Nation's economic and environmental security, and is a fundamental part of NOAA's mission. Diagnostic studies, for which CDC has exceptional breadth and expertise, vitally contribute to this process by linking basic observational and theoretical research to improvements in operational climate predictions and, ultimately, to the development of new climate products that better serve the needs of the public and decision-makers

Brief History

CDC was formed in 1993 through a Memorandum of Agreement (MOA) between the Office of Oceanic and Atmospheric Research (OAR) and the Office of Global Programs (OGP), with personnel derived from what had formerly been the Climate Research Division of the Climate Monitoring and Diagnostics Laboratory. The purpose of the OAR-OGP agreement was to establish a unique, focused center of expertise within NOAA to develop and apply diagnostic methods that would aid in understanding the dominant processes influencing climate variability and link observational analyses to model testing and evaluation. Under the terms of the MOA, CDC is managed as one of the Research Laboratories in OAR.

Organization

CDC is staffed by NOAA personnel and affiliated scientists from the University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES), with approximately forty CIRES staff and fourteen federal staff directly affiliated with CDC. In order to more explicitly recognize this large and focused set of joint activities, a University Center within CIRES, also named the Climate Diagnostics Center, was formed in 1997. This organization integrates and coordinates climate research in NOAA/OAR and CIRES with other existing University research and instructional programs, thereby enhancing prospects for mutually beneficial collaborations among NOAA and university scientists over a broad range of disciplines.

CLIMATE MONITORING AND DIAGNOSTICS LABORATORY

Mission and Purpose

The Climate Monitoring and Diagnostics Laboratory (CMDL) is the only federal laboratory whose mission is to monitor atmospheric greenhouse species that affect climate and those that cause ozone layer depletion. Long-term, continuous, precise measurements of climate forcing and ozone layer depleting species are required for climate and ozone layer projections which are delivered to customers through international assessments such as the IPCC Climate Assessments and the UNEP/WMO Ozone Assessments. These assessments provide policy-relevant information on future climate and status of the ozone layer. Linkage to the NOAA Strategic Plan is through Mission Goal 2: *Understand climate variability and change to enhance society's ability to plan and respond.* In the case of ozone and ozone-depleting gases, NOAA, along with NASA, is mandated to report to Congress on their status by the Clean Air Act of 1990. CMDL's research is linked closely to the U.S. Climate Change Science Program which has as its Mission Goal 2: *Improve the quantification of the forces bringing about changes in the Earth's climate and related systems*, which has been adopted for the NOAA Climate Program Mission Goal 2. CMDL accomplishes its mission through five baseline observatories and a global cooperative flask sampling network including more than 50 sites with analysis done in Boulder using CMDL-produced gas standards. Climate forcing species monitored include carbon dioxide and methane and their isotopic carbon content, nitrous oxide, the CFCs, stratospheric and tropospheric ozone, aerosols, solar radiation, and for stratospheric ozone depletion, all the chlorine- and bromine-bearing species that deplete ozone. In addition to policy-relevant information made available in assessments, CMDL uses its data (about 85% of the world's carbon dioxide data) together with data from other countries to form global greenhouse gas data bases (GlobalviewCO2 and GlobalviewCH4) available on the web and experiences 80-100 file download requests per month from government agencies, universities and private citizens in numerous countries. Recently an interactive data visualization program has been added to CMDL's web site which allows non-specialists and students to graph any of CMDL's data.

Brief History

CMDL was formed in 1990 from climate-related elements within the Boulder branch of the Environmental Research Laboratories' Air Resources Laboratory, in particular, the Geophysical Monitoring for Climatic Change (GMCC) program and the Climate Research Division (CRD). The latter became the Climate Diagnostics Center (CDC) in 1993. Four of the Baseline Observatories (Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and South Pole Station, Antarctica), are staffed sites established shortly after NOAA's creation in the early 1970s. A fifth observatory, currently unstaffed, was established at Trinidad Head, California in 2002 to monitor Asian emissions incidents on the west coast of the U.S. The Mauna Loa Observatory carbon dioxide record constitutes the longest continuous carbon dioxide record in the world (more than 40 years) and is considered by many to be the most important long-term environmental record in existence, being the origin for concern about potential long-term climate change.

ENVIRONMENTAL TECHNOLOGY LABORATORY

Mission
The Environmental Technology Laboratory (ETL) supports the strategic goals of NOAA and OAR through regionally specific research efforts in weather, climate, and air quality using the Laboratory's unique expertise in remote sensing of the geophysical environment.

Brief History
The Wave Propagation Laboratory (now ETL), like a number of the original Boulder Laboratories, grew out of the research of the Central Radio Propagation Laboratory in the late 1960s. The laboratory, formed in 1967 under the leadership of Dr. C. Gordon Little, focused on developing remote sensing methods (optical, radio, and acoustical) as a new means to study the geophysical environment. In the 1970s and early 1980s, ETL began focusing on a number of practical problems including applying its acoustical and optical remote sensing methods to the study of regional air quality. The transfer of the boundary layer research group from the Air Force Cambridge Labs to ETL in the mid-1970s accelerated these efforts. In addition, ETL began developing and demonstrating the value of operational networks of radar wind profilers for weather forecasting. In the course of these activities, the Prototype Regional Observing and Forecasting System (PROFS) and the Wind Profiler Demonstration Network were spun off from the laboratory and later formed the nucleus for the Forecast Systems Laboratory in 1988. Most recently, in response to a number of external reviews, the laboratory has narrowed its focus to developing and refining remote sensing technology for regional weather and climate applications while maintaining its unique blend of physicists, engineers, and meteorologists necessary to promote science and technology transfer. Currently, two of ETL's four Divisions focus on technological innovations in the areas of optical and microwave propagation, including airborne remote sensing, while the other two focus on 1) applications to surface, cloud, and radiative processes, and 2) applications to problems in regional weather and climate.

FORECAST SYSTEMS LABORATORY

Mission
The mission of the Forecast Systems Laboratory (FSL) is to transfer scientific and technological developments in atmospheric and oceanic research to the Nation's operational services. It conducts programs to integrate, and apply developments to, observing, information and forecast systems. These programs are important in helping NOAA meet its objectives to improve its ability to observe, understand, and model the environment and effectively disseminate its products and services to various users. The following are FSL's essential functions:

- ***Exploratory system development.*** Developing and validating information systems to satisfy NOAA's operational services.

- ***Research applications.*** Using advances in understanding atmospheric and oceanic processes to develop improved data management systems, forecasting systems, and analysis systems for geophysical data.
- ***System validation***. Testing systems in realistic environments to assess their usefulness in improvement of NOAA's services.
- ***Technology transfer.*** Facilitating transfer of new techniques and systems to operational status, working directly with users.

Brief History
FSL was formed in 1988. It developed from three Environmental Research program areas: the Program for Regional Observing and Forecasting Services (PROFS), the Profiler Technology Transfer Group (PTTG), and the Weather Research Program (WRP). These programs along with several other major activities make up the nucleus of FSL today.

SPACE ENVIRONMENT CENTER

NOAA has proposed to transfer the Space Environment Center to the National Weather Service in the FY 2005 President's Budget.

Mission
The Space Environment Center provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. SEC's Space Weather Operations Center is jointly operated by NOAA and the U.S. Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment. The Center is both a laboratory in NOAA Research and one of the centers in the National Weather Service's National Centers for Environmental Prediction.

Brief History
SEC's predecessor, the Space Environment Laboratory, was formed in 1962, and began disseminating daily forecasts of space environment conditions in 1965 before NOAA existed. The service came into being during World War II when variations in the space environment adversely affected communications radar and radio navigation. The importance of these services has increased with the flourishing and expanding use of electronic devices, vulnerable to space weather, the use of satellites for communication and radio navigation, the deregulation of the electric power grid, and increased passenger flights at high; attitudes and altitudes.

In 1995 NOAA and the other government agencies interested in space weather initiated the National Space Weather Program (NSWP) to coordinate the nation's R&D, transitions to operations, and services efforts in space weather. The NSWP participants are the Departments of Commerce, Defense, Energy, Interior and Transportation, with NSF and NASA, and is administered through the Federal Committee for Meteorological Services and Supporting research (FCMSSR and the Office of the Federal Coordinator for Meteorology. SEC is a member for the International Space Environment Services (ISES), which traces it's parentage to the International Council of Scientific Unions (ICSU).

SEC, like what the National Weather Service has done for meteorology, has developed devised and implemented models to guide forecasters, pursued data assimilation, and partnered with the United States Air Force for data and models, and relied upon a services industry to tailor products for individual users. SEC has also performed world-class research to better understand the space environment.

Appendix IX
Air Resources Laboratory (ARL)

History: The Air Resources Laboratory emerged as the Weather Bureau's Special Projects Office in the early 1950s. It was formed to provide meteorological (especially dispersion) guidance to national security programs, mainly nuclear. The evidence of its beginnings is still noticeable. To this day, ARL serves as the source of atmospheric transport and dispersion capabilities to the National Weather Service, to NOAA as a whole, and to a wide range of external users (both national and international). Whereas the early focus was simply on the prediction of concentrations downwind of some specific emission source (e.g. a nuclear test), the dispersion skills have now broadened into many related areas of specialty. Out of the early awareness that radioactive fallout was a global issue grew the current activities related to climate and global change. From the need to consider the chemistry of pollutants arose the present emphasis on air quality and its prediction. From the recognition that mankind could modify the atmosphere on global scales came the ARL emphasis on climate and methods to detect changes in it. And from the awareness that pollutants are removed from the air through deposition processes came the ARL role in measuring and understanding wet and dry deposition and the growing activity in multi-media modeling of the whole environment. All of these activities are directly related to NOAA's core mission - the protection of people, the stewardship of the environment, and the prediction of changes in it.

Mission Statement: The Air Resources Laboratory (ARL) studies the atmosphere as a component of the total environment, primarily in the context of air pollution, deposition, emergency preparedness, and climate change; much of this work is conducted in collaboration with other agencies such as the Department of Energy (DOE), the Department of Defense (DOD), and the Environmental Protection Agency (EPA). ARL conducts research on processes that relate to air quality and climate, concentrating on the transport, dispersion, transformation, and removal of trace gases and aerosols, their climatic and ecological influences, and exchange between the atmosphere and biological and non-biological surfaces. The time frame of interest ranges from minutes and hours to that of the global climate. Research in all of these areas involves physical and numerical studies, leading to the development of air quality simulation models. ARL provides products to NOAA and other Government agencies in the form of scientific and technical advice, research publications, and prototype tools for operational application.

Organization: ARL operates with six research groups, each with its own research agenda but also each with a specific function within the ARL structure. The Atmospheric Turbulence and Diffusion (ATDD) at Oak Ridge, Tennessee, develops models to describe the processes of diffusion and deposition of pollutants. The Atmospheric Sciences Modeling Division (ASMD) in Research Triangle Park, North Carolina, assembles the process understanding into coupled meteorology and air chemistry models, for application in air quality programs of the Environmental Protection Agency and other organizations (e.g. states). A further role of the Research Triangle Park group is to extend its air quality modeling to the provision of real-time forecasts, and activity that calls for close collaboration with elements of the National Weather Service. The Field Research Division (FRD) at Idaho Falls, Idaho, specializes in conducting field studies to test the validity of dispersion models. At Silver Spring, Maryland, Headquarters work concentrates on the development of dispersion models tailored for operational use, such as by the National Weather Service. At the Special Operations and Research Division (SORD) in Las Vegas, Nevada, the dispersion capabilities are applied routinely in support of the nuclear missions of the Department of Energy. In recognition of the fact that new models require increasingly more information on the surface energy budget, the Surface Radiation Branch (SRRB) in Boulder, Colorado, operates research-grade measurement stations where the surface radiation balance is documented. In whole, the set of ARL field offices constitutes an end-to-end model development, testing, and implementation capability. The success of the process is well illustrated by the fact that many models developed by ARL scientists are now fully operational, in DOE and the EPA as well as in the service Line Offices of NOAA.

FY 2003 Funding and Staff

Division	Base 1/	Cong'l Add-ons	Other NOAA 2/	Other Agency 3/	TOTAL
Hdqtrs (MD)	$3,420,600	4,071,200	1,190,100	429,800	9,111,700
ASMD (NC)	220,000		1,022,000	6,247,500	7,489,500
ATDD (TN)	1,008,600	623,800	864,100	1,272,900	3,769,400
FRD (ID)	269,800		240,000	1,756,700	2,266,500
SORD (NV)	25,000		0	2,000,700	2,025,700
SRRB (CO)	545,000		295,000	501,700	1,341,700
Total	**$5,489,000**	**4,695,000**	**3,611,200**	**12,209,300**	**26,004,500**

Legend:

1/ Base - Permanent appropriated funding received every year.

2/ Other NOAA - Funding from NOAA programs; awarded on a competitive basis (not guaranteed every year).

3/ Other Agency - Includes both long-term agreements w/EPA & DOE (50+ years) as well as competitive funds awarded annually.

Detail on Reimbursable Funding by ARL Divisions in FY 2003

Division	EPA	DOD	DOE	USDA	NASA	Other	TOTAL
Hdqtrs (MD)	42,700	100,100		115,000		172,000	429,800
ASMD (NC)	6,228,000					19,500	6,247,500
ATDD (TN)		126,900	580,000	51,300	202,700	312,000	1,272,900
FRD (ID)		1,056,200	700,500				1,756,700
SORD (NV)	273,000		1,722,200			5,500	2,000,700
SRRB (CO)	98,300		50,000	260,600	87,700	5,100	501,700
Total	**$6,642,000**	**1,283,200**	**3,052,700**	**426,900**	**290,400**	**514,100**	**12,209,300**

Detail on research areas and staffing by division:

1. **Headquarters - Silver Spring, MD**
   Staffing -- 25 total staff - 18 Federal Employees
   Three principal areas: development of improved dispersion models (HYSPLIT Model); detection and quantification of climate variability and climate change; and air surface exchange, with emphasis on wet deposition.

2. **Atmospheric Turbulence and Diffusion (ATDD) - Oak Ridge, TN**
   Staffing -- 38 total staff - 12 Federal Employees
   Three principal areas: The Climate Reference Network; Air-Surface Exchange (with emphasis on dry deposition and carbon dioxide); and) Air Quality and Dispersion Research.

3. **Field Research Division (FRD) - Idaho Falls, ID**
   Staffing -- 21 total staff - 11 Federal Employees
   Principal activities: dispersion field studies;) development of high technology instrumentation; and research on mesoscale meteorology and dispersion in support of the Idaho National Engineering and Environment Laboratory.

4. **Special Operations and Research (SORD) - Las Vegas, NV**
   Staffing -- 21 total staff -- 16 Federal Employees
   This division was originally formed to provide meteorological (primarily dispersion) expertise in support of national security programs headquartered in Nevada and developed jointly with DOE and EPA weapons and chemical testing programs. Following redefinition of the group's role in 1997 and the generation of the NOAA Cooperative Institute for Atmospheric Sciences and Terrestrial Applications (CIASTA) to work with them the principal areas of research are mesoscale dispersion research, atmospheric aerosols, and lightning.

5. **Surface Radiation Branch (SRRB) - Boulder, CO**
   Staffing -- 13 total staff -- 3 Federal Employees
   This group is a component of the Headquarters Division of ARL. It concentrates on the factors that drive weather and climate –the surface radiation balance, aerosol/radiation interactions, and UV and IR radiation. This group operates the national Central UV Calibration Facility, as a joint activity with NIST.

   SRRB operates the SURFRAD program, which is the mainstay of the ARL integrated monitoring program that brings together all aspects of measurements related to air-surface exchange conducted across four ARL Divisions. Specific SRRB contributions address surface energy balance measurements as necessary to address numerical weather forecasting and climate change.

6. **Atmospheric Sciences Modeling Division (ASMD) - Research Triangle Park, NC**
   Staffing -- 46 federal staff, 53 total staff
   Three principal activities: development and quality assurance of air quality and atmospheric deposition models to underpin EPA's policy and regulatory activities; development of air quality models for joint (NOAA and EPA) provision of air quality forecasts;) air-surface exchange; and iv) the air quality/climate interface.

Major Types of Activities across multiple locations

- Long-term development of air quality forecasting and assessment models (process research at Oak Ridge; model development at Oak Ridge, Research Triangle Park and Silver Spring).
- Development of dispersion models (process research at Oak Ridge and Idaho Falls; model development at Oak Ridge, Research Triangle Park, Idaho Falls, Las Vegas and Silver Spring; and field testing at Las Vegas and Idaho Falls).
- Operation of long-term monitoring networks (deposition networks at Oak Ridge and Silver Spring, and surface radiation networks at Boulder).
- Studies of air-surface exchange (experimental work at all ARL locations; model development at Oak Ridge, Boulder and Research Triangle Park).
- Atmospheric mercury and its deposition (involving Research Triangle Park, Silver Spring, and Oak Ridge).
- Integrated monitoring (the ACORN program, with surface radiation studies at Boulder, total heat budget work at Oak Ridge, CO2 exchange at Oak Ridge, wet deposition at Silver Spring, and dry deposition at Oak Ridge).
- Support of national security programs (all Divisions).
- Atmospheric aerosols (exchange studies at Oak Ridge, Research Triangle Park, Silver Spring and Las Vegas; modeling developments at Research Triangle Park and Oak Ridge).
- Air quality and climate variability (Silver Spring, Research Triangle Park, and Boulder).
- Urban meteorology (all ARL groups).

Appendix X

Article: The Customer for R&D Is Always Wrong," by Robert Frosch,

from the Nov.-Dec. 1996 issue of Research-Technology Management, pp. 22-27.

Frosch, Robert A. 1996. "The Customer for R&D Is Always Wrong!" *Research*Technology Management* 39 (November/December) :

THE IRI MEDALIST'S ADDRESS

The Customer for R&D Is Always Wrong!

Effective R&D management depends upon interconnected knowledge and the interconnection of people who possess that knowledge. Current fads in corporate restructuring ignore that.

Robert A. Frosch

OVERVIEW: *The current fad of corporate managements, taking short-term views and distributing R&D assets to operating divisions, is like a farm investor who is interested only in harvesting and will not invest in planting, cultivating or irrigating; neither is likely to get much good harvest for very long. Applications R&D depends on using the interconnectedness of many kinds of knowledge, and thus depends on the close interaction of research people with that knowledge. The destruction of these key connections, together with the fact that the customer for R&D is always wrong about the requirements, will ensure future trouble.*

An admiral with whom I worked in the U.S. Navy Secretariat used to come into the office occasionally to talk about the technological issues for which we both had responsibility. Once a year he would say, "Well, boys, let me tell you about the spring styles in warships. This year, destroyers will be wearing . . ."—and he would go on like that for a while.

Having been in the R&D business for some time, I keep my eye on the spring styles in R&D and try to decide whether I think they are hot stuff or not. The current fad seems to be: "Let's break up all that central R&D, which does something or other but we don't know what, and put it out in the divisions. If we can't pull it all out, then let the divisions buy what they need instead of letting those people in the ivory tower do all that stuff we don't understand. We must have relevance now, with everything results-oriented, and small improvements the big thing."

I listen to all this (I've heard it before) and it reminds me of someone investing in a farm who insists upon saying, "Don't ask me to buy any seed, please don't bother me with investing in planting, I don't want to be around when you're cultivating, and I don't care about irrigation. But when you get to the harvest, call me, and I'll be there to help you out."

We know what happens to that farmer. That farmer—or that investor—ends up with no crop and no harvest. I have a feeling that in a few years we shall discover that the farm that was going to be planted, seeded, irrigated, and produce a good harvest, will for some reason be producing no fruit or stunted fruit.

Robert Frosch is the Industrial Research Institute Medalist for 1996. His article is adapted from the address he delivered upon accepting the Medal at the IRI Annual Meeting in Colorado Springs, Colorado, May 1996.

0895-6308/96/$5.00 © 1996 Industrial Research Institute, Inc.

Knowledge: Cumulative and Connected

Newton said, "If I have seen further then other men, it is because I have stood upon the shoulders of giants." He didn't invent the phrase; it was much older (*1*) What he meant, of course, was that knowledge is a cumulative, slowly developing thing; others before us have been tall and seen much, and therefore we can see even farther. If you want to do new things, then you had better know about the old things, and you had better know a broad collection of what is known: what the giants discovered. We stand upon the shoulders of Newton and Gibbs, Bohr and Einstein, Brunel and Steinmetz, the Wright brothers and Watt, and others more recent.

Francis Bacon, even earlier, wrote, "Nature, to be commanded, must be obeyed" (*2*). This was a profound statement—if you want to develop a technology, if you want to use knowledge, you had better understand how the universe works or you may be trying to create something that cannot be done. Any R&D fad that tries to destroy the connectedness and the deep roots of knowledge that lead to technological capability is going to put the business in trouble.

It is the structure of knowledge and the structure of the background of technological creations that forces some of the organizational aspects of R&D. We ignore this at our peril. Think, for a moment, of the kinds of knowledge that we use and take for granted, and the connections of knowledge that are necessary to solve any real industrial or commercial problem. I can think of it most easily, because of being most recently involved, in terms of automotive problems—but each reader will be able to translate what I am going to say into their own experience.

A common desire in the automotive industry is to build a more efficient engine. This is frequently seen as an automotive engineering task of a classical kind. However, if you think about what is inside trying to do that, you will discover that you are dealing with a piece of combustion chemistry, and chemical kinetics and thermodynamics, all of which is developing inside a fluid-dynamic flow system, with heat transfer working with the chemistry. That is all embedded in a firing chamber which has a shape, and a structure, and is made of materials, and which has to be designed in those terms. You find yourself dealing with computational fluid dynamics and computational structure. You may be up against a set of equations in chemical and combustion kinetics that you may or may not have seen before, and new problems in mechanical and structural design, and in friction as well.

So the problem is not a simple old problem, it is a problem in the connectedness of knowledge: past knowledge and practice, recent knowledge, new knowledge, and as yet unknown knowledge. If you are trying to do something new, then you had better have access to people who can solve the equations, help you with the computations, tell you some things you didn't know about structural dynamics, solve the material problems that you thought you had solved when you picked the new material, but you didn't quite, and so on.

If you take any such problem, you get a similar set of interconnectedness and deep roots in past history. You find that you are living on the shoulders of the giants of the past, but also upon the current inventions of colleagues you may not have thought about: physicists, chemists, other engineers, and so on. If you do a problem in structural mechanics to build a body design, or a problem in the molding of polymers to create a part, you will be able to trace a similar set of roots.

The problem of R&D management is, in a sense, the problem of the management of a variety of forms of knowledge that are deeply interconnected, and whose interconnectedness one learns as one tries to solve the problem. It turns out to be a problem of maximizing collision cross sections among kinds of knowledge: making sure people who need knowledge they don't have—and may not even know they need—have a good chance of learning about it.

This is what led naturally to the industrial research laboratory: no single investigator is likely to be able to capture all of the richness of the knowledge connections, both into the past and with present colleagues. To destroy that connectedness by distributing the pieces conveniently among a set of divisions, with the idea that then everybody will be closer to the problem, is to destroy the root capability to solve the problem, and even the root capability to understand what the problem is.

The Customer Is Always Wrong

After 40-odd years of working in application-and mission-oriented research, I have come to believe profoundly that the customer for technology is always wrong. Now, the technologists are usually wrong, too; they tend to be wrong in complementary ways. I have seldom, if ever, met a customer for an application who correctly stated the problem that was to be solved. The normal statement of the problem is either too shallow and short-term, or, even more likely, is a formula for the widget that the customer thinks is required to solve what the customer thinks is the problem. The technologist, of course, is usually peddling "that wonderful thing we did in the laboratory yesterday," and if it happens to be square and the hole is round, a little force-fitting may help.

> ***I have seldom, if ever, met a customer for an application who correctly stated the problem that was to be solved.***

What really happens in successful problem-solving endeavor, the successful definition of a product or of a new process, is the redefinition of the problem, along with the redefinition and creation of the solution. A dialogue process has to go on in order to achieve this redefinition. It is in that dialogue process that the rich collection of knowledge gets employed on the technological side and a good deal of implicit knowledge on the customer side. There is a certain logic to saying that the R&D ought to be close to the divisions and to the customers for technology, and, indeed, it should be.

That works neatly if the problem is more-or-less a current problem to be solved, so that the time scale is such that it is, in fact, a divisional time scale and within the division's imagination. However, a good deal of what is required in industrial R&D is not on the time scale of the division. Divisions do not normally think long technological thoughts about the future. A GM platform engineer with whom I was having lunch said, "Do you people work for me?" My answer was, "Yes, but, as a matter of fact, the R&D people who are working for you now are the people who were in the research labs 15 years ago."

Working for the Division's Grandchild

Much of what research people do, and should do, is working for the divisional person's professional grandchild; that is to say, the person who will be in the job after the person who takes it from the current occupant leaves it. If there is to be a technology that that person will need, R&D people have to think about it *now*.

Of course, the person who is building today's product may or may not be any good at talking about the product after next. There is a natural misfit between the time of longer-range R&D and the time for current products. In that sense, the dialogue is very difficult. Nonetheless, somehow the R&D function must be informed of the processes of the divisions and the processes of the corporation thoroughly enough to exercise the knowledge and imagination to determine what should be done for the future.

So, close dialogue and connection are important. The R&D people must somehow swim in an ocean of corporate problems, present and future. The necessary dialogue and connection, of course, take place through that other important function of R&D, besides creating the future: the function of solving current problems and helping with the business day to day. To suck up the entire R&D into the day-to-day business is to destroy the possibility of a future new business; that is, it is to say, "Call me at harvest time and don't bother me with planting, cultivating and irrigating."

A Heisenberg Uncertainty Principle

We have an inherent dilemma of time scales that don't fit, of knowledge, breadth that has to be captured in one place, and at the same time a connection to be made between the day-to-day operation of the business, with R&D people solving its problems, and together creating the future at the same time.

There is a kind of Heisenberg uncertainty principle about the coordination connections that are necessary in R&D. One needs all of these deep connections among kinds of knowledge, and the ability to think about the future, that works best in an institution that puts all those people together. One also needs connection with the day-to-day, market thinking, and the future thinking of the operating side of the business, which suggests to many that the R&D people should be sitting on the operating side of the business.

The R&D people must somehow swim in an ocean of corporate problems, present and future.

This is an insoluble problem; there is no organizational system that will capture perfectly both sets of coordination. Organizational matrices do not have eigenvalues; they are not diagonalizable. There is no perfect organization that will solve this problem—the struggle is inevitable.

Consider organization in the Department of Defense. There are two simple ways to organize the Pentagon: functionally by kinds of warfare or knowledge, or by weapon systems projects. There is always an uneasy compromise between the two. As the Pentagon was reorganized, it turned out that what was being done was flipping the matrix from one way to another, and back and forth, with the rows relabeled columns and the columns rows. Everyone was somehow under the impression that the way that they weren't organized must be the right one because they were dissatisfied with the current one.

The uncertainty principle forces a kind of oscillatory behavior, where, as I have seen it, the full wave is somewhere between 10 and 20 years between organizing one way and deciding that the gospel is the other way. What happened during the last wave, when many places

R&D Management 101

1. In order to harvest, you must first seed, plant, cultivate, irrigate, and wait. This is as true of R&D as it is of farms. R&D's mission is to imagine and create the seeds of the future.

2. Remember what Sir Isaac Newton and Francis Bacon said: "If I have seen further than other men, it is because I stood on the shoulders of giants," and, "Nature to be commanded, must be obeyed."

3. Matrix your industrial problems to be solved vs. the kinds of knowledge that are needed to solve them (e.g., more efficient internal combustion engines require chemical kinetics, heat transfer, fluid dynamics, mathematics, computational compatibility, and more).

4. Great R&D must preserve the connections between various kinds of knowledge; i.e., keep the R&D people together.

5. R&D also needs connections with the operating side and its needs for problem solving, especially for future problems. R&D should work for the operating divisions of the future even more than for the operating divisions of today. The operating/R&D dialogue is an imperative.

6. Connections among knowledge forms and people, and between R&D and the divisions, will inevitably be imperfect. Keep searching for better ways to connect, including, for example, "synthetic alumni" of the R&D lab.

7. If it is considered such a great idea for the divisions to buy all of their R&D—and jeopardize future R&D possibilities in the process—then ponder the implications of having them choose how much financial accounting, auditing and central management they wish to buy.

8. Measure R&D by:

- Past performance, not promises/predictions.
- Summing the value of the successes and comparing with the total cost of the research lab, not individual projects.
- Projecting the value of successes over their product or process life—the internal rate of return can be surprisingly high.

9. Institutions are needed to synthesize knowledge-connecting R&D for small and meso-scale business networks (e.g., machine shop, small foundries).

10. Keep fighting the good fight for the future of the business—and society at large. **—R.A.F.**

destroyed central R&D, was that they put all the R&D out in the divisions, and for as long as three or four years the business was deliriously happy because the divisions were getting what they needed. They then suddenly discovered there wasn't anything new, they had eaten that all up, and the people who were to be creating the new were now so busy solving the old that they had no time for the future. The more unusual and difficult-to-understand forms of knowledge, difficult for the divisions to see the need for on a day-to-day basis, had vanished.

Now a problem would turn up and somebody would say, "Where is that person who was the great expert on, whatever that was?"

"Oh, that person isn't here any more because we didn't have any use for that knowledge last year. Now we need it badly but they've gone away."

Putting it in the diffused-into-the-divisions system makes no sense to me. I would rather struggle with the problems of connecting with the divisions—and there are techniques for that—and by holding the R&D laboratory together, be able to solve what I think is the more long-term and difficult problem of the connectedness of knowledge.

It is reasonable to have the divisions, the operating side, buy short-term help from R&D and solve day-to-day problems in that demand-driven way. The idea that R&D should be totally and entirely supported by divisional purchases, however, is merely a slightly longer-term version of the destruction of R&D for the future than actually breaking it up and putting it in the divisions.

I suggest that the next time the business side of the house explains to you that that is the proper way for the firm's internal market to work, you suggest that if it is such a lovely principle, there is a modest proposal to run the whole place that way: Let's have the divisions buy their accounting and their auditing from the financial people; let's have them buy the CEO's time, let's buy personnel services from Personnel (pardon, "Human Resources") by the inch when they need it. Let's see whether, in fact, that internal market system is a reasonable way of running a business. Everybody knows it is not, but it is sometimes convenient to apply the idea to the pieces we don't understand.

GM's Synthetic Alumni

Earlier, I mentioned schemes for connecting R&D with the operating side, and I am sure everybody has their own versions of these. One, which was invented at GM by Larry Howell and others, and actually reduced to practice while I was there, was the construction of what we called "synthetic alumni" of the research laboratories. The underlying observation was that a good deal of the best connectedness with the operating divisions came from people who had been in the research labs and were now on the operating side.

A way was created of bringing people into research who really wanted operating careers, not R&D careers. After a year or two in the Research Labs, they moved to a division, with special knowledge of some new technology that was of interest to that division. In this way, we created connections that brought the new divisional problems back to Research and kept it clearly up-to-date on what was happening on the operating side.

From their research experience, these alumni had usually developed an "ear" for what might be a question or problem to bring to the attention of the Research people. Naturally, Research Lab people visited the divisions a lot, and there was frequent contact, at the level of "bench" people, as well as managers, between Research and many divisions; there was much visiting back and forth. Certain Research Lab departments worked intensively with particular divisions for many years.

Helping Smaller Businesses

So far, I have spoken in terms that make sense for large companies that can afford to have the research and development capabilities of many kinds of knowledge, can afford to have, for example, a good stable of mathematicians. (By the way, how many divisions do you know that need a mathematician all the time, and how many divisions do you know that never need a mathematician? The answer is usually none in both cases, but you had better have them somewhere.)

What does a smaller business that cannot keep a stable of these different experts do for the knowledge connections? I have become acquainted with this problem recently through research I have been doing on the way metal flows through, and is handled in, the metals manufacturing business in New England: foundries, machine shops, stamping shops, jewelry manufacturers, and so on. These tend to be businesses that don't do much R&D because they cannot afford much R&D. And so they are not, in fact, on the cutting edge of the technology that they could be using. Sometimes they can buy it from suppliers, but they are more likely to be victims than real customers for R&D.

It is clear that some means of cooperation in the generation of R&D capabilities that a number of companies in the same business could use is a missing piece in some industries. It may also, in terms of the breadth of knowledge, be a missing piece for many not-very-large companies.

I had thought naively that trade associations and professional organizations could be a means to doing R&D in these situations, or a means of getting it done in a cooperative way. However, I discovered that most of the trade associations I talked to were so worried about liability issues if they became recommending organizations for R&D results and technology, and also worried about appropriability of intellectual property and antitrust, that they had not found a way to play a really useful role. I suggest that there is a missing piece of our R&D business institutions (it occurs in some places, like the utility industry, but not in others) which is a way for small- and medium-sized businesses to cooperate in the creation of knowledge systems that they can use as though they were large businesses.

There are university-connected situations where people have done this over a period of years in a reasonable way. None of them that I know of has grown into a real equivalent to a major industrial R&D capability. I think there is a missing opportunity for what I might call the meso-scale and the small scale of U.S. business, something perhaps worth thinking about.

Measuring the Payoff

I have no illusion that the interconnectedness of knowledge will be a convincing sales pitch to most of the business side of most corporations. However, I have had some success in convincing the business side that one needs a breadth of knowledge by illustrating the matrix of problems versus kinds of knowledge needed to solve them and showing that, in fact, the way in which many new ideas arise and problems are solved is by collisions among old kinds of knowledge, and different kinds of knowledge, which create new views and knowledge.

Part of the issue in making that sale is understanding what the payoff of the R&D system really is. There are a couple of rules about measuring it, and only a few successful attempts have been made.

Rule one is that you cannot measure the future; the only thing you can measure is past performance. You have to measure R&D by what you have done.

Incidentally, the business side of the house doesn't measure the future either, although it frequently pretends to. In fact, most businesses refuse even to measure their predictions of particular projects against the statistical history of the success of past projects.

After watching a number of new product presentations at GM, I suggested that an additional slide be in view at all times that displayed the fiscal history of the past projects, just to see whether the predictions of the new ones were consistent with the statistics of the past. It was clear that nobody was interested in looking at such a slide, of past data together with the predictions.

The second rule is that it is useless to measure payoff project by project. The only measurement successes I have seen—and I've seen a couple of them in measuring R&D—are to measure the sum of the value of the successful projects against the total cost of all the R&D. We made some measurements of that sort at GM when I was there. It is very labor-intensive because you have to trace a lot of projects and determine their value to the company. You use the total cost of the research lab as the denominator.

> ***The only measurement successes I have seen are to measure the sum of the value of the successful projects against the total cost of all the R&D.***

We took a sampling of successful projects, went to the divisions and found out what they thought the projects were worth over a standard corporate project life. This was a lower bound because frequently it was difficult to find out the real history of a project, so some successes were left out. However, we collected enough that had been successful to give us some numbers for the numerator. We did this on a one-year slice as well as we could, and divided it by the total cost of having the research lab for a year—all lab costs. We projected the value of these for their project life (usually the standard corporate project accounting period), and did an ordinary internal rate of return computation.

We did this twice, several years apart, using the second time partly as a check computation on the first, to see whether the projects had lasted, but also to do a semi-independent examination. Our internal rate of return was about 70 percent. That is a very large internal rate of return! What this result really meant was that we did a lot of projects and although many of them never came to anything, a few were big successes and did a lot more than pay the rent.

GE has done a study of that sort and it produced an IRR of about 38 percent for a corporation rather different from GM in structure and product line (*3*). Both numbers are large enough that the difference between them doesn't matter, and they are enough larger than the IRR of anything else in most corporations that they ought to be interesting. These large values come because the R&D process creates useful change.

To sum up, in spite of the demonstrable value of R&D, the current fads in corporate restructuring turn out to be a replay of some old ones that were bad for industrial research. We are finding out once again how to make it difficult to do R&D, and we will probably discover in a few years that we have succeeded in that endeavor, and go back to reconstructing the system on the basics that work, the basics of interconnected knowledge and the interconnection of people who have that knowledge. ⓐ

References

1. Robert K. Merton. *On the Shoulders of Giants*. Chicago, University of Chicago Press, 1993.
2. *Novum Organum*, 1620.
3. Walter Robb, private communication.

Appendix XI
Acronyms List

AA .... Assistant Administrator
AER .... Atmospheric and Environmental Research, Inc.
AGU .... American Geophysical Union
AIDS .... Acquired Immune Deficiency Syndrome
AIS .... Aquatic Invasive Species
AL .... Aeronomy Laboratory
AMS .... American Meteorological Society
AO .... Announcement of Opportunity
AOML .... Atlantic Oceanographic and Meteorological Laboratory
ARL .... Air Resources Laboratory
ASCAC .... Advanced Scientific Computing Advisory Committee
AWIPS .... Advanced Weather Interactive Processing System
BCI .... Basic Commerce and Industries
BERAC .... Biological and Environmental Research Advisory Committee
BVOC .... Biogenic Volatile Organic Compound
CASA .... Collaborative Adaptive Sensing of the Atmosphere
CCSP .... Climate Change Science Program
CDC .... Climate Diagnostics Center
CICOR .... Cooperative Institute of Climate and Ocean Research
CIMMS .... Cooperative Institute for Mesoscale Meteorological Studies
CIRA .... Cooperative Institute for Research in the Atmosphere
CIRES .... Cooperative Institute for Research in Environmental Sciences
CJS .... Commerce, Justice, State (Appropriations Subcommittees in Congress)
CMDL .... Climate Monitoring and Diagnostics Laboratory
CORE .... Consortium for Oceanographic Research and Education
CRD .... Climate Research Division
DDT .... Dichlorodiphenyltrichloroethane
DOC .... Department of Commerce
DOD .... Department of Defense

ENSO .... El Niño/ Southern Oscillation
EPA .... Environmental Protection Agency
ETL .... Environmental Technology Laboratory
FTP........ File Transfer Protocol
GEOSS .... Global Earth Observing System of Systems
GFDL .... Geophysical Fluid Dynamics Laboratory
GLOBEC........ Global Ocean Ecosystem Dynamics
GMCC........ Geophysical Monitoring for Climate Change
HRD .... Hurricane Research Division
IGBP .... International Geosphere-Biosphere Programme
IOOS .... Integrated Ocean Observing System
IPCC........ Intergovernmental Panel on Climate Change
JI........ Joint Institute
JIMAR........ Joint Institute for Marine and Atmosphere Research
JISAO........ Joint Institute for the Study of the Atmosphere and Ocean
METOC........ Meteorological and Oceanographic Command
MOA .... Memorandum of Agreement
MOU .... Memorandum of Understanding
MSI .... Minority Serving Institutions
NACP .... North American Carbon Program
NAO........ North Atlantic Oscillation
NASA........ National Aeronautics and Space Administration
NCAR .... National Center for Atmospheric Research
NCEP .... National Centers for Environmental Prediction
NESDIS........ National Environmental Satellite Data and Information Service
NEXRAD........ Next Generation Weather Radar
NHC/TPC........ National Hurricane Center/Tropical Prediction Center
NIH .... National Institutes of Health
NIST........ National Institute of Standards and Technology
NM .... Nautical Miles
NMFS........ National Marine Fisheries Service
NOAA .... National Oceanic and Atmospheric Administration

NOS ... National Ocean Service
NSF ... National Science Foundation
NSSL ... National Severe Storms Laboratory
NURP ... National Undersea Research Program
NWS ... National Weather Service
OAR ... Office of Oceanic and Atmospheric Research
OGP ... Office of Global Programs
OMB ... Office of Management and Budget
ONR ... Office of Naval Research
ORPG ... Open Radar Product Generator
OU ... University of Oklahoma
PCB ... Polychlorinated Biphenyl
PDO ... Pacific Decadal Oscillation
PMEL ... Pacific Marine Environmental Laboratory
PPBES ... Planning, Programming, Budgeting, and Execution System
PPI ... Office of Program Planning and Integration
R&D ... Research and Development
ROTC ... Reserve Officer Training Corps
RRT ... Research Review Team
SAB ... Science Advisory Board
SEC ... Space Environment Center
SHIPS ... Statistical Hurricane Intensity Prediction Scheme
TOGA-TAO ... Tropical Ocean Global Atmosphere-Tropical Atmosphere-Ocean
TRL ... Technology Readiness Level
UNH ... University of New Hampshire
USWRP ... United States Weather Research Program
VV&A ... Verification, Validation, and Accreditation