DORMAN REPORT

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
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THE DIRECTOR

SSD

MAR 25 1999

Mike Smith

Dorman Report

MEMORANDUM FOR: Distribution

FROM: W - John J. Kelly, Jr.

SUBJECT: Technology Infusion Panel Final Report

Attached is a copy of the final report from our Technology Infusion Panel. The report covers many areas that are critical to our future and provides recommendations on possible courses of actions. It also poses a series of interesting questions; how we answer them will profoundly impact our future. The section on Hydrology (enclosure 3) is both enlightening and troubling.

I would like your comments on the report and suggestions on how we can best use it.

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15 March 1999

MEMORANDUM FOR JACK KELLY

Subj: Technology Infusion Panel - Summary Report

Attachments:
A. Initial Report of 13 August 1998
B. Revision & Supplement of 2nd, 2 November 1998 Report, of 23 February 1999

Over the last eight months, the Technology Infusion Panel has given you advice on the basic approach we suggest NWS adopt toward technology infusion, on an initiative to implement the results of the US Weather Research Program (USWRP) through balanced improvement of observations, assimilation and modeling, and on what we believe are your most pressing technology-related issues. We have appreciated the opportunity to discuss our views and recommendations with you at length.

We see no reason to reiterate the detailed findings and recommendations from our two earlier reports; you are well aware of their contents. We do however include them here as Attachments, for the record. Rather, in this Summary Report we want to simply reemphasize a very few of our major points, and then to raise some long term strategic issues that we have talked about but not been able to resolve. It is to these issues of philosophy and strategy for the "NWS After Next" that we urge you and your fellow NOAA AAs to turn your attention, as soon as you complete the process of implementing the "Kelly Report" and are satisfied that your have "Today's NWS" under control, and the vector for the "Next NWS" pointed in the right direction.

First, to reiterate:

Technology Infusion is the continuing, evolutionary process by which any organization or system maintains its health and improves its performance through the disciplined incorporation of new ideas, procedures, and capabilities. We have described some essential elements of this evolutionary and disciplined process, based on conducting trade-offs within a overall system architecture and concept of operations for the Service, and founded on the principle of continuous open interaction with the external community. We have further suggested that key mechanisms of infusion include teaming, training, demonstration, partnerships, and focusing on affordability.

We have recommended that to maintain a dynamic and intellectually growing organization, you fashion specific technology infusion procedures to target three distinct if overlapping system perspectives of the organization. These we have termed

- **Today's NWS,** where the basic approach is continuous refreshment;
- The **Next NWS,** where technology infusion occurs through evolutionary improvements; and
- The **NWS After Next,** where the focus is on stimulating innovation, then motivating the examination and enabling the evolution of a spectrum of alternative future architectures.

We provided some specific recommendations, based on our perceptions of your major problems, for each of these:

For Today's NWS, you must make the case for orders of magnitude increases in computational capability, restore the health of EMC and NCO, conduct a strategic review of your telecommunications (and those of NESDIS), rationalize your relationship with and use of the OAR labs, effectively employ the SOOs, ensure training and education are core budget items, and revitalize your efforts in hydrology.

For the Next NWS, which will be heavily influenced by your requirements process and by the progress of USWRP, we stressed five steps you should take now: maintain a clearly defined system architecture and CONOPS, revise the EMC CONOPS to stress external contributions and common model infrastructures, revitalize the TROIKA and institute parallel mechanisms to enhance collaboration with OAR and NESDIS, gain better control of NOAA's weather and climate developments and an enhanced ability to guide its research agenda, and support people-oriented programs to speed evolution and build professional skills. These are all consistent with, and in many ways extensions of, what we suggest for Today's NWS.

For the NWS After Next, we noted that a critical deficiency is NWS's inability to substantially influence the direction of the innovation agenda. We stress the need for openness and broad thinking, but lest you have no control over where you're headed in the long run, you must have the wherewithal to influence the direction of the work of others. Budget accordingly.

We also outlined -- or rather 'flew high cover' for the efforts of your staff with the OAR labs as they defined -- an initiative entitled PREDICTIONS, that is designed to reap the full benefit of the Modernization Program, and of the scientific and technological advances anticipated from USWRP. PREDICTIONS as we outlined it included the resources and programmatic elements to address some, if not all, of your current shortfalls at EMC and in R&D, as well as several of our central recommendations for all three system perspectives. We understand that it is unlikely to be implementable as we have outlined it. Nevertheless we see PREDICTIONS, or something very much like it, as the best path to simultaneously fixing some major problems, and providing the public full value from the investments in the Modernization Program and USWRP.

Although we didn't really start to dig into hydrology until near the end of our work, we note that you also will need an initiative of some sort, though nowhere near the magnitude of PREDICTIONS, to revitalize that very important segment of the NWS portfolio. And we are aware of the rather desperate need of your Climate Center for computational resources no less capable than those that have been accorded 'weather'.

In sum, even within the bounds of our limited view of NWS's tasking, we note that **your legitimate needs are far greater than the resources you are likely to be able to garner.** This merely verifies our emphasis upon a rigorous requirements definition and prioritization process, based on trade-offs within a clearly defined architecture and a concept of operations that stresses leverage of the total national resource base. We hope that our efforts have been of some use to you in this regard.

We would also like to comment briefly on one issue we discussed with you at our last meeting: the formation of a 'customer' advisory board or group, involving the media and commercial value-added producers. We understand that your request for a FACA is unlikely to be approved. While we can't to comment on issues of law and politics that may be involved, from the standpoint of technology and architecture we believe that such a group would be extremely valuable. Private industry and NGOs already play a vital role in analysis, interpretation, application, and dissemination of weather and climate information. The public-private partnership in this area is, we assert, one of the most productive in the country. It could easily be extended to significantly enhance US global competitiveness. Weather and climate forecasts can be powerful commercial, national security, and policy tools, should we choose to so use them.

Nurturing the partnership, and indeed encouraging additional private participation in all aspects of the process, from observations through broadcasts, would therefore seem to us to be one of the more effective ways of infusing (and diffusing) technology in the nation's interest. Further, we pose a number of questions below that bear heavily on NWS's future strategy and architecture; and the answers to these questions lie as much in the intent and actions of industry as of the government. While an officially sanctioned and ongoing consultative process is likely the best way of strengthening the already-established partnership, if it does not occur, we urge you to use other means, for example funded assessments, polls, and analyses, to help you frame and delimit the federal role in weather and climate warnings and forecasts.

Finally, we would like to raise with you a few questions for which we had no answers, but which we believe are central to thinking about what NWS should be, and may become. Our discussions in this regard were stimulated in part by our talks with Rick Anthes on the Road Map Study, in part by interaction with other parts of the weather and climate community both in and outside NOAA, but perhaps in largest part by our own diverse experiences in facing similar questions about the nature of our own jobs and organizations, present and past. We don't pretend that answers to these types of questions are easy, or perhaps even possible. But we do believe that you should worry about them.

1. What are the limits on the products NWS should provide? This question has several parts, some of which have at least partial answers already. It is clear for example that NWS is responsible for 'public warnings', particularly of severe weather related events. But how precise should NOAA strive to be, how far out should it try to predict, and is the list of parameters the right one? Of course NWS also provides 'forecasts', of certain parameters for certain periods. Are these the right ones at the right scales? And is the hand-off to the 'value-added' producer and other interfaces to the public at the right spot? What are the principles underlying our determination of what should be provided by NOAA as a free good, and where commercial enterprise should take over? And not only what should the government provide, but how good is good enough? Just as the early generations of weather satellites were driven by what COULD be fielded, not by detailed scrutiny of what was truly essential, could it be that we are either providing, or headed toward providing, things that we shouldn't or needn't? Or is it simply our objective to be as good as we possibly can be based on science and technology, irrespective of cost? This is perhaps the basic line of questioning that you have to keep addressing, since the answers influence virtually all your resource decisions.

2. Even if we can resolve the issue of NWS responsibility for basic hydrometeorological products, what is its role in other less traditional areas? For example, what products should NOAA produce to fulfill its seasonal and interannual forecasting goals? Should, e.g., NWS provide seasonal climate forecasts for the Military CINC's throughout the world to help them understand the stresses in their areas of responsibility, and better prepare their troops and equipment for response? Similarly, how does the Department of Agriculture use NOAA's climate forecasting capability in

its crop estimates? Or are our DoS Country Teams provided alerts of impending weather and climate problems to assist in their interactions with host nations? Or is NWS's climate (like weather) responsibility bounded by US territory? And if NWS doesn't support the CINCs, or DoA, or the Embassies, who should? Or shouldn't we, even though we are on the verge of having enough skill that the information can be very valuable? We also note that DoE has a major climate prediction program, focused on global change. To what degree are the DoE and DoC efforts redundant or mutually supportive? Further, what is NWS's role in a Global Disaster Information Network? Does it extend to forecasts past week one, and if so to whom and for what events? What is the role and responsibility of the evolving space weather forecasting capability with regard to private power companies? Again these are only examples. There are a host of such issues which deserve thoughtful attention in thinking about the Next NWS and the NWS after Next; and they shouldn't be put off too long, we since with each investment in a new capability there is an associated opportunity cost for what didn't get done (this was our concern with TDL).

3. Beyond NPOES and GOES, what is NOAA's role in environmental remote sensing? Are there additional environmental parameters that we should be attempting to monitor (e.g., soil moisture; GHGs or other atmospheric chemicals; pollen or other particulates)? Should we in the future put as much emphasis on climate observations as we now do on 'weather'? If there are such parameters, how does NOAA provide for the associated R&D? Which of the NASA EOS sensors, if any, is likely to transition to 'operations' and what if anything is NOAA's role in the transition? What is the role of industry in future weather and climate observations from space? Do any other platforms beyond satellites have a significant role in the remote observation architecture (e.g., we talked about some intriguing balloon-based concepts), and how can they get a fair shake in trade-off decisions given the power of the satellite community?

4. Given the increasing power of NWP, when and where does the human really add value? Is there a point in forecast-time, or a spatial scale, where 'automated' predictions are about as good as we're going to be able (or want) to do? NOAA is already taking advantage of machine capability to produce automated forecasts to enable the WFO staffs to focus on severe events when such are in their vicinity. Are we taking full advantage of this in staffing or interaction with value-added industry? Further, as we move to finer scales of modeling (we assume that our suggestion of nested models will be adopted), what is the best way of developing and managing local observing networks to enhance their performance? Should the associated assimilation and modeling be done locally, or at a central location by targeting just those areas where action is imminent? We

have alluded to these questions in the body of our report, but suggest that they are worthy of strategic thought because they have such a fundamental influence on system architecture.

Again, we doubt that you'll ever have crisp answers to questions like these. But, we contend, formulating and thinking about them is a very important part of your technology infusion process.

In conclusion, on behalf of the Panel, let me express our appreciation for the opportunity you have offered us to work together, to learn, to provide advice and to be listened to. And we want to offer special thanks to Ted David, Skip Wright, and Steve Smith for their help with our activities.

Craig E. Dorman
For the Panel

Attachment
A. Initial Report of 13 August 1998

13 August 1998

Memorandum for Jack Kelly

Subj: Technology Infusion Panel Initial Report: Plans, and impressions from the first meeting

1. Introduction

The Technology Infusion Panel met on 27-28 July 1998 at NWS Headquarters. This memo summarizes our initial impressions and plans, recapitulating our out-brief to you at the end of that meeting. Lists of members and attendees and our Terms of Reference are attached.

We share your belief that there are many important issues for NWS which require the infusion of technology; many more in fact than we will be able to address. We therefore will initially focus on those aspects of technology infusion where we believe our experience should be most relevant; and we will concentrate on NOAA's "Advance Short-term Warning and Forecast Service" strategic goal. In recognition of FY2001 budget preparation timing we will provide preliminary comments at the conclusion of our next plenary meeting, 6-7 October 1998 (at Forecast Systems Lab, Boulder). In the interim, the Panel will work in two teams, one for each initial focus area, and I will coordinate with the NRC "NWS Road Map Study" to try to ensure that our somewhat parallel tasking does not lead to conflicting advice.

2. Technology Insertion Issues. Overall, we see four broad technology-insertion issues that require significant NWS attention:

a. Evolutionary, continuous refreshment of the baseline warning system developed by the Modernization Program. The principal 'technology' elements of this system comprise AWIPS, ASOS, and NEXRAD, plus data from the polar and geostationary satellites, the primary NCEP supercomputer and its models, and the associated telecommunications backbone. These all are or soon will be state of the art (assuming successful acquisition of the new Class 8 computer), and the objective is to keep them in that condition so that there will never again be a need for another "Modernization". We share your view that this is the absolutely essential first step in any long term technology infusion process.

Your report of 14 October 1997 (in particular the "Research/Development and Technology Development/ Refreshment" section) and the briefings we received have convinced us that:

- NWS is very aware of the importance of this task,
- well equipped to it carry out (with one significant exception), and
- the major building blocks for continuous refreshment (in particular a planning and prioritization process) are being assembled.

There already are an abundance of efforts directed at the issue of continuous refreshment. Thus, while I comment further below on one particular immediate concern and also offer in an Attachment some personal opinions based on my visits and our meeting, the Panel believes the major overall challenge to be the development of a **national consensus, leading to an adequate budget**, that continuous refreshment of the baseline Modernized NWS is essential to maintaining quality service to a public whose reliance on warnings and NWS-product based forecasts and model output will continue to grow.

Given the variety of initiatives already underway on this issue, extensive work by us at this juncture could be counterproductive. Rather it's best for us to support and encourage your and is a primary source of associated national requirements. Nevertheless it is a relatively small and indirect partner in the nation's and even NOAA's weather and climate research. We question whether this is desirable.

There are two parts to this issue: NWS's role as sponsor, and as user. There are several mechanisms to ensure that NWS remains closely attuned to the very broad program of relevant national atmospheric, oceanographic and climate research. Notable among these are NWS's own CSTAR and similar hydrology programs, and the Office of the Federal Coordinator of Meteorology. While these both seen effective, we believe that two issues need attention. The first is the relationship between NWS and OAR, which I discuss briefly in an Attachment. The other, which will be our second initial topic, is exploitation of the results of the interagency US Weather Research Program (USWRP).

NWS requirements fed the community-wide process that set the objectives and priorities for the USWRP. That program is now gaining momentum, and should make very significant contributions to physical, natural and socioeconomic realms of weather related science over the next decade. USWRP has been planned, however, only to produce "proof of concept". We believe that our panel is appropriately constituted and charged to examine the important link from such proof to implementation. In doing so we will address both USWRP products to help ensure that the program serves its intended purpose, and the more generic aspects of leveraging research from a wide variety of performers and tying them to the NWS process. Our concerns start with linkages between the evolving NWS Requirements Generation Process and external research, and extend to the methodologies for validation and insertion into operational observing networks, EMC and research models, and the other operational aspects of the weather and climate warning and forecast system.

3. Next Steps.

As noted above, we believe that our initial efforts should focus on issues 2.b (including the health of EMC) and 2.d. The first will be addressed principally by the team of Dr MacDonald (Chair), Dr Clifford, and Dr Merilees; the second by Dr Nelson (Chair), Dr Holland, Dr Hooke, and Mr McNulty. Their objectives prior to our next plenary meeting on 6-7 October in Boulder are to definitize a POA&M for addressing their issues, and to develop a set of preliminary findings and suggestions that may impact your development of the FY2001 NWS budget.

In addition to providing these teams any assistance they may request, I will try to harmonize our efforts with the NRC Road Map Study, coordinate with Mr Wright, and further definitize some of the concerns of issues 2.a. and 2.c.

Craig E. Dorman, for the Panel
Attachments: Terms of Reference
Lists of Members and Attendees
Chairman's Initial comments on 'Continuous Refreshment'

Terms of Reference

1. The panel shall review and advise NWS on plans for technology infusion. The review will encompass research and development activities covering all aspects of weather, hydrology and climate observing, analysis, modeling, prediction and communication. The panel shall primarily focus on science based technology research and development, but will also address system aspects of infusion, where appropriate. The review shall include an assessment of funding, timing and resources necessary to infuse new technology. In assessing NWS plans, the panel shall consider the rationale for new technology initiatives and determined linkages to societal needs-- defined as improved services and/or lower cost to end-users.

2. The panel shall advise the National Weather Service on their development of a requirements generation and validation process.

3. The panel shall provide recommendations on potential collaborative technology efforts which should be pursued by NWS with other government, university, private industry or national laboratory entities.

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Chairman's Initial Comments on 'Continuous Refreshment'

Your Report and our briefings identified many prime targets for early action. I would like to reemphasize a subset of these.

We concur with your contention that the success of technology infusion depends very strongly on the culture of an institution, its basic planning and prioritizing processes, and its internal and external organizational relationships. All of these are currently in flux at NWS. An external group like ours can advise on the elements of the process, but the most critical task is the role of management in melding them into an effective whole.

It is worth reiterating that the health of EMC and the central computing system are of central importance. EMC must have tightly defined priorities and adequate base funding, very soon. The UCAR 1997 report on NCEP Central Operations should be repeated as recommended, just as soon as the computer procurement process permits. While this repeat review should concentrate on the critical concerns previously identified, it can also help address the basic issues of justifying HPC upgrades and assessing alternate means of meeting NOAA's overall HPC needs (weather forecasting and warnings, climate, model and technique development, etc) in the long run.

NWS faces some immediate staffing issues in critical positions, both at NCEP and at Headquarters. It should take full advantage of the Intergovernmental Personnel Act during this transition period. We believe that there are many excellent scientists, technologists and managers who can and would be delighted to help, but who neither want nor need long term employment at NWS. Similarly, NWS should avail itself of the talent within the OAR labs (and perhaps even the DoD) via details.

Resources must be effectively reallocated before NWS can even think about increases or upgrades. In this regard the decision to eliminate N-AWIPS in favor of AWIPS is commendable, and the schedule should be expedited. Some dissemination systems also appear to be prime candidates for consolidation and cost savings, particularly given opportunities offered by the internet.

Headquarters realignment and reengineering should also offer some early resource savings, which may be able to be applied to the EMC problem. A model where headquarters responsibilities are restricted to policy functions should be considered. Developmental and operational tasks in particular belong in "field" organizations. There are opportunities for consolidation both within NWS, and with organizations that perform similar or supportive functions in other parts of NOAA and in other agencies.

The NWS relationship with ERL labs needs to be revisited and definitized. Soon. Issues with OAR range from fundamental policy (separation of ops and research), to transition of SEC and potentially other operational/developmental elements, specific roles and plans for core NWS system upgrades, and longer term tasking and funding including interface with academia. The long term procedures and opportunities for technology infusion depend critically on the OAR/ERL-NWS relationship, and it needs much work.

The "Cooperative Institute" approach seems to work well for the small amount of external research that NWS funds, but this needs to be rationalized with the relationship with ERL labs. A consistent approach to competitive research vs assigned tasking also should be developed.

The TROIKA appears to have been an effective mechanism for coordination between NWS, NESDIS and OAR. It should be reinstituted soon.

It was not clear from the briefings that the variety of technology infusion and evolution initiatives underway at Hq and NCEP are yet thoroughly coordinated. The Systems Coordination Council would appear to have the lead in this. At issue will be how its authority and responsibility evolve as the Requirements Generation Progress and reengineering proceed.

From my short visits to WFOs in different stages of transition it is clear that there will be a large variance in both the timing and the process of implementing and effectively using the new systems, irrespective of the national timetable. Growing pains are inevitable, as are differences based on local and regional conditions and concerns. One caution is that the local manager and SOO need strong control over any and all "new" things introduced beyond the baseline systems; it's hard to dedicate much effort to learning how to employ new tools when it's unclear that the tools will remain and be supported, particularly while the overall system is changing so rapidly. Similar considerations apply to removing "legacy" systems before there is adequate acceptance of the new ones. How this is handled will influence the "climate" or culture for tech insertion for many years to come.

Attachment

B. Revision & Supplement of 2nd, 2 November 1998 Report, of 23 February 1999

23 February 1999

MEMORANDUM FOR JACK KELLY

SUBJ: Technology Infusion Panel Findings and Recommendations - Revision and Supplement of 2 November 1998 Report

Ref: Technology Infusion Panel Initial Report of 13 Aug 98

Encl: (1) Panel Members
(2) PREDICTIONS Outline
(3) Comments on OH/HRL and OSD/TDL

1. Introduction[1]

The Technology Infusion Panel met for the second time on 6-7 October 1998 at the Forecast Systems Laboratory in Boulder, Colorado. We discussed the relationship of our work to the NRC "Road Map" study with its Chairman, Dr Richard Anthes of UCAR, commented on the draft NWS Requirements Generation and Validation Process, and reviewed progress on the four major issues we identified in our initial report (see Reference):

- Evolutionary, continuous refreshment of the baseline warning system developed by the Modernization Program;
- Evolving the integrated observing and assimilation system;
- Roles of the WFOs and RFCs as Technology Infusion Ports;
- Leveraging Research.

We met for the third and final time at NWS Headquarters on 5-6 January 1999 to review our report from the second meeting, to discuss comments we had received from NWS and a review of the Office of Hydrology that had been led by Dr Holland, and to give you an out-brief. As a result of that meeting we have made some minor modifications to our 2 November report (highlighted by lines in the margins), and appended in Enclosure (3), summaries of our brief reviews of OH/HRL and OSD/TDL[2]. This report therefore constitutes the body of our findings and recommendations. It and our first report will be attached to our final Summary Report.

Our recommendations fall into four categories: NWS's basic approach to the process of technology infusion; an initiative ("PREDICTIONS", outlined in Enclosure [2]) to address the second and fourth of the above major issues (the two we told you we would focus on) and simultaneously serve as a good model of and catalyst for technology infusion; a number of specific actions related to issues one and three above, with emphasis on the health of EMC and NCO; and our suggestions regarding OH and OSD, in Enclosure (3).

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[1] Because this report is primarily for internal use, we have freely used the normal set of NWS and NOAA acronyms and jargon.

[2] We agreed at the meeting that a brief discussion with TDL would be appropriate because some hydrological functions are performed there, and because the work of TDL is so important to the WFOs' ability to interpret and use the NCEP output. This brief review was led by Dr Dorman with the assistance of Dr Smith, supplemented by questions from Dr Holland.

Although we received our charge from you and have focused as requested on improvements in hydrometeorological warnings and forecasts[3], it was obvious from the start that the process of Technology Infusion for NWS involves OAR and NESDIS about as much as it does your own staff. Therefore we urge you to discuss this report with those offices, as well as with NOAA and DoC management. Responding to even this limited set of recommendations will require Agency-wide coordination and action.

2. A Technology Infusion "Philosophy"

We define technology infusion as the **continuing, evolutionary process by which any organization or system maintains its health and improves its performance through the disciplined incorporation of new ideas, procedures, and capabilities.** All organizations need technology infusion, though for some like the NWS (and the US military) that *rely on technological superiority for global leadership* in their fields, it is particularly crucial. Failure to perform it properly leads to obsolescence and systemic malfunction. Technology infusion is an **evolutionary continuum.** Much like preventative medicine and physical fitness, it can often prevent the need for corrective surgery. As we noted in our initial report, the NWS Modernization Program is an excellent example of what a good technology infusion process is designed to avoid.

Two key features of a successful technology infusion process are **evolution** and **discipline. Evolution** implies preplanning, and the ability to assemble the resources -- personnel, system, operational and financial -- to effect the plans. Elements of the process which promote **discipline**, tailored here to the case of an operational organization like NWS, include:

- A thoroughly understood and widely accepted vision and mission, so everyone involved knows what they are trying to improve, and why;
- Clearly articulated goals and performance metrics (outcome and output), tied to the mission, that serve as guides for planning as well as benchmarks for assessment (and satisfy GPRA);
- Consistent adherence to a "system" perspective; that is, to maintaining a well defined overall architecture and concept of operations for the Service, within which to conduct trade-offs and against which to assess major change, and to guard against imbalance;
- A rigorous but open requirements definition and validation process (or processes) such as you are fashioning[4], focused on results and tied to goals and metrics;
- Proactive coupling to the interested external community -- direct and indirect users of NWS products, the scientists and engineers from whom many new ideas derive, independent advisory groups, other sponsors and service providers throughout the world -- to stimulate advice and support, to intellectually partner with the NWS staff, to inspire long range conceptual thinking and maintain a competitive drive for world leadership, and to maximize the socioeconomic return to the nation from the public investment in NWS[5];

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[3] We recognize that we did not address all of NWS's responsibilities. In particular we paid little attention to space weather, aviation weather, and climate; and only a subset of the Panel looked in any detail at hydrology.

[4] Although we caution that this must be very flexible, since any one process will work well for only some aspects of the system, and even then only for so long. We commend to you Peter Drucker's "Management's New Paradigms", *Forbes*, Oct 5 98; Drucker stresses the fallacy of the assumption that there is "one right way" to organize and run a business, as well as other outdated assumptions about management. All our recommendations should be viewed with his caveats in mind.

[5] This coupling can take a variety of forms, and while it can never replace the need for top talent and a continuous flow of good ideas from NOAA staff, it is both essential to quality control and critical to building national support for NWS initiatives. In this regard we commend your initiative to create a FACA-approved 'customer' panel. We also note that we have relied throughout our efforts on the work of UCAR/NCAR advisory panels, and of NRC

- Decentralized, harmonized allocation of responsibility, plus mechanisms to promote collaboration among and between the decision makers and the subject matter experts and implementers within NWS, and between NWS and other NOAA organizations, particularly OAR Labs and NESDIS satellite offices (e.g., the TROIKA, IPTs);
- A rigorous training and professional development program for the entire work force, in recognition that it is people that infuse and use technology;
- Promotion of healthy competition and intercomparison of procedures and results among the world's major weather and climate forecasting centers; and most importantly,
- Clear exposition of cost-benefit relationships of NWS operations, products, and plans, which is essential to obtaining NOAA, DoC, OMB and Congressional support for a budget that promotes and sustains a disciplined approach to continuous improvement[6].

Although these tenets are fundamental to the success of all technology infusion, the specifics of the process must vary with needs and characteristics of the organization. We believe, for example, that a single monolithic process will not work well for NWS. There is simply too great a spread among the scope and time frames of infusion that a nationwide, dispersed operational federal mission agency like NWS needs -- say from adding an algorithm to work stations at the WFOs, to designing, fielding, and assimilating data from new global moisture and wind observing systems for QPF -- to yield to a single approach.

We recommend therefore that you fashion processes that target three distinct if overlapping 'system perspectives' of the organization: these we term "Today's NWS", the "Next NWS", and the "NWS-After-Next"[7]. These overlapping NWS's evolve through the continuum of effort required to improve through technology infusion. We suggest that this time-based perspective is a useful construct both for planning the evolution of the Service, and for actually implementing the processes of technology infusion, which operate somewhat differently in each time frame ... shifting from an emphasis on "refreshment", to "insertion", to "research"[8].

Boards and Committees such as BASC and the NWSMC. We urge you to continue to avail yourself of their service. NRC support and advice are particularly important because of congressional reliance upon the Academy structure for independent review and assessments.

[6] This recommendation sparked a very useful dialog on the pros and cons of, and proper uses of, cost-benefit analysis. Without reiterating all the arguments, the main points are that cost-benefit analyses are always simply one factor in the decision making process, can not often be quantitative and rigorous, often invoke expression of benefits in non-monetary terms (e.g. lives saved, minutes of warning time), and are perhaps of most value in making trade-off assessments among alternate technical approaches within a common systems architecture. The issue is particularly problematic for research, the 'invention and discovery' aspects of innovation. Nonetheless, to gain support for funding it is essential to articulate the benefits to be gained from new mission-oriented research, even if they can only be stated in qualitative terms or themselves require research to define (as in assessing the value of assimilating new observations in operational models), or are amenable only to peer review of projects or programs. We faced this problem in our own recommendations, with the normal difficulties and lack of complete success. The bottom line however, as exemplified by GPRA, is that the Administration and Congress both demand clearly articulated justification for expenditures of public funds.

[7] This approach is derived from Paul Bracken's "The Military After Next", *The Washington Quarterly,* 1993, 16:4, 157-174. It has been adopted in a form similar to what we recommend by both Army and Navy, eg by the Office of Naval Research which focuses on the "Navy and Marine Corps-After-Next". The concept is intended to apply to rolling windows of time, differentiated by planning horizons. Thus while our specific examples are based on the NWS of 1999, the same principles apply as time advances and the system changes.

[8] Obviously, work on all three occurs simultaneously; the tasks call on skills of different parts of the organization. In your case, e.g., the balance of effort shifts from the operational personnel at NCEP and the WFOs/RFCs who are most concerned with current operations, to Headquarters staff and SAO and other managers (like NESDIS for

"Today's NWS" we take to mean the Modernized Weather Service that comprises Headquarters, NCEP, and the six Regions with their 119 WFOs and 13 RFCs. It is the immediate concern of the "operators and maintainers", the folks who produce the warnings and forecasts, and run the observational, computational, communications and modeling systems that feed them. For this NWS, technology infusion has two aspects: first is completing the Modernization as it has been scheduled, including the transition to the new Class 8 computer and any changes you may be contemplating to your organization and its procedures. Finishing the major Modernization program and implementing the "Kelly Report" obviously are the first order of business; they establish the base from which all improvements[9] must derive.

Equally important, technology infusion into Today's NWS (the NWS of **any** today) involves the **continuous refreshment** that we identified as our first major issue. This currently includes, for example, the sequence of planned builds for AWIPS, the convergence of N-AWIPS and AWIPS, upgrades to ASOS and NEXRAD, enhancements of the communications system, and improvement of the operational numerical weather prediction (NWP) codes and thus the guidance from NCEP. We stress that this process must be both continuous and disciplined: a part of the daily job of your operators and maintainers and their supervisors, carefully planned and managed by Configuration Control Boards and similar entities, and routinely budgeted as part of your baseline operations. This aspect of technology infusion must be 'hardwired-in' to the organization. Indeed we note that such entities as the SOOs with their charter for innovation, and EMC that evaluates and updates the operational models that produce guidance and forecasts, indicate NWS's fundamental structural commitment to this process.

"Today's NWS" is and must be continuously improving, forever refreshing; such improvement is essential to maintaining quality service to a public whose reliance on warnings and NWS-product based forecasts and model output will grow dramatically, as stressed in the "vision" portrayed by the NRC Road Map study. Your budget must, as a first step, accommodate this process...not just in 2001, but every year, for all key aspects of your system: hardware, software, procedures, and people (thus training and education).

One aspect of continuous refreshment deserves special emphasis: the principal NCEP computer(s). The Road Map study stresses the coupling of science, technology, and computation as the basis for improvement in NWP. We discuss the role of computation at some length under our recommendations for specific actions, but want here to stress that **order of magnitude improvements in computation** will be required over the next several years, and that such improvements must become a matter of routine planned upgrades, as opposed to the tortuous (and still hazardous) process of acquiring and shifting to the Class 8[10]. Maintaining adequate computing power and the expanding skill base needed to maintain and exploit it are forever issues for *today,* not something that can be put off to the future[11].

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satellites and OAR for models and sensors) who are responsible for system architecture, planning and acquisition, to the OAR labs and universities who focus on innovation.

[9] We note that the Modernization was designed to produce "no degradation" in service while putting in place the new baseline systems and skills essential to maintaining quality public warning services. Thus, the notion of further improvement based on but following the Modernization was implicit in the very design.

[10] This requirement derives from several interacting factors, including:

- Public demand for completely new types of products such as climate warnings and forecasts (stimulated by El Nino), plus greater temporal and spatial specificity of watches and warnings for such features as flash floods, hurricane landfall, and tornado tracks;
- the rapidly increasing socio-economic value of commercially produced products based on NCEP output (which generates additional demand pull),

The **"Next NWS"** is what we can expect the Service to evolve into within about a decade. That is, it will incorporate the architectural, system, hardware, software, and personnel changes that can be defined and programmed over the next few years. If our recommendations regarding technology infusion are followed, the Next NWS will be achieved by continuous evolution from Today's NWS through close interaction with the research community and customers, under the guidance of designated leaders charged with implementing the process of evolution, infusion, and thinking about the future.

The Next NWS will contain substantial **evolutionary improvements**; and some of these will have to be achieved through dedicated development programs (like the one we suggest in paragraph 3), since nothing will happen without focused effort. But in general, it can be expected to comply more or less with the operational and organizational architecture in service today, albeit with significant additions and modifications. Some elements of this Next NWS are already on the drawing board -- the next generation polar and geostationary satellites for example[12]. Others may be expected to evolve from the USWRP and other ongoing efforts such as NAOS; we will make specific recommendations in this regard (our major issue 2).

The Next NWS is what will be most strongly impacted by the Requirements process you are developing. Certainly some of the ideas and needs that emerge from the field will address near term needs, Today's NWS. But by and large, they will have to be analyzed and subjected to trade off and cost-benefit analyses, and a process of verification (of both need and solution), then budgeted for, then developed (generally not in NWS but in OAR labs, universities, or industry, thus mandating close cooperation with partners), then integrated and tested, then fielded along with appropriate training programs. While there are ways to expedite parts of this process -- algorithmic changes for example can be inserted into models fairly rapidly -- the planning, programming, budgeting, development and acquisition processes typically take about 5-10 years for anything very significant.

- the fact that large amounts of important observations now go unused because of the inability to develop, test, and verify the procedures for assimilating them in operational models, and
- the demonstrated improvements in warning and forecast quality and timeliness available with higher resolution models and improved data assimilation schemes (e.g. 4DVAR)...

not to mention the coming need to incorporate, in the next few years (for the "Next NWS"), the scientific advances of the USWRP and the observational improvements in the next generation of polar and geostationary satellites as well as other available and planned observational systems, including an integrated operational ocean observing system.

We note that the central NCEP computer and its operational models are currently a bottleneck in the entire process - they are the limiting factor for the quality of US weather and climate warnings and forecasts. Even with the new Class 8 computer, NCEP is well behind where we believe they should be in terms of computational capacity; and we anticipate that the transition to the massively parallel processing environment on that machine will not be easy.

We discuss EMC and NCO in some detail in paragraph 4.

[11] This principle seems to be well accepted for stockpile stewardship at the DOE labs; we suggest that it is equally viable for operational weather forecasting and warnings, which if anything have a more continuous and immediate impact on the American people.

[12] We discussed at our meeting the recent draft of requirements for the next generation geostationary satellite, and have two concerns. The first is whether adequate testing has been done to demonstrate the impact on metrics and the associated costs and benefits of suggested new measurements. The second -- where cost really becomes a driving consideration -- is whether the 'required' data must all be taken from geostationary satellites; i.e., whether the document was prepared within the context of a total observation-assimilation-NWP architecture wherein different observational approaches were traded off. We suspect that little consideration was given to such alternatives.

It is for this timeframe that normal governmental mechanisms, including the military services' FYDP and Acquisition Commands, and NOAA's comparable budgeting process and SAO, are principally designed. Your challenge is to make optimum use of such processes and organizations by first making and justifying hard strategic choices about priorities, and then coercing or cajoling the 'system' -- through performance metrics, tests, payoff assessments, cost comparisons, external review, etc. -- to work to fund and manage the effort to buy, build, test, deploy and operate the most crucial advances. While NOAA's and NWS's track records in this regard are not stellar, the Agency as a whole, and your NWS team, have made significant improvements in recent years. But we do not mean to minimize the difficulties in doing this job well; to this end our specific suggestion outlined in paragraph 3 and Enclosure (2) is intended both to offer advice on what we see as the most pressing science and technical issues, and to suggest aspects of an approach that should serve as a model for other efforts of similar nature.

Focusing for a moment on this coming decade, we believe that very significant improvement over today's baseline can be achieved for the NWS of 2005-2010. We base this belief on projected advances in information technology, maturation of Today's Modernized NWS, and the expectation that scientific output from the USWRP, in conjunction with currently underutilized observational systems, plus NAOS-based initiatives, will yield the assimilation, QPF, and hurricane landfall metrics that the multi-agency USWRP promises.

In fact, we expect that the quality of warnings and forecasts that this Next NWS will produce, will cross the threshold of demonstrated accuracy required to generate significantly increased demand based on proven socioeconomic benefit. Americans should be able to plan their lives and business activities with much more certainty about, weather and climate predictions a decade from now. Associated with this will be a dramatic rise and broad diffusion of the US 'value-added' provider sector, involving widespread use of very high resolution 'local' short-term NWP models that use NCEP gridded output as boundary and initial conditions. But basically, the structure (Headquarters, NCEP, WFO/RFCs) and products (observations, warnings, forecasts, model output) of NWS a decade from now will be more or less the same as today.

As we have already stated, we will be more specific about programs for the coming decade in the next section and Enclosure (2) of this report. We do suggest however that there are *five steps* you can take *now*, in addition to implementing a rigorous Requirements process as the basis for defining priorities and assigning responsibility to meet them, that will significantly enhance the process of technology infusion to evolve the Next NWS:

(1) Maintain, as we have already suggested, a clearly defined System Architecture and Concept of Operations against which to conduct analytical and cost-benefit trade-offs. We emphasize this because of the importance of observations and their assimilation to the envisioned system, and the large number of alternatives for taking the observations [13], each of which has major cost and operational concept implications.

(2) Revise the concept of operations of EMC to make much better use of external resources (the labs, NCAR, academia), and to this end expedite the development of *both global, and nested (local, regional, national) mesoscale* "common" (for operations and R&D) model infrastructures (more on this in paragraph 4).

(3) Revitalize the "TROIKA" (periodic structured meetings of the Assistant Administrators of OAR, NESDIS and NWS) to facilitate communications among the NOAA line offices most directly responsible for weather and climate R&D, observations, and operations.

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[13] E.g., profilers, aircraft based observations or drop-sondes vs rawinsondes; drifting vs moored buoys; ground/ship or balloon based profiling systems vs satellites; COSMIC vs GOES soundings.

(4)Develop much closer and more clearly defined customer-supplier relationships with the ERL Labs. If necessary, redistribute funds within NOAA to give **NWS substantially better control of NOAA's weather and climate related developments, as well as an enhanced ability to guide its research agenda**[14].
(5) Implement people-oriented programs to inculcate an attitude of continuous improvement, exploit opportunities (like the SOOs) inherent in the organization to speed evolution, and build the professional skills needed to envision new opportunities and operate new systems.

The **"NWS-After-Next"** -- or rather one potential version of it -- is what the NRC Road Map study points to in its Vision. It is the NWS of 20 or more years hence. Far from being ethereal, however, only by thinking seriously about this NWS -- what it should do, how it may be structured -- can the organization effectively guide the research of today that may enable it; and only by paying close attention to today's findings and trends of cutting edge science and technology, is it reasonable to postulate alternative futures to which the service can evolve.

These two approaches are mutually reinforcing. The technology infusion process must keep such interactions in mind, lest it preclude potentially important advances by blocking avenues of development or implementation. This is the key to avoiding another catch-up "Modernization" program...you want to get to the NWS-After-Next via a sequence of continuously improving Today's NWS's and Next NWS's, not through heroic perturbations; through programs of health and fitness, not surgery.

There are two major tasks for a technology infusion process focused on the NWS-After-Next. The first is to stimulate **innovation**, which we define as **invention and discovery, plus exploitation**[15]. Both parts of this equation are essential. NSF may have the national lead in funding invention and discovery, but NWS must actively sponsor and guide key parts of long range research. Only by being a credible 'player at the table' can NWS understand and then leverage the work of the other sponsors. And NWS, as a primary ultimate 'customer' for academic and industrial meteorology, hydrology, and climatology research, must be continuously attuned to take advantage of its results. NWS also must fund the necessary applied development and transition for its use of these results, whether these tasks are done in

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[14] The basic principle for any mission agency should be **control by the customer over most R&D** (by control we mean stating *capability requirements* that the research should address, *not* control over the solution to problems). In this case, NWS -- the operational weather service -- is the customer for much of the NOAA base-funded R&D in ERL labs. We fully recognize the need for the labs to have the ability to exercise their own imagination and discretion in long range discovery and invention targeted at operational capabilities, and they should therefore have direct control over a substantial portion of their base funding. We further note that they are an extremely important **national resource**, and perform critically important developmental work for DoD, FAA and other sponsors, as well as participate fully in national and international research programs. On the other hand, NWS now has *almost no ability* (certainly much less that DoD) to orient the work of the labs toward its needs, which significantly impedes partnering and infusion. One part of the problem is money; NWS can't now 'buy' lab services. Another is the fundamental issue of balancing "tech-push" vs "requirements pull"; the system in NOAA is currently very unbalanced. We discuss this further in Paragraph 4. Improving this situation will require close collaboration between NWS and OAR leadership, as well as attention and support by senior NOAA and DoC management; but we view the establishment of a **better requirements definition and response process, and enhanced NWS-OAR partnerships**, as absolutely essential. Similar arguments pertain to the NWS-NESDIS relationship. It too needs work.

[15] This is a slight modification of the definition used by Edward B. Roberts in "Managing Invention and Innovation", *Research-Technology Management*, Jan/Feb 1988: "Innovation is composed of two parts: (1) the generation of an idea or invention, and (2) conversion of that invention into a business or other useful application, (or,) Innovation = [Discovery and] Invention + Exploitation."

ongoing efforts to prioritize requirements and complete and integrate these initiatives. At the same time we fully recognize that an internal culture of technology management for continuous improvement, and a NOAA/DoC/OMB/Congressional funding environment that encourages it, are the essential bases for the longer range improvements on which we will focus. We will help you develop these any way we can.

There is however one area where we have grave immediate concerns that warrant both your and our close attention: the **health of EMC and NCO**. Danger signs include the empty leadership positions at NCEP, EMC's continued dependence on non-base funding, its process of prioritization which is compounded by the 'soft-money' situation, the difficulties associated with the procurement and installation of the Class 8 computer and the associated migration to a massively parallel processing environment (as highlighted in the 1997 UCAR report on NCO, and exacerbated by the delays), the condition of the NCEP computing and communications environment, and even the basic EMC concept of operations -- in particular the need for an expanded 'test bed' and greater outreach. EMC and NCO are at the core of the entire NWP process. Problems or bottlenecks there have an adverse impact throughout the system. Because they are so central to the process, and integral to our concerns with observations and modeling, we will include them in our considerations of the second major issue (2.b.).

b. Evolving the integrated observing and assimilation system. The watchword of the Modernization program was "no degradation" in service while putting in place the new baseline systems and skills essential to maintaining quality public warning services. This focus mandated that improvements to, or in some cases even maintenance of other elements of the total weather, hydrology and climate system -- notably significant parts of the observing and dissemination networks -- be temporarily ignored. Significant improvements to warnings and forecasts, however, will require observations of additional parameters, and of currently measured parameters at different scales and greater accuracy. We believe that this issue warrants significant attention, now. This is one of the two main topics on which we will initially focus; and it includes the health of EMC because of the tight connections between the observing system and the modeling and assimilation system that will use the data.

We recognize that there are several major aspects to this topic. First, "improvements" in warning and forecasting must be justified on the basis of socioeconomic impact, not simply the ability to do better. And for some very significant factors, such as climate (where the appetite for knowledge and predictions was whetted by the recent El Nino) even the concept of "need" is imprecise at best. The forthcoming NWS User Advisory Committee, various NRC committees, and the socioeconomic research of the USWRP should help address these issues.

A second aspect of the observation and assimilation problem is that there are already many more data available to NCEP than are being analyzed or even looked at. And while NWS is acquiring the new Class 8 computer and moving toward a "common model" for research and operations, there are also serious scientific debates about basic assimilation methodology, about data accuracy and precision, and about the value of different types and densities of information.

A third aspect of the problem is that technology advances, e.g. GPS, offer exciting new opportunities for observations; yet there is a continuing need to maintain continuity of observations (and thus continuity of the climate record) while introducing better and cheaper procedures. There are in addition several existing observing networks -- e.g. the cooperative observing network, the marine data buoys, the profiler network -- that demand attention as part of the integrated system; and yet other vital networks that are eroding. Further, many WFOs have established their own local networks of various types to support regional and smaller scale needs.

And there are a variety of national and international programs (e.g. NAOS, GCOS, etc) directed at improved observations. All these must be considered.

Evolution of the observational system and application of its data are thus complex as well as important technology infusion issues. This topic is a "target rich environment" in its own right. At the bottom line, however, NOAA has responsibility for the nation's overall environmental monitoring system, and NWS in particular bears much of that responsibility for weather, water and climate. We believe that we can help NWS define an improved 'system' of observation, and establish the new roles and partnerships among collectors, researchers, assimilators, modelers, forecasters, and customers, needed to evolve our integrated observing and assimilation system.

c. Roles of the WFOs and RFCs as Technology Infusion ports. The modernized Weather Service has distributed the responsibility for warnings and forecasts to over 130 operational offices, supported by some 13 regional and national centers. Many of these have direct connections to or are located at research labs. Each of them has a SOO or DOH responsible for "science" operations, and many either have visiting scientists in residence or ongoing R&D projects with scientists at cooperative institutes, universities, or NOAA labs.

Such a highly decentralized system with such close connectivity to science and research, and with the formidable array of new techniques provided by the Modernization program, creates the potential for rapid flowering of new ideas and abilities. It also poses significant management and planning challenges.

The SOOs and DOHs are simultaneously at the end of the pipeline for technology infusion in terms of application, and at its front end in terms of requirements and innovation. At issue is how to train, maintain, support and enhance this network, and thus ensure that good new ideas are shared and quickly brought to bear, without undermining the coherence of the total national (and global) system. Related long term questions include the number of WFOs really required to service the nation's needs, and the desirability (indeed, inevitability - it's going on already) of local modeling to obtain even higher precision in support of specific regional needs (such as fire weather and flash floods), even as the resolution of national models approaches storm-cell scale.

We see this as a significant NWS issue, but not an urgent one because the focus of effort over the next couple years will be learning to fully use the capabilities of the Modernized system. We do however see management of the total national human resource base as a central aspect of technology infusion, and want to stress the role of field offices and their SOOs and DOHs.

Although we do not believe it appropriate to devote much of our time to this issue, we do have one immediate suggestion. Because the SOOs and DOHs are so critical to the technology infusion process throughout the system, it will be very important to develop a spirit of team work among them, and to have them share their 'best practices' as a matter of routine. This will require frequent face-to-face interchange. We recommend that they meet together twice a year, once at the Regional level and once at the National level. The Regional meeting should be timed to garner and integrate their input to the annual Requirements process that your staff is developing. The National-level meeting would provide an opportunity for them to meet and hear from NWS leadership, to share information about their activities, and to interact with representatives from the OAR/ERL labs, NCAR, the Universities and industry. We will develop this suggestion further during our deliberations.

d. Leveraging Research. NWS has the starring role in US weather and climate operations, manages the development and insertion processes by which S&T impacts its products, the OAR labs, NCEP/EMC, the WFOs, or academia and industry. No one else can be expected to perform the 'exploitation' job for the Service; for themselves, yes, but for you, no[16].

This aspect of technology insertion requires recognition on the part of the Administration and Congress that NWS must have the wherewithal to influence the direction of the work of others. This means regular funding for, as well as the development of an improved capability to act as both a sponsor and a manager of extramural R&D[17]. The funds and staff to do this need not be large; but we see **NWS's current inability to substantially influence the direction of the innovation agenda as a critical deficiency.**

The second task of technology infusion for the NWS-After-Next, again stressing one of the tenets of discipline, is to pay careful attention to system architecture. In this case, however, the focus must be on strongly motivating the examination of a *wide range of alternative architectures*, in which NWS (and other parts of NOAA) may in fact be playing a very different role than today, in the overall warning and forecast process.

We above expressed the opinion that the Next NWS will produce products of greatly enhanced socioeconomic value. In response to resulting marketplace demand, and taking advantage of continued advances in technology and computation, industry's initiatives may well enable the NWS-After-Next to focus almost exclusively on obtaining and quality controlling observations (many if not most of which may be made by contractors). Assimilation and NWP will be performed at a range of nested scales from local to global and may be much more dispersed, in commercial as well as government offices; and there may well be many fewer (or indeed many more) WFOs[18]. As another example, we foresee commercial and research as well as NOAA, NASA, NRO/DoD and international operational satellites, plus a very wide range of ground, ocean, and autonomous vehicle based observing sensors and platforms, feeding data into a total-environment oriented global observing system. The range of possibilities for both observation and modeling/NWP is great. The point is that the long range innovation-oriented aspects of technology infusion must not arbitrarily preclude any of them from evolving; rather, they must enable them, so that the opportunities for lower cost, higher performance options to emerge are enhanced.

Your Requirements process is unlikely to be of much assistance in this regard. Almost inevitably, such processes tend to work 'in the box', to fix or improve (and defend) the current system (and properly so). What we suggest is that you need to develop in parallel some mechanism to inspire and reward 'out-of-the-box' thinking, not dissimilar to what's reflected in the 'vision' of the Road Map study. But rather than just develop a vision, or the general recommendations that an NRC group can provide, your folks need to grapple with the structural issues of alternatives and associated technical, organizational, skill-base, and 'CONOPS' changes needed to get to such an future state. This is a tough job that requires considerable breadth and wisdom, a willingness to shed institutional prejudices, and the continuous infusion of new ideas from both NWS staff and the external community. But we believe that the continuous, dedicated evaluation of and cost-benefit based tradeoffs between future alternative architectures is essential to

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[16] USWRP is a good, if rather near-term, example. NWS partners with NSF and DoD in setting the agenda for, as well as funding this research program. However it will take a complementary program like PREDICTIONS to translate the research results into operational improvements.

[17] We recognize that in addition to its role in USWRP, NWS now does support some external work via programs like CSTAR at the Cooperative Institutes, and the shorter term COMET projects. However neither the level of effort, nor the breadth of participation, nor the involvement of management are even close to what we would consider adequate for a long term innovative R&D program.

[18] We note that a similar evolution of responsibilities already has occurred in other parts of NOAA. Hydrographic survey is a good example, where NOS can now rely upon the private sector for both data collection and value-added chart production, and thus focus on quality assurance.

meeting the dramatic future growth in socioeconomic demand and impact. This analytical process also must be coupled to the formulation of plans for your program of innovation, to ensure a continuum of evolution.

Finally, just as the tenets of a disciplined technology infusion process apply to all three perspectives of NWS, so too do a few **mechanisms**, particularly ones which enhance connectivity among participants:

- **Teaming**: Technology infusion involves many steps, from the generation of a idea, to its development, evaluation, and then incorporation in some 'system'. Whether this process takes a day or decades, it requires the effort of many people and frequently many organizations. Interaction among the participants, and 'handoffs' from one stage and 'culture' to the next, are thus central to the process. Control of the interfaces involved in these transfers, and development of mechanisms to facilitate the process, are two of the most important tasks for managers of infusion. There are a variety of formal and informal schemes for enhancing teamwork -- Configuration Control Boards, committees, IPTs, common areas for breaks or meals, office arrangements, e-mail and electronic 'collaboratoriums' etc -- each of which has its place. The important point is to recognize that technology infusion is a 'team sport', and not to trust the development of the required linkages to chance. Once a decision has been made to try to infuse some technology into a system, the individual responsible must focus at least as much on the relationships among the participants as upon the technical and financial details. This 'people' side of the infusion process is too often neglected, and ignoring it is a frequent cause for failure[19].
- **Training:** Technology comes in two flavors: explicit technology, that is embodied in hardware and software and can be bought or developed. And implicit technology, that resides in the minds and hands of people. The second is needed to use the first. Perhaps even more importantly, it is what's needed to develop the vision and ideas that ultimately lead, again through the efforts of people, to explicit technology. Just as technology infusion is evolutionary, so must the work force continuously grow professionally. This is too often forgotten at budget time: training, education, interaction with colleagues and customers, and the associated travel are baseline costs, not optional extras.
- **Demonstrations:** Because infusion requires transfer of responsibility from one person or organization to the next, the receiving party must have reason to believe that it's worth his or her time, money and effort to accept what's being offered and move the process forward. Demonstration serves this purpose; it lets the recipient judge how to incorporate the technology, and reduces his risk in doing so. Simultaneously, putting an idea to practice in a realistic environment, repeatedly, is a basic part of the process of learning. Thus while formal demonstrations are effective means of achieving milestones, the concept of demonstration should pervade the technology infusion process right from the very initiation of an idea. This concept is central to our recommendations in both Paragraph 3 and 4.
- **Affordability:** Cost is one reason that we argue for evaluation of options within an overall system architecture. There usually are several ways to achieve an objective, and pre-determination of solutions or even approaches to solutions (e.g., satellites vs ground based, balloon launched, etc observations) without trades and analyses is seldom optimum (to this end, we reiterate our recommendation that you revisit the recent draft requirements for the next geostationary satellite). Our first point is that R&D itself is a generator of options and thus value[20]; properly stated with regard to your specific issues, this is a powerful argument for enhancement of your R&D budget. Second, to succeed at the exploitation part of innovation you often need be as concerned with process development as with product development, in order to reduce cost and risk and ensure manufacturability. And of course there are a number of basic principles of acquisition (learned the hard way in DoD) like use of

[19] Teaming also is often too narrowly construed. To be effective teams must include representatives from all organizations participating in a project; not just NWS staff, but also key individuals from the Labs, NESDIS, OAR, universities, non-profits, and industry as appropriate.

[20] See, e.g., Investment Under Uncertainty (Princeton Univ Press, 1994) by Avinash K. Dixit and Robert S. Pindyck (copy provided to the NWS CFO at our January meeting), and Real Options (MIT Press, 1997) by Lenos Trigeorgis.

COTS, open architectures, requirements-based procurement, etc, that are applicable to most infusions of S&T.

- **Partnerships:** The USWRP is an excellent example of an R&D partnership among agencies to accomplish mutually agreed objectives. In addition to generally encouraging NWS to form partnerships for development and infusion of technology, we believe that there are several specific partnerships that need attention. One already stressed is the relationship between NWS and the OAR-ERL labs; another is the interaction with NESDIS, in defining, justifying, and using satellite observations[21]. A third is the interface with UCAR/NCAR for R&D[22], support for connections to the university community, and impartial external review. A fourth is with DoD labs for S&T and development, and DoD METOC commands for operational forecasts[23]. We also recommend that NWS maintain, and preferably enhance, its global stance. Actions to this end range from continuing if not expanding the international desks at NCEP, to a leading role in NAOS, structured collaborations and personnel exchanges with the Canadian Meteorology Center, ECMWF, and the major European national weather services, and a strong presence at WMO. Weather and climate are among the most global of disciplines, and assured access to data, shared commitment to observations, leverage of others' developments[24], and the benefits from ensemble-based forecasting, are just a few of the reasons the US national interest is well served by active global partnering.

Finally, perhaps the most important partnership of all is NWS's partnership with NOAA Management, the Department, OMB and Congress, to develop a shared vision of the future NWS, a recognition of its value to the nation, and a commitment to the support the Service will need to achieve it.

3. A Model Process for Evolving [part of] the Next NWS

We noted in the report from our first meeting that

> "The watchword of the Modernization program was "no degradation" in service while putting in place the new baseline systems and skills essential to maintaining quality public warning services. This focus mandated that improvements to ... the total weather, hydrology and climate system -- notably significant parts of the observing and dissemination networks -- be temporarily ignored. Significant improvements to warnings and forecasts, however, will require observations [and assimilation] of additional parameters, and of currently measured parameters at different scales and greater accuracy...there are several major aspects to this topic. ...

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[21] But note the caveat implied by our advice on affordability. NESDIS's job is to build and operate satellites. Thus if you go to them for a solution to a requirement, you can be assured they will use a satellite to provide it. Be sure that's what you want before you ask, or at least ensure that they know you're also looking elsewhere for better and cheaper ways to do a similar job.

[22] E.g., development of the WRF model, the common infrastructure for research and operations. We note here that there is a great opportunity for synergy between NWS's relationships with the labs and with the academic community; the labs can provide an excellent 'impedance match' between the operators and the researchers, as well as an avenue for moving funds and overseeing/collaborating in the research, with UCAR/NCAR, with the OAR and NWS CIs, with other academic groups, and with industry.

[23] Space Environment Center's relationship with the Air Force appears to be particularly strong, and may serve as a good model.

[24] An exciting opportunity in this regard, which forms part of our PREDICTIONS initiative, is participation in COSMIC, the global atmospheric sounding program which is roughly 80% funded by Taiwan, with considerable additional NSF contribution. NWS/NCEP evaluation of the impact of these soundings would provide an extremely useful and quite inexpensive comparison (and potential alternative) to current and planned GOES soundings.

First, "improvements" in warning and forecasting must be justified on the basis of socioeconomic impact, not simply the ability to do better. ...
second ... there are already many more data available to NCEP than are being analyzed ...
third ... technology advances, e.g. GPS, offer exciting new opportunities for observations; yet there is a continuing need to maintain continuity of observations (and thus continuity of the climate record) while introducing better and cheaper procedures. There are in addition several existing observing networks ... that demand attention as part of the integrated system; and yet other vital networks that are eroding.
Evolution of the observational system and application of its data are thus complex as well as important technology infusion issues. ...[and]
USWRP ... is now gaining momentum, and should make very significant contributions to physical, natural and socioeconomic realms of weather related science over the next decade. USWRP has been planned, however, only to produce "proof of concept"."

Based on these observations, we elected to concentrate on developing recommendations for evolving the integrated observing and assimilation system and for leveraging research, in particular the USWRP (which itself addresses socio-economic impact and the optimal mix of observations and assimilation, in support of probabilistic Quantitative Precipitation Forecasting (PQPF) and hurricanes at landfall). We note that this approach is commensurate with the perceptions of the academic community, that the "evolution of the [Next] NWS in the next decade or so" will be driven by

"atmospheric observation and numerical prediction capabilities ... integrated and optimized as a seamless, end to end system that takes advantage of new opportunities for measuring critical variables and observing key processes on the appropriate scales of time and space ... [and] delivery of warnings and predictions to a wide range of constituents ... increasingly through computer-to-computer links."[25]

We therefore propose that, as one aspect of its technology infusion program, and as a model and catalyst for similar efforts, NWS initiate a program that capitalizes on several confluent streams of current and planned activity in order to make large improvements in operational skill of storm and precipitation warnings and forecasts in the 0-72 hour period. The contributing streams of activity include:

- Completion of the Modernization Program over the next couple years, providing a stable baseline for the infusion process as well as improving greatly our ability to observe the lower atmosphere;
- Transition to the Class 8 massively parallel processor and establishment of a program of frequent staged upgrades of computing power at NCEP, plus comparable increases in computational power accessible to the research community[26];
- Evolution of the Next Generation Internet and national information infrastructure, dramatically increasing the opportunities for data access and dissemination;

[25] Dutton, John A., Leonard J. Pietrafesa, & John T. Snow, "Priorities of the Academic Community for the National Weather Service", *Bulletin of the American Meteorological Society,* **79**;5, 761-763, May 1998
[26] The QPF Prospectus Development Team notes: "Over the next 5 yr, sufficient computing power will become available for operational numerical models to resolve and predict meso-g scale distributions over large regions of the country. This will occur with the full implementation of the new observing networks. These coinciding events will facilitate more accurate identification, mapping and forecasting of heavy precipitation events. Furthermore, they will enable multimodel ensembles to run in real time and thereby allow us to quantify more accurately the uncertainty in model forecasts ... the opportunities inherent in the new databases and electronic technologies will be brought to fruition only if we aggressively pursue several areas of supporting research and development"; J.M.Fritsch et al, "Meeting Summary, QPF, Report of the Eighth Prospectus Development Team, US Weather Research Program", *Bulletin of the American Meteorological Society,* **79**;2, 285-299, Feb 1998

- Planning with Canada and Mexico under the NAOS program for the next generation upper air observing system for the continent and adjacent waters, with the objective of moving from loosely connected subsystems to an integrated network of observing platforms and sensors linked through modernized national communications systems; and
- Implementation of the USWRP, which can be expected to provide a sound scientific basis for assimilation of both currently underutilized observations and new operational observations as envisioned in NAOS and offered by the highly leveraged opportunity to participate in COSMIC, and for the implementation of enhanced NWP in NCEP.

Basically we suggest that **rather than wait until USWRP is concluded, NOAA start now to put in place a parallel, evolutionary implementation effort that will simultaneously enhance the process of research, and rapidly incorporate the emerging new knowledge, in conjunction with better observational data, in its operational NWP systems**. We believe that such a parallel, rather than serial process, is not only justified by the status of the ongoing programs outlined above, but will be much more efficient and less costly.

The program we propose would call on the expertise of a consortium of NOAA labs and centers from NWS Headquarters and NCEP, from OAR/ERL labs, and from NESDIS, to work together to develop, validate and implement operational capabilities while interacting closely with UCAR/NCAR and with the academic community that will be executing the bulk of the USWRP research agenda. Thus this effort will seek to establish new alignments of operational and research personnel to lubricate and catalyze infusion not only for this particular purpose, but for the full range of NOAA and NWS strategic objectives.

The elements of our proposal, entitled **PREDICTIONS**, have been developed over the last few months by members of our Panel in conjunction with the staffs of several NWS offices and OAR labs. The PREDICTIONS proposal is briefly outlined in Enclosure (2). You were exposed to it on 6 November, and your staff with OAR personnel are continuing to refine the objectives and plans. We also discussed it at some length at our 5-6 January meeting[27].

We note that our recommendation that you undertake PREDICTIONS has significant budget implications (@$40M/year) for 2001 as well as later years[28], for both NWS and OAR. We believe however that the relatively modest costs of what we propose are fully justified by the degree to which they:

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[27] One concern on which we spent considerable time was the perception that PREDICTIONS is a NOAA-alone initiative that can or does compete with USWRP. This concern is exacerbated by NOAA/NWS's inability to convince DoC, OMB, and Congress to provide the funds NOAA previously envisioned as its contribution to USWRP. The panel recognizes this concern, and the likely reaction of the scientific community to inadequate NOAA support for the extremely important, community-planned USWRP; and of course we are keenly aware that unless USWRP achieves its goals, PREDICITONS will have little to implement. After extended discussion we reconfirmed our support for PREDICTIONS as an essential concomitant to the research, to operationalize and thus gain the societal benefit of the research from USWRP. We note that it is normal, indeed inevitable for the implementation phase of any program to be considerably more costly that the S&T (e.g. compare the research-advanced development and dem-val budgets in any of the Military Departments); and further, we believe that it may well be easier for NOAA to justify to DoC, OMB and Congress a program to apply scientific advances mutually agreed upon but funded principally by NSF, than to actually help pay for the science itself. Given these views, we urge detailed discussion between the proponents of USWRP and PREDICTIONS (indeed, many of them are the same) to ensure that these efforts are appropriately aligned and mutually supportive of common goals, in perception as well as in fact.

[28] The budget implications of PREDICTIONS evoked considerable additional discussion among our panel members, and with AA Kelly and his CFO. We recognize that NWS will be unable to sell a new-start initiative of

(1) leverage and employ the Modernized NWS of Today and other efforts to which the country has already committed, like USWRP, NAOS, and the National Information Infrastructure;
(2) provide for (and integrate) operational and training upgrades that we believe *you will need in any event*;
(3) address *several of the immediate problems, notably with EMC*, that we discuss below; and
(4) set the stage for the evolutionary development of the NWS-After-Next as postulated in the NRC Road Map Vision.

We want to stress that PREDICTIONS is not the only initiative we believe you should undertake to evolve to the Next NWS, although it is the one that we have stressed as most central to resolving our major issues. It focuses on the observation/assimilation and PQPF aspects of USWRP, and while this is at the core of the NWP process and hydrometeorological warning and forecast system (and similarly advances severe storm and aviation weather predictions), you will want also to improve climate, space, marine, and hurricane products.

PREDICTIONS is thus intended as a model, and as a catalyst for these other efforts. And although we believe it should receive priority consideration in your analysis, programming and budget preparation process, it should not be your only technology development and infusion thrust. We recognize that you will face many demands from your new Requirements process; and while we have tried to anticipate some of them in our proposal, there will be many competing ideas that you must analyze and trade off in the context of the overall system architecture via performance metrics and cost-benefit analyses. We also caveat our recommendation by noting, as did the Academic Community[29], that NCEP -- and in particularly EMC and NCO -- are central to the entire process; and if they are less than healthy, the entire enterprise is in trouble. Thus in the next section of this report we make some specific suggestions for near term actions designed both to fix problems, and to build a sound basis for and process of technology infusion. PREDICTIONS addresses some but not all of these.

4. Some Immediate Concerns and Suggestions

In the Philosophy section we tried to provide you a framework within which to structure your management approach to technology infusion. The PREDICTIONS proposal is intended to address deficiencies that have long been acknowledged, but that needed the Modernization program improvements and a formal multi-agency commitment to USWRP as preconditions to implementation. Here we make more pointed and immediate observations and suggestions, to help you rectify some deficiencies and start to improve the overall climate for technology infusion. Many of these we have already mentioned briefly in our first report.

a. NCEP. One immediate problem is glaringly obvious: several unfilled senior positions[30]. The Acting Leadership is very competent and doing a commendable job of maintaining output (and the ripple effect on their subordinates can even have some benefit through the experience and training offered by

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this magnitude on the heels of the Modernization program (and in the face of other NOAA priorities such as climate change), even assuming that the perceptions associated with USWRP have been completely rectified. A funding and marketing plan however was beyond our capability, because such must be carefully developed over time, by NWS management, in conjunction with other NWS needs, such as enhanced computer power and hydrology. We therefore contented ourselves with the programmatic cop-out of merely outlining and supporting the concept in-toto, leaving implementation to management.

[29] Op cit 17, paragraph 1.d

[30] We note with pleasure that the position of NCEP Director recently has been filled, and look forward to his swift action to fill the open positions on his staff.

temporary expansion of responsibilities). By the very nature of 'lame duck' Acting appointments, however, they can not be expected to provide the long term dynamic leadership for change that the organization desperately needs. We have previously suggested, and reiterate here, that you consider using IPAs or, perhaps even better, detailees from then OAR labs, if the desired level of permanent talent is not immediately available. Not only are there highly qualified leaders who would, we believe, be willing to serve for a few years but not want to take on a permanent NWS Washington job, but these types of assignments help build and extend the partnerships you need with the labs and with the non-federal research structure. The same argument of course applies to open leadership positions at Headquarters[31].

We reiterate that NCEP is at the heart of the NWS field operational warning and forecast system. NCEP guidance, derived largely from NWP model output and statistics, is the basis for the 'value added' work of WFOs, RFC, industry, the media, and the research community. "Enhancements in NCEP capabilities stimulate improvement throughout the NWS; reductions in NCEP capabilities redound throughout the NWS in deteriorating capabilities to protect lives and property"[32]. And at the center of NCEP, as graphically depicted in its organizational diagram, are the Environmental Modeling Center (**EMC**) and NCEP Central Operations (**NCO**). We, and many of those we have spoken to during this study, are **extremely concerned with the health of these two offices.**

(1) EMC[33]: The danger signs at EMC include lack of effective prioritization processes, insufficient base funding which compounds the work allocation problem, and an insular concept of operations that fails to adequately access the national talent and resource base. EMC is a **bottleneck**, and the contrasts between its operations, attitudes, and working atmosphere and those of comparable organizations in Navy and Europe are palpable. Its problems are severely compounded by inadequate computational and financial resources (which we treat separately below), but not fundamentally due to them.

We believe that one of your first steps with regard to EMC must be to identify resources to fund an adequate base level of operations[34]. EMC now operates on about half 'soft' money; and although those funds are derived largely from other NOAA offices (e.g. NESDIS, OAR), they are both a source of friction and a cause for distraction since attention follows money. NCEP and EMC are the heart of the entire NWS Field operational apparatus; and while there is and must continue to be an element of "R&D" in EMC's work, it should be very far to the D end of the spectrum and very tightly applied to upgrading the operational models. NWS and NCEP management must regain control over an adequately staffed EMC, direct its priorities, and focus its efforts on well defined and approved requirements; even at the cost of sacrifice of significant resources in other parts of NWS.

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[31] We are not alone in recommending that use of detailees and IPAs be considered not just as a stop-gap measure, but a preferred means of supplementing and invigorating the Federal technological work force. For example, the recent Defense Science Board study, "The Defense Science and Technology Base for the 21st Century" suggests that DoD and the Services "fill key science and technology management positions with limited term (4-6 year) high-quality scientific personnel from the private sector (universities, non-profits, and industry)", and likewise revitalize the DoD labs with similar IPAs.

[32] Op cit 22, paragraph 1.d.

[33] We received a number of comments on our report from the Acting Director of NCEP. Most of them pertained to our concerns with EMC. The EMC and NCEP staff clearly saw their situation very differently than we did. We therefore discussed the comments at length on 5 January, and while we have made some minor changes to our write-up, we emphatically reconfirm our basic concerns and urge immediate attention to what we believe are required changes to EMC resources and CONOPS.

[34] This is of course included in PREDICTIONS; but whether as part of such an initiative or simply as a isolated action, it is **essential**.

While this is a necessary first step, it is only a stop-gap measure. The **coupling between observations, assimilation and models** is the core feature of the entire system architecture for the Weather Service, and the current EMC concept of operations pays inadequate attention to the dynamics of these interactions. The result is underutilization of vast observational resources, inadequately defined and validated requirements for new systems and capabilities, and relatively poor recent performance (compared both to others and to what should be expected) in NWP. The evolving Next NWS and its successors will rely even more heavily than Today's on the quality of NWP gridded model output (as well on output at a range of nested scales, from global to local), so *attention to the structure and concept of operations of EMC becomes a matter of top priority.* We make some recommendations along this line as part of our PREDICTIONS proposal. Here, we want to stress two aspects of EMC CONOPS that we believe are critical to any future technology infusion.

First, it is essential to have a *"test bed" structure that operates in parallel with the operational models.* This is obviously a major driver of computational capacity; some degree of testing is built-in to the current architecture, but we believe that *much more parallalism* of test-evaluate-upgrade and operations, and *much greater duration and scope of testing and validation*, are essential. Again and again we heard complaints that observations weren't being used, or that new system requirements (in particular those for the next generation satellites, where billions of dollars are at stake) are inadequately validated in terms of cost-benefit and outcome metrics, because it is impossible to run the model-based tests to determine how much difference adding, subtracting, or changing the nature of observations makes[35]. This situation is the epitome of penny-wise pound-foolishness.

We note that this deficiency will only be exacerbated by projected (and inevitable) "improvements". For example, data assimilation is a crucial part of model operation, and advances like "4DVAR" that allow for asynchronous and continuous data ingest promise solid improvements in model skill. Such advances however increase computational intensity, for both operations and for test and validation. We also believe that that it will become increasingly more important to effectively incorporate into operational models, data from research-oriented observational systems (e.g. NASA satellites, the COSMIC soundings, University of Wisconsin cloud winds, buoy and ship-based radars and profilers), which in turn can drastically shorten the transition time (and cost) from research to operational observation[36], and equally dramatically change the process of requirements development and validation. But the price for these improvements is yet more computation, and more testing.

Another inexorable improvement is model resolution, driven to a degree by increasing computational capacity and physics, but perhaps more fundamentally by concept of operations. Weather warning and short term forecasting, we believe, is headed to "human" scales. This implies a need for a highly compatible system of nested NWP activity from global to local. Whether this is implemented through

[35] We note that this is as true for climate as it is for weather. Although we focus here on EMC, the same problem pertains to CPC, that essentially fulfills its own EMC-like function. This deficiency takes on added importance as NOAA and the other agencies strive to respond to the request from Congressmen Saxton and Weldon for an integrated national plan for ocean observations. Climate is a major customer for ocean observing systems, and an inability to determine which measurements have the most relevance to model output severely degrades the quality of any requirements for observing systems. For climate the current problem is primarily computing capacity; but our CONOPS concerns regarding EMC should be heeded for the future.

[36] Perhaps the best extant example of this is the evolution of the TAO array for El Nino observations in the Pacific, directly from OGP's earlier TOGA/COARE research program. This is a very powerful approach to technology insertion that can knock decades off the cycle time. We argue that this approach should become a normal way of doing business. Our point here is that for this to happen, the fundamental EMC concept of operations, and the partnership between NWS and the research community, must change.

dispersion of NWP responsibilities or through central NCEP modeling focused on 'hot spots' remains a matter of debate, although we believe that local offices should play some significant role given their local knowledge and increasing communications and computational capabilities. The Navy employs nested models because of its worldwide responsibilities, and is testing a concept of fielding NWP on some major ships; distributed modeling is intrinsic to the European system; and over 20-some research groups in the US, several of them closely aligned with WFOs, are already conducting NWP at very fine scale using NCEP output as initial and boundary conditions. NWS policy currently prescribes that all operational NWP occur at NCEP. This is simply unenforceable (as well as obverse) given the dispersion of NWP interest and capability. NWS must reassess its approach, and reconsider NCEP and in particular EMC CONOPS as a result. As a first order of business in this regard, NWS needs to work with NSF in the development of common model infrastructures at both global and mesoscale levels, accompanied by the extension of its architectural strategy to incorporate nested models at regional and local (down to about 1 km) scales.

The dispersion of NWP capability, driven by its power to address local needs and develop value added products, argues for yet another change in EMC CONOPS, namely dramatically expanded outreach and partnering. This has already occurred to a degree, e.g. GFDL's role in hurricane model development and FSL's in RUC. We argue that such shared responsibility, calling much more than at present on the computational capabilities and intellectual talent at outside organizations (OAR labs, UCAR/NCAR, DoD, NASA, Universities) should become the basic modus operandi. We recognize that this implies willingness on the part of the outside partner to accept maintenance as well as development responsibilities; but we do not see this as an impediment to the concept. In fact we believe it essential, given the trends of information technology and the public appetite for environmental warnings and forecasts. We argued in the Philosophy section for much more teaming and partnering across NWS, and EMC is an ideal place to start. Dramatic improvements (and much easier, cheaper, and more rapid evolution to the vision of the NRC's Road Map study) are possible with a willingness to harness the national infrastructure in such projects of shared interest[37].

(2) NCO and Computing. We commend to you the findings and recommendations of the 1997 UCAR Review Team Report on NCO. Now that the Class 8 has been selected, the **Review Teams' recommendation for a follow-up should be implemented immediately**. The concerns they expressed regarding staffing expertise needed to operate the advanced parallel architecture system and provide adequate support for geographically decentralized operations were reiterated during our interactions, and deserve close attention.

NCO personnel expressed grave concern about the condition of their facilities and the security of the computer systems. We have similar concerns with the adequacy of the support services staff, particularly given additional projected NCEP drawdowns and the strains of the transition. Adherence to common formats (BUFR and GRIB) and the establishment of a common distributive network are commendable developments, but they need to be reinforced. We comment further on communications issues below; our main point here is that the transition to the Class 8 computer -- for EMC as well as NCO -- will put

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[37] We note that NCEP's previous suggestion to move NCO and EMC to Goddard in parallel with the acquisition of the Class 8 computer indicated their recognition of the advantages of immersing these functions within a much larger community of interested scientists. Certainly a physical move -- whether to Goddard or to other centers of excellence such as Norman, Oklahoma or Boulder, Colorado could have enormous benefit both for intellectual broadening and for access to detailees. However we believe that our concepts of expanded test beds and partnerships within a common model infrastructure can be executed even from their currently inadequate physical confines; "virtual" or extended centers are perhaps even better than physical centers of excellence given the pace of dispersion and the power of information technology.

severe strains on the system, and we are convinced that the organization is not well posed for the challenges. NCO needs senior management attention and staff training, augmentation and modification, very soon.

We understand that NOAA has agreed to shift to a policy of routine major upgrades to the primary computer on a 3-year cycle. Such a policy plus the very nature of the parallel-processor Class 8 which allows for incremental increases in capacity, will go a long way to alleviating the grave problems caused by the current upgrade. Even so, we are not convinced that the "team" needed to provide and maintain adequate computing capability (NWS, NOAA, DoC, OMB, and Congress) for NWP, fully appreciates the magnitude of the problem. We addressed this briefly in our comments on EMC and in footnotes above, and reiterate our belief that **orders of magnitude upgrade**, not simply marginal improvements, will be needed if we are serious about significantly improving the quality of our weather and climate products with concomitant socioeconomic impact.

We believe that it is very important for NWS to establish an unassailable case for maintaining a leading position in high performance computing, comparable to that accorded nuclear stockpile stewardship, both at NCO and at the distributed sites we envision as essential to effective performance of EMC (and the other NCEP Centers, especially CPC). We have heard many justifications based on comparison with other major weather services and computing centers around the world[38]; while we sympathize with these sentiments we do not find such comparisons compelling *by themselves*[39]. Rather, to reiterate some of our arguments, we contend that the case for order of magnitude upgrades can be made, based on empirical and theoretical evidence and the history of NWP, as well as even first-order quantification of computational power needed to support:
- Improvements in mesoscale model resolution to the limits of already demonstrated dramatic improvement in warnings and forecasts (nominally <<3 km) and the implementation of nested models;
- Improved data assimilation and probabilistic or ensemble forecasting techniques evolving from ongoing NWS/ERL efforts and USWRP (and PREDICTIONS);
- Significantly increased parallel testing and experimentation to advance assimilation capability, ensure continuity of physics and parameterizations in the coupled global-to-local model suite, incorporate the currently under- and un-utilized observations that have already been demonstrated to yield significant performance improvement, and adequately define the characteristics and validate the utility of proposed new observations - particularly those from extremely costly satellites and ocean observing systems -- and to make cost-benefit tradoffs among alternate observational approaches;
- Transitioning to a much more geographically distributed system of NWP (and associated testing and development) in order to adequately address regional and local needs (a matter both of resolution, and of the basic nature of warnings and predictions which vary greatly with topography, demography, and

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38 E.g., we were told at UCAR that NCO barely makes it to the bottom of the June "top-500" list (see http://www.top500.org). I couldn't even find it in the November list, although this is probably because that list was issued prior to selection of the Class 8.

39 They are nonetheless very powerful arguments for serious concern about out national program. As we said at the start of this report, technological superiority is essential for global leadership in NWP, and computational capacity is one of the three building blocks cited by the NRC Roadmap Study. A spirit of competitiveness is essential to building and maintaining quality, and it becomes progressively more difficult to attract the best staff if the resources for their discipline are less than adequate. At some point -- and we believe that NCO is at that point *even with the Class 8 -- inadequate computing means not just doing less well, but not doing some essential tasks at all.* Inability to adequately test new model components, assess the impact of various observations, frequently upgrade model resolution, etc., has extremely negative impact on the entire enterprise. The associated waste and lost opportunity costs may be difficult to valuate, but nevertheless this should be attempted. A "cost-detriment" analysis of failure to invest is called for here. We see no reason why NCEP -- our nation's premier operational NWP office -- should settle for being less than the best. At present it clearly is not.

season -- e.g. flash flood, volcanism, severe storms, tornadoes, snowfall during rush hour, allergens, contaminant spill dispersal, and on and on and on, all with huge socioeconomic impact);
- Significantly expanded climate products (week 2 out; climate is the subject of two of NOAA's Strategic Goals which we haven't ever addressed in our review, but which have computational needs very comparable to what is today accorded EMC/NCO);
- Extension of "weather" warning and prediction to currently under served communities through, e.g., global ocean models, atmosphere-ice-ocean coupled models focused on the Arctic, and regional ocean-atmosphere coupled models in support of NOAA's (and national) responsibilities for fisheries, coastal zone management and the protection of living marine resources.

In sum, we believe that both the current and planned computational systems centered on NCO are dangerously sub-marginal and that a compelling case can and must be made for the type of improvements that will be needed to evolve to the Next NWS and the NWS-After-Next. We note that given both currently available capabilities, and projections of continued improvements in computational capabilities, what we suggest is neither technologically unreasonable nor unaffordable.

b. Communications. We were briefed on the astounding proliferation of communications systems. We have three basic areas of concern.

The first is compatibility among, potential excessive redundancy between, and likely future limitations of, major data distribution systems. At least three major NOAA networks/offices move massive amounts of data product to users: NESDIS for satellite data, OSO for AWIPS, NOAA Family of Services and other users, and NCO for distribution within NCEP and to OSO[40]. NPOESS and the next generation geostationary satellites alone will generate orders of magnitude more data for these systems to digest and move. It is not at all clear that the communications architectures are adequate to handle the expansion. Nor is it clear that three separate systems are needed. We believe that NWS (with NESDIS) would do well to **commission** (from appropriate industrial telecommunications firms) **a strategic telecommunications survey**[41] to assess this issue in depth, and in time to be able to plan infusion for evolution rather than having to take remedial action.

The second issue is NOAA's policy against use of the internet for "operational"[42] data. We fully appreciate and support the use of dedicated circuits for the transmission of strategically important operational data such as implemented for AWIPS. However it is not wise to deny the WFOs routine and integrable access to other products that can improve their warnings and forecasts (e.g., output from FNMOC and ECMWF, and the wide range of other weather products available on the web); and information from their 'local' networks, or from other tools disregarded at NECP, can be equally as important as the AWIPS feed[43].

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[40] The NCO system is not well documented, and in fact was described by its developer as a bit of a 'rogue' system that grew from the need to manage communications for the Atlanta Olympics. The efforts of the in-house team to meet NCEP needs are commendable but there is natural concern about robustness and expandability.
[41] We note with pleasure NWS's establishment of a Telecommunications Tiger Team, and reiterate our strong recommendation that this review must consider NESDIS as well as NWS architecture and operations.
[42] We are concerned with the process by which something is designated "operational", and with the implications of such designation. Certainly some method to assess and certify data resources is essential. However, imposing a somewhat arbitrary and ill-defined constraint on systems which can contribute to NWP can seriously impede the evolution from research to operations, and exclude extremely valuable information and data. The practice of various NECP Centers and Headquarters offices varies in this regard. We suggest you review the use of this term.
[43] A September 1998 UCAR Review Panel of NCEP's Aviation Weather Center reached a similar conclusion.

Further, we believe that future global "networks" will be sufficiently robust that they can be routinely employed to support significant aspects of "operations" (concern for infrastructure protection should center on the interface to the network, not the network itself). Such use could help eliminate the need for multiple redundant feeds to academia and industry, and encourage partnering. It could lower the load on dedicated AWIPS links. Some such technique would seem to be required to support the concept of a dispersed or virtual EMC, and the routine use of NCEP gridded output as BC and IC for geographically distributed, locally run high resolution NWP models, which we envision as not only inevitable but highly desirable. The policy should be changed immediately to encourage an 'ensemble' approach to the use of central guidance at the WFOs, and options for enhanced and systematic use of the NGI should be addressed as part of the strategic telecommunications planning.

Third: we were impressed by the number and diversity of distribution channels for tailored warnings and other products to both the public and emergency managers at federal, state and local levels. We fully appreciate the benefit of such systems as NOAA Weather Radio. However it was not apparent that all of the various channels and distribution systems are well integrated with an overall national (or global) disaster information or emergency management infrastructure. The panel does not have the experience necessary to properly assess this issue, but does recommend that it be included in an overall evaluation of the NOAA strategic telecommunications architecture.

c. Relationships with OAR Labs. Concerns and recommendations regarding NWS's relationships with the labs (and with NESDIS) have been sprinkled throughout this report. We see the strengthening and restructuring of the relationships to be a matter of central importance to the process of technology infusion, and in fact assumed such while developing our PREDICTIONS proposal. To be effective, any specific changes must derive from discussions and planning between the AAs and their staffs; we merely suggest that the following points be considered during that process:

- Improved partnering in support of NOAAs strategic goals is the basic objective.
- Shifts of line office affiliation should be on the table[44]. SEC is an obvious example; it is an NCEP element but remains under OAR/ERL and does in fact conduct significant research in support of its own operational activities. NWS headquarters elements that perform lab-like functions, e.g. TDL of OSD, are similarly *obvious anomalies*.
- Detailing in both directions should become a core element of personnel management, both to optimize the use of talent and to enhance partnering.
- Customer-supplier relationships should be carefully but rigorously defined. This must include the establishment of some basic principles of interaction, as well as specific focal assignments of responsibility. As one important example, we believe customer "**requirements**" -- deriving for example from the new NWS process -- should whenever possible be stated in terms of **capabilities;** all parties involved in meeting these requirements must be then involved in developing solutions to meet the requirements. In particular, the labs must be able to initiate, evaluate and propose alternative technical (and CONOPS) approaches. The requirements process should never dictate solutions[45].

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[44] The incorporation of OGP in OAR and COP in NOS are examples of the sort of organizational changes that can enhance NOAA's effectiveness.

[45] Developing a good requirements definition process is never easy. The process being put in place by NWS is a good start, but it is mostly applicable to internal activities and the Next NWS. It should be extended -- with the participation of OAR and NESDIS -- to comprehend different time frames, transition and partnering, and budgetary responsibilities. We can not prescribe what this process should be; but hopefully we have provided considerable guidance about its qualitative features, the most significant being equitably meeting the needs and concerns of all partners.

- NWS-Lab relationships must also comprehend the use of the CIs of both offices[46], as well as broader relationships with industry and universities. Again the emphasis must be on partnering and mechanisms to broaden outreach, assure access to the best performers, and stimulate intellectual competition. *Public-private competition for work must be avoided at all cost.*
- The labs are a national resource and must be encouraged to solicit and accept outside government work. Not only does NWS benefit from the resulting research, it is extremely important for other customers such as DoD and the FAA. However, the NOAA labs' primary loyalty should be to their NOAA operational customers.
- While our primary concern is with the Labs' R&D role in support of NWS technology infusion, the labs can also be a source of data and of direct operational assistance. Our recommendations for an "extended EMC", for example, mandate that *labs accept responsibility for maintenance and upgrade of portions of the operational modeling* suite. This may not require a significant commitment of personnel (*and should be funded by NWS*), and over time such responsibility diminishes or changes as the model elements mature, but the labs must recognize what the commitment entails. Similarly, some labs are responsible for the operation of data collection systems -- be they 'research' or 'operational' (the distinction is often in the eyes of the beholder) - that provide input to NCEP operational models. Just as with NESDIS for satellite data, such relationships should be formally structured[47] to provide rigorous evaluation and outcome-based justification by the data user of the data requirements, within the construct of an overall system architecture. The *CPC relationship to the GOOS office at AOML* (and TAO management at PMEL) is a specific case in point.

d. The Role of the SOOs. We alluded in our first report to the central role of the SOOs in formulation of locally-based requirements, and infusion of technology into the operations of their offices. As the dispersion of NWP that we predict (and promote) increases, their roles and relationships to local partners (for both modeling and data) will take on even more critical importance. We expect that the distributed system of WFOs and RFCs will lead to a flowering of innovation at the local level as the turmoil associated with early changes in the Modernized offices diminishes and their capabilities mature. This is evident already in some of the more 'advanced' offices, and those with the closest connections to major academic centers. Some care will be needed however to keep the entire system convergent, and to prevent the evolution of 'haves' and 'have-nots'.

We suggest therefore that NWS start early to promote bonding and partnering among the SOOs, and to involve them in establishing some basic NWS corporate guidelines for infusion into their dispersed centers. This can really only be accomplished by face-to-face gatherings with adequate opportunity for informal interaction as well as structured training and discussions. We recommend therefore that the SOOs (and their RFC counterparts) meet formally (at least) twice yearly. One of these meetings should be at the Regional level, where local issues can best be discussed in depth; this meeting should be timed to obtain the SOOs' input into the formal Requirements process.

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[46] We suggest a review of the CI MOU's to ensure the CIs are not artificially restricted in their ability to support multiple line offices. It may be advisable to consider a single NOAA-wide system as opposed to current LO-centric agreements, particularly given the need for better partnering between ERL labs and NWS. The NWS CIs could clearly benefit from labs' help in impedance-matching, as well as a different form of tasking and funding; OAR CIs could profitably become more involved in operational support and be a source of NWS IPAs.

[47] The 'formality' of such a relationship should in no way impede research collaboration. Formality and structure in requirements definition are essential, however, when one office must base its plans and defend its budgets based on the data needs of another, as it certainly true of satellites and ocean observing systems. NWS's partnership with NESDIS also would be improved if this approach was adopted.

We also see great value in an annual 'convention' at the national level. We discussed several features of such a meeting which we believe would contribute to the overall objectives of sharing best practices and building a culture of technology infusion. Just a few examples include[48]:

- Senior NOAA and NWS leadership should brief major plans and programs, and provide schedules for and information about projected upgrades (e.g. AWIPS releases) for the coming year;
- Each SOO should prepare a poster describing his or her most significant development activities, and there should be adequate time in several sessions for poster presentations and discussions; prizes and awards for outstanding posters would encourage quality;
- Each meeting should be held at a different OAR lab, NCEP Center, or academic or industrial center of excellence, with adequate time to visit facilities and discuss research;
- OAR labs, NESDIS, UCAR/NCAR, universities and industry should be invited to have 'booths' to display their ideas and promote opportunities for teaming and for research under COMET or similar programs;
- The SOOs should participate in working sessions devoted to discussions of technology infusion policy or techniques;
- The meeting would provide a good opportunity for short formal training sessions on new systems and techniques.
- Informal activities such as sporting competitions among regions, or visits to local cultural features, should be used to promote interaction.

We believe that these *types of meetings are of sufficient importance* to both the culture and the practice of technology infusion and teamwork in the NWS *that they should receive priority in budgeting* at the national level.

e. The "Soft Money" issue: We have already commented on the importance of adequately funding the base operations of EMC, even at the cost of reallocation of resources from Headquarters activities. There is however a broader issue of budgeting and funding allocation overall within NOAA that needs some consideration. NESDIS representatives, for example, expressed concern that they not only provide data and products to NWS, but have to fund NCEP to get them to use them; fixing this problem is not simply a matter of money, but of closer NWS user involvement, support, and budgeting, from the very start of the satellite development process. Similarly, we have commented on NWS's inability to either set requirements or even 'buy' effort at the Labs (or for that matter from academia or industry when they are the better performers for some tasks)[49]. The entire system seems over constrained.

We believe there are two parts to this problem. The first is that NWS must make a better case for an adequate research and technology infusion budget. We have tried to suggest several ways this can be done throughout this report. We recognize that many if not most of our recommendations exacerbate the problem by pointing out deficiencies that need to be fixed, or suggesting activities for improvement, that all cost money. Restructuring the organization to develop resources that can be reallocated is part of the solution (on the optimistic assumption that they'll let you keep what you save - a practice to which

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[48] We spent considerable time discussing the importance of the SOOs at our third meeting. An additional suggestion which arose was rotating the SOOs into the OAR labs and into Washington offices (especially NCEP) both for training and to take advantage of their new ideas. One concern with this concept is that NWS staff traditionally has been immobile. Noting that mobility is an essential aspect of work for most professionals in industry (as well as the military) these days, we suggest that this philosophy must change, and encourage NWS to make willingness to relocate several time throughout a career an essential part of the job description for SOOs.

[49] The use of CI's, for example, is overly structured, with each getting the same amount under the Long Term Activities portion of the CSTAR program (and a similar practice, although with even less funds, for the hydrology CIs). The system must become more open and intellectually competitive.

comptrollers are unaccustomed and IGs allergic), but there is no escaping the need to provide a compelling rationale, including where appropriate cost-benefit arguments and metrics, that engenders a sense of partnership between NWS and the chain of management that must generate and allocate funds.

The second part of the issue is allocation of responsibilities and resources within NOAA. Since much of the "soft money" spent by almost all of the offices we talked to comes from some other office within NOAA, it may be worthwhile to examine alternate schemes of allocating resources to the operational line offices. NOAA has for example adopted a cash-based process for "Data Acquisition" for ship time, and may wish to do the same things for Lab support, or even for Satellite products[50]. Such approaches make the service-providers much more cost-conscious, and the type of improvements demonstrated by ONCO may be able to be replicated in other parts of the organization. Other agencies have found that these procedures can work even for R&D (e.g. the Navy and Army Corps of Engineers labs operate under a working capital fund system) and inspire not only efficiency but enhanced sense of ownership by customers. We urge you to study such alternatives, to discuss them with the other AAs, and *if appropriate* recommend changes to NOAA and DoC management.

f. Training and Education. We have described a future in which NWS may operate very differently than at present. NWS recognized the significance of the changes associated with the Modernization Program, and put in place the training programs needed to provide the skills to use and service the new systems. We have noted that we anticipate (as did UCAR) that a similar shift in skills will be needed to properly employ the new Class 8 computer. Our suggestion regarding SOO meetings should likewise be considered as part of essential training. Our recommendation here is simply to ensure that for each new capability that comes out of your Requirements process, you include training and education as one of the essential elements of solution-development.

For the Panel:

Craig E. Dorman

[50] There are so many of these just for the polar orbiters that a rather sophisticated computer program is required to track them. It is not at all clear in many cases who the users are, or how and how much they benefit from the products.

Enclosure (1)
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Enclosure (2)
PREDICTIONS

Much of the high cost to society of weather related events can be attributed to the user not believing the forecast, or not having enough time to take effective preventive action. The proposed PREDICTIONS Program addresses these issues by implementing a more **site specific, highly accurate, weather forecast system that can provide extended warning times.** This is possible because of recent progress in several of the components that make up the weather prediction system. The NWS Modernization Program plus research and development in the areas of observing, assimilation and modeling, have brought us to the threshold of major weather service improvements. When properly integrated, these advances will make it possible to deliver the required site specific, highly accurate service that will reduce the present large societal costs. The Program objectives are:

* To double the time available for taking effective preventive actions prior to potentially dangerous weather events, and

* To reduce by half the area affected by weather warnings.

An important conceptual foundation of PREDICTIONS is that a **balanced improvement of the observing, assimilation and modeling components is needed.** If these three components are thought of as a pipeline, starting with observations, it is clear that investing to bring each to a level matched by the other two is essential for an optimal system. Achieving the Program objectives will require a concerted effort to improve and refine each element of the weather prediction system, and to integrate these advances to create a capability with no weak links. The defining question is: what combination of scientific understanding, observing system improvements, better assimilation, and advanced numerical models are required to achieve our objectives? As answers to this question emerge, in large part from the US Weather Research Program (USWRP), they will be validated in regional demonstrations which will also serve as critical decision points before full operational implementation of the proven capabilities.

The first phase of PREDICTIONS (FY2001-05) will focus on two demonstration regions. One is over the eastern land area of North America, from the Mississippi river to the coastal Atlantic, including the area from the southern Caribbean to central Quebec. This domain is large enough to capture a variety of severe weather types ranging from ice storms to hurricanes, and is ideal for demonstrating the economic and safety benefits of the program. The second domain includes the eastern Pacific, from the pole to the equator, and from the dateline to, and including the entire west coast of North America. This region is critically important for validating new ocean observing systems, and determining the impact of richer upstream data sets on weather over the North American continent. The second phase of the Program will concentrate on full operational implementation in the initial two demonstration regions, in parallel with demonstrations in the western and central United States.

PREDICTIONS comprises **five tightly interrelated thrusts**, targeted at problems and opportunities described by the NWS Technology Insertion Panel:

1. A world class central prediction capability is critical to the success of the program. Currently NCEP's dependence on "soft funding" is a threat to their ability to maintain this position. Because of **NCEP's critical role, PREDICTIONS will enhance this important function by placing it on a firm financial footing.**

2. In recent years there has been a revolution in modeling, with full physics, non-hydrostatic models now running at resolutions below 10 km. These models realistically depict mesoscale weather like blizzards and severe thunderstorms. These models do very well when the initial conditions are from areas of dense observations like the central U.S., where there are many automated aircraft observations and the profiler demonstration network. At NCEP, efforts are underway to replace the hydrostatic primitive equation models, which have been dominant the last 40 years, with the new full-physics non-hydrostatic models. **PREDICTIONS will extend and expedite the work with NCEP, NCAR and ERL/FSL to develop a next generation community mesoscale model**, for wide use in both the research and operational communities.

3. The advanced observing systems put in place by the NWS modernization, specifically the NEXRAD radar network and the GOES satellites with their improved imagers and sounders, have value that is yet to be exploited. PREDICTIONS will "mine" this untapped resource. For example, the newest generation of mesoscale models, those that would be used by PREDICTIONS, are the first to have full microphysics with rain, snow, cloud water, and cloud ice carried explicitly. First order measurements from satellites and radar, such as cloud radiation and meteor reflectivity, would become fully useable in these models. Numerical weather prediction models have historically been initialized twice a day using the radiosonde network. As "asynoptic" observations increased, assimilation systems that use these data have slowly evolved. It is only now that truly sophisticated assimilation (e.g. four dimensional variational formulations) are maturing sufficiently that the dominantly asynoptic satellite and radar data can be properly incorporated into the initial states of the predictive models. For example, if cloud drift winds are used only at the radiosonde time , (e.g. 12 Z) they include only 1/12 as much data as they could if an assimilation included the hourly data from 0 to 12 Z. There have also been major advances in the mathematical understanding and the computing power needed to implement the "4D VAR" techniques. **PREDICTIONS will assure that the full benefits of the investments in GOES and NEXRAD accrue to the public in the form of better numerical weather prediction.**

4. The forecast specificity and accuracy called for in PREDICTIONS require these higher resolution models that are driven by improved physics and in many cases observation densities that are not possible with the existing instrument mix. Very accurate short range prediction over the continent will require knowledge of the dynamic (i.e. winds, temperature and pressure) and moisture fields down to scales as small as 100 km where amplification and decay of small dynamic disturbances are difficult to predict. Since dynamic fields are coupled, it can be regarded as a single unified problem to properly diagnose the three dimensional winds, temperature and pressure fields. Over the land much of the required resolution can come from detailed and temporally dense soundings from commercial aircraft. However the program (ACARS) that provides these data is not "operational". PREDICTIONS will operationalize ACARS and add capabilities like moisture sensors for many of the aircraft. An ground-based remote sensing network, consisting of approximately 120 wind, temperature (RASS) and moisture profilers also would be reviewed for phased operational implementation. **PREDICTIONS will certify and bring to bear on NWP, important observations already funded by NOAA.**

5. In addition to these existing but not yet "operational" observational systems, **several promising new (and alternative) sensing approaches will be evaluated for their future impact.** The ability to sense integrated water vapor between ground based installations and individual GPS satellites suggests that the moisture field could be completely defined in four dimensions down to the 100 km scale. COSMIC, a new satellite based system, would deliver global temperature soundings above the mid-troposphere, and would provide information to a variational assimilation on moisture and

temperature down to lower levels. **PREDICTIONS would allow the United States to ingest and test COSMIC data**, leveraging a very promising global observing technology which is being funded mainly by Taiwan. Efforts are underway to **design and test concepts needed for global wind diagnosis** using lidar, **and** to use microwave scatter to determine the **wind speed and direction at the surface over oceans**. PREDICTIONS will play an important role in the validation of these techniques and in implementing the ingest and assimilation of these new data sources.

PREDICTIONS is complementary to and designed to exploit two major existing programs. **NAOS**, the North American Observing System, has the mission of systematically determining the optimal composite upper air observing system. It involves the United States, Canada, Mexico, and a representative of the Caribbean region. It is using numerical models, both in Observing System Simulation Experiments and in Data Denial Experiments, to evaluate the role and determine the best mix of observing systems. **PREDICTIONS would use the results of NAOS** as information **to guide the planned demonstrations** and their operational implementation. The multi-agency **USWRP** has effectively marshaled the U.S. research and development community to participate in the on-going effort to improve weather prediction. **PREDICTIONS is required take the ideas and recommendations of USWRP and make them operational.**

Other existing programs, such as geostationary and polar orbiting satellites, the national radar network, and the on-going cycle of keeping state-of-the-art supercomputers at NCEP, serve as the foundation for the advances envisioned in PREDICTIONS. By building on and leveraging these existing capabilities, PREDICTIONS can concentrate on implementing the needed augmentations.

The National Weather Service has developed a state-of-the-art field system through its modernization. Its radar, satellite and information systems (AWIPS) are the best in the world. However, most observers agree that the U.S. is no longer the world leader in centralized numerical weather prediction. PREDICTIONS main goal would be to provide the people in the United States with the **world's best short range weather predictions.**

In summary, PREDICTIONS will achieve its
Program Objectives and **realize for the nation the full promise envisioned in the NWS Modernization Program through**:

- Revitalization of EMC
- Improved NWS/ERL and extramural partnerships in development, validation and operations
- Implementation of scientific advances (from USWRP and other research programs) such as better model physics packages and assimilation techniques
- Certification and employment of existing valuable observational systems
- Fielding, demonstration, and validation of new observing technologies
- Refinements in the use of information from satellites and radars, via better ground processing for satellite observations and improved four dimensional assimilation
- Full exploitation of the improvements in the Modernized NWS operational system

The budget estimate for the first (5 year) phase of the program is $200M. Follow-on efforts for an additional seven years to complete the program, at approximately $40M/year, would be contingent on the success of the first phase.

Prepared by A.E. MacDonald

Enclosure (3)
Comments on OH/HRL and OSD/TDL

We comment first on each organization separately. We then present a summary set of suggestions.

A. Office of Hydrology (OH) and Hydrologic Research Laboratory (HRL)

1. Introduction

These comments are based on a 3 December 1998 visit by Dr Holland and Dr Smith to OH, review and discussions of their report by the Panel members and with AA Kelly, and questions posed to TDL on their role in flood prediction.

OH comprises three components co-located at NWS Headquarters: the Office of the Director, the Hydrologic Research Lab (HRL), and the Hydrologic Operations Support Division, each headed by an SES. OH also maintains a Remote Sensing Center in Chanhassen, MN which is co-located with an RFC and a WFO.

OH is a small (about 5% of NWS in trems of both FTE and budget), compact component of NWS whose traditional customer base has been the RFCs. Interaction with the WFOs themselves is growing significantly however, due to the increasing hydrologic capabilities being incorporated in AWIPS, and in part to the co-location of RFCs with WFOs. This co-location has generally been a positive move, but has weakened some traditional ties between RFCs and other agency field offices (such as the Army Corps of Engineer's Reservoir Regulation Centers in Corps Division Offices that were previously located in the same buildings with the RFCs).

RFCs are normally staffed at the 7-day, two shift level with 3rd shift backup from headquarters, but operate full time during riverine flood events. The activities of RFC staffs center on **river flood forecasting**. All warnings (e.g., flash and systemic flood warnings) are issued by the WFOs. All aspects of tropical and extra-tropical storm predictions (e.g., storm surge resulting from storm landfall or near-coast storm track) use models developed by the Office of Systems Development's (OSD) Techniques Development Laboratory (TDL) and NCEP's Tropical Prediction Center (TPC) in Miami. There is no apparent connection between coastal storm surge predictions and river forecasts even though each obviously affects the other. Similarly, work on flash flood prediction (in, e.g., SCAN) derives from TDL (with NCEP, the labs, and UCAR/NCAR). This partition of responsibility for hydrologically-related forecasting frames the structure, R&D, technical support activities, and operational paradigm of today's (and it appears, at least tomorrow's) OH.

2. OH Today

OH's products are fielded on workstations within the RFCs and WFOs (there is no interface to NCEP). All of these products are slated to become components of AWIPS; but to date, RFCs have had to upgrade their workstation computing capabilities to execute OH products, because of implementation dates within AWIPS. Several prototype applications developed by HRL are however already operating in AWIPS, and the situation will be alleviated with future AWIPS releases. Major products fielded by OH include:

- WFO Hydrologic Forecast System (WHFS)
- NWS River Forecast System (NWSRFS)
- Hydrologic Applications System, a hydrologic database software capability

- Algorithms and software for processing a variety of hydrologic data including NEXRAD weather radar data, digital elevation data (from several non-NWS sources), and various rainfall and stage data (principally from the USGS and the Corps of Engineers)

OH is behind the state-of-the-art in the combination of modeling, decision support system, software engineering, and information technology known as hydroinformatics. E.g., OH only recently has begun integrating geographic information systems (using COTS software) with their modeling and database software. Such integration has been a standing capability within other Federal agencies for several years[51]. Further, most production-level scientific and engineering software is simply enhancements of the old mainframe versions of their lumped-parameter models, still primarily written and updated in FORTRAN[52]. As discussed below, we believe this may indicate an in-house development staff that has been unsuccessful in recruiting. Failure to bring on board new personnel, use open software paradigms, and leverage marketplace advancements, will result in increased systems maintenance costs in the future.

OH development activities are *dominated* by conversion of legacy programs to AWIPS as the delivery vehicle. Much of the richness of OH's history of research has given way to today's focus on centralized advanced development and demonstration/validation for fielding current OH software in AWIPS. This emphasis is all the more important given that OH has had to provide their software to the field on workstation platforms in anticipation of OH product delivery via AWIPS.

OH clearly has a strong user base in the RFCs, and is growing its connectivity with the WFOs. Current R&D and technical support activities are prioritized on the basis of input from these field entities, transmitted through long-standing contacts. While there is no formalized system for user requirement surveys or prioritization, there are annual meetings with the regional Hydrologic Service Division Chiefs, RFC Hydrologists-in Charge, and the Development and Operations Hydrologists (DOHs, the parallel to SOOs). Technology exchange among RFCs also is founded on longstanding interactions, and this process is growing for WFOs.

Today's OH conducts very little basic research, and appears to be headed toward even less applied research. It currently supports less than $200K per year of extramural research. OH does bring in 5-10 UCAR researchers per year, and it is these scientists who conduct most of the in-house research. This is a solid step toward filling personnel gaps, and provides for infusion of external thinking. The process is somewhat problematic however, since there does not appear to be a funded, formalized transition philosophy that enables the UCAR research to be routinely fielded as new science in OH's software. OH staff note that many of their newest fielded algorithms derive from UCAR researchers. This merely reemphasizes the need for a formal, funded mechanism to assess and field all appropriate such advances; Today's OH is missing some opportunities to infuse new thinking into its in-house staff, and to field new science to its user base.

OH maintains close working relationships with several Federal agencies including the Army Corps of Engineers, the U.S. Geological Survey, the Department of Agriculture, Federal Emergency Management Agency, U.S. Bureau of Reclamation (USBR), and others. These partnerships appear to be heavily weighted toward data sharing (e.g., bathymetry, remotely-sensed imagery, digital

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51 The delay is at least in part due to the drive to field OH products in AWIPS; OH thus depends on AWIPS for the deployment of COTS GIS software.

52 OH personnel note that newer developments are being written in C and C++.

elevation data, etc.). Opportunities for greater partnering with these agencies in areas such as hydrologic/hydraulic research and modeling and simulation, largely have yet to be realized.

OH is leveraging new research in some areas, though. For example, the USBR won a grant from the NEXRAD Operations Support Facility (OSF, a tri-agency funded [DoC, DoD, FAA] component of NWS's Office of Systems Operations) to produce a new snow algorithm. Thus while OH did not award this grant, it is leveraging the NWS investment. However, OH has no in-house component with which to partner in a NOAA lab (such as it available to, even if not well availed of, by OM), nor is there any hydrologic component of NCEP (except that TPC runs TDL's SLOSH model for tropical storm surge). This loss of opportunity for infusion from NOAA labs insolates OH from developments within the rest of NWS and NOAA. .

Today's OH conducts technology outreach, and receives a level of peer review, through attendance at conferences and workshops, through interactions in technical societies and their committees, and through publications. Few of its publications however are in refereed journals. It has collaborations with some international groups, although these most often involve sponsorship within OH of applied or advanced development. OH also appears to have minimal connectivity to OM at the management or technical level, and in general appears to be, at best, a step-child within NWS when compared to OM's (relative) sonship. It may be that OH is actually quite comfortable with this status (which gives concern if this is a defining point of OH's corporate identity). TIP's own relative neglect of anything except meteorology is typical of the way hydrology is treated.

We believe that many of OH's difficulties are traceable to recruiting/retention problems, specifically in the area of computer programming, software development, and computer science. Young professionals in these fields in the greater Beltway area command salaries well in excess of the GS schedule. Even when new young talent is hired, retention is difficult in spite of educational opportunities afforded by OH. People resource limitations are particularly evident in the area of watershed modeling. Current OH models are primarily lumped parameter models that have been the mainstay of the hydrologic engineering community for over 20 years. Reviews by NRC panels have been critical of NWS's rather 'deliberate pace' in embracing distributed hydrologic modeling. The inability to hire but a few new graduates who have been trained in distributed modeling and the newest programming techniques and languages is adversely affecting Today's OH[53].

Having said all this, however, Today's OH does have an excellent relationship with its customers, specifically the RFCs, and its products are meeting a specific subset of today's field needs, i.e., river flood forecasting, albeit with legacy models being modified to be incorporated into AWIPS. OH is not involved in other aspects of hydrology such as flash or coastal flood forecasting.

3. Next OH

The OH of the next decade will face the same basic challenges as those of the 'Next NWS'. One initiative mentioned by OH personnel that would prepare it for these challenges is the development of the Advanced Hydrologic Prediction System (AHPS). Funding for this development (about 10% of that required for PREDICTIONS), which would take much greater advantage of probabilistic forecasts, has been sought unsuccessfully for several years Distributed hydrologic modeling, and other UCAR initiatives being promoted by OH, also hold promise for fielding new technology within the Next OH. Extension of the ESP initiative would also be useful to OH and its users.

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[53] OH did recently recruit a PhD trained in distributed watershed modeling

These efforts however all appear to represent 'good ideas' without any funding base to see them implemented.

OH is concerned about the effects of Headquarters reorganization. As opposed to the meteorological side of the house with its 'dispersed' operations, virtually all of hydrology (as OH defines it - again, read river flood forecasting only), from basic research through implementation, lies in the one office. The potential for devolving OH such that HRL would be in a separate organizational element from the field support division is perceived as a potential loss of technical support to the field. OH clearly views itself as a fully integrated operational arm of the NWS whose mission is to develop, validate, and deploy mainstem river stage forecasting models to support the RFCs and through them the WFOs.

While this philosophy seems to serve Today's OH customer well, we question its viability for the long term. As Today's OH staff continues to age, and if current retention and recruitment difficulties persist, the ability of the Next OH staff to be a "good buyer" of new hydrologic technology -- indeed, even its viability -- will be compromised. A certain level of world-class, in-house expertise must be maintained if credible acquisition is to be made by Next OH. One way to maintain this technological base within the current structure would be through a return to the conduct of focused, quality in-house research by a component of OH, coupled with increased partnering, improved recruitment, and greater use of the work of visiting researchers. All this must be planned and budgeted for, to be certain – it will not occur by chance. But if NWS does not acquire quality hydrologic technology, it is a self-fulfilling prophecy that it cannot infuse quality hydrologic advancements into its users' business practices.

4. OH After Next

Most of Today's OH leaders will be retired by the time of the OH After-Next. Thus, unless NWS soon begins a rigorous effort in recruitment, mentoring, and retention, at least the research component may be completely empty. This would leave OH as an organization that supports either old technology, or the technology of others, making it very difficult to remain at the state of the art.

Clearly, for the OH After Next, indeed even for the Next OH, it is important for NWS to decide what it wants OH to be and do. The Panel believes that a strong NWS needs a strong capability in hydrology as a full partner with its meteorological side, as well as a full partner with and user of the technology developed by, other Federal, academic, and industry researchers. For this to occur, changes in OH's status as a development <u>and</u> research organization must be formulated and funded. Such changes must be made to signal emerging professionals in the hydrologic sciences, and researchers in other organizations, that NWS's hydrologic component is a solid and vital place to work.

5. Summary

OH has served NWS and the nation well for many years, and is fully capable of continuing to provide similar valuable services to the RFCs for years to come. However it is an aging group that has grown comfortable in doing lumped parameter modeling for mainstem river stage forecasting. It is doubtful that without major changes to the organization they have the wherewithal to move into new (to them) areas of development to advance capabilities in their area of principal tasking (e.g., distributed modeling, hydroinformatics), let alone to undertake integrated hydrological forecasting responsibilities (e.g., coastal and flash floods, soil moisture), even if they were willing to do so.

B. Office of Systems Development (OSD) and Techniques Development Laboratory (TDL)

1. Introduction, and Today's OSD. These comments are based principally on a brief review and tour of TDL by Dr Dorman on 5 February 1999, and written responses to questions submitted by Dr Holland.

OSD's "Actual" (as opposed to paper or official) organization comprises the (Acting) Director's Office, TDL, and a smaller Systems Evolution Group. It has a proud 35 year history, dating to its start as the Office of Meteorological Research of the Weather Service. Its budget supports 73 FTE, plus $1M 'other than labor'. In addition, some 27 contractors (which supplement 12 OSD FTE) in TDL's Products Development Branch are funded by the AWIPS Project Office. The Systems Evaluation Group (27 FTE, 7 contractors) also plays a major role in AWIPS development; the 10 FTE and 2 contractors of its Systems Engineering Integration and Test Office essentially function as an arm of the AWIPS PO, the 2 FTE of the Advanced Prototyping Team are stationed at FSL to coordinate AWIPS architecture development, and the 5/1 members of its Development and Test Facilities Team maintain the hardware used for AWIPS and applications development at SSCM2.

TDL describes itself as the "development arm of the WFOs", much as OH is the development arm for the RFC's. Its primary mission is to help WFO forecasters interpret and apply the model outputs from NCEP; as those models evolve, so must the interpretive products. In addition to the direct support of AWIPS releases, and development of associated interpretive tools to be used by the WFOs (being integrated into the Interactive Forecast Preparation System [IFPS]), TDL's products include the twice daily MOS guidance (from 6 hours to 5 days) produced at NCO , a "Local AWIPS MOS Program" (LAMP) run at the WFOs that applies MOS at local time and space scales (at one hour increments) and includes a QPF element, the National Verification System that scores and thus provides performance measures for local forecasts, and the SLOSH model run by TPC for hurricane storm surge simulation in support of evacuation planning, and by NWS coastal forecast offices for extratropical storm surges. With support from NCAR and OAR labs, TDL is also developing and transitioning an innovative AWIPS module called SCAN for very short-range forecasting associated with deep-convection events. Between SLOSH and SCAN (which includes a flash flood element), TDL is responsible for those aspects of hydrological forecasting not under OH cognizance.

Over the last several years, particularly after the decision to employ the FSL architecture as the basis for AWIPS, TDL (or least the branches associated with AWIPS) has been squarely in the mainstream of development and fielding of this central analytical and interpretive segment of the NWS field Modernization Program. Thus in addition to responding to needs voiced by the WFOs, it has derived its requirements interactively with the AWIPS Program Office, of which much of its staff is almost an integral part. TDL is similarly very closely associated with NCEP through its responsibility for updating and maintaining the MOS guidance. It also is at the forefront of developing and fielding, either alone or in partnership with the labs, CIs, and NCAR, some extremely innovative and valuable interpretive and forecasting tools. And it keeps close track of its extensive list of publications.

At the same time, TDL is very clearly a product of its history. It contains the Marine Branch, for example, largely because the developer of SLOSH did not want to move when the NCEP Marine Products Center was formed. And to a large degree, this Branch's principal model, like those of OH, is an extension and modification of legacy systems, and is subject to the same criticisms and concerns[54]. Similarly, TDL is so heavily involved in AWIPS development largely because of the mid-90's decision to conduct much more of the development in-house, and because it had or could acquire the technical talent needed to support the Program Office. TDL also is opportunistic. It tackled the flash flood problem largely as a result of OH's failure to do so, and as a natural concomitant to the other effects of deep convection.

2. The Next TDL, and the TDL After Next

There is no doubt that many of TDL's products will be needed for many years to come. As long as AWIPS remains the software basis for WFO operations, some organization will have to maintain it and develop the periodic upgrades. And as long as NCEP's models change, so too must the associated statistically-based guidance, and the interpretive tools. And with the institution of the new requirements process, and the increasingly important role played by the SOOs, there will be a need for some group to respond to requests for new developments, incorporate best-practices into the system-wide tool set, and maintain configuration control of the total system. Similarly, there will be a continuing need for storm surge simulations and predictions, and for innovative developments like SCAN.

The demands on OSD however will change, perhaps quite significantly within the next couple years, after the full fielding and first upgrade or two of AWIPS. At issue, as a minimum, will be how to redistribute the AWIPS-dedicated FTEs as the Modernization process ends and the system matures. Similarly, in recognition of the need to fundamentally reconsider the NWS's approach to hydrology, including ways to couple forecasts of soil moisture, runoff, flash floods, river stage and coastal processes, the small Marine Techniques Branch and the hydrologic interface to SCAN and its successors are prime candidates for reorganization.

In the longer run, or perhaps even sooner, OSD/TDL's tasking raises some fundamental issues about the NWS organization and mission. Even leaving aside the fact that a "laboratory" within a Headquarters organization whose primary concerns should be policy and top level management, not development and operations (the same of course can be said for much of OH), is an organizational anomaly, elements of OSD/TDL's tasking would appear to need reevaluation. Why, for example, should its central functions of 'interpretation', at least from the standpoint of early research and development, not be part of the mission of an OAR lab as are so many other aspects of the end-to-end observation-NWP-forecasting[55] process? Why shouldn't a program office have its own SEIT staff (to the degree that such is dedicated and not matrixed from a central engineering group into a number of project offices, as seems to be the case here) so that when its functions change or disappear its organization can likewise be rationalized as a coherent whole? Why shouldn't NCEP be responsible for its own statistical base, and associated guidance ? We recognize that much of the present reality stems from history, but note that now, as NWS is reviewing its total organization and management, may be a good time to ask such basic questions.

Perhaps the most significant question, however, relates to the issue of NWS output: what are its products, who are the customers, how good is good enough...and perhaps most importantly, where

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[54]The responses to Dr Holland's questions indicated that not only are there other models in use and devlopment by other agencies -- some of which use more intensive modern computational schemes -- but that NOAA's Coastal Ocean Program also runs a Coastal Forecast System. While there is much to be said for competition if it is appropriately tempered and exploited (which does not seem to be the case here), one does question the need for redundancy within NOAA.

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In summary we commend TDL for having done an exceptional job throughout its history, particularly for the key role that it has played at critical points in the Modernization Program, and for its innovative work in such programs as SCAN and the Interactive Forecast Process. We simply argue that at this point, it is worth asking whether the functions it performs will all continue to be needed, and for those that are essential, where they may best be performed.

C. Suggestions

We are aware that NWS has been developing strategies and goals, and reevaluating its Headquarters organization, while our panel has been doing its assessment. We have not been privy to this work, and thus are not in a position to make any specific recommendations regarding organizational structure. As the same time, as should be clear from our discussion above, we do believe that OH and OSD, if for very different reasons, should receive very close scrutiny by NWS Corporate Management during this process. We also suggest:

- Operational and R&D functions are more appropriately the province of field commands or designated Project Offices, than of Headquarters. Mixing policy and requirements-setting with the actual performance of the work creates inherent opportunities for conflict of interest that should not be permitted, no matter how conscientious the staff.
- Perhaps with the assistance of an outside review panel, and certainly with the advice of other NOAA groups and federal agencies involved in the nation's hydrology and water management programs, NWS should reevaluate the direction of its hydrologic developments - starting with a fundamental prioritization of requirements and including a strategy for observations, numerical modeling, and forecasting, including heavy leverging of the ongoing work and capabilities of others. With such a document in hand, NWS will then be able to budget and reorganize to effect what we see as badly needed revitalization[57]. We see a small but coherent hydrology program as a prime candidate for a FY02 initiative.
- If NWS accepts our first admonition, OSD/TDL functions should be assigned to appropriate parts of NWS or OAR, rather than being simply moved in-toto.

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[56]We recognize that there are limits - some tools, of course, are basic to the core NWS functions. At what point however does a large organization dedicated to the development of tools become more a proponent for its work than simply a a responder well scrubbed requirements? Our concern is particularly great when such a group is located at Headquarters, where it is in a position to influence policy and resource allocations in its own behalf, rather again than being responsive to customers.

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