SUMMARY REPORT

Earth System Research Laboratory Review
Physical Sciences Research
March 9-12, 2010

Review Panel

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1. Overview

This Physical Sciences Review covered the broad range of activities in the Physical Sciences Division (PSD) and the Global Systems Division (GSD) in the Earth System Research Laboratory (ESRL). The vast majority of the presented materials, as well as useful background information, were provided in advance of the meeting, allowing the panel a welcome opportunity to preview even the posters. This was certainly very helpful as the review schedule was very intense with the many exciting activities and results that the Divisions were obviously proud to display. The materials can be found at: http://www.esrl.noaa.gov/research/review/. Additional information, such as a draft PSD Strategic Plan and the report on the *Attribution of the Mid-Atlantic Snowstorms*, was provided at the review. ESRL senior management and PSD and GSD staff are to be commended for their hard work and preparation for the review, for their openness, and for their willingness to provide additional information requested during the review. The care given to preparing presentations and posters was very apparent, as was the enthusiasm of all the science staff for their research and the pride they take in contributing to NOAA's mission in both advancing science and serving society's needs. Every review panel member gave expression to being overwhelmed and generally impressed by both the high quality of all we saw and the breadth of activities across the two divisions.

The review was organized along five themes:

1. Climate, Weather and Water Science
2. Modeling, Data Assimilation and Advanced Computing
3. Climate, Weather and Water Services
4. Technology Transfer and Outreach Activities
5. Earth System Observations and Analysis
    - 5a. Weather Systems Observations and Analysis
    - 5b. Climate Systems Observations and Analysis

A summary of reviewers' evaluations and recommendations for each theme is presented below, with focus on the three areas of our charge:

> **Quality:** Assess the quality of research over the last four years, and whether appropriate approaches are in place to ensure high quality work will be performed in the future.
> **Relevance:** Assess the degree to which research and development is relevant to NOAA's mission and of value to the nation.
> **Performance:** Assess the overall effectiveness with which the laboratory plans and conducts its research and development.

Consistent with the charge to the panel, we attempted to limit ourselves to research and development and technology transfer over the last four years, although it wasn't always apparent if accomplishments belonged to an earlier time. In accord with FACA rules, the review panel did not seek consensus in our evaluations. Nevertheless, there was a lot of agreement in the high level view of the two divisions and the relevance of their research to NOAA's mission. Since it is relevant across all themes, this view is summarized next, followed by the summary for each theme. The report closes with a summary of key recommendations including some thoughts on

these two divisions *vis a vis* the emerging NOAA Climate Services (NCS), and on the NOAA-wide environmental modeling program.

In what follows, ESRL will often be used as shorthand for ESRL's PSD and GSD.

2. General

These two divisions have emerged from the 2005 ESRL consolidation in a very strong position in terms of both scientific research and technology development and transition. As will be seen below in the discussion of the separate themes, elements of PSD and GSD should be considered to be national "treasures". Their work exemplifies the weather-climate connection and continuum and the relevance of this connection for water research and applications.

Their exceptional standing comes from both a strong leadership and an outstanding group of talented scientists. Dr Bill Neff is to be commended for how he has shaped PSD into a highly successful organization from pieces of what were previously separate laboratories. Dr Steve Koch, who took over the helm of what was already a strong organization in the Forecast Systems Laboratory, has continued to evolve and advance GSD in many areas. A particularly noteworthy achievement has been his success in engaging NOAA/NCEP in important planning for the agency, with focus on technology development and transfer. Both Division Directors are ably supported by outstanding Deputy Directors and Branch Chiefs. It was readily apparent that the leadership is well engaged with science staff at all levels.

2.1 Overall Quality and Performance

The quality of the scientific research undertaken is very good, with many identifiable and noteworthy scientific achievements. Many of the staff have won awards within NOAA, and in the case of PSD, several scientists have been recognized by professional societies or with international awards. One reviewer noted that, "the list of awards provided to the review panel was very remarkable. Clearly the top scientists at GSD and PSD are amongst the world elite." The divisions share a strong sense that evaluation of research quality is best done through the peer-reviewed literature. One reviewer noted that, "In general a research unit in a National Meteorological and Hydrological Service (NMHS) that strikes a value of 1–2 for its publication index would be considered well balanced." GSD, with a strong emphasis on technology transition (and a publication index of ~1.1), has done well in the last few years. PSD (with a publication index from Ph.D. staff of ~1.3) "appears to be on the low side since PSD seems to put more emphasis on fundamental research. In academia it is not uncommon to have a publication index in the range of 3–4." However, another reviewer felt that the publication rate "appears healthy given the other metrics for job performance in NOAA. The managers appear aware of the tension between publishing and products."

The list provided of innovative technologies transferred to stakeholders was certainly impressive, and the presentations and posters affirmed their importance for NOAA's mission. However, several panel members noted an inability to assess the quality of some of these technologies due to the "lack of exhaustive and systematic quality monitoring." Given the emphasis placed on technology transfer (from Dr MacDonald's closing remarks), metrics for the quality of technology transfers to stakeholders is just as important to ESRL as a publication metric. The

"metrics" provided to the panel were the number of transitions (although some of these were older than 4 years), selected testimonials from users, and a number of DOC/NOAA awards. More effort should be placed on developing "suitable indices for measuring the effectiveness and efficiency of technology transfer." This issue is discussed further under Theme 4.

2.1 Relevance – Portfolio Balance

In spite of the strong emphasis on contributing to NOAA's mission, the absence of direct operational responsibilities for either weather or climate allows ESRL to foster a highly stimulating research environment with a good balance between overall guidance (towards mission-oriented goals) and individual freedom. One reviewer noted: "A culture of entrepreneurship and creativity was clearly evident; the opportunities for funds both from the two division directors and CIRES is to be commended." Another noted that ESRL management has "struck a good balance between providing the necessary freedom to PI-level researchers on one hand and maintaining critical mass around major lab-level efforts on the other." Support for high-risk endeavors with discretionary funds helps to maintain an exciting environment necessary to attract strong new talent. Going a little beyond mission goals is acceptable to keep a vibrant work force. Panelists generally felt that 10-15% discretionary funding for high-risk projects is a good investment.

Over time, PSD has reduced the level of non-NOAA support to what seems like an acceptable level of about 15%. GSD, on the other hand, maintains a high level of non-NOAA funding (about 35%), which would seem to place projects and the workforce at some risk. A high level of reliance on external funding does broaden the scope of the effort, but there is a risk that it diminishes the impact for transition to NOAA operations. GSD seems to be developing air quality analysis and prediction capabilities for the Air Force as well as potentially NWP coupled modeling capabilities for the Navy. The panel was given very little insight into these activities. While the move toward fewer operational models in the U.S. is a step toward a more unified modeling effort, the links to DoD seem stronger than to operational NOAA capabilities in these areas. Several panel members expressed concern that they potentially detract from the Lab's responsibilities to OAR and NOAA.

Recommendation

- GSD's heavy reliance on external funding should be reduced to alleviate the risk that it may not be capable of achieving its NOAA mission. This will be especially important in the ongoing process of establishing a robust relationship with NCEP.

2.2 Core competencies

As mentioned above, there are several activities in both divisions that can be viewed as significant for NOAA, and some have broader implications as a resource for the nation. These are core competencies that should be preserved in whatever evolution is envisioned as NCS moves forward. Briefly these are:

- Modeling and assimilation development in support of Numerical Weather Prediction (NWP) (specifically the Icosahedral grid dynamical core (FIM and NIM), Ensemble Kalman Filter, reforecasting developments, and software developments for new computer architectures);
- Atmospheric reanalysis for the pre-satellite/data-deficient era;

- Climate diagnostics, including weather and climate attribution and climate predictability;
- Water resource R&D and applications (Hydrometerological Testbed, the emerging HydroClimate testbed, Western Water Assessment, NIDIS, work on atmospheric rivers, extreme precipitation);
- Ocean-atmospheric flux parameterization development; and
- Observing system developments (e.g., unmanned aircraft, GPS-Met, Arctic observatories).

2.3 The Workforce

The strong leadership at ESRL is reflected in organizations that know what their own mission is and how their scientific goals contribute to NOAA's mission – even as there is some sense of uncertainty about what the incipient NCS will mean to some of the staff and to interactions between the two divisions. There is a strong sense of, and dedication to, NOAA's mission, a culture of involvement with end-users in an end-to-end process, and keen desire to transition developments from research to operations. This high level of comfort with ESRL's identity translates to high morale within every level of the workforce with whom we met, including ESRL staff, cooperative institute scientists, and postdoctoral scientists and students. Clearly, there is a strong sense of teaming – a positive, energetic, collaborative atmosphere.

The Cooperative Institute (CI) scientists are essential to many of the ESRL successes and they obviously take pride in being part of the ESRL science team. The panel did not get enough insight into the processes by which CI scientists are engaged in ESRL research projects to make any comment on those processes and the time constraint prevented us from pursuing any questions panelists had. There was a level of independence for some CI scientists, whereas others are clearly very strongly connected to the highest priority projects in the Divisions. There were no standard procedures apparent in, for example, the engagement, mentoring, or review of the junior CI science staff or in their ability to handle regular procedures like getting visitors through security. The procedures, or knowledge of procedures, seemed to vary on a case-by-case basis. Some CI scientists expressed concern about a lack of status at either ESRL or the university. However, generally CI scientists seemed to feel a strong benefit of working within the NOAA environment and felt that there was a support safety net in place for them. ESRL is clearly looking to some of the top CI scientists as future civil service hires. One reviewer noted that "some scientists in the cooperative institutes weren't as engaged in the mainstream research as others; one wonders if a little more interaction might bring some extra talent into the many efforts going on in the two divisions. Fostering a diverse workforce is important not only to match EEOC guidelines, but improves the ability to seek out and work with diverse stakeholders."

Postdoctoral scientists and students were also enthusiastic about being at ESRL. They obviously appreciate the strong mission focus at ESRL, a reflection that the NOAA mission ethic is very strong in the every-day working environment. The post-docs expressed a desire for more opportunities for involvement in the Divisions, such as receiving seminar announcements and other communications regarding procedures and activities within ESRL. They also wanted opportunities for their own meetings since our meeting with them was the first time that some of them had met their peers. Nevertheless, both postdoctoral and CI scientists feel that they are welcomed and encouraged to participate in ongoing projects. Since there are many opportunities

for them to do so, one caution would be to ensure that in their enthusiasm these scientists do not get involved in too many projects at one time.

There is a good balance between the Federal and contractor workforce. Although the IT support comprises a large fraction of the support staff, they provide networking and supercomputing support to all of ESRL and manage the High Performance Computing Systems as a NOAA-wide resource. It was not clear if the IT support is shared among the various ESRL divisions. Given the size of the laboratory, information does not seem to flow freely or in a timely fashion. It is recommended to create a lab-wide electronic bulletin board, facebook, or wiki. A committee of junior scientific and administrative staff could be formed to develop and implement an internal communication system.

Planning for the future: PSD and GSD look very healthy from a workforce standpoint and ready for their near-term agenda. Management needs to focus on maintaining the current scientific strengths and excellence over the next 10 years, particularly in developing the next generation of leaders given the apparent lack of ability to hire federal employees. It is obvious that ESRL is doing a good job in nurturing its next generation of science leaders. It is less clear as to what is being done to nurture its next set of managers. One reviewer notes that "demography will drive the need to bring in younger people in greater numbers in the future as people retire …. the personnel hump in the older ranks is stymieing normal growth of future managers and leaders." Another notes that "there appears to be few ways to hire young people, figure out which ones have skills as managers and leaders, and bring those up through the ranks to guarantee a succession of research leaders and planners." Of course this problem is not unique to PSD and GSD; however, these Divisions need to be proactive in developing a plan to address the problem. One approach would be to encourage or require science project management training. As one reviewer notes, "This is especially important for potential scientific managers, but also for all employees, to insure a good understanding of the technological transfer process in which they need to participate and contribute."

Recommendations:

- ESRL mentors and sponsors should ensure that CI and postdoctoral scientists are not tasked with too many projects.
- ESRL management should ensure there is at least a modest level of mentoring of junior staff and nurturing of career pathways; ensure that the workforce encompassing CI scientists can be refreshed as needed; review the value of the annual appraisal and promotion processes.
- ESRL should recognize the challenge of being part of a large work force in a modern federal office building – web-based information about general procedures and resources (seminar announcements, availability of extra-curricular resources such as the gym, and so on) would help with communications that are especially important for the junior workforce. Having the post-docs arrange seminars, providing opportunities for post-docs to meet together, and creating natural gathering areas throughout the building would also help.
- ESRL should start planning now for replacement of senior management, with a strong mentoring program for potential replacements.

3. The Themes

3.1 Climate, Weather and Water Science

There is a very strong linkage between many of the efforts presented under this theme and those under the Services theme (consistent with Dr MacDonald's emphasis on ESRL's approach as end-to-end, science to services and technology transfer in the support of NOAA's mission). Thus, some of PSD posters presented in the PSD tour, especially those studying predictability at various time scales, could be included under either theme.

Quality
Clearly there is good leadership within the group, which is scientifically very solid and with high stature internationally. A few outstanding research efforts being conducted are mentioned here.

Dr Sardeshmukh's analysis of the representation of tropical SST variability in models used for the IPCC's Fourth Assessment Report (AR4) is a very important contribution to our understanding of the limitations of current climate models and an important piece of information to inform climate model development. Clearly the current climate models are failing to represent atmosphere-ocean coupling and feedbacks well. Of some concern is that these results will have little impact on the development of models that will contribute to AR5 since those models are already scientifically frozen and production runs have already started. ESRL should find a way to interact with model developers during the validation phase as models are being finalized for the next set of climate simulations.

ESRL's work on Atmospheric Rivers (AR) is impressive. The work, by Drs Newman, Nieman, and Ralph, shows that synoptic variability drives about half of the extratropical meridional mean moisture transport and that this transport is focused within fairly narrow meridional bands called "atmospheric rivers." One reviewer notes that AR provides one example of "overlapping weather and climate research that has applications for the NWS as well as NCS." The proposed "atmospheric river" field campaign offers an excellent opportunity to blend modeling and observations and to evaluate the next generation of climate models.

Dr Fairall's work on air-sea fluxes is outstanding. All panel members noted his long-standing contributions in measurement of fluxes over the ocean and in developing flux algorithms. "He has been and remains at the forefront of this field, addressing fluxes in high winds and the impacts of sea spray – something of concern for decades." Another reviewer noted Dr Fairall's leadership with SURFA, where the operational modeling centers are exposed to the comparison of their fluxes with accurate *in situ* fluxes, as a good example of a research effort that also had significant outreach and transition impacts.

Relevance
The research conducted under this theme is highly relevant to both NOAA's mission goals and societal needs. For example, having solid scientific analysis of the realism of models (such as whether or not they capture fluxes and processes such as moisture transport accurately) is essential to improve prediction. Several of the studies presented in posters – experimental seasonal forecasts, MJO monitoring and prediction, coral bleaching outlook – are obviously very

applied research topics of direct relevance to NOAA's short-term climate prediction portfolio and could have just as easily been included under Theme 3.

Performance
The co-location of first-class scientists working on both weather and climate offers the opportunity to bridge these two topics, with water as the integrating topic. The topics tackled are quite broad in scope, but there appears to be strong connectedness for many areas so that scientists are not working in isolation.

There was some concern about the Arctic research, not regarding quality, but rather planning and coordination. There is cutting-edge Arctic research ongoing in several groups (observations, diagnostics, and modeling). Despite tremendous potential for synergies, there was little evidence of interaction between the groups. For example, the soil-moisture, snow, and surface-energy budget data being collected in the Arctic provides an excellent opportunity for collaborations on land-surface model development. According to one reviewer, "this is but one facet of potential synergisms that could result from the creation of a crosscutting Arctic group within the two divisions. With the combined expertise in Arctic fieldwork, diagnostic studies and modeling, PSD could easily emerge as a national and international focal point for Arctic atmospheric research, linking small-sale field measurements to the global context. This would fill a major need in Arctic research, and could position NOAA to facilitate some of the broader international coordination that Ms Uttal (and others) have rightfully said is needed in the Arctic."

In terms of planning for the future, reviewers comments included: "Dr Wilczak's wrap up presentation showed a group actively thinking about future directions and thus healthy and not stagnant" and "for the size of the group and the expertise in hand the present foci and potential ways forward look very good." One reviewer noted that the planned developments in renewable energy "will be a classic example of public-private partnership that will benefit from government research."

Recommendations:
- PSD should attempt to get out in front with respect to climate model diagnostics. Like most groups, they are analyzing the last generation of climate models at a time when the next generation of climate models have already been advanced and frozen for AR5. It would be helpful to short-circuit this feedback loop so as to not skip a generation of model development.
- ESRL should establish a mini-Arctic program (a cross-division theme) to encourage dialogue and collaboration. The potential synergies between Arctic research efforts and model development/validation efforts should be exploited.
- ESRL should position itself to become a leading hub for Arctic atmospheric research. NOAA should take a leadership role in facilitating some broader international coordination for Arctic observations. With the highlight given to the Arctic in the upcoming NOAA Strategic Plan, the time seems right for ESRL to exert itself in the Arctic. Perhaps the upcoming "Arctic Watch" will be one vehicle for broadening ESRL's visibility in the Arctic. Partnerships with CPC and GFDL on Arctic variability and predictability research would make NOAA more prominent in broader programs such as SEARCH (Study of Environmental Arctic Change).

- ESRL management should have a plan for the sustenance of the scientific leadership of this group while planning how to identify, nurture, and groom the future leaders. The lack of Federal positions and the use of CI staff who have little hope of moving to Federal positions appears to provide challenges to sustaining ongoing excellence in science and science leadership.

3.2 Modeling, Data Assimilation and Advanced Computing

There is a very strong linkage between many of the efforts presented under this theme and those under the Technology Transfer theme (again, consistent with Dr MacDonald's emphasis that successful research developments are those that "get into operations"). Over time, the regional focus of model and assimilation development has shifted to encompass the global domain. As the computational burden has increased with this change, and also the increase in complexity associated with coupling to chemistry and ocean models, ESRL's advanced computing facility and the advanced software development efforts have obviously played a very important role in GSD's achievements. Noteworthy contributions in this theme arise from both GSD and PSD, with good interactions in testing an implementation of the EnKF for the FIM.

Quality
The model and assimilation developments, especially the FIM, NIM, and EnKF are impressive achievements. One reviewer noted that the "R&D activities in NWP are leaders nationally and amongst the first tier internationally." Another reviewer highlighted the significance of the decision by the Hurricane Forecast Improvement Project (HFIP) to use FIM and by NCEP to include FIM in the multi-model ensemble suite. The NIM "development has the potential to take a significant step toward global high resolution cloud resolving model." Another noted that the EnKF development effort "has reached international stature" and the FIM has" very good potential for doing the same." Reviews also highlighted the Warn-on-Forecast concept as "a novel new approach to extend warning lead time."

The software developments for the model dynamical core on the Graphical Processing Unit (GPU) are important contributions to weather and climate modeling on a national basis, especially if the group connects with similar activities in other national laboratories. Reviewers noted that the high performance computing R&D are "leaders nationally and internationally."

Relevance
Reviewers noted the high relevance to NOAA's mission of the work under this theme. Most of the research has direct application in the operational environments. Comments included: "The core GSD research activities have direct traceability to the NOAA mission goals, 5-year research strategy, and 20-year research vision." The GPU work is relevant "not only to the goals of the divisions and ESRL itself but also to the goals of the agency as a whole. The GPU computing initiative is a high risk/high reward field, and it is a good example of an emerging field that is appropriate for ESRL to be involved in."

The dynamical core developments, and the associated developments to take advantage of GPUs, and the EnKF are important contributions to weather and climate modeling on a national basis. The full potential of these contributions would be enhanced with a strong commitment to the

Earth System Modeling Framework (ESMF) whose core team has now moved to ESRL/CIRES as part of a new NOAA Environmental Software Infrastructure and Interoperability (NESII) group. Not only does ESMF provide the foundation for NOAA Environmental Modeling System (NEMS), but it is also the basis for the common modeling architecture being developed for the National Unified Operational Prediction Capability (NUOPC) (see http://www.weather.gov/nuopc/).

Performance

The model and assimilation developments, especially the FIM, NIM, and EnKF are impressive achievements. Nevertheless all review panel members expressed some level of concern about the coordination with both NCEP and GFDL in terms of defining requirements and setting priorities and responsibilities in an iterative development-evaluation-transition-implementation roadmap. In our view, this represents a NOAA-wide planning issue. In ESRL, priorities for model development appear to be driven more by good, interesting science rather than the identification at the agency level of specific problems that need improvement. Hence developments are not undertaken as part of a transition process, but rather as a competitive process. As one reviewer noted, the "requirement development and prioritization process seems to be a little *ad hoc*." For regional NWP applications, requirements appear to be defined through an FAA planning process rather than through a NOAA planning process. To be fair, both ESRL and NCEP have made important inroads into collaborative evaluation-implementation agreements, but there is still tension associated with the lack of up-front coordinated planning and with competitive pressures forcing the issue of transition.

One reviewer noted "ESRL's latest accomplishments in NWEP [Numerical Weather and Environmental Prediction] could pave the way to excellence nationally and internationally, but it will be necessary first to implement some important recommendations found in this report. These recommendations will not only make the ESRL NWEP technological transfer process more efficient and disciplined, but also impact on the quality of the NWEP systems themselves by creating collaborative synergies and a rigorous test bench for modeling activities." He notes that "the PSD and GSD long-range strategic plans are very well aligned with NOAA's mission, but more effort is needed to better engage some customers in the implementation of ESRL's long-range plan. As an example, we agree that FIM and GPU are promising NWEP technological advances, but there is a long and tedious series of numerical experiments to be done in close collaboration with NCEP before it can be declared suitable for an operational implementation. ESRL needs to set realistic expectations and understand the operational constraints of an operational NWEP system, including computer efficiency of models. A modern NWEP system needs to attain in parallel a certain level of quality and accuracy for a multitude of geophysical variables and products: this can only be achieved with the help of numerous and complex R&D numerical experimentations."

Finite compute resources and operational schedules dictate a fine balance between different approximations in numerical algorithms, advanced physics, 4D data assimilation techniques, and utilization of new observational systems. "This is a tremendous challenge that requires a tightly coordinated critical mass of scientific and technical personnel. This challenge is getting more and more difficult because of the increasing complexity, space-time resolution, quality, and accuracy requirements of these NWEP systems. This increasingly jeopardizes the efficiency of carrying

out technological transfer activities in a timely and affordable manner in a multi-model and multi-disciplinary environment. Hence more and more it is recognized worldwide (e.g. UKMO, Chinese Meteorological Agency, Environment Canada, BoM, Meteo-France) that this scientific and technical bottleneck can be surmounted resourcefully by a teamwork approach based on a unified modeling system (UMS). The UMS is also considered by many NMHSs as the low-cost and shortest pathway to seamless NWEP at all space and time scales."

The reviewer articulated thoughts and strong recommendations for model transition that were also supported by several other review panel members: "some actions could significantly increase the efficiency of technological transfer. More specifically, the complexities of the NWEP systems have increased tremendously in the last two decades and demand more and more rigorous technology transfer processes and quality management procedures. Many successful NMHSs have an ISO9001 certification (e.g. a well articulated procedural checklist and customer feedback mechanisms) for their chain of innovation (i.e. R2O). The NWEP R&D short- and long-term planning and technological transfer processes in ESRL need to be improved and implemented in close collaboration with NCEP. …We recommend that the status of main projects (e.g. RUC, Rapid Refresh, etc.) should be monitored and documented regularly by a formal technological transfer management and scientific committee. The membership of this committee should include the principal investigator of major projects, senior scientists, and managers of ESRL and NCEP. An important term of reference of this committee would be to review and document the performance (e.g. each month) of the existing and future NWEP systems, including comparison with other NMHSs, using agreed operational validation and verification methods and metrics with standard WMO recommended practices and metrics used by the majority of the NMHS centers around the globe. The participation and contribution of scientists to the technological transfer process should be tracked formally by this committee. This committee should be formally involved in the process of appraisal and promotion of scientists."

Another reviewer noted that "ESRL's vision to develop coupled atmosphere-land-ocean-chemistry global modeling which span minutes to months time scale is very ambitious. A 5-year strategic plan on what needs to be accomplished in order to realize this vision and an implementation plan on how and when to research and develop the new capabilities and scientific understandings is highly recommended. These documents will work as guiding roadmaps for the CI scientists, post-docs, and graduate students to follow. Given the large amount of non-NOAA funding, these documents will help the R&D activities stay focused." On the other hand, one has to wonder how this development fits into the agency's strategy for Earth System Modeling. Assigning GFDL the decadal-to-centennial time scale and justifying the ESRL developments as appropriate to shorter timescales seems to one reviewer to stretch credibility somewhat, especially as the modeling community in general favors a seamless approach to timescales. ESRL's approach could set up a confrontation for resources for the future unless managed/coordinated/planned under the larger NOAA Environmental Modeling Program. Of course one could argue that ESRL does not have the manpower necessary to accomplish this very ambitious undertaking.

Recommendations

- ESRL needs to set realistic expectations and understand the operational constraints of an operational NWP system, including computer efficiency of models.
- ESRL's short- and long-term planning and technological transfer processes for NWP systems need to be improved and implemented in close collaboration with NCEP. ESRL, NCEP, and stakeholders need to establish the requirements, roadmaps, and detailed implementation plan (e.g. including schedule, critical path, etc.) for NOAA's chain of innovation for NWP (research, development, operation, and service).
- GSD should continue to monitor the skills of FIM forecasts. Care must be given to ensure FIM is using the same operational data stream (including QA/QC) to minimize any difference in the operational environments between ESRL and NCEP and to break down barriers to transition.
- The status of key projects (e.g. RUC, Rapid Refresh, etc.) should be monitored and documented regularly by a formal technological transfer management and scientific committee that would review and document the performance of the existing and developing NWP systems, using agreed operational validation and verification methods and metrics with standard WMO recommended practices and metrics.
- GSD should develop 5-year strategic and implementation plans, firmly embedded within a NOAA plan for environmental modeling and prediction, for its vision of a global coupled atmosphere-and-ocean-chemistry model. Such a plan should leverage off and contribute to and coordinate with existing efforts within NOAA, including GFDL.
- In developing the EnKF, FIM and NIM, ESRL should establish stronger collaborations not only with other NOAA labs and operational entities but also with labs in other agencies. The use of the ESMF is absolutely critical to enhance these collaborations. It is recommended that ESRL commit to ESMF fully – not only at the superstructure level but also at the infrastructure level. The NOAA Global Interoperability Program has provided funding and direction and should be taken very seriously.

3.3 Climate, Weather and Water Services

Although there were many activities within ESRL that elicited praise from the review panel, those presented under Theme 3 elicited superlatives. This was due to the high quality of the services presented, the strong research-services connection, and the strong experiential connection with particular applications that translated to understanding the importance of the activities presented. Again, water provided a strong theme to integrate services across weather and climate time scales.

Quality

According to one reviewer, "ESRL's provision of weather, climate and water services is one of the Lab's strongest contributions, in my view. It makes the lab a valuable national resource, and positions it well to be a major player in the new climate services arena. A key to success is ESRL's fusion of research and service, as many of the scientists who provide services also publish in the peer-reviewed literature. Many of the scientists involved in the provision of services also have strong publication records, as demonstrated by their H indices and numbers of publications. The quality of the ESRL service activity was captured well by Robin Webb's comment about the need to 'balance the tension between what users want and what is justifiable scientifically'. PSD staff seem skilled at the balancing act. A repeated theme of the service-related presentations was the importance of education. The guiding principle seemed to be that

users are better able to utilize (and embrace) climate/weather forecasts and products when they understand the basics of climate and weather. To me, this indicates a high-quality approach to user services." A few of the service activities are highlighted here.

The National Integrated Drought Information System (NIDIS) and the Western Water Assessment (WWA) epitomize ESRL's existing contributions to climate services. NIDIS is a multi-agency approach to providing an effective drought early warning system. The NIDIS Program Office has been established within PSD, presumably because of the strong leadership from PSD (and CDC before it) in making the case for NIDIS. The WWA is at the vanguard of the NOAA Regional Integrated Sciences & Assessments (RISA) program, and its success is due in large part to the parlaying of ESRL expertise with the interdisciplinary skills of the CIRES employees. Reviewer comments included: "particular strengths of water services provided through the Western Water Assessment are user engagement and an interdisciplinary scope (including economics and social science)" and "NIDIS and WWA are examples of integrated approach to addressing key issues and can serve as prototypes for other organizations to emulate."

The climate attribution work of Dr Hoerling and colleagues is exciting, well grounded theoretically and technically, and of great value in clarifying likely causes of historical and ongoing events. Led by PSD, it represents a successful collaboration between PSD, NCEP/CPC, NCDC, and GFDL. One reviewer found this effort to be "one of the most exciting things I witnessed during the review." Several reviewers noted that this activity appears to be underfunded relative to its importance. "This presents an important opportunity to get one step ahead of the climate skeptics to focus the media on what is actually happening and why." The attribution work "deserves more attention from NOAA hierarchy."

The Hydrometeorology Testbed (HMT) was created to help identify science and service gaps, to accelerate innovation (the infusion of new technologies, models, and scientific results), and to improve daily forecasting operations of the NWS and its River Forecast Centers (RFCs). With its development led by PSD, the participation in HMT now includes several NOAA laboratories, universities, agencies and NWS offices (see http://hmt.noaa.gov/). For one reviewer, ESRL's end-to-end, iterative interactions between scientists, engineers, and stakeholders in the testbed concept is "a model to be admired and emulated. Similarly, collocation with the Western Water Assessment group ensures strong interaction between stakeholders and scientists." Collaboration between PSD and GSD has targeted some transitions from HMT science to operations. According to another reviewer, "It is good to see the Hydromet Testbed and Atmospheric River Observatory (ARO) focusing on rugged terrain, high volume precipitation regions of the West Coast. This work is providing some new perspectives on winter land-falling storms along the West Coast. The analysis of moisture transports (M. Newman) and the forecast activities in GSD are a nice synergy to the AR work. In general, across the mountainous western U.S., there is great need to invent and implement improved 3-D monitoring, coupled with high-resolution modeling and prediction. There is concern about how the present observational capabilities will be sustained once the Testbed regional focus is moved to the eastern U.S."

Dr Hamill's development of reforecast-based re-calibration of two-week forecasts is also very noteworthy. The large training sample size from the historical reforecasts improved upon the

more limited statistics used for MOS (Model Output Statistics). The development "transformed" operations at NCEP and has also been adopted by ECMWF for shorter-range forecasts.

Relevance
In addition to the activities presented at the review, PSD's draft strategic plan shows clearly that its priorities are closely aligned with that of NOAA, and that it is responsive to both national and international imperatives in climate and water science. PSD scientists contributed to the IPCC's AR4 and they serve on national and international panels and committees that shape the priorities for the U.S. Global Change Research Program (USGCRP) and World Climate Research Program (WCRP). PSD is clearly well positioned to be a primary contributor to the emerging NOAA Climate Services.

One reviewer expresses the view of the panel: "ESRL has become the 'go to' place for weather, climate and water services. Several examples are telling in this regard, including the decision to locate NIDIS and much of the Western Water Assessment work at ESRL. In addition, CPC came to ESRL with the requirement for improved 'week two' forecasts, to which ESRL responded with by the innovative 'reforecasting' approach. … When Congress recently came to NOAA for information on the attribution of the severe winter weather in the East during the 2009-10, ESRL responded with a diagnostic assessment pointing to the combined influences of ENSO and the Arctic Oscillation. This 'rapid response' capability … is an excellent example of service drawing upon research. This is 'climate service' at its best. … The Lab is well positioned to provide diagnostic services relevant to weather events ranging from mesoscale severe storms to floods and droughts." According to another reviewer, "the Attribution group should and likely will be a key resource for NOAA and the nation in providing climate information."

Performance
As noted above, the quality of work we saw relevant to this theme was exceptional. Available metrics, including publication counts, external recognition, requests for service on national and international committees, indicate a strong performance. Publication/citation counts are generally high (in many cases comparable to those of university scientists), and there seem to be abundant and relevant services provided for weather, climate and water. The panel found it a powerful combination to have direct applications (NIDIS, WWA) embedded with the modeling groups. It is also invaluable to have NIDIS and WWA as interfaces between physical scientists and end-users rather than having all scientists involved with stakeholders. In our view, NIDIS and WWA provide building blocks for climate services. One reviewer noted that the "idea of linking research to decision-making vs to operations is a paradigm shift from a traditional view that might pay big dividends in the end." It would have been helpful if the panel had been given more metrics of the services provided, but those will probably emerge as the NCS becomes a reality.

PSD's testbed approach of prototyping functions and then transitioning them when appropriate (rather than running technologies forever) is a good one. On the other hand, one reviewer noted that although the "HMT concept is an excellent approach, it is a long prototyping process with no apparent end game."

The planned development of a HydroCimate Testbed (HCT) is an important follow-on to the HMT and an example of the important weather-climate linkages within ESRL that NOAA should continue to nurture even as the NCS emerges. Unfortunately, there was not enough time in the review to provide us with any information regarding the maturing of the plans for HCT. However, the PSD draft Strategic Plan provided some information such as the development of an Extreme Precipitation Portal (XPP) using lessons learned from NIDIS and the HMT. One area of concern is that it is not clear if and how PSD coordinates the development of climate services currently with NCEP/CPC. It is clear that at the research level there are many outstanding examples of collaboration that have resulted in co-authored papers. However, CPC is also a major contributor to NOAA's climate activities and services (providing, for example, the drought monitor information on the NIDIS drought portal and the seasonal climate forecast consensus), yet there was no discussion of how the two groups work together on strategic plans.

Recommendations

- ESRL should look to define additional metrics (beyond publication count) on the transitions of products to operational services.
- ESRL should have a stronger connection to CPC in its planning of climate service products. The unknown in this recommendation is the role of CPC in the NCS. Surprisingly, CPC, which has been a co-leader within NOAA (with CDC and then PSD) in developing climate products, is currently not planned to be part of the NCS.
- There should be clearer roadmap plans for testbed activities, including transition to operations and/or maintenance of observational capabilities that have been identified as essential for particular applications.

3.4 Technology Transfer and Outreach Activities

As noted above, the ESRL Director places a great deal of emphasis on the transfer of technology to operations. In the provision of services, emphasis is also placed on educating stakeholders. Review panel members lacked detailed information on the education/outreach mandate for NOAA. Although we were told that NOAA's role in science education is defined in the America COMPETES Act, the Act states that the NOAA Administrator "shall build upon the educational programs and activities of the agency." The panel felt that we needed more information on NOAA's educational programs and activities to provide a detailed evaluation of the relevance and planning/prioritization of the education and outreach portfolio at ESRL.

Quality

Many of the review panel members were unfamiliar, and so pleasantly surprised, with the breadth of important technologies developed by GSD, a stunning portfolio of excellent work. One reviewer commented, "ESRL expertise is recognized and sought after by agencies other than NOAA. The results have been very good; the 'clients' have been served well. The Precision Air Drop System (PADS) exemplifies an efficient application of ESRL expertise to address a need and develop a work solution in a timely way." According to another reviewer, "the list of innovative technologies already transferred to stakeholders that was provided to the panel was impressive (e.g. RUC, PADS, GPS-Met, AWIPS, FX-NET, SOS, etc.), but it was not possible to judge objectively the quality of some of these technologies due to the lack of exhaustive and systematic quality monitoring. As an example, the objective comparison of RUC to other NWEP systems (e.g. NAM, GFS, ECMWF, Environment Canada Regional Forecasting

System, etc.) is not systematically documented (e.g. by annual report)", although some evaluations are available on the web. ESRL should complement their current evaluation procedures for their flagship products with evaluation and comparison reports in close collaboration with the stakeholders (e.g. NCEP, FAA) on a regular basis. "These reports would be valuable decision-making tools for ESRL and NOAA management and long-range planning." Another reviewer noted, "The prototype systems FX-net and FX-C have been fielded in other operational environments. These are solid proof of the quality of work accomplished."

Reviewers commended the outreach efforts of the two divisions. "Visualization and 'packaging' of science and scientific results are being pursued here with very nice results." Reviewers were impressed with the Science on a Sphere (SOS). It "has had and will have enormous impact. … Content is of high quality, but there is so much more opportunity here." One reviewer called this an innovative program and suggests that "it would be interesting to see a series of video/SOS presentations that communicate to the average public viewer the 'whole story' about the work NOAA performs to benefit the public, and at the same time increases public awareness of the best uses of information readily available to them." Another reviewer suggested, "a virtual version to be run on a flat screen would be great." Given the familiarity of the modern generations with everything networked, a virtual version linked to Google Earth (for example) could have a much broader outreach potential.

The on-line "virtual world" is "truly novel" but "not quite so complete." A "formal development – feedback – formal evaluation process is missing." One reviewer questioned how well virtual worlds taught science concepts to children. "Can schools use it? Or is meant for home use? … How could 'virtual worlds' complement real-world hands-on activities both in the classroom and in the outdoors? Such questions need to be addressed in partnership with end users. As in the case of the other technologies, a robust evaluation effort should be developed."

Relevance
One reviewer noted that "scientists in PSD and GSD exhibit a culture of strong interaction with stakeholders in developing their technology-transfer efforts." Clearly, those technologies relevant to weather forecasting support NOAA's mission, but as another reviewer noted ESRL also serves a national, perhaps international community with its expertise. The "ultimate" customer is a "real world decision-maker, in many cases outside NOAA, including in many cases the lay public." The reviewer found that the "laboratory is reaching the appropriate stakeholders and realizing value from the research investment."

Performance
A reviewer commented that "the research to operation transition process was very well executed. The only area of concern is the weather information system. The past success was due to the tight integration with the end user and stakeholders. It does not seem the tight integration has been maintained currently. …. Besides the obvious near-term opportunity with the FAA NextGen program, ESRL management should engage in serious discussion with the NWS AWIPS-II program. ESRL should collaborate with the NASA Short-term Prediction Research and Transition (SPoRT) center and the U. Wisconsin Direct Broadcast Supported Project International MODIS/AIRS Processing Package (IMAPP) to transition a new technology to the NWS forecast offices. The weather information system research and development has been there

since 1990s and the aging of the program is observed. A new long-term strategy for this research should be developed in conjunction with the NWS. Given the national broadband communication initiative, a high-speed network may be available to every household in the near future. Social media, cell phones and PDAs are pervasive. ESRL needs to rethink the ways forecasts may be created and disseminated in the new connected world. Through advanced weather information research ESRL may define and prototype the future weather enterprise information system architecture."

Other reviewer comments were that "there is a pattern of success and efficiency of moving through transition;" transition plans "might benefit from economic evaluation to clarify the back-of-envelope estimates that are often made to measure success and quantify decision-making options;" in some cases it appeared that "there did not seem to be a clear, common understanding of what are the specific steps that are required for a transition activity." It is important to "perform analysis, perhaps using outside experts, to assess the measures of utility in operational use that increase due to specific scientific improvements. This could also assess quantitative measures of the effectiveness of the Operations and Services Improvement Process (OSIP)."

One reviewer noted that the exposure numbers for SOS (14 million annually) are impressive, however, outreach goals that go beyond "more people, more systems" need to be identified. "A regular plan for creating new modules for SOS and distribution to the installed base will be needed to keep the material fresh and relevant. Regular refresh for virtual world applications will require an even more intense refresh cycle to keep web audiences engaged and the cost may be prohibitive."

The reviewer also commented: "FAA's Research, Engineering and Development Advisory Committee (REDAC) completed a study in 2005, *Transitioning Air Traffic Management Research into Operational Capabilities,* which contains discussion of transition barriers worth consideration by ESRL. The report is available at http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/nextgen/research_tech_dev/research_planning/redac/reports/media/pdf/redac_report_TWG.pdf
The lessons must be institutionalized deeply in the organization and not just among the technology transfer staff. Senior executive intervention and championing can be effective in overcoming cultural barriers, including NOAA/NWS headquarters/Field laboratory tensions. Candid discussion of differences and incorporation of lessons learned into documented institutional processes can advance the technology transfer process."

Recommendations

- ESRL management should engage in discussion with the NWS AWIPS-II program. Collaboration with the NASA SPoRT center and IMAPP could help transition new technology to the NWS forecast offices.
- GSD should work with NOAA and other US and or international science oriented organizations, such as NASA, DARPA, or NSF to develop indices suitable for measuring the effectiveness and efficiency of technology transfer.
- ESRL should obtain and review FAA's REDAC report on barriers to research transition into operations for lessons learned.

- Technology transfer roadmaps that track investment in science to ultimate value in use should be developed.
- ESRL should consider working with the private sector to rethink the ways forecast information might be created and disseminated in the new broadband connected world.
- A multi-year strategy for targeting outreach activities should be developed. The resources and outcomes achieved in this area should be assessed.
- For major education and outreach efforts like virtual worlds and SOS, a formal evaluation process that includes educational value should be developed and implemented.

3.5 Earth System Observations and Analysis

3.5a. Weather Systems Observations and Analysis

ESRL undertakes activities both in new observations to support weather prediction and in evaluating the existing observing system, primarily through the ESRL-developed models such as the RUC.

Quality

Several activities on the observational side were recognized as significant accomplishments, including the Atmospheric River Observatory and the Unattended Aerial System (UAS) applications, both for quasi-operational work and for research. One reviewer commented, "A new emphasis on the Arctic and Antarctic has already yielded interesting and important results (reflected, for example in Dr Neff's Walter Orr Roberts lecture at AMS, and in the poster (O. Persson) revealing the existence of supercooled clouds in the Arctic and their influence on the surface energy budget)."

In general the reviewers were impressed with the work on GPS-Met and felt that the operational community should take ownership of this valuable data source. One reviewer considered that the dropsonde developed for the UAS "significantly reduced forecast error; GPS-MET provided important IPW information in a very cost-effective way; and MADIS provided an integrated data assimilation system to the private sector. These are new technologies ready for prime time."

In applying OSE and OSSE technology, ESRL's interests are focused on their own observational developments, not on the weather observing system as a whole. This is fine up to a point, but it is always best if an independent group takes responsibility for evaluating new observing systems to avoid conflict of interest. For example, it seemed that some of the observation error input parameters needed to be tweaked to get some of the results presented. Tuning is a part of assimilation system development, but all such tuning should be very carefully and openly documented. Radiosondes were used as the standard for verifying results and one reviewer suggested that there might be other options that should be examined.

Several reviewers agreed with the opinion expressed by one reviewer: "While the continued emphasis on OSEs for e.g. the RUC is to be commended, this effort would gain from aligning itself with standard WMO-recommended practices and metrics used by the majority of the NWP centers around the globe." One reviewer recommended that cost as well as benefit for these observation systems should be included in the assessment, and that ESRL consider addressing geographic areas identified by the 2009 NRC report, *Observing Weather and Climate from the*

Ground Up: A Nationwide Network Of Networks, as challenges for network design, namely urban areas, coastal region, and mountainous terrain. In addition, the reviewer felt that OSEs for applications other than NWP are important since the Network of Networks (NON) will have multiple applications. "This more holistic approach is consistent with the phenomenon-based approach for instrument needs done by Tom Schlatter, which is summarized in the NRC report."

Relevance
The work under this theme addresses NOAA's goals of advancing *in situ* data collection capabilities and associated platforms and system and accelerating the development of new environmental observational technology and sensors. NWS operational procurement decisions are critically informed by these experiments. ESRL has input to these decisions through their participation (Dr MacDonald) on the NOAA observing system council.

One reviewer commented: "NOAA's work in this area has already contributed significantly the background work necessary for the development of the Nation's NON, as proposed by the recent NRC report and currently being actively pursued under auspices of the AMS. An essential part of the design is the determination of an optimal design of a network that can be used for several applications. … MADIS has a lot to contribute to this effort as well. Containing a combination of public (state, local, federal), private, and even citizen-science data, it is in a sense a test-bed to ferret out some of the opportunities (the ability to evaluate/report deficiencies in reported data) and the challenges (good metadata, entraining stakeholders) into the network. It is impressive that ESRL was one of the first players (if not the first) in this important area."

Performance
One reviewer felt that "the scientists in PSD and GSD continue to be pro-active in identifying observational needs. Their described approach of identifying both geographical gaps and gaps from an applications point of view is a good one. … Their looking at promising technologies (UAS) and invention of new technologies (WISDOM) for needed observations continues a history of observational innovation." Again, "ESRL should also be commended for its leadership role in developing GPS Met. The integrated water-vapor measurements have relevance on all scales, from short-term forecasting to documenting the changes in water vapor associated with climate change. And the surface-based systems are relatively inexpensive." Another reviewer also praised the UAS program described by Ms Summers as putting NOAA "at the forefront of useful observations by unmanned aircraft. The variety of applications (Greenland melt, seals on ice, tropical systems) shows that ESRL is a leader in establishing the capabilities of this observing tool, which is likely to become a key part of observational programs in the future."

Work is just beginning in wind energy, with a focus on both modeling and accessing the necessary data for validation and measurement. One reviewer commented "one sees the same bubbling up of novel ideas and new collaborations developing as in ESRL's earlier efforts. The wind through the 'wind-turbine boundary layer' is not well documented – being too low for radiosondes and standard radar wind profilers and too high for surface measurements. This is a useful direction. … I was pleased to see that the emphasis is on impact on weather and climate as well as forecasting for wind farms, and the co-variability of solar radiation and wind."

Another reviewer recommended "GSD and the national and international satellite communities would benefit if the division were to position itself much more strongly as a ground validation resource." It was not apparent that the division was pursuing applications based on the synergy with the satellite systems. This issue was also raised *vis a vis* the comparison of water-vapor content from satellite and GPS-met (S. Gutman). This was "a good example of what can be gained from comparing ground-based to satellite data. Should more such work be done? Are we using satellite data in models as well as we could?"

Recommendations

- The OSE activities should include standard WMO-recommended practices and metrics used by the majority of the NWP centers around the globe. Cost as well as benefit for new observation systems should be included in the assessment. ESRL should consider addressing geographic areas identified by the NRC report as challenges for network design, namely urban areas, coastal region, and mountainous terrain.
- Given the extent of observational activities within ESRL, together with in-house modeling capabilities, ESRL should build a stronger effort in observing system evaluation and optimization.
- ESRL should position itself as a ground validation resource for satellite data.

3.5b. Climate Systems Observations and Analysis

There is strong synergy between the efforts relevant to this theme and those of climate and weather science.

Quality

PSD develops and maintains a suite of modern observation and analysis tools. The review panel regarded the work under this theme very highly. The importance of Dr Fairall's measurement and parameterization of surface fluxes over the ocean has already been noted. In addition, reviewers saw a lot of potential for the Arctic observatories to provide a fundamental component of an Arctic climate service. "The Arctic atmospheric observatory network (International Arctic System for Observing the Atmosphere, IASAO), coordinated by Ms Uttal, is also a high-quality contribution to Arctic observations. … The central role of ESRL in establishing IASAO resulted from a combination of (a) ESRL's reputation for high-quality work in the Arctic, (b) the impetus provided by International Polar Year, and (c) ESRL's ability to work with other parts of NOAA, e.g., the Arctic Program office in Silver Spring."

A lot of emphasis in this sub-theme was given to the extended 20th century reanalysis based only surface pressure observations. There are many good scientific reasons for undertaking this activity, which all panel members regarded extremely highly, some reviewers calling it "pioneering" and "revolutionary." From a climate record perspective, it is, as one reviewer states, "a break-through contribution to the climate record of the last century and more, and potentially a valuable contribution to the fundamental science questions of how the atmosphere works." Another reviewer noted, "the project is generating some important data archeology in feeding data to the model and in verifying the model estimates. I believe this will be valuable in providing detail to many climate and applied studies." Several reviewers noted the importance of using ensembles to provide measures of uncertainty.

According to one reviewer, the 20th century reanalysis and reanalysis portal are "gold mines for the atmospheric research community. … The 20th-century reanalysis is a truly innovative product that shows the ability to maximize the information content of historical data while maintaining homogeneity to the extent possible in a reanalysis product. The idea behind this reanalysis was original…The PSD scientists deserve tremendous credit for conceiving and carrying out this activity (and management deserves credit for letting it happen). I have no doubt that this reanalysis will spawn a huge number of diagnostic studies by the weather and climate communities."

Another reviewer commented, "The expertise in surface-based observing systems is second to none and adds a welcome complement to the much more visible space-based development efforts of NOAA in certain areas that do not naturally lend themselves to observations from space, in particular for the atmospheric boundary layer."

Relevance
"High quality climate observations and analyses are foundation stones for NOAA climate capabilities. This works closely allies with Theme 1 of this review, climate and weather science, and the work serves the lab well." The reanalysis was valued highly by another reviewer: "It is an invaluable community resource that has returned the investment many times over. In my view, this activity has greatly raised the visibility of ESRL (and NOAA) in the broader atmospheric community. It has enabled studies that serve all of the mission goals of NOAA."

The IASAO Arctic observatories also have high relevance for Arctic research, and one reviewer identified them as "one of the most prominent legacies of the International Polar Year." In addition to monitoring Arctic climate, "they will contribute to process studies …and will provide suites of observations that can be used to test and enhance parameterizations of Arctic processes in models."

Performance
Reviewer comments included: "Posters on the Boulder tower observatory, Ron Brown observing, *in situ* vs NWP fluxes, Arctic program leadership, EM sampling, and remote sensing round out a good portfolio." The projects presented under this theme "have led to an enviable combination of scientific publications as well as products and services. … The completion of the historical reanalysis essentially 'on schedule' points to a strong performance by the Whitaker/Compo group. The successful establishment of the IASAO network, including the deployment of the Tiksi instrumentation by NOAA, also points to effective performance. More generally, the publication record of scientists working under this theme is impressive; especially considering that observational projects and service activities often soak up large amounts of researchers' time."

As for other themes, the panel expressed concern that the shortage of Federal positions represents a challenge to training and nurturing the next generation of scientists and science leaders. One reviewer noted "one needs to recognize observing expertise, including down to the evaluation of sensors, as an expertise that is precious." In that light, ESRL personnel should be considered a national resource. "Is the lab sustaining this cadre? Is the influx of CI people leading to a permanency of competency at ESRL? Is ESRL supporting the rest of NOAA and

the country with this expertise?" Is more synergy between NCAR/NSF ATM facilities support and NOAA ESRL observing capabilities possible to foster and sustain community competency in climate observations?

Recommendation

- ESRL should identify the NOAA and national context for sustaining their climate observing competency and excellence and thus the core expertise ESRL needs to maintain. A plan should then be developed to do so.
- ESRL should consider hosting summer schools to sustain the core competency in key climate observing areas.

4. Future Directions

ESRL faces some significant challenges in the near future. The first is the development of the next generation of science leaders and managers. The second, perhaps more challenging, is the strategic positioning and planning of model and data assimilation development and climate product development throughout the agency. The first is a challenge faced by most organizations. The second is a NOAA-wide issue that is pursued further in the final section.

The establishment of NOAA's Climate Services casts a slight air of uncertainty on future directions of the two divisions in terms of their ability to act as a Physical Sciences unit (and on those elements of PSD that might not transition to the NCS). With all the best intentions not to stovepipe activities, funding from different line offices is usually a hindrance to coordinated planning, not an aid. This is clearly manifested in the interactions between NCEP and ESRL where not only are the funding streams and the reporting lines different between organizations belonging to NWS and OAR, but they also often find themselves in direct competition for some of the same agency resources. The fact that there is no existing culture of strategic planning across PSD and GSD lines means that "barriers" will be easily erected if management does not play an active role in encouraging and facilitating interactions. Currently, the interactions appear to be fairly good, because of the good relationship between Drs Neff and Koch. As PSD evolves to contribute to the NCS, it is important to preserve linkages between disciplines and organizational units within ESRL. Some panel members would go so far as to recommend that, like CPC, the move of PSD into the NCS be reconsidered.

Nevertheless, PSD is clearly well positioned to play a leading role within a Climate Services, and both NIDIS and WWA already provide prototypes of service activities that should be emulated by other services. One reviewer questioned whether there are enough scientists in WWA and NIDIS to "carry the decision maker support that will be required with the additional burden of stakeholder interactions that will likely arise in topics associated with water resources, water hazards, forests and other ecosystems, disaster management, etc. To make progress commensurate with that achieved by WWA and NIDIS may require expertise in the science underpinning these systems and in the decision-making framework of the managers and stakeholders involved, well above and beyond general climate and weather literacy. … Strengthened interactions between ESRL and other Federal agencies would be useful in producing climate services. … if whole watershed monitoring is a route that PSD will pursue, … close alliances with USGS and other agency science and management groups will be necessary."

Several recommendations above noted the need for strategic planning in some areas. We were provided a draft strategic plan for PSD, but no comparable planning document from GSD. Although there are several examples of cooperation between the two divisions (e.g., the PSD support of the EnKF development), there does not appear to be any joint planning or prioritization of activities. As one reviewer expresses it: "while there may be a well considered approach to the work that is undertaken, there wasn't strong evidence of program management artifacts, roadmaps, data architectures and other planning and management tools that would guide the selection and execution of the scientific efforts. While the scientists are primarily focused on the scientific process and content of their work, a clear understanding of its place in the whole of the Laboratory's scientific planning and its objectives in terms of reaching an ultimate non-science end user would set a guiding context."

A few comments about specific future directions emerged.

One of the strengths of the laboratory efforts lies in the connections made between weather and climate. The community is more and more placing emphasis on the continuum rather than the separation of scales. One reviewer considered it appropriate that "GSD has increased the range of time/space scales to include seasons: one needs to expand to the longer time scales to address the NOAA strategic plan goals of improving predictability (and reducing uncertainty), lead time, and accuracy of forecasts of severe weather and water events." On the other hand, another reviewer noted that NCEP is already addressing prediction on the sub-seasonal to seasonal time scale. Just as for NWP, developments on longer timescales should be coordinated with NCEP. The reanalysis and attribution efforts both offer opportunities to look at the regimes under which severe weather and water events occur, as does the longer-term look at atmospheric river situations, the idea of a HydroClimate Testbed, and the Calwater Phase II field program. PSD's concept of a HydroClimate Testbed should definitely be developed further. Water is a most precious resource and water availability, both now and in the future, is of considerable economic and security concern.

There was also some support for involvement with ecosystem scientists as a "future direction." One reviewer felt that this is extremely important "since weather and climate are not the only things that need to be considered in managing our environment. Such efforts are obviously helped by collocation with groups such as the Western Water Assessment, though collaborations will probably have to involve more different disciplines. Such work appropriately should reach well beyond the two divisions reviewed." Another reviewer noted that there appears to be "little ecosystem expertise in ESRL; however, some strategic partnering with ecologists and other specialists might be a nice complement to ESRL monitoring, modeling and diagnostic talent."

On the observational front, one reviewer commented that as PSD evolves to the NCS, it is important to sustain the observational development. "Developing an unmanned aircraft along with miniature sensor packages would have application to many phenomena and problems."

5. Comments for the Next Review

All of the review panel members appreciated the opportunity to participate in this review. However, all noted the tightness of the schedule and lack of opportunity to follow much of the

work in depth (unless one was already quite familiar with the topic and the work being done). The shear breadth of topics being addressed in the two divisions was quite overwhelming and quite surprising to most of us. Having more of an opportunity to engage scientists in a slightly more informal setting, with time to ask questions, would have been helpful. In principle, the poster sessions should have provided this opportunity, but even there the schedule was too tight to do justice to the work presented. One suggestion would be to reduce the repetition. For example, the overview presentations for each theme were very useful guides to both presentations and posters, but the wrap-up presentations often repeated material. Posters that gave little additional information on work already presented could be cut back. Although we were all very excited and impressed to see the SOS in action, two presentations of it were not needed.

Many panelists also found the distinction between the ESRL and the CIRES contributions confusing. As one reviewer said, "Yes, the funds for CIRES are in large part paid through ESRL, but there are two categories of employees here and it is difficult to determine who actually does what." Panelists could not determine who the CIRES employees were. Perhaps this could be made clearer in the next review.

6. Final Comments

Without repeating all of the recommendations provided above, there are a few recommendations that emerged from individual reports and discussions that have broad support across the panel. These are highlighted to finish this report.

First and foremost are the recommendations made to address concerns regarding strategies for modeling and data assimilation, both for NWP and also the broader goals of a more comprehensive global coupled atmosphere-land-ocean-chemistry model. Clearly strategic planning agency-wide is needed in this area, both to avoid conflicts between ESRL and NCEP on the one hand and GFDL on the other and also to ensure that the many talents in all of these organizations can be used to ensure that NOAA's modeling is first class. The connections with NCEP are perhaps more obvious and several recommendations were made above to improve on the planning and also the execution from an ESRL perspective as well as a NOAA perspective. Perhaps the most important recommendation is that ESRL should continue to develop stronger connections to NCEP in weather and short-term climate modeling and data assimilation and, in doing so, should work closely with them to identify the priority development areas and the metrics to be used for system performance. The recommendation regarding metrics encompasses not only model and data assimilation development, but also OSE and OSSE activities. As ESRL extends the time scales of interest for model development and application and increases the complexity of their modeling efforts, they should also develop strong partnerships with GFDL. In general, model developments should be integrated within a NOAA-wide strategic plan for environmental modeling.

Similarly, ESRL should build stronger connections with NCEP/CPC and GFDL in planning climate service products. ESRL has a very strong record and exemplary capabilities in this area, as well as strong research collaborations with CPC scientists. Hence they can be expected to play a leadership role in many climate service areas. Nevertheless, NOAA's capabilities will be of

higher quality, more comprehensive, and of greater utility to end users with better coordination and planning between these groups. Under the Climate Services umbrella, there should be increased emphasis on model diagnosis and attribution activities.

Planning issues were noted in several areas. In addition to strategic planning in modeling and data assimilation, there should be clearer roadmap plans for testbed activities, including transition to operations and/or maintenance of observational capabilities that have been identified as essential for particular applications. ESRL's short- and long-term planning and technological transfer processes for NWP systems need to be improved and implemented in close collaboration with NCEP. ESRL, NCEP, and stakeholders need to establish the requirements, roadmaps, and detailed implementation plan (e.g. including schedule, critical path, etc.) for NOAA's chain of innovation in NWP (research, development, operation, and service).

In several areas/themes, several reviewers raised issues regarding the evaluation metrics used to assess progress, quality, value to the end-user, etc. Metrics for NWP developments, OSEs and OSSEs have been mentioned above. In addition, some panel members recommended that technology transfer roadmaps that track investment in science to ultimate value in use should be developed. Indices suitable for measuring the effectiveness and efficiency of technology transfer should be developed. In education and outreach efforts like SOS and Virtual Worlds, a formal evaluation process that includes educational value should be developed and implemented.

While the panel was impressed with the quality and vitality of the workforce and their dedication to NOAA's mission, there were a couple of areas that could benefit from increased attention. One area is more systematic mentoring of young scientists and increasing their involvement in the scientific activities and communications across the organization. The other, more difficult, area is planning for succession of senior management, with a mentoring program for potential replacements. Strategic planning should be undertaken for the future workforce in critical areas. For example, it was felt that ESRL should identify the NOAA and national context for sustaining their climate observing competency and excellence and thus the core expertise that should be maintained in the ESRL workforce.

In closing, ESRL is to be commended for their many contributions to NOAA's mission in particular, and to the weather and climate research activities of the nation in general. The review panel was impressed by both the high quality of all we saw and the breadth of activities across the two divisions. There were several areas in which the panel viewed ESRL capabilities (and personnel) as "gold mines" – essential (or potential) resources for the nation, not just for NOAA. The two divisions are well positioned to continue their contributions to weather prediction, climate services, and observation development for both weather and climate into the future. There are core competencies that should be preserved and nurtured as the plans for the NOAA Climate Services mature. It is especially important that key linkages across the two divisions – linkages that recognize the strong connections between weather and climate and the need to address the continuum especially in water science and applications – are maintained as the two groups evolve under different line management and funding streams.