Summary Report of the Review of the Physical Sciences Division, NOAA ESRL

DATES OF REVIEW: May 12-14, 2015

PERIOD OF REVIEW: 2010-present

REVIEW PANEL:

Dr Anjuli Bamzai (Chair), National Science Foundation, Arlington VA

Dr Susan Avery, Woods Hole Oceanographic Institution (WHOI) MA. Dr Avery was unable to attend in person; however she actively participated in all aspects of the review *via* telcon.

Dr David Bromwich, Ohio State University, Columbus OH

Dr Lisa Goddard, International Research Institute for Climate and Society (IRI), Columbia University, NY

Dr Jonathan Overpeck, University of Arizona, Tucson AZ

Dr Peter Stott, U.K. Met Office, Exeter, Devon U.K.

Dr Andy Wood, Research Applications Lab, National Center for Atmospheric Research (NCAR), Boulder, CO

Dr Chidong Zhang, University of Miami, Miami FL

OUTLINE

Page

Scope and Context of Review

The review covered a range of activities in the Physical Sciences Division (PSD) of the Earth System Research Laboratory (ESRL). The period covered by the PSD review is 2010-2014. Dr Neff was the Division Director for the period 2010-2013. Dr. Webb has been Division Director of PSD since January of 2014. The purpose of the review is to ensure research is linked to the NOAA strategic plan, and strategically position PSD in its planning of future scientific efforts. The review website http://www.esrl.noaa.gov/psd/events/2015/review/ includes science presentations, and supporting documents.

Prior to the review, Oceanic and Atmospheric Research (OAR) management conducted two telecons to clarify the charge to reviewers and clarify any questions that arose during the discussions. In the first telecon, one of the panelists asked for additional materials (list of all observing facilities of PSD, where and when facilities have been deployed, and the PIs within and outside NOAA in the last 5 years) and these were provided by PSD prior to the panel date. The panelists also conveyed to OAR their interest to have concurrent working lunches with two groups of employees: NOAA federal employees including non-scientists; and Cooperative Institute for Research in Environmental Sciences (CIRES) employees. These telcons were helpful not only in terms of the panelists acquiring a good perspective of their charge, but also in the panelists co-planning the review agenda.

For the purpose of this review, PSD activities were divided into four themes: (i) Observing the Physical System; (ii) Understanding the Physical System; (iii) Modeling the Physical System; and (iv) Research to Applications, Operations and Services (R2X). Reviewers mutually agreed on the assignment of a theme. Each reviewer provided a formal review on the theme assigned to them using the following evaluation criteria:

Quality: Assess quality of research over the last 5 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

The choices for the overall evaluation rating are as follows:

Highest Performance (HP)--Laboratory greatly exceeds the Satisfactory level and is outstanding in almost all areas.

Exceeds Expectations (EE)--Laboratory goes well beyond the Satisfactory level and is outstanding in many areas.

Satisfactory (S)--Laboratory meets expectations and the criteria for a Satisfactory rating.

Needs Improvement (NI)--Laboratory does not reach expectations and does not meet the criteria for a Satisfactory rating. The reviewer will identify specific problem areas that need to be addressed.

Input for OAR and Lab Management: OAR leadership also asked the reviewers to consider filling out the Reviewer Feedback Worksheet; these comments are provided in the Section on Findings.

While we attempted to limit ourselves to the period of review, it was clear that some accomplishments were a result of sustained activity that had been initiated prior to 2010. In accord with FACA rules, the review panel did not seek consensus in our evaluations.

The panel was provided a report of the previous review of ESRL. The previous review was somewhat larger in scope since it covered two Divisions, the PSD and Global Systems Division (GSD). It had several key recommendations. For example, the previous panel had expressed a concern about the planning and coordination of Arctic research. They recommended a cross-division program on Arctic be established at ESRL, and the laboratory position itself as taking on a leadership role nationally and internationally. The previous review panel also strongly recommended an implementation pathway for technology transfer systems from the lab to NOAA National Centers for Environmental Prediction (NCEP). The previous review panel also identified the need to succession planning; while this issue may have been partially addressed, the current panel emphasizes the continued need to proactively plan for the replacement of senior personnel through a strong mentoring program.

PSD is in the process of developing its strategic plan; given his broad experience and stature in the field, we are pleased that Dr. Dole is guiding its formulation. We were informed of the new priority areas, *viz* water, extremes and Arctic. We believe the themes are appropriate; each of them align with expertise in the Division to varying degrees. Under the leadership of Dr Webb, the Division is also undergoing a reorganization to better achieve the goals of the new strategic plan. We kept the backdrop of all these changes taking place while conducting the review.

Evaluation Ratings

Table 1 below gives a breakdown of ratings for Quality, Relevance, and Performance for each of the four themes. Based on these, the summary ratings for the four themes are HP/EE; HP/EE; EE and EE, respectively. The overall rating for the lab is HP/EE.

	Theme 1: Observing the Physical System			Theme 2:Understanding the Physical System		
	Quality	Relevance	Performance	Quality	Relevance	Performance
Panelist 1						
Panelist 2						
Panelist 3				HP	EE	HP
Panelist 4	EE	EE	EE	EE	EE	EE
Panelist 5	EE	EE	EE	EE	EE	EE
Panelist 6				EE	HP	EE
Panelist 7						
Panelist 8	HP	HP	HP			
Average Score	EE**/HP*	EE**/HP*	EE**/HP*	EE***/HP*	EE***/HP*	EE***/HP*

*=number of reviews in category
Green indicates panelist was assigned to theme

	Theme 3: Modeling the Physical System			Theme 4: Research to Applications, Operations and Services		
	Quality	Relevance	Performance	Quality	Relevance	Performance
Panelist 1						
Panelist 2	EE	HP	EE			
Panelist 3						
Panelist 4	EE	EE	EE	S	S	S
Panelist 5	EE	EE	EE	EE	HP	EE
Panelist 6						
Panelist 7				EE	EE	EE
Panelist 8						
Average Score	EE***	EE**/HP*	EE***	S*/EE**	HP*/EE*/S*	EE**/S*

Findings

The review panel was impressed by both the high quality of all it saw and the breadth of activities across PSD. The Division is poised to make advances in all three topics identified in the strategic plan, *viz*. Arctic, water and extremes.

1. Theme 1: Observing the Physical System

1.1 Quality:

There are three categories in this research area: (1) instrumentation innovation and deployment, (2) data archiving, processing and products, and (3) leadership in organizing national and international field projects that leverage resources from outside PSD to address emerging issues that are relevant to NOAA/ESRL/PSD missions and bear national and global importance.

Led by a world-renowned leader in observations of surface fluxes, who has been a critical mentor for PSD scientists involved in this area, the sustained efforts of measuring air-sea fluxes from all over the world by the PSD flux group has yielded a rich dataset that is regarded as the gold standard. The flux algorithm developed by PSD scientists based on this dataset is superior to all other flux algorithms. PSD scientists' participation in the Dynamics of the Madden Julian Oscillation (DYNAMO) and CalWater 2015 field campaigns was key to their success. The flux group excels in all three categories of research described earlier.

PSD's ground-based remote sensing observing expertise (S-band profilers, 404 and 915 MHz wind profilers, W-band cloud radars) is second to none. The Division has contributed to several national and international field campaigns (recently, DYNAMO and Midlatitude Continental Convective Clouds Experiment (M3CE)) with high quality data collection and processing. Despite the decision not to maintain the scanning radar facilities at PSD, the Division is still home of unique expertise in this area. Applying this expertise to Quantitative Precipitation Estimates (QPE) in mountainous regions is a wise choice, which yields high quality rainfall data that otherwise would not be available. The quality of both PSD's profiler observations and QPE exceeds expectation in categories (1) and (2); there is no evidence as of now, that PSD has played a leadership role in national and international field projects that involved multiple institutes and nations.

There appears to be a clear niche for PSD in the observations of Arctic atmospheric and surface processes and leadership is starting to emerge. Much of this is currently in the basic R&D domain. The potential participation in activities associated with Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) and Year of Polar Prediction (YOPP) will further highlight PSD as a leading institute for Arctic observations and research. PSD scientists have demonstrated strong leadership, in upcoming programs, e.g., MOSAiC.

The PSD Arctic observing capability currently covers the following activities: long-term commitment to Arctic research issues through participation; the Arctic data portal service, International Arctic Systems for Observing the Atmosphere (IASOA); and leadership in the field in the past and at present. The panel recommends a more proactive leadership role by PSD in the contribution to real-time use of observational information.

1.2 Relevance:

Surface flux is a critical component of the Earth's energy and hydrological cycles. Accurate reproduction of surface flux by Numerical Weather Prediction (NWP) and climate models is paramount to their fidelity. The NOAA/ESRL mission of predicting the Earth system cannot be achieved without reliable representations of surface fluxes based on knowledge gained directly from observations.

Ground-based PSD profiling radar observations provide detailed data for the atmospheric boundary layer and the troposphere that have helped researchers to better understand physical processes critical to modeling of the Earth system. The radar-gauge combined QPE analysis is a niche among NOAA labs and benefits rainfall forecast validation in the mountain states. Satellite rainfall retrievals suffer from large errors in regions of complex terrain, especially for snow. The radar-gauge combined QPE analysis provides the best reliable ground truth and is urgently needed to advance NOAA's capability of forecasting the water cycle. CalWater2015 is a field campaign of high visibility. Its success of data acquisition paved the road to advancing understanding of water cycle dynamics crucial to the west coast. It is a case in point that successful field observations on the large scale cannot be done by a single laboratory or institute.

The Arctic observing facilities of PSD are subcritical for fulfilling the NOAA/ESRL observation need for Arctic prediction. It is paramount to integrate observing capabilities both internal and external to NOAA to meet the challenge of the very complex and little understood system of the Arctic. This requires leadership with knowledge and vision, which has been provided by PSD scientists.

1.3 Performance:

Many national and international field campaigns have benefited tremendously from PSD participation, the performance of which has always been at the top class.

Based on the table of PSD Field Programs, some PSD instruments (e.g., W-band radars, W-band radar, Surface met, Air-sea fluxes) are frequently deployed, others are not (see Table 2). Some infrequently used instruments might have been developed only recently (e.g., UAV, Snow level radar), but others are mature instruments (e.g., S-band radar, Lidar, Radio Acoustic Sounding System (RASS)). It not clear whether their different deployment frequencies come from availability of funding, manpower of scientists and engineers, opportunities, or other factors.

TABLE 2: Field deployment of PSD instruments during 2000 - 2015

PSD Instrument	Field Campaign	Time
W-band radar	CALNEX 2010 DYNAMO ACSE SWERUS-C3/ACSE	2010 2011-2012 2014 2014
S-band radar	MC3E	2011
Snow level radar	HMT	Ongoing
449-MHz wind profiler	HMT MC3E DJBAQS ACSE FRAPPE	Ongoing 2011 2012 2014 2014
Lidar	ICECAPS DYNAMO	2010-present 2011-2012
RASS	DJBAQS	2012
Radiosonde system	ICECAPS DYNAMO	2010-present 2011-2012
Dropsonde system	HS3 WISPAR	2010-2014 2011
Microwave radiometer	ACSE RV Mirai Arctic Mission DYNAMO	2014 2014 2011-2012
ceilometer	ACSE	2014

	DYNAMO	2011-2012
Rain gauges	HMT ICECAPS	Ongoing 2010-present
Surface met (wind, T, q, p, radiation fluxes)	HMT DJBAQS UBWOS FRAPPE	Ongoing 2012 2012-2014 2014
Soil moisture	HMT	Ongoing
Air-sea fluxes	IASOA CALNEX 2010 WHOTS DYNAMO TORERO HIWINGS RV Mirai Arctic Mission	Ongoing 2010 2010-present 2011-2012 2012 2013 2014
Surface waves	HIWINGS	2013
Aerosol sampling	SJMSS	2015
Snow sampling	SJMSS	2015
Tall tower	XPIA UBWOS	Ongoing 2012-2014
UAV	COALA	2014
Acoustic array	ATA	2010-present

Theme 2: Understanding the Physical System

2.1 Quality:

Research carried out under this theme is outstanding in many areas. This includes the work under the heading *Explaining Extremes to Improve Prediction* that is related to attribution of climate change and of extreme events. PSD's specific niche of bringing process-based understanding to the attribution question is particularly insightful and valuable. Event attribution science requires a healthy portfolio of approaches to be successful and PSD's provides a valuable perspective in the mix of existing approaches by considering mechanisms and relating attribution to prediction. It complements other approaches such as those that rely more heavily on very large model ensembles or sophisticated statistical techniques. Members of PSD have published some key papers in this area.

PSD researchers have also been active in international collaborations organizing and attending meetings of the Attribution of Climate-related Events (ACE) group, attending ad-hoc International Detection and Attribution Group (IDAG) meetings and taking an active part in related sessions at international conferences such as AGU. There is a wider portfolio of work under this theme than that related to attribution grouped under the heading *Atmosphere and Ocean Dynamics*, and here too excellent work is being carried out by internationally leading PSD scientists. The work carried on processes underlying the Pacific Decadal Variability is insightful. The work done by PSD scientists in the area of tropical dynamics has been at the leading edge of the field. They and their collaborators have invented powerful tools to diagnose various types of tropical waves through spectral analysis and explore predictability of the coupled systems through a linear inversion model. In the past five years, they continued to push the envelope and advance our knowledge in this field.

It was not clear if/how impressive research findings from efforts (e.g., the research on stable boundary layer that addresses a persistent issue in models) impacts model development. The engagement with stakeholders was uneven in quality and extent, although it is possible this perception was due to the content in the presentations and time constraints.

2.2 Relevance:

Work under this theme has outstanding relevance to the mission of NOAA. Only by understanding the physical system is it possible to build the tools that will enable better prediction. Only by understanding the physical system is it possible to assist stakeholders in making optimal decisions for the people and societies they represent, so that societies are enabled to be more resilient to extreme weather and climate change and to become more prosperous. So PSD is absolutely right to have a theme devoted to this topic and to give it the priority that it clearly deserves. A key aspect of any weather and climate service offering is to provide the underpinning science needed to support the mission in a way that links user needs back to the required research and delivery. Focus on the mechanisms of drought and atmospheric rivers stands out in its high relevance.

There is a healthy variety of outstanding examples of products and services PSD produces. Examples include involvement in co-editing the annual Bulletin of American Meteorological Society (AMS) attribution report, the contributions to Intergovernmental Panel on Climate change (IPCC) and Stratosphere-troposphere Processes And their Role in Climate (SPARC) and the PSD contributions to the National Integrated Drought Information System.

The review panel members were all praise for the PSD Climate and Weather Data portals and user tools including the Facility for Climate Assessment (FACTS) Data Access and Visualization portal, the NOAA Climate Change Web portal and the PSD Web-based visualization and analysis tools. These excellent initiatives indicate strong user engagement. On a cautionary note, it is important that provision of information such as visualization of CMIP5 ensembles of projections needs to involve careful communication with users as to the meaning of such information (e.g. what does an ensemble of opportunity of imperfect models represent for a user of such information?). There is no doubt that PSD has the skills and capability to provide that support to users.

2.3 Performance:

While PSD is performance is outstanding in many areas, more could be done to ensure transition of research to applications. The concern is not with the very high caliber quality of leadership from the senior leadership team including Director and Senior Scientist. Rather, the concern is with the extent to which PSD science is fully integrated with communication and applications in such a way that science developments made at PSD realize their full benefit in improved advice and predictions.

There are two areas of particular concern where PSD could do even better working in collaboration with other institutes. One is in the pull-through of physical understanding into improvement in models. For a few presentations made by PSD scientists during the review, on questions from the panel about how this science might be translated into improved predictions, it wasn't at all clear from the responses how developments in theoretical understanding that were undoubtedly being made were feeding down the line into model improvements. This aspect needs some further careful thought by the leadership team as to how to facilitate the take up of PSD science into operations. It seems there could be a greater awareness by some (but certainly not all) scientists at PSD as to user requirements, in particular, as to the potential benefits of their research and the possible mechanisms for allowing operational benefit to be realized from that research.

The second aspect concerns the issue of communication of attribution results. It is obvious that it is a major challenge for scientists engaged in this field to ensure clear communication of research results and to avoid confusion, particularly among journalists and the general public if they receive apparently contradictory messages. It is advisable that assessments include not just the views of lab members, but also take account of a wider view where results can be suitably supported by scientific information. Note that this does not mean providing an uncritical review of all views, but does require a nuanced view of a possible range of views. Critical here is an appreciation of the framing of the attribution question. Particular approaches may frame the attribution question in a particular way, and it is important to clearly communicate that framing to users and to consider what alternative framings might produce. For example, it could be that given a particular set of dynamical circumstances heavy flooding is more likely as a result of climate change, but that climate change has not altered (or even reduced) the chances of those dynamical conditions. Without more careful and coordinated framing and messaging, the public could end up receiving apparently contradictory messages that lead to unnecessary levels of confusion among the audiences that NOAA must serve.

As well as continued participation in workshops such as ACE, IDAG, *etc.,* it would be good for PSD scientists to consider where possible how to best engage in U.S. coordinated efforts to ensure clear communication. For example, in the U.K., informal networks exist whereby discussions can take place, disagreements aired, *etc.,* before communication activities are initiated, recognizing that it doesn't help if an apparently strongly divergent set of views is communicated without proper explanation. For example, during the recent wet winter of 2013/14 in the U.K. the dissemination was aided by press offices coordinating among themselves and importantly the U.K. Science Media Centre (SMC), which provides a coordinated means of communication between scientists and the media. It seems that such an institution doesn't exist in the U.S., although the U.K. SMC would be happy to engage with interested parties if there would be interest in setting up such a body in the U.S. Where communications are seen as an overall assessment, potentially led by PSD contributions, they can have a greater impact and applicability than a single view, especially if that view appears divergent from others.

While the lab has many outstanding researchers, and notwithstanding PSD's mission to support weather and climate services, the average number of papers per scientist across the institute is good; it could be even better given sufficient focus on developing strategically core areas. It is extremely important that PSD continues to maintain and build the expertise needed to develop the underpinning science base in a strategic way taking account of the core strengths of the lab. Suitable levels of collaboration across the portfolio of research need to be nurtured. The Director of PSD and his senior staff need to be supported in their efforts to recruit and maintain a core cadre of leading scientists on the core federal budget. If PSD is to fully realize its immense potential to serve the nation in increasing resilience to extreme weather and climate, etc., collaborations with leading scientists in universities is clearly key, but such collaborations are not possible without a core international leading scientific credibility in the lab which PSD currently has.

There were illustrative examples where the review panel felt that based on the presentations, the work by relatively junior scientists was not totally convincing. This is not to preclude the possibility that the line of scientific inquiry being pursued may eventually develop into very promising avenues of research, or even that our criticisms of individual points could legitimately be challenged. However based on the presentations, the panel was of the strong opinion that mentoring from more experienced scientists in PSD would aid the development and the quality of research of more junior scientists.

Research leadership and planning is strong and the Director and his senior team have a strong vision for what needs to be done to make PSD even more effective, but their hands are tied to some extent by the operating environment in which they have to work. A perspective from the non U.S. panel member was that NOAA would be better served if it were possible to underpin a larger proportion of the PSD research with permanent staff.

Theme 3: Modeling the Physical System

PSD researchers are addressing issues on a variety of timescales, from Numerical Weather Prediction (NWP) to long-term. For a Division of the size of PSD, the number of projects seems appropriate.

3.1 Quality:

The approaches employed by PSD are a healthy mix addressing issues ranging from basic R&D, modeling processes to improve forecasts, and applications. The key projects deal with the following: (i) out-of-the box ideas challenging conventional wisdom based on analytical solutions; (ii) models of intermediate complexity, e.g., the stochastic Linear Inverse Modeling (LIM) that has been developed, nurtured and applied at PSD itself; (iii) examination of feedback processes incorporating radically new approaches to coupling dynamics and radiation within the IPCC-class models, (iv) development of state-of-the-science tools, *e.g.,* super-parameterized model for representation of clouds in Weather Research Forecasting model (SP-WRF); (v) use of high-resolution modeling to understand future climate impacts; (vi) 20th Century Reanalysis; and (vii) modeling of Arctic cloud processes.

The work aimed at improving the representation of radiation processes in models used for climate change simulations, is elegant and based on innovative considerations. It aligns nicely with one of the six World Climate Research Program (WCRP) challenges, *viz.*, clouds, circulation and climate sensitivity. There is a good synergy with international activities on this topic and the likelihood the work will provide useful input to model developers engaged in the model intercomparison and assessment activities such as Coupled Model Intercomparison Project (CMIP6) and IPCC is high.

The effort on SP –WRF attempts to ameliorate vexing issues associated with the parameterization of clouds in current General Circulation Models (GCM). It integrates the existing expertise in PSD, both in observations (e.g. ocean surface fluxes) and modeling (e.g., running the WRF model).

Much of the work within this theme challenges conventional wisdom and demonstrates the value of creative thinking and perseverance in pursuing ideas over a period of time; the best may yet to be come. The Linear Inverse Model is proven valuable to the prediction and understanding of dynamical systems, and thus to climate variability, on timescales of weeks to years. The framework is elegant and complements relatively expensive GCM simulations. The 20th Century Re-Analysis (20CR) is a major contribution to work on modeling and observations of long-term variability and change. This global leading approach was thought to be impossible, until demonstrated otherwise, and now similar efforts are being initiated in other countries. The theoretical study on change in probability density function (pdf) of temperature/precipitation under changing climate is unique. Climate science needs original ideas such as these.

3.2 Relevance:

PSD has carefully crafted its activities keeping in mind NOAA strategic goals of weather-ready nation and climate adaptation and mitigation. The initial ideas of the 20th Century Reanalysis project as described in BAMS, has culminated in a Reanalysis product that NOAA (and PSD, in particular) can be immensely proud of in terms of delivering a unique product that is of great importance to placing events in the context of the past 150 years or so.

The modeling efforts address strategic goals of NOAA to various degrees. Several of them contribute directly to the goal of a Weather-Ready Nation. While some are still in basic R&D mode and not ready to transition from Research to Applications (R2X), they are well-motivated and focused towards elucidating key climate processes and feedbacks to forcing.

A couple of projects deal with themes (extremes, water, and Arctic) identified in the new strategic plan. The researchers are well-poised to make substantial contributions in the years ahead. PSD does not have a critical mass of researchers to address the Arctic theme as well as the hydroclimate theme solely by itself. It will need to build and retain critical in-house expertise and then make the required partnerships with others outside PSD and/or ESRL as well as NOAA. In discussing with members of the PSD leadership, Drs. Webb and Dole, it is clear they are well aware of this. It is anticipated they will leverage off PSD strengths and develop the needed partnerships.

3.3 Performance:

It is critical to have experienced scientists leading, or at least mentoring, activities. This becomes even more important when the research is intended for uptake by decision makers. In some of the studies presented during the review, the scientific foundation appeared to be lacking currently for that stakeholder-driven work. This not only detracts from the relevance of this work, it also sets a bad example for other scientific efforts, especially given NOAA's assumed credibility. For example, regarding the high-resolution simulations of future climate projections, PSD researchers are cautioned to validate the results using observations, else the credibility of their results will be questioned by both stakeholders and the climate science researchers.

There is a lot of great work being done on process understanding and model evaluation, that either directly leads to work on model parameterizations, or at least has clear implications for that. The diffusion of this knowledge to model development may happen eventually, but collaboration could and should be more deliberate. The panel was cognizant of the fact that PSD modelers undertake improvements in a suite of models; nevertheless PSD researchers are encouraged to either participate and/or work in Climate Process Teams (CPTs)-like efforts with other modeling groups such as NCEP and GFDL.

Theme 4: Research to Applications, Operations and Services

First and foremost, PSD is to be commended for taking this research area so seriously; probably no other NOAA lab is attempting to engage with stakeholders across the full range of their work as is as PSD. For example, the way PSD has stepped up since their last report to lay the foundation for services in the rapidly thawing Arctic is laudable. They are also heavily engaged in establishing the basis for operational support of wind energy production, and they are well integrated with RISA-style stakeholder partnership and co-production.

R2X is perhaps the most difficult of the four thematic areas that PSD has outlined. Whereas observing, conducting experiments to understand, and building models to represent the physical system can all be approached within a community that is comfortable with science and engineering, R2X requires navigating a landscape of interactions that involve a much wider range of perspectives and expertise, and that lack a common *lingua franca* – i.e., one that spans science program managers, scientists, engineers, sectoral experts and managers, resource operators, decision makers. The effectiveness of R2X depends on the strength of the integration of effort and communication across the end-to-end networks that ultimately link developmental resources to the operational adoption of new information products and practices. This foundation influences all three categories below -- the quality, relevance and performance of R2X at PSD.

A shining example of successful R2O is the ensemble data assimilation developed at PSD and implemented at NCEP. The panel noted that one of the reasons this was successful was there was commitment both from OAR as well as NCEP in terms of resources for the various tasks involved in the R2O process.

4.1 Quality:

It appears that interaction with the National Weather Service (NWS) is on good footing – the way PSD has stepped up to help a wide range of partners and stakeholders with the Southwest/CA/Colorado River drought is certainly to be applauded. Given the funding level, PSD is doing an excellent job. The reorganization appears to have been structured well to enhance the continued quality of the research through (a) increasing the number of group leads in specific focus areas, sharing duties between PSD federal and Cooperative Institute (CI) personnel; and (b) providing for potential additional oversight *via* a Science Board. Ideally, the science review function of this Board will include perspectives on the quality of the research as it may influence potential operational transition into NOAA projects and services. In any case, PSD's commitment to R2X is clearly evident across a diverse range of mission-appropriate sectors (*e.g.,* wind energy assessment and prediction, weather forecasting, climate attribution) and this commitment has resulted in R2X outcomes of undeniable quality.

PSD is also using this research area also to provide innovative integration across their other three research areas, and this is an approach that should be used much more widely internal and external to NOAA. Research labs (not just within NOAA) are notorious for focusing exclusively on areas where their primary interests are, often providing lip-service to integration with other research areas and especially to the users of scientific knowledge. PSD is to be applauded for working hard to break down such barriers, and although they have a way to go with some research foci (and insufficient funding may preclude doing too much more integration in some foci), PSD is nonetheless well ahead of the most other labs within NOAA and beyond.

According to one of the panelist, two issues need resolution. The first is a strategic decision on whether to build more hydrologic expertise in-house (either in PSD or in CIRES) or to integrate hydrology *via* partnership. Both approaches have pros and cons, and PSD must do one or the other to provide the integrated climate-hydrology support needed by stakeholders. The second issues has to do with PSD's pilot efforts to provide definitive assessment and attribution science and services for the growing number of climate trends and extreme events that are taking place in the U.S. and around the globe. PSD has highly qualified science talent to do this work, and has provided useful insights into what's likely behind climate trends and events world-wide. They rightly try to provide rapid response assessments, as well as to do the more careful and time-consuming research that leads to peer-review assessments. All of this work is thus a credit to PSD.

This issue came up in the discussion of *Theme 2, Understanding the Physical System*, but the perspective of reviewers assigned the R2X theme is elaborated here. The assessment/attribution enterprise requires more care and effort than PSD is currently investing. Many decision-makers and the public want to know the details of what is behind climate trends and extreme events, as well as implications for what might be ahead. NOAA and the scientific community thus need to meet this need. In a non-trivial sense, the process of explaining trends and extreme events also provides the science community with an unusually good opportunity to build scientific understanding in society, and also build trust in the science and the scientists. Thus, if it is done well, it is a big win not just for NOAA, but also the broader climate science community. However, if it is not done well, it has the potential to do as much damage as good with decision-makers and stakeholders.

The critical challenge is the need to work efficiently and fast, versus the need to maximize quality and consensus (including on the uncertainties that exist not just in the mind of NOAA scientists, but in the broader community). The PSD work to date has been very good in terms of its science, and given the growing visibility of climate trends and extreme events, as well as increasing importance to the well-being of communities, ecosystems, the nation, *etc*. However, PSD must figure out ways to coordinate better with the broader research community so that the public learns, but is not confronted by a confusing array of opinions on each trend or extreme event in question. Debate, uncertainty and disagreement are central to the scientific process, and are also central to sophisticated climate assessment. For example, IPCC assessments do not strive to obscure disagreement and uncertainty, but rather to be clear about both, while at the same time attempting (not always with success, and it is OK to admit that) to find and communicate where the science consensus lies, and with what uncertainties. PSD must learn to lead, facilitate, or participate in ensuring that the proper science community mechanism(s) is (are) in place to do it right.

An analogy might be to look back to the 1980's when the Geophysical Fluid Dynamics Laboratory (GFDL) was one of very few leading research groups informing political debate about the nature of present and future climate change. It would now be ridiculous if NOAA promoted GFDL as THE national definitive word on climate sensitivity or the exact likely future patterns of climate change in the U.S. Instead, GFDL is a leader within the IPCC, National Research Council and National Assessment processes that are the definitive source of knowledge about climate change.

It is important to note, however, that the IPCC, National Research Council or National Climate Assessment process are not ideal for what is needed in the case of climate trend and extreme event assessment and attribution. These are too slow. PSD and colleagues need to figure out a faster process. This is even more acute for events occurring outside the U.S., where NOAA often isn't the definitive source of knowledge, but has important roles to play nonetheless. Please refer to the Theme 2 discussion for more on this issue.

NOAA, and thus PSD, perhaps have the biggest responsibility to do the job well, and thus to be a leader both nationally and internationally. Nationally, NOAA has the biggest voice with many decision-makers and the public by virtue of being the nation's weather agency. This gives NOAA and the PSD the 'bully pulpit', but also the responsibility to do the job well. Figuring out how to do the job is part climate science and part communications science. PSD has strength in the former, but not in the latter. The process PSD works to implement, perhaps as the leader, needs to be comprehensive and one that learns how to improve, much as the IPCC does.

This leaves the last key innovation that PSD needs to tap, but that is currently missing. If PSD is going to work with operations, stakeholders and services, they need to embrace formal scientific evaluation science and practice. This is an area that the NOAA Regional Integrated Science Assessments (RISAs) have been embracing for a few years now, and is also an area that is also seeing ever-wider integration in other use-inspired climate work. PSD is investing a good deal of funding in this research area, and needs to be able to measure how well its doing, and also to identify ways to improve more objectively than is now possible.

PSD is leading NOAA in their embrace of this enterprise, but they need to be innovation leaders to stay ahead. Once again, greater partnership could be the key.

The viewpoint of another member of the review panel was that overall, PSD has exceeded expectations for a NOAA research lab in the R2X area, though the quality of PSD's work ranges from extremely high (worthy of the 'highest performance' rating) to well-intentioned but limited ('needs improvement'). PSD's creation of certain datasets and techniques that have re-shaped operational practice and/or have gained international following attests to the sufficiency of PSD organization, practices, partnerships, personnel and resources to provide a foundation for high quality research that supports successful R2X.

Another factor influencing R2X is organizational investment. From a disciplinary standpoint, the roughly 1/3 breakdown of science expenditures between climate analysis, water cycle, and weather and climate physics aligns fairly well with the trio of priorities in the PSD Strategic Goal of integrating ‘climate, weather and water’ research. Yet within this alignment, the balance of emphasis appears to support some sub-goals more than others. For instance, PSD’s climate analysis investment directly supports activities such as attribution, diagnostics, improved dynamical understanding, model development, and possibly dataset development, such as the 20th Century Reanalysis product. As a result, PSD is regarded as a leading source of expertise in these areas, and accordingly has notable accomplishments, including leading notable analyses and reports (such as those on recent droughts), generated notable useful techniques (*e.g.,* reforecasting and associated downscaling/calibration techniques, extended reanalyses, NWP-oriented ensemble methods such as Data Assimilation), developed effective outreach models or practices (e.g., climate change stakeholder interactions; FEWS work), and developed useful tools (AR analysis website, the three wx/climate analysis websites).

Despite PSD’s conducive foundation, several R2X areas strike one as being relatively underdeveloped, given their potential importance to key NOAA strategic goals. The first is months-to-seasons climate *prediction*, especially for key variables of interest to stakeholders (*e.g.,* precipitation, surface air temperature). This is a critical capability connected to high profile and high value stakeholder impacts (*via* phenomena such as drought). For climate prediction, the engagement as PSD appears to be somewhat incidental or indirect (i.e., ‘better understanding should eventually lead to better predictions’; LIM-based predictions and predictability studies for fields like SST and OLR; or small scale and even somewhat *ad hoc* state-oriented predictions). Efforts like LIM are commended in the R2X area not the least because LIM is not only an innovative tool/technique for diagnosing predictability, but also an operationalized approach that strengthens NOAA’s climate prediction capabilities. It seems that the LIM ‘X’ will not directly address stakeholder climate needs (*e.g.,* precipitation next month in my ‘decision-shed’) for a while. Of course, PSD is far from the only NOAA center involved in climate prediction R&D and R2X – certainly EMC and CPC have rolled out relevant model-based initiatives like NMME in recent years. Yet, NOAA needs PSD to play a stronger or more comprehensive R2X role in this area, leveraging EMC/CPC efforts but adding PSD-specific value through innovative dynamical analysis, statistical-dynamical downscaling, ‘problem-centered’ product development, perhaps adding a regional dynamical understanding that Climate Prediction Center (CPC) cannot undertake given their national focus.

PSD may have more freedom than Environmental Modeling Center (EMC) and CPC to expand the scope of climate forecasting R&D, and could play a valuable complementary role. In this context, the CA- and CO-oriented seasonal forecasts appear to be the current primary PSD R2X seasonal forecasting effort connecting stakeholders. Yet this effort appears isolated (not supported by collaboration with other PSD or external lab science or community efforts), locally targeted (toward individual state agencies), and lacks a rigorous, transparent foundation. Based on available information, no peer-reviewed publication or comprehensive verification on the state-level forecasts exists, which gives the effort an *ad hoc* feel. While the work is well-intentioned and may even constitute a seasonal forecasting ‘advance’ (it’s hard to tell), it still needs more rigor and broader community and agency connection to be held forth as such by PSD. At least one stakeholder interviewed echoed a desire to see ‘*more connection to NCEP/CPC to spur prediction capability advances’*. In summary, although PSD’s activities arguably will provide a foundation of understanding that eventually leads to improved monthly to seasonal climate prediction, PSD may consider whether it can more actively and directly target this objective.

A second major area that strikes one as containing gaps is the water cycle focus. In the words of one stakeholder interviewed, PSD is not seen as a "*source of hydrologic science excellence, despite water being in … a lot of their stated goals*." 'Water' is one of 3 PSD priority research areas, and improving 'predictions of … water' is an overarching PSD Science Goal. Clearly PSD cannot tackle every earth system physical science discipline, but 'water prediction' appears to be a legitimate aim for which PSD's activities can be assessed. Advancing water prediction requires advances in a number of areas, chief among which are (1) meteorological analyses and predictions and (2) hydrologic modeling. Secondary advancement areas are relevant, including hydrologic data assimilation and statistical post-processing. From the possible slate of water area activities, in PSD's water cycle area, resources appear have largely gone toward improving understanding and observations of precipitation, particularly in California – for instance, detecting the AR phenomenon and developing tools around it; or developing alternative QPE/QTE products for California. A smaller effort has been mounted toward the kind of watershed modeling that would be relevant to flow prediction, flood and water management. Certainly precipitation is often the most important input to the water cycle (and California is an important state!), but the water cycle and NOAA's mission in the water area are significantly more extensive. Indeed, NOAA's 'Understanding the Water Cycle' white paper (from a workshop dedicated toward identifying grand challenges and opportunities in the water cycle area) highlighted a wide range of the research required to move water prediction forward.

PSD clearly has produced good quality research into precipitation processes in the West (through ARs, mainly, which have changed the lexicon on precipitation in California). As the investigation into analyses such as AR alignment versus watershed alignment (and impacts on orographic enhancement of rainfall) proceed, it may lead to further R2X benefits related to flood prediction. The Hydrometeorological Testbed (HMT), always much more of a 'met' testbed than a 'hydromet' testbed, has also benefitted water prediction through developing radar-based snow-level analyses. That some of PSD's work along these lines has developed a following in the NWS and other agencies (federal, state) is a good sign of R2X success. The main limitation of the precipitation work, perhaps, is that it is unlikely to lead to advanced or improved precipitation analyses that will have nationwide utility. The watershed modeling efforts appear, in contrast to the precipitation work, to be less innovative or strongly connected to broader initiatives and activities in the water modeling and prediction research community. For example, the distributed model being used for flash flood prediction with Weather Forecast Offices (WFOs) is an NWS model Research Distributed Hydrologic Model, but its strongest acceptance in the River Forecast Centers (RFCs) for flow prediction may be for only experimental use in Hawaii; it is not used in the science community, nor is it a key part of the National Water Center plans.

The idea of using limited record point soil moisture observations to assess or correct model states has seen some traction in model development contexts, but is not a priority technique for advancing prediction accuracy (versus improving real-time precipitation analyses, wx forecasts, model parameters, increasing model realism and complexity, assimilation of streamflow and SWE, use of ensembles, streamflow post-processing, to name a few). While it is commendable that PSD has activities underway that include hydrological modeling and PSD research be strongly connected with some water stakeholders, the projects nonetheless seem overall to be quite localized relative to weather and climate observation and research at PSD, and less connected with NOAA and other agency's hydrological science, or the hydrological science community.

Notably, none of PSD's highlighted papers (from review packet) describe techniques advancing water prediction, and most of the R2O/R2X transitions and research products only indirectly contribute to water prediction workflows, nationwide. The most directly valuable transition product is the GEFS reforecasts, which are a key part of the strategy for NWS ensemble water prediction.

A key challenge facing PSD is whether it can tackle water as a priority research area and deliver on its water prediction strategic goals without developing a stronger in-house expertise in both hydrologic science and hydrologic prediction science. Clearly, other parts of NOAA (e.g., EMC) are charged with land surface modeling and improving operational hydrology (OHD, now NWC), thus one could well argue that it is enough for PSD to focus on some narrower water cycle aspects (ARs and associated tools, a few watershed studies, etc.) while other NOAA entities do the heavy lifting on hydrology (in particular, modeling). If so, however, the quality of PSD's efforts in this area could be greatly strengthened though improving PSD scientists' connection with external sources of expertise (NWC, eventually, and EMC; National Severe Storms Laboratory (NSSL); NASA hydrological science; USGS; university research; NCAR). It is a really striking fact that while weather and climate system modeling and prediction have both advanced remarkably in the past few decades, with PSD playing an often key role, the hydrology component of water forecasting in NOAA/NWS (both its fundamental science and its results) has not advanced significantly in 2-3 decades (see recent academy reports such as 'Becoming Second to None…'), and aside from reforecasting, PSD has not played a notable role.

In summary, the high-level allocation of effort at PSD and organization appears well poised to support quality research meeting strategic goals, but for certain sub-goals, the distribution of expertise and prioritization of effort appears to be more patchy. This could be a result of resources being divided between dedicated base support and more opportunistic project specific grants (and partnerships of opportunity), and of the distribution of PSD personnel expertise, both of which inevitably influence the focus of projects and effort. In its most successful areas, PSD maintains strong and effective partnerships not only with other federal agency labs, but also with stakeholders and the research/science/applications community in general. Other hallmarks of success at producing quality research in these areas include: leads have nationally/internationally recognized expertise; the product or transition capability includes a serious consideration of uncertainty (e.g., ensemble work); transition path has resources and a proactive plan for the end game (i.e., some energy and capacity on target side to support a 'pull'); and users/stakeholders are advocating for products.

4.2 Relevance:

PSD is doing an excellent job of working on highly relevant efforts to link research to applications, operations and services. As noted above, their work in the Arctic, with wind power generation and the drought/climate change in the West is without doubt highly relevant. Their work on assessing trends and extreme events is also highly relevant. That said, PSD could do well to develop a clear process for setting priorities. Some of their efforts seem like they are merely opportunistic and/or set up to help consulting companies. This work is not necessarily of high relevance to NOAA. At the same time, the need to maintain a large complement of soft-money researchers requires that PSD allow flexibility for these researchers.

Priority setting requires strategic and implementation plans with clear metrics for setting goals and priorities, for evaluating how well the priorities are met, and also for evaluating how each activity meets goals and priorities. PSD can either build an evaluation capability within PSD/CIRES, or instead partner with another evaluation team, such as those being utilized by NOAA RISAs.

Efforts, such as the re-forecast project are doing a great job transferring research to operations. This is probably because NCEP-EMC was involved at an early stage in the work and have worked together towards common goals. The re-forecast product is used to inform humanitarian efforts, for example. There are strong connections to NIDIS and Famine Early Warning Systems. There is also the potential to help NOAA develop high resolution wind forecasts for the energy sector together with DOE.

PSD's research in the R2X area is directly relevant to NOAA's mission and it is easy to connect the dots between high level strategic goals (e.g., improve predictions of weather, water and climate) and PSD project activities. That so much of the work has found an off-ramp from research to operational practice, and/or has given rise to steady partnerships not only with other labs but with stakeholders attests to this relevance. A stakeholder on the FEWS project highly valued PSD's efforts to help their stakeholders understand 'the role of water, and predictability of climate and water systems', largely through providing 'added context and tailoring of information'.

Success with R2X, however, is not uniformly distributed across PSD's projects, though value (and to some extent 'impact') can be difficult to judge. Among a number of great positive examples, the operational reforecasts that are becoming a basis for new products used by NWS forecasters (e.g., Extreme Forecast Index; downscaled precipitation, short to medium range inputs for ensemble streamflow prediction) provide a clear case of high value to NOAA and the nation, as is also evinced by the computing resources made available to support them. Other examples of high value work include climate (extremes) attribution efforts and drought analyses that provide clarity and context for many millions of weather and climate information stakeholders impacted by climate extremes; or the radiation parameterization work that is improving long range climate projections through inclusion in GCMs to be used in CMIP6.

The value proposition may be lower for work that is more locally tailored or motivated (e.g., in one state or watershed, or for one stakeholder, e.g., a winery), with possibly indeterminate generalizability. Though the work may be of sufficient quality to improve the project setting at hand, and may directly serve a small set of stakeholder needs, it would more powerfully support NOAA's mission if it created services or impacts at least at a regional if not national scale, and/or connected with national-scale science or R2X initiatives. Some of the projects that are the hydrology-related ('water') fall into this category.

Another element that may limit a project's potential value is the degree to which it requires a sustained hands-on presence of PSD staff. In the high-relevance example of FEWS given above, for instance, it also appeared that the value of the work depended on an almost consulting-style continuity of PSD effort in helping stakeholders interpret climate information and answer locally motivated questions, which is more of a climate service model than a research model. Though the line between the two is not clear cut, a capacity-building interaction that allows PSD to turn its attention and efforts toward other stakeholder settings in due course might be a more effective way of broadening the impacts and value of the research to NOAA and the nation.

In stakeholder discussions, panelists heard about the importance of obtaining information as extreme events are developing, and in this regard, the considerable value delivered by PSD on the following: what is driving onset, intensification, and the value of evaluating the likelihood of persistence. It is clear that what is needed is the best available assessment at the time. The latter requires agility of scientific input to align with what is required. What is not suitable is a hand-off of information or an over-reliance on one paper or one group's sole view; rather what is crucial in the stakeholder's view is for such services to have the benefit of researchers' networks. PSD has clearly demonstrated its capability in this area. As the stakeholder put it "The PSD team has proven to be extremely responsive on conducting work in a rigorous and timely manner to assess emergent events and provide direct input into ongoing Drought Early Warning System (DEWS) development instead of only as a post hoc input (i.e., after the event is over) to increase response timeliness. PSD researchers are widely-recognized as leading in their respective fields strengthening credibility and receptivity of research outputs in the public domain."

One other consideration that was echoed by one of the stakeholders interviewed was that PSD's efforts are most relevant to, and provide the most direct service to, NWS. This is a defensible priority, given that NWS operational products, information and services in turn provide support for mission objectives in other NOAA line offices, and to other agencies that rely on weather and climate information. The value to the nation *via* this route is extremely high, but there may be room for PSD to consider more non-NWS and even non-NOAA linkages that create value for broad classes of users – e.g., going beyond supporting NWS operational products that may be constrained by formalized NWS directives (i.e. http://www.nws.noaa.gov/directives/010/010.htm), to enhancing sector specific information that serves needs outside of typical NWS products (e.g., in agriculture, forest management, energy management, and perhaps others).

4.3 Performance

The existence of a number of home runs in the R2X area leaves no doubt that PSD has developed this type of integration, and has highly effective processes and personnel that can deliver top performance in research supporting applications and services; this quality seems strongest for weather and climate themes, and somewhat weaker for the water theme. Integrating and coordinating a slate of work that is a mixture of base-funded and opportunistic (in a good way) projects and their associated personnel is a challenge, and PSD has generally done well to reap a healthy share of real successes from this mix. PSD's leveraging of cyberinfrastructure capabilities and expertise is a valuable component of this effectiveness (e.g., in the Arctic science area among others).

There are some steps that PSD can take to ensure that effective performance extends uniformly across all research areas. During the review, there was not much discussion on whether an explicit process for the prioritization of projects or efforts exists, and connected with this, whether PSD employs metrics for progress and impact. These would be useful if they do not exist. It is likely that PSD leadership considers at some stage whether a given project is the best way that PSD can use its personnel and technical/scientific resources to serve a targeted NOAA need area or respond to NOAA strategic directions. A periodic assessment of the mapping of effort to higher level objectives, coupled with periodic project check-ins to gage whether a project is on target to make an impact, can help ensure that project priorities make sense. Are the right supporting linkages or partners in place to ensure that the work is cutting edge, is well-designed, and is there a clearly scoped potential end game or R2X off ramp? In cases where a project's effectiveness or potential impact is in question, an external review might be called in. Most R2X projects that fail do so at the tail end, after a great deal of time and money has been spent doing a great deal of applied research; thus potential end-to-end scopes should be at least partially assessed early on.

To further enhance PSD performance, one stakeholder interviewed suggested a need for greater cross-NOAA coordination on some areas (e.g., water, climate research). It is better to compensate for single-lab gaps in expertise and find synergies in similar efforts or interests. Another stakeholder found that individual project areas (citing example of HMT) could also benefit from greater sub-project coordination. HMT at times seemed to be a nominal 'collection of projects' in single PI interest areas, which was off-putting to the stakeholder.

5. Comments on Recent Reorganization

The panel learned of the reorganization upon arrival at PSD on May 12, 2015. The new organization is based on good intent. It in general moves toward the right direction by removing unnecessary layers of management and encouraging interactions. Most PSD scientists and supporting staff recognize its potential benefit. Reactions to the reorganization details are, however, mixed.

Most CIRES team leaders welcome the opportunity of career development and the 15% coverage of their salaries (most of them were on 100% grant support). Most of them are successful scientists with national/international reputations. There is a question as whether it is beneficial to burden them with administration duties at the productive and developing stages of their careers.

The panel got the impression from lab personnel that the appointment of team leaders is considered a promotion, even though none of the team leaders received promotions when they assumed their roles. Some CIRES senior scientists are not content about being by-passed by this opportunity. They wish there had been an open process that allows everyone to apply for the team leader positions and that the selection was more merit based.

Additionally, there are worries among some CIRES researchers about the uncertainties of PSD future support in terms of overhead waiver (providing office space and facilities without extra charges). Such uncertainties should be easily removed by making a clear policy as soon as possible.

The panelists had the following suggestions:

(1) The issue of who to recruit when new federal positions open, is tricky. Whilst being open to recruiting new expertise from outside, hiring officials should be aware that young talent among CIRES scientists working at PSD cannot be taken for granted. Some members of the panel were of the opinion that as/when appropriate PSD should recruit CIRES young scientists.

(2) The panel was somewhat divided on the issue of 'free-lance' research. One of the panelists was of the opinion that PSD should not discourage any free-lance research supported by grants and conducted by CIRES scientists. The best science is done by scientists who are genuinely interested in a certain topic, not forced into any area. The NOAA and ESRL mission is sufficiently broad to embrace almost all research related to the Earth system. Elsewhere in the report panelist opinion was the research should be mission-relevant; PSD should not be engaged in unfettered basic R&D.

(3) The contribution of CIRES scientists to PSD science should be better recognized and supported. Two-third of the presentations given at the review were delivered by CIRES scientists. The contribution received by PSD from its CIRES scientists is out of proportion of the support given by PSD to them. Some CIRES scientists who have played key role in PSD research should be considered for increased salary support (in addition to the 15% salary coverage for the CIRES team leaders). Since funding is the issue, at least more moral and logistical support should be provided to CIRES scientists. For example, sufficient hardware and software engineering support should be made available to CIRES scientists to ensure their future success in observations and modeling work at PSD.

(4) The panel expects that the excellent senior leadership team including Director and Chief Scientist will call on some of the experienced scientists within PSD for strategic input. It wasn't immediately obvious how this will happen under the new structure (*i.e.,* the process by which such input will be solicited from a structure containing research teams, some of them led by relatively junior scientists, in parallel to a Science Board). It was the panel's understanding that

the Science Board had not yet met; if this is indeed the case it was not entirely clear if this is a theoretical idea whose success is largely unknown at this point in time.

Based on conversations with staff and management, it was clear that the re-organization into teams was viewed positively for fostering stronger connections across scientists in PSD. The concern of some of the scientists is the leadership of these teams. In particular, the process lacks transparency. There are typically two things that staff want in the definition of a career track. The first is transparency; decisions by management should have a sound reasoning that can be explained to staff. The second is a logical career path that is based on merit.

The fact that many junior scientists are now in leadership positions, without a clear explanation of why, could pose a threat to staff morale and confusion on what is needed for one to advance in their career. Additionally, too much administrative responsibility for early career scientists could be harmful to their research and publication productivity. One possibility for the early career leadership issue would be to make these team leader positions rotating, which would allow them to develop those skills, but then give the opportunity to others – thus not locking in anyone for too long. The actual mentoring responsibilities should be delegated to suitably senior personnel, who have a talent for leadership and an interest in helping the younger ranks.

6. Comments for NOAA OAR Management:

6.1 Research Related:

Role of NOAA in wind power forecasts: The panel was of the opinion that NOAA needs to decide if the agency is going to step up in the future to provide the operational wind observing support needed for wind power forecasts. This seems like it should be a priority, and if so NOAA should push for appropriation to do this, starting with the research-intensive phase that PSD is partnered in with DoE. The inefficiencies associated with transferring funding from DOE to PSD are staggering, and NOAA should make it a top priority to fix this.

Internal science review: PSD should ensure that sufficient project review processes exist so that research activities are properly poised to advance the science and are well supported within the science. Where internal expertise may be lacking for such review, PSD should seek it elsewhere in NOAA or the community. A corollary capability would be program review within the different elements under the Research Council, to ensure that a thoughtful prioritization of projects is achieved (a kind of mid-level assessment, after ensuring that project are relevant to high level goals). If these review processes exist; their effectiveness in leading to well-balanced, prioritized high impact efforts should be monitored.

Strategic Science Partnerships: Given the ESRL mission to observe, understand and predict the Earth system across space and time, a greater emphasis is needed on coupling between the atmosphere and other components of the climate system; this is evident in hydrology, Arctic, and tropical variability activities. This could be accomplished through selective hires or strategic partnerships with external organizations.

Serve as coordinator for regional science initiatives: PSD should look for and engage with high-impact opportunities to bring together regional efforts to focus on key problems (e.g., water scarcity in the west), develop comprehensive, shared visions for how to surmount them, and build effective partnerships for sustained progress in the requisite science and R2X. PSD is in a privileged position as a powerful research lab that could help galvanize weather, water and climate communities to overcome long-standing challenges that have formerly been addressed in an ineffective, piece-meal fashion. PSD's engagement and leadership of the THORPEX initiative is a possible example of this type of community coordination.

Messaging: PSDs effort and the associated public-facing outcomes spans a wide range of issues, from the application of techniques that might still be considered 'experimental' or lacking solid consensus in the field, to widely accepted approaches or datasets arising from years of foundational work in a community. PSD could likely benefit from developing or adhering to a clear protocol for communicating about this range of efforts to the public, particularly since some research areas (e.g., attribution of extreme events such as the California drought; or the experimental seasonal climate forecasts) now carry a distinct political charge for some stakeholders. It's possible that NOAA Public Affairs has contended with this issue and can assist.

6.2 Workforce Related

There is expertise in many of the areas of the WCRP Grand Challenges. PSD leadership (i.e., management and Team Leaders) should encourage engagement with these Grand Challenges.

The panel also reiterates the need for succession planning of leadership positions at PSD. For example, as mentioned in the Section on Observations, PSD and OAR management should take steps to ensure succession planning of one of its senior scientists, Chris Fairall.

One of the reviewers found the morale, commitment, professionalism and positive/optimistic attitudes of the PSD staff members (both from CIRES and Fed) to be 'impressive.' PSD appears to maintain an excellent environment for constructive research. This may be due in part because it's a great location – but it also indicates that the management practices are effective, and the quality and empowerment of the personnel is high. Having worked in NOAA and particularly NWS, the reviewer has seen that this is not always the case, and that it does not happen by accident.

6.3 Feedback on Review Process: This was an information-packed review process and quite good. Ideally, labs would present more of their own self-assessment based on clear evaluation metrics and evaluation processes. That said, this type of review is only just starting to see wide use, and NOAA should just see if they could move in that direction too.

The working lunch with PSD scientists and staff was a great idea. Two important constituents of CIRES, however, were not represented: women and PIs who actively write grant proposals to support their research. While we realize time constraints, the CIRES scientists at the lunch meeting were supported by other CIRES PIs. We thus, could not get an idea of the fiscal and other challenges faced by CIRES scientists who need to bring in their own monies. Similarly we did not get an opportunity to discuss issues with senior NOAA leadership from the line offices in the short time available for the review.

The teleconference with the stakeholders provided an opportunity for extra information of how PSD is working with its partners. But the format did not prevent run-away conversations that had nothing to do with PSD, or fault of the panelists.

There was some concern regarding the reorganization of PSD prior to the review. It made it somewhat difficult to review the status up to that point given that the lab will work differently going forward. The review process was very well planned and executed. The information provided in advance was comprehensive. Teleconferences helped clarify certain issues in reviewers' mind. The presence of OAR and ESRL leadership teams was a crucial part of the review; they provided broad perspectives for specific issues pertaining to PSD. PSD scientists enthusiastically participated in the review and are well prepared with their presentations. The PSD leadership team was very responsive to inquiries from the review panel. Dr. Webb deserves special compliments for his leadership skill in motivating PSD scientists to tell their stories in a compelling way, and for sharing his vision and concerns of PSD with the review panel.

It is a challenge for both PSD and the review panel to cover issues across the breadth and depth of PSD research in a short period less than three days. The format of oral presentations followed by discussions worked generally well. The poster presentations were equally interesting but a little rushed. It would have allowed ample time for interaction between panelists and poster presenters if panelists focused only on posters in the research areas they are responsible for providing detailed review.

Materials provided in some introductions and summaries of grouped theme presentations to cover research that was not presented to the panel was very informative, since it gave the panel a more complete view of work done by PSD. But they were not included in all summaries. Repeating the presented materials in summaries is not necessary. Their connections to other ESRL divisions should have been emphasized, especially for the themes of modeling and observations.

Overall, the content provided to the review panel was excellent and the organization of the review activity was highly effective. The breadth of the presentations (to which all reviewers were exposed) was remarkable, and the flow of the review schedule, which interspersed panel/discussion sections with posters and breaks during which reviewers could interact with PSD scientists, was well crafted. The review website, which proved a valuable supporting resource was very well set up.

The time with stakeholders at the end was particularly valuable, and it may be worth considering whether that slot could be enlarged. In general, the stakeholders were high-level, thoughtful professionals, with a wealth of experience over the years with PSD, and it felt almost unseemly to give them such a short time (20 minutes) to express their assessments, and to allow reviewers to explore various points with them. For most of the stakeholders having perhaps 45 minutes would have been quite valuable. Incidentally, some stakeholders also felt that it would have been useful to able to speak during the main review plenaries, to provide perspective on the presentations and reviewer questioning.

Another consideration for future reviews might be to trade some breadth for depth. Since reviewers' responsibilities were divided toward 4 themes, an alternate configuration for the review would be to begin the first day with a plenary in which all reviewers would hear higher level overview presentations (perhaps with one key focus/project talk to give a flavor) for all the research areas, but then the reviewers would split off into groups to hear more in depth or a greater number of varied presentations in their areas of review responsibility. Another panelist was of the opinion that it was useful to hear all the talks, rather than being separated into groups for talks just on specific themes. That said, the experience overall was quite successful, and this alternative organization likely also has its downsides since it might lead to less in-depth understanding of the lab's efforts.

Summary of Recommendations

These recommendations should be taken in the context of remarks made on each of the four themes in the earlier section on Findings.

Theme 1

Observation is the foundation of the ESRL mission: *To observe, understand and predict the Earth system through research that advances NOAA's environmental information and service from minutes to millennia on global-to-local scales*. PSD has played a key role in building this foundation. But the required set of observations for understanding and predicting the complex Earth system is far beyond the capability of any single institute. PSD, and for that matter, ESRL, cannot single-handedly take all the needed observations. The key challenge for PSD is how it systematically determines relevance, sets priorities and evaluates how well these priorities are met. Once priorities are set, a strategy needs to be developed for sustaining and enhancing the chosen priorities and leveraging observing capabilities from other ESRL Divisions, other NOAA laboratories, and other non-NOAA laboratories and institutes nationwide and worldwide. Currently the following priorities seem to exist for PSD: air-sea interaction, Arctic, profiling radars, and QPE of complex terrains.

PSD observational expertise in surface flux measurements is of the highest caliber. Its intellectual leader is in many ways irreplaceable; however the legacy of the flux group leadership should be sustained so PSD continues to be an international leader in this area. Some suggested names for PSD to consider as successors to the senior scientist of the flux group are being provided directly to OAR leadership by the review panel.

Serious attention is also needed to maintain a strong engineering team to support science.
The flux group has been supported by a wonderful team of engineers and also by other scientists at ESRL who have provided instruments complementary to flux instruments. PSD's flux

observation capability cannot be sustained without these supporting engineers and collaborating scientists.

Should such additional funding be available, enhancement of instrumentation must go in tandem with increased support to engineers and scientific leadership. There are instruments in ESRL Global Monitoring Division (GMD) and Chemical Sciences Division (CSD) that contribute substantially to Arctic observations. Coordination among ESRL Divisions is already occurring but could be furthered. Sharing engineering expertise and support among Divisions is one area that is beneficial to all.

The success of various efforts (e.g., the IASOA data portal, web-based visualization and analysis tool, and the 20th Century Reanalysis) is testament to the fact that PSD's provision of data service to the research community is highly appreciated and widely needed. It has earned PSD unparalleled reputation of capability and innovation. The panel encourages PSD to continue this role of serving NOAA and the entire research community as a provider of raw and processed data collected by PSD and by the research community-at-large. These data are used by scientists from ESRL, NOAA, and external to NOAA, to advance understanding and prediction of the Earth system. Provision of such data is well on target and will help accelerate the accomplishment of NOAA/ESRL missions.

Following the examples of the surface flux measurement, PSD's involvement in Arctic observations, and CalWater 2015, the panel encourages PSD to enhance its participation in national and international multi-institutional, and/or multi-national field campaigns. PSD should also seek opportunities to play more leadership roles in such large-scale field projects in the future. In many respects, PSD's observing capability yields the best results when it is leveraged with capability from other NOAA laboratories and non-NOAA institutes. Such involvement in national and international field campaigns brings external expertise and capability to help fulfill NOAA and ESRL missions.

To facilitate such collaborations, the PSD instrument website (http://www.esrl.noaa.gov/psd/technology/instruments.html) needs to be updated, with crucial information, such as contact points, provided for all instruments and broken links fixed. PSD should work with NOAA and other agencies to develop a plan to transition some research-based observations (e.g., NSF-funded Integrated Characterization of Energy, Clouds, Atmospheric State and Precipitation at Summit (ICECAPS) project) to real time use/uptake.

Theme 2

A solid working relationship between PSD scientists working on the *Observations* and *Understanding* themes is critical, so that both models and observations can be viewed in the proper skeptical light. PSD also needs to be more systematic in how they determine relevance, set priorities and evaluate how well these priorities are met. Also as detailed in an earlier section, PSD efforts in climate trend and extreme event assessment and attribution, while already strong, are in serious need of key improvements.

PSD should continue to maintain a core underpinning science capability in understanding the physical system that can provide the underpinning science clearly needed for a range of applications. Seek to ensure the core funded staff is maintained and enhanced where possible particularly on the key strategic areas of strength. Leadership should ensure that there is a clear appreciation by all Division scientists of the potential benefits of their work. One mechanism to do this would be to require short briefing documents to accompany pieces of work such as papers, reports *etc*. that may be only a page or two in length, but which would draw out the implications of the piece of science for model development and for potential future applications, including where appropriate a follow up plan as to who would be contacted, etc. This isn't the only way to do this, and something similar may well be in place already. Nevertheless it would have been good to see some evidence of the development of such an appreciation amongst all staff of how their work fits into the overall PSD vision and mission to provide the nation with the scientific information necessary for decision making and to improve weather and climate predictions on global to local scales.

Processes should be set in place to enable pull through of scientific research into model improvements. Again there are various mechanisms for ensuring this, some of which may be in place already, but the evidence is that this pull through appears to be patchy, albeit there are some examples of excellent work of this sort being done by PSD scientists.

Finally reiterating yet again, public communications around attribution should be undertaken with more care. This might involve clear statements of the framing of the attribution question or questions involved, the framing of the attribution question being a key element of assessment. The work done by the team at PSD is excellent and it would be a shame if its impact were undermined by a perception that such science confuses rather than enlightens.

Theme 3:

Some of the projects such as C20C, LIM, challenges in modeling extremes, improved coupling of radiation and dynamics, are world-class. They are a result of sustained funding at PSD and not something that can be achieved by the 3-year grants that research programs at NOAA OAR and other agencies (e.g., NSF) make. NOAA needs to be cognizant of the fact that success on mission-relevant activities needs sustained funding and perseverance on the part of the researchers. It is hoped that OAR management recognizes the need to nurture such talent so that the desired scientific outcomes for NOAA mission goals is achieved.

Presentations by CIRES researchers who have NSF-funded projects demonstrated synergistic interactions between CIRES and PSD scientists. The panel was impressed by these interactions since they enrich the basic R&D flavor of PSD. A certain amount of external funding is probably essential so PSD remains competitive; however the team should not need to spend its valuable time writing proposals to keep its mission-relevant research enterprise alive. High priority activities unique to NOAA mission needs and PSD core capabilities need to be sustained through core support.

Dynamical downscaling work should be validated through observations. “Model world” without the reality check through observations, especially on aspects that are threshold related, is not *Best Practices.* This is particularly important when dealing with impacts, applications, and/or decision makers.

Theme 4:

The review panel highlighted the importance of acknowledging scientific contributions of collaborators, otherwise such omission could damage otherwise good working relationships. The review panel noted (this recommendation is to NOAA not PSD) the need to make it easier for other agencies to invest in NOAA work that can delivers NOAA science and products to facilitate the missions of other agencies (e.g., DOE and wind energy forecasts)

Research projects that are perceived as potentially useful to applications, operations, and/or services may benefit from a ‘reboot’ with new ‘terms of reference’ in order to collaborate with stakeholder and reframe goals of project. PSD needs a clear way to set priorities, as well as to evaluate how priorities are being met. A five-year review process helps, but it would be much better if PSD has their own evaluation process that could rank each activity’s success in terms of well-articulated metrics and priorities.

PSD, and NOAA more generally, is a mission agency operations and thus needs to judge each and every effort on whether it is serving applications, operations or services. Is the science needed by users, and is the science used? PSD probably leads a substantial number of activities within NOAA in the R2X arena, but could do even better. PSD is also leading in the integration of observations, understanding and modeling where these are integrated with each other and with applications, operations and services. Working with partners, they could do more of this, particularly with respect to focus on regional or thematic stakeholder-driven objectives. Thus PSD could do well to mimic their focus on the Arctic, western US and wind-power generation, each of which integrates across multiple research areas in service of decision-making in society.

The PSD climate trend and extreme event assessment and attribution activity deserves real kudos, but PSD should be more of a leader or partner in creating an activity in this area that strives for rapid consensus and clear communication of scientific uncertainty. It is not wise for PSD to issue their findings without better coordination with the rest of the scientific community, or without integration of sound communication science - and this is an area where PSD could be a leader, or co-leader with others in the U.S. and internationally. Otherwise, the public and decision-makers in society are underserved, and a great opportunity to build scientific understanding with these same constituents is optimal.

PSD is doing really well in this research area as noted repeatedly above. Perhaps this is one of the single best achievements of PSD. That said, this success stems from PSD’s basic scientific capability and credibility. It is critical that this be maintained carefully, and that the expanded strategic planning recommended above take this into account – that is, striking the right balance.

An overarching recommendation to PSD is simply: "Carry on!" This arises from recognizing PSD's success in delivering R2X science of which NOAA is rightfully proud. That said, PSD can strengthen its quality, relevance and performance in a number of ways. The following additional recommendations are suggested:

- Enhancement in the water area: PSD is encouraged to consider expanding its emphasis and strength in hydrometeorology to encompass not only precipitation, but also other aspects of the water cycle and water cycle applications that were highlighted in the Water Cycle report. Water cycle science is undergoing an exciting evolution at present due to advances in modeling, super-computing, large-scale analyses and predictions, connectivity and other technologies, and PSD could be bolder in scoping their participation in this evolution. Where the line is drawn between PSD and efforts at other labs (EMC, NWC) to best leverage their potential capabilities is a question well worth thinking about.
- Broaden stakeholder focus: NOAA OAR may at present be too myopic in serving NOAA-specific stakeholders, e.g., NWS, to the detriment of potential broader service and value to the nation through conducting research that benefits external agency aims and service objectives (e.g., in water, in energy, in agriculture, in environmental quality, and other areas). Some movement in this area is already apparent (e.g., with the DOE-led Wind Forecast Improvement Project with Reclamation) but more could be considered.