Summary Report of the Science Review of the NOAA National Severe Storm Laboratory

November 15-19, 2021

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I. Overview

The review of the National Severe Storm Laboratory (NSSL) occurred virtually from November 15-19, 2021. This review focused on the research of NSSL over the last six years. The three activity areas of the review were: 1) Observations and Understanding; 2) Engagement of Customers, Stakeholders, and Users; and 3) Numerical Modeling and Forecast/Warning Applications.

The eight panel members comprising the review team are listed in Table 1. The review team was provided with written and video materials before the virtual site visit that included guidance to the reviewers, overview and scientific presentations, stakeholder questionnaires, and numerous supporting documents. The site visit consisted of virtual presentations encompassing OAR and Laboratory overview and highlights and the three activity areas of the review, with time for discussion and questions and answers after each. Closed meetings were held between stakeholders in each research area and Panel Members. Two closed virtual lunches with young scientists were also included. The provided meeting agenda, presentations, and supporting documents are online at https://www.nssl.noaa.gov/about/events/review2021/#home_tab.

Table 1. Science Review Panel Members

Panel Member	Title	Organization	Location
Frédéric Fabry	Associate Professor, Department of Atmospheric Oceanic Sciences; Director, Bieler School of Environment	McGill University	Montreal, Canada
Marc L. Levitan, Chair	Lead Research Engineer, National Windstorm Impact Reduction Program	National Institute of Standards and Technology (NIST)	Gaithersburg, Maryland
Peter Manousos	Consultant and Senior Meteorologist	FirstEnergy Corporation	Akron, Ohio
Gretchen Mullendore	Director, Mesoscale & Microscale Meteorology Laboratory	National Center for Atmospheric Research (NCAR)	Boulder, Colorado
Stephen W. Nesbitt	Professor and Associate Head, Department of Atmospheric Sciences	University of Illinois Urbana-Champaign	Urbana-Champaign, Illinois
J. Marshall Shepherd	Georgia Athletic Association Distinguished Professor of Geography and Atmospheric Sciences; Director, Atmospheric Sciences Program	University of Georgia	Athens, Georgia
Olga Wilhelmi	Head, Geographic Information Science Program; Project Scientist IV in the Research Applications Lab	National Center for Atmospheric Research (NCAR)	Boulder, Colorado
Sepi Yalda	Professor of Meteorology, Department of Earth Science; Director, Center for Disaster Research and Education	Millersville University	Millersville, Pennsylvania

This report is not a consensus document, but rather a summary of individual reviewer reports. Each panel member prepared an independent report that was transmitted to the panel chair, who then developed this Summary Report. Panel members were provided with a copy of the draft Summary Report for review and comment. The Summary Report was then submitted to the OAR Deputy Assistant Administrator for science and the Evaluation Coordinators, along with the individual reports.

The purpose of this Summary Report is to identify key issues and overall themes from the reviewer's comments. Consistent with past practice (Chang, 2015), "Similarly themed comments are merged in the interest of efficiency. Any oversimplifications, significant omissions, errors, or misstatements are strictly the fault of the author of this Summary Report and not of the individual reviewers. The process of identification of themes requires an emphasis on issues mentioned in more than one review, so there is the potential to overlook important nuances or dissenting opinions."

Despite extensive efforts of NSSL and OAR staff to make the best possible experience for the reviewers and through no fault of theirs, the virtual site visit was still not the same as the full immersion experience of spending several days at the Laboratory with an in-person site visit. While the briefings may not lose too much efficacy with the change in format, discussion is more challenging in virtual meetings, and informal and side conversations and explorations during tours, meals, and breaks are irreplaceable. There was a strong sentiment among the Panelists on the need to return to in-person reviews when it is safe to do so, as noted in Recommendation R3.

II. Summary of Laboratory-Wide Findings and Recommendations

The 2021 NSSL Review Panel found that the Laboratory as a whole had very strong performance, with 2 panelists providing a rating of *Highest Performance* and six panelists rating as *Exceeds Expectations*, as shown in Table 2. The unanimous overall rating for the Observations and Understanding research/activity area was *Exceeds Expectations*, while the other two areas (Engagement of Customers, Stakeholders, and Users; Numerical Modeling and Forecast / Warning Applications) had a mix of *Highest Performance* and *Exceeds Expectations.* The full set of ratings for each of the three research/activity areas of the review are provided in Table 3, including the Overall rating and ratings for Quality, Relevance, and Performance.

Table 2. Overall Rating for Laboratory

Reviewer	Highest Performance	Exceeds Expectations	Satisfactory	Needs Improvement
Frédéric Fabry		X		
Marc L. Levitan		X		
Peter Manousos		X		
Gretchen Mullendore		X		
Stephen W. Nesbitt	X			
J. Marshall Shepherd		X		
Olga Wilhelmi		X		
Sepi Yalda	X			

Note – the performance ratings are defined by NOAA as follows. Detailed criteria for what constitutes Satisfactory ratings are provided in NSSL (2021).

- *Highest Performance*--Program greatly exceeds the Satisfactory level and is outstanding in almost all areas.
- *Exceeds Expectations*--Program goes well beyond the Satisfactory level and is outstanding in many areas.
- *Satisfactory*--Program meets expectations and the criteria for a Satisfactory rating.
- *Needs Improvement*--Program 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.

A summary of common themes, findings and recommendations are presented in this section for the Laboratory as a whole, OAR and NOAA, and in Sections III-V for the three research/activity areas. Comments on the laboratory review process are given in Section VI. Finally, Section VII provides a summary list of all recommendations in this report.

Summary of Themes:

NSSL is a world-class laboratory. It produces impactful research which is successfully translated into operational products. Laboratory staff include some of the top experts in the world in severe storm research and are widely recognized for their contributions in this field.

NSSL is fulfilling its mission of serving science, stakeholders, and society. From basic science to tool development, the work is relevant to address the threat from severe storms, and there is impressive body of work since the last review.

Table 3. Rating for Research/Activity Areas

Research/Activity Area	Reviewer	Overall	Quality	Relevance	Performance
Observations and Understanding	Frédéric Fabry	EE	HP	EE	EE
	Marc Levitan	EE	HP	HP	EE
	Gretchen Mullendore	EE	HP	EE	EE
	Stephen W. Nesbitt	EE	HP	HP	EE
	J. Marshall Shepherd	EE	HP	HP	EE
Engagement of Customers, Stakeholders, and Users	Peter Manousos	EE	EE	EE	EE
	Stephen W. Nesbitt	HP	EE	HP	EE
	J. Marshall Shepherd	EE			
	Olga Wilhelmi	EE		EE	EE
	Sepi Yalda	EE	EE	HP	EE
Numerical Modeling and Forecast / Warning Applications	Frédéric Fabry	EE	HP	EE	EE
	Gretchen Mullendore	HP	HP	HP	EE
	Stephen W. Nesbitt	HP	HP	HP	HP
	J. Marshall Shepherd	HP			

HP=*Highest Performance*, EE=*Exceeds Expectations*

There was an impression that many of the activities ran in silos, not aware of how they could impact each other, especially in the longer term (was this perception wrongly induced by order/content of review presentations, or is this a reality?)

The integration of social sciences into more components of the research and hiring of social scientists is a very positive development. However, the growth was all in the Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO), raising concerns about the ability for long term planning and stability.

NSSL stakeholders provided numerous positive reports on the value of the Laboratory's work and on responsiveness to stakeholder needs. There were however some concerns from several key stakeholders (both external and internal) related to challenges with communications and coordination.

There is very strong Federal employee satisfaction. The Laboratory has made significant progress in increasing the number of women, including in management positions, as well as the number of young researchers. Despite some efforts, the same progress has not been made in recruiting a more racially and ethnically diverse workforce. While mentoring opportunities for staff exist, it is not clear how much these are being promoted and used.

Findings

NSSL Programs

- Overall, NSSL is very productive and is a tremendous asset to the meteorological community across the nation and the world. The Laboratory performs its mandate well, and the laboratory scientists include many of the leading experts in severe storms

meteorology, climate, modeling, and observations. The activities in research to operations and operations to research areas are particularly impressive.

- There was a concern from several reviewers that the Laboratory lacked a strong strategic message for what it is doing now, and where it is going, at least in the materials presented. Messaging of how the individual focus areas of the Laboratory conduct their activities seemed very "siloed". Is that true? Are there strategic synergies that are currently being leveraged, and where is this lacking? This was not well articulated in the materials presented.
- The process of cross-collaboration amongst the various teams within NSSL does not appear to follow a formal strategy. The process for selecting collaborators appears to be rather ad-hoc, based on presentations and conversations during the review process.
- It appeared that a more intentional prioritization strategy across both base-funded and soft-money funded research projects is needed. The challenge of balancing lab priorities with requirements of sponsored research are recognized, but staff are spread thin. For many of the groups that presented, it wasn't clear what the highest priorities were, and/or how priorities are set and supported.
- Actions 1.2, 1.6, and 2.2 of the *NSSL's Final Implementation Plan Report on Responses to Review Recommendations* from the 2015 review did not appear to address the review comments.
- The expansion of the Laboratory's research into social science is seen as an excellent direction, as there is a lot of exciting progress to be made in this area. However, the research is largely soft funded and conducted by the CIWRO and not by Laboratory scientists. Hiring one or more federal scientist(s) in this area would greatly benefit the long-term viability of this research and would help the Laboratory with strategic planning for future directions in this important topic area.
- The Field Observing Facilities Support Division (FOFS) stated function from the briefing slides is to "Support the entire Lab's observational needs and Develop and deploy innovative technologies." It was described as a "Mini-Division", with a staff of four. That Division seems to be severely understaffed given its very significant responsibilities. Also, when asked about safety protocols, the response was that there was some safety training but that they *will* be requiring formal written safety plans and training.
- The Laboratory has taken a few small steps to connect with the wind and structural engineering community, for example, participation in the joint American Society of Civil Engineers / American Meteorological Society committee developing the ASCE/AMS Standard on Wind Speed Estimation in Tornadoes and Other Windstorms, and inclusion of one meteorologist/wind engineer on the VORTEX-SE Scientific Steering Committee. However, the engineering community represents a critical stakeholder audience with needs for NSSL science that are not being met. One of many examples, advances in risk assessment and design of buildings to resist thunderstorms and tornadoes require much greater knowledge of surface-level wind and wind-driven rain characteristics than exists today.
- Engagement with the engineering community may also bring awareness of other tools and resources that can benefit existing NSSL research, for example, the automated impacts guidance (using machine learning from past damage indicators, structure types,

and building code information) being developed as part of the Probabilistic Hazard Information (PHI) effort.

Stakeholder Interactions and Feedback

- Many very positive comments received from wide range of stakeholders, documenting the
    - importance and value of NSSL work and products
    - engagement with stakeholders
    - responsiveness to stakeholder needs and suggestions
- Other comments from several important stakeholders indicated some challenges, including
    - Need for more communication/information sharing
    - Concerns about delivering final products in a timely manner
    - Concerns about lack of coordination with intermediate stakeholders and going directly to end users
    - Concerns about announcements of products becoming operational before agreements with NWS
- It was evident more careful coordination with internal stakeholders is required when announcing projects externally. It is important for NSSL to continue to self-promote and communicate its initiatives with the media, however, coordination must occur with internal stakeholders prior to media releases so the stakeholder can be prepared to field questions from the media or its user base.

Workforce

- NSSL staff include some of the top experts in the world in severe storm research and are widely recognized for their contributions in this field.
- There is strong Federal employee satisfaction with NSSL as a good place to work, employees are recognized for quality products and services, the agency is accomplishing its mission, and that supervisors are trusted and doing a good job.
- NSSL has taken effective steps to improve the lack of diversity (gender, age, and educational background) at the Lab, most notably the selection of a female scientist as the FRDD Division Chief, some women in management roles as group leaders, and a more equitable number of women and early career scientists as a percentage of recent hires.
- NSSL seems low on some diversity issues compared to peer labs. While this is not unique to NSSL, the “cruise control” statement that ‘we know it is a problem and we are trying’ is concerning. NSSL is going to have to think way out of the box to attract diversity given the geographic, cultural, and other barriers of being located in Norman, Oklahoma. REUs and recruiting at HBCUs is not going to be enough. Additionally, there is a chicken and egg problem too. As long as line managers and much of the staff is not very diverse, it creates a "belonging" and "cultural purgatory" issue for younger, diverse staff who actually might be attracted to come. They ultimately leave. Such retention or “leaking pipeline” issues are a concern in parts of academia also.
- The Lab has worked on improving its diversity but admits that there is work to do in making the lab more representative of the USA as a whole in terms of its demographic

makeup. Efforts in this must be redoubled. This activity must include hiring practices in the lab, but also in terms of OAR working as a whole to support scientists' careers from the beginning.

- The development of the NSSL Diversity & Inclusion Plan since the last review has helped to guide several activities to address the various diversity issues, but much has changed in the intervening years and elements of this plan are out of alignment with the OAR DEIA plan.
- Improvements have been made for CIWRO staff in terms of clearer path for promotions
- For both NSSL and CIWRO staff, although mentoring opportunities were mentioned, it is not clear how much uptake there is for these programs and there does not appear to be a formal mechanism for mentoring early career scientists, regardless of their affiliation.
- Although staff indicated that they had received a clear message from management that prioritizing work/life balance was important, several staff indicated that they didn't feel they could make the changes to achieve better balance. This was a challenge for several reasons, e.g., personal pressure to be successful and how they defined success. The workforce could benefit on more mentoring on work/life balance strategies.

Recommendations

Note- Recommendations for the Laboratory begin with L. Recommendations for OAR and NOAA are designated with O.

NSSL Programs

L1. The Laboratory should develop a strategy for prioritization of projects and for cross-collaboration and for the various teams within NSSL that can help break down silos and encourage further collaboration and integration of research initiatives and can also provide an opportunity for more enhanced external research partners, stakeholder, and user engagement.

L2. NSSL should add social scientists to the Federal staff as well as the CIWRO. This will enable better long-term research and development planning and improved program continuity.

L3. The FOFS mini-division should have a staff size commensurate with its responsibility to "support the entire Lab's observational needs and develop and deploy innovative technologies". Development and implementation of formal safety plans and training should be a high priority.

L4. Recommend to engage the wind and structural engineering stakeholder community to learn more about their unique science needs, so these could be considered for incorporation into NSSL research plans, and to learn about windstorm research in engineering that could benefit current and future Laboratory projects. A workshop at NSSL for key engineering stakeholders such as ASCE, FEMA, NIST, NSF, academia,

the National Storm Shelter Association, National Association of Home Builders, and others would be one possible step in this direction.

Stakeholder Interactions and Feedback

L5. Recommend additional oversight for interactions with external stakeholders, to assure adequate levels of communication and information sharing, and more careful coordination with internal stakeholders prior to external announcements of projects, products, and other results.

Workforce

L6 Recommend continuing to push forward on Diversity, Equity, and Inclusion (DEI) and look to partner with other agencies and institutions working on similar issues. We can learn from each other across the scientific community on what works and what doesn't

L7. NSSL should update the existing NSSL Diversity & Inclusion Plan to be better aligned with the OAR DEIA plan to specifically address equity and accessibility and to expand on existing initiatives through engagement with external groups focused on DEIA efforts.

O1. OAR should be working as a whole to support scientists' careers from the beginning, in order to advance diversity. This includes more K-12 education and outreach that can reach students from all socioeconomic backgrounds, targeting students at minority-serving undergraduate institutions with fellowships and internships, as well as underrepresented students at traditional universities, targeted graduate fellowships, and guiding these students into careers at federal labs. It really takes an "all of the above" approach to enact long term, sustainable change in this area.

L8. Participation in mentoring opportunities should be encouraged. A formal mentoring strategy for early career scientists would be beneficial and should include an element that connects to NSSL strategy for cross-collaboration across research areas both internal and external to NSSL, promotion and retention. This may also address some of the different experiences of employees based on their affiliations and internal networks and create a more equitable and accessible environment for everyone.

FINDINGS AND RECOMMENDATIONS BY RESEARCH AREA

III. Observations and Understanding

Summary of Themes:

The Observations and Understanding research/activity area received overall evaluations of *Exceeds Expectations* scores from all five panelists who rated this research area

NSSL is a world leader in the observations and understanding of hazardous weather. The resources that they have are put to good use, and the breadth and depth of expertise in this area is impressive. VORTEX-SE is a success story on several fronts, including integration of physical and social sciences and broadening the geographic focus of NSSL activities.

There were significant concerns that the Phased Array Radar (PAR) program was not forward-looking enough. "Matching the NEXRAD, but faster", does not seem sufficient to justify the cost. A high-level review of the PAR program is recommended.

Findings

Quality: Rated *Highest Performance*

- Research quality remains unquestionable and sets the standard for the field, including high quality work by leading experts demonstrated by all groups and disciplines.
- The Laboratory has a good blend of instrument-development efforts, field experiment activities, and basic science work to support the development of future knowledge and applications. Instrumentation development in general may benefit from more collaborations within and outside the organization to improve both the design and use of the developed technology.
- The VORTEX-SE program has made tremendous progress in addressing societal needs, and NSSL has executed this program in a highly effective manner. The integration of basic science, operations, and social science research is highly commendable. Further integration with the wind and structural engineering disciplines can extend the reach of this research even further.
- Good to see NSSL scientists working in less traditional areas for the Laboratory, like S2S.
- NSSL has had measurable impacts on increasing the timeliness and quality of outlooks and weather warnings issued by the National Weather Service. However, to improve warning usefulness, the use of warning information needs people to act on the information provided appropriately. It was noted that social scientists are doing this work, however this is being done almost exclusively by the NOAA CIWRO. These researchers noted that the lack of collection of social science data by the NSSL and CIWRO post-event is a fundamental limit in understanding the effectiveness and improving hazardous weather warnings.
- The MRMS national radar composite system is a national resource of tremendous importance for severe weather operations, hydrometeorological applications, and increasingly, a resource for machine learning and big data applications. Currently, there

exists no permanent archive of this data, nor a uniform analysis of this data going back to the beginning of the NEXRAD era. This resource would help many scientific and engineering applications.

- Open-source code and FAIR data principles are not being followed uniformly across NSSL and CIWRO. The lack of these practices and the human and computational infrastructure that accompanies adherence to these widely accepted practices harms the scientific process and the impact of the research and products produced within the FFRDC.

Relevance: Rated *Highest Performance* and *Exceeds Expectations*

- Overall, the activities undertaken are appropriate and relevant to the mission of a laboratory targeting severe storms research. They also seem to satisfy NSSL's partners and stakeholders. The combination of the traditional strengths of NSSL in observations and meteorology with the burgeoning interest in social science activities gauging people's perceptions on weather events and forecast information value reinforce one another in ways that would not have been thought possible a few years ago. The work is highly relevant to the needs of the research and operational communities and the mission of NOAA. In fact, it is so relevant that many areas could be transferred into practice with more vigor and pace.
- NSSL continues to be a leader in innovative deployments of great value to the community. The deployment and field campaign teams bring together multidisciplinary, multi-institution groups to tackle challenging hazard situations. These teams are also uniquely experienced in conducting safe deployments in the highest risk situations, filling an important niche in the observational community. The strong coordination with social science in field campaigns provides a new dimension for more robust data collection.
- The elevation of FOFS to a division-level entity was a positive development, recognizing and supporting the importance of observational needs and fieldwork for the entire Laboratory.
- The expansion of Planetary Boundary Layer (PBL) research is notable. However, another thrust area of PBL research is needed, to understand surface level wind characteristics in different storm types in the lowest 5 to 30 m above ground. This reflects the heights of the overwhelming majority of all buildings and other structures, where the severe weather impacts are occurring. This would include a better understanding of gust structure, effects of terrain roughness, topographic speedup, velocity profiles, and other characteristics needed by engineers to develop improved wind loading codes and standards.
- Some activities seem to lack strategic focus and coordination among each other. For example, while the thermodynamic profiling and boundary layer science efforts are rightfully considered important, little information was provided beyond some illustrations of the potential value of the data or anecdotal description of remote-sensed imagery: it is not clear what innovative scientific goals are being sought or what meaningful questions relevant to severe storm research are being answered.

- Phased Array Radar: NSSL scientists demonstrated the value of more rapid scan available with PAR, adding value for forecasters assessing short-term hazards and providing improved performance of forecasting via more frequent data assimilation cycling.
- The PAR effort deserves particular attention. It has had a tumultuous history outside of NSSL's control and it now acts as the main response to a Congressional mandate given to NOAA. It is particularly challenging and sensitive for many reasons, a few of which include:
    - PAR is a somewhat immature and evolving technology, more so than was the case for past upgrades. This makes the evaluation of one class of designs, let alone three, particularly challenging.
    - The target or threshold of what constitutes a successful demonstration is not clearly stated nor justified in the context of the magnitude of investment considered.
    - It is not clear that the capacity issues are being considered in these tests (e.g., how much more observational data can a forecaster ingest during a severe event?). Also, there was not much discussion on whether PAR is the best method to improve forecaster and model performance. For example, what is more beneficial to the community: More rapid scans (PAR) or improved coverage at low levels in high-risk areas (more radar and/or mobile radar)? How should these new needs influence design recommendations? These questions may not be for NSSL to decide; the understanding is that NSSL has been charged to investigate the feasibility of PAR and not investigate alternative platforms. Therefore, this comment may be more for NOAA management than for the PAR group at NSSL.
    - As a result, NSSL is being watched closely. Impatient stakeholders and future users wonder what you seem to be waiting for. In parallel, because NSSL has sole control of that technology evaluation, there does not seem to be an extensive communication effort undertaken concerning the progress of this activity outside of the usual academic research circles.

Performance: Rated *Exceeds Expectations*

Research Leadership and Planning

- The VORTEX SE effort is a very good example of how NSSL has expanded its geographic focus and integrated social sciences.
- There was not as much mention of the NSSL work related to climate change and severe storms in the "read-ahead" or presented materials. Going forward, this probably needs further attention as recent National Academies reports continue to highlight uncertainty in the relationships between severe storms and climate change.
- The Phased Array Radar research program is a high priority as an avenue for increasing the nation's resilience to hazardous weather. This is a challenging technology to implement operationally, and NSSL is uniquely positioned to lead in this area. The way that this program was presented was that the PAR program will meet the current NEXRAD radar performance, with an increase in time sampling. There were concerns

among the committee members that the PAR research is not bold enough and that the pace of development could be accelerated. Does the NSSL dominance in this research area stifle competitive innovation?

Efficiency and Effectiveness

- Performance in research and understanding is very good overall. Some of the instrument activities seem to be miraculously handled by very few people. Though all efforts appear valuable, it was not clear how priorities are determined within and between the different activities; this may then lead to mission creep.
- Use of the instrument simulators in planning for field campaigns and other deployments in difficult environments is commended. The phenomena and regions being required to survey get ever more complex and expensive. Anything that can help increase chances of success for deployments are worth investment. Also, big kudos for emphasis on personal safety for diverse field campaign participants. Finally, VORTEX-SE a real success in reaching new communities and tackling new problems.

Transition of Research to Applications

- Vortex-SE collaboration with Mississippi/Alabama Sea Grant is an excellent example of forward leaning engagement with key stakeholders and a model for other Sea Grant and Land Grant institute engagement. Great to hear VORTEX-USA expansion is underway.
- It is not clear that the PAR program is fully considering the applications and user needs to adequately define the optimal research plan. A more forward-looking approach is needed in assessing the value of PAR for NOAA operations.

Recommendations:

Note- Recommendations for Observations and Understanding area begin with U. Recommendations for OAR and NOAA are designated with O.

U1. Recommend looking for ways to get even more visibility for instrument simulators (and continue to share that technology). There is a lot of potential for better integration of observations and models both pre- and post-campaign. Promoting, sharing, and supporting that work is another way that NSSL can be a leader in the broader community.

U2. Recommend that the successes of the VORTEX-SE program and the paradigm of basic research – operations – social impacts can be duplicated for other phenomena and hazards across the nation.

U3. NSSL (and NOAA) should consider taking social science integration with atmospheric/earth system science to the next level by supporting routine data collection for social science. This support would need to be for the data collection itself (technology and staff) and for full-time staff to support and analyze these data. As was

pointed out by several staff, our current understanding of human responses is limited to the most extreme events, which is possibly skewing the findings in significant ways.

U4. Recommend a greater focus on connections between severe storms and climate change within the research portfolio.

O2. There is a mismatch between NSSL's research recommendations and actions at the NOAA level on some boundary layer processes. For example, NSSL continues to show the value of Wind Profilers, yet there has been a reduction in operational profilers in recent years. It is recommended that this inconsistency needs to be rectified at the Agency level.

U5. It is recommended that an internal and/or external review of the Phased Array Radar activity be conducted. This should include a more holistic assessment of what radar data will be most beneficial to forecasting. For example, do faster scans provide more value than increased low-level coverage?

U6. Recommend better communication of current progress and issues concerning the PAR effort should be initiated with key stakeholders.

U7. In the near term, NSSL should consider performing research on other possibilities for increasing radar scan timing, especially in areas where radar coverage by NEXRAD is poor. Continue to research the use of gap-filling radars for severe weather operations, either using a network of fixed radars in high-risk areas, or through the use of deployable C- or X-Band radars based on convective outlooks.

IV. Engagement of Customers, Stakeholders, and Users

Summary of Themes:

The Engagement of Customers, Stakeholders, and Users research/activity area received *Highest Performance* score from one panelist and *Exceeds Expectations* from four panelists.

It is evident that the lab is committed to the stakeholder/user engagement through the FACETS paradigm, R2O efforts, the new hires (e.g., with background in emergency management) and incorporation of more social/behavioral sciences.

The Hazardous Weather Testbed (HWT) has been hugely successful. However, some stakeholders felt that it has gotten perhaps too large and some engagement has been lost.

Improvements and a well-defined strategy for cross-agency and broader weather/water/climate enterprise engagement are needed for better communication, collaboration, and integration.

Findings

Quality: Rated *Exceeds Expectations*

- Research conducted at NSSL in the area of Engagement is of high quality and provides significant contributions to NOAA and to the broader scientific community. Specifically, important contributions have been made in the areas of severe weather warning/communication systems and improving forecast/warning reception, understanding, and decision-making with uncertainty information.
- The quality of the work has external recognition and is evident by the growing number of publications, contributions of policy solutions to NWS, WMO, and the Academies, as well as several awards from the AMS. External stakeholders, particularly from other NOAA agencies, noted that the quality and timeliness of research done by the Laboratory and the CIWRO in this area had many excellent components. However, there was some noted variability in the research quality.
- The quality of the research benefits from innovations in convergent science and community engagement and the infusion of social and behavioral sciences.
- The Hazardous Weather Testbed continues to be the gold standard of R2O/O2R engagement, research, and community-building. As the HWT continues to grow, tackling more diverse research questions and engaging with an ever-broadening (and more valuable) diversity of researchers and end-users, the support for this effort (financial, technological, personnel) should likewise grow. There was some discussion in stakeholder meetings that the HWT is a "victim of its own success", meaning in some instances its impact or engagement were slightly diluted compared to prior years because of the large number of participants and more tasks to accomplish.
- The approaches and processes are in place to ensure high quality and effective R2O and O2R. Integrating an O2R practitioner from the EM sector and an R2O Scientist from academia makes the end-to-end process for SBE very watertight.
- Excellent move in establishing the Severe Weather and Societal Dashboard as a baseline.

- NSSL and their CIWRO partners recognize the research and operational challenges in reaching most vulnerable segments of the US population and are working on developing innovative interdisciplinary strategies and mixed methods approaches to reach most vulnerable communities. Identifying research priorities in this complex interdisciplinary research space and increasing collaborations with social / behavioral scientists in other institutions could be beneficial.
- Some stakeholders felt that a lack of communication led to less than optimal outcomes in the development and release of developmental/operational products. They identified cases where a product was released as "operational" by NSSL before they were willing to approve that release, or that a news release was issued about a product before they were prepared for the product being public.
- NSSL is making progress in contributing data to national databases and making data accessible by researchers, educators and practitioners outside of NOAA. More work can be done to continue to expand open data/open science priorities.

Relevance: Rated *Highest Performance* and *Exceeds Expectations*

- NSSL remains a go-to organization for NWS and other stakeholders in NOAA and the federal government for high-impact weather science, information, and products.
- The relevance of this work is evident through the impressive body of work in the R2O-O2R, NSSL's leadership within NOAA's OAR to include social and behavioral sciences, adoption of the user-centered approach and focus on actionable information in the FACETS paradigm, as well as the new hires (including staff with Emergency Management background).
- AWARN is a fantastic and "on-point" initiative that will clearly save lives.
- FACETS is forward thinking in part by not limiting itself to severe storms and including all environmental hazards.
- The NSSL staff frequently interacts with and seeks feedback from stakeholders and end users. Since the last review, 450-500 forecasters, 93 emergency managers, and 150-170 broadcast meteorologists were engaged and provided feedback on various activities. Stakeholders' engagement workshops and Hazardous Weather Testbed (HWT) have been very successful. Inclusion of social and behavioral science methods and research instruments into the HWT is a strength and can be modeled by other NOAA testbeds.
- The social science research involving emergency managers conducted in two different divisions shows the understanding of the relevance of NSSL's work to this group as well as to other stakeholder communities.
- Recognition that there is no one size fits all approach when it comes to adopting new forecasting tools and technologies to the needs of end users, ongoing research in this area, and the inclusion of the bi-lingual R2O efforts also increase the relevance and value of R&D to users beyond the scientific community. NSSL staff also recognize the need to evaluate different products (e.g., probabilistic information) and their usability for different groups, highlighting this as a priority for the next upcoming years.
- There were some stakeholder concerns that without a continuous dialog with the stakeholders, new R2O ideas focused on end users or alternate operation concepts, may

not harmonize with existing weather service operations. Likewise, the research ideas on new products, especially those supported by short-term grants rather than long-term sustained research funding, could create discontinuity in the infusion of the research ideas into the NWS operations thus creating potential challenges.

Performance: Rated *Exceeds Expectations*

Research Leadership and Planning

- The emphasis on engaging stakeholders and end users was clear and evident from the successful implementations of the HWT, the R2O-O2R process, and the inclusion of social and behavioral science concepts and methods into NSSL research and outreach activities. Very positive comments from a wide range of stakeholders on the importance and value of NSSL work and products as well as the responsiveness to stakeholder suggestions reflect past and ongoing efforts to conduct user-informed research and development strategies.
- The HWT MUST continue. Enhancing the end-to-end process of obtaining a baseline, testing in "naturalistic environments", involving stakeholders (mostly), R2O, and O2R feedback, was watertight.
- The new hiring model with bringing O2R practitioner with emergency management (EM) background and R2O scientist further demonstrates the commitment of the NSSL to the user / stakeholder engagement activities and has potential to develop deeper connections with EM community.
- There is a need for increased staffing (federal and perhaps CI) to offset the perceived scatter and over-subscription perceptions that were detected.

Efficiency and Effectiveness

- NSSL is working on expanding the workforce needed to conduct user-informed research and incorporate social sciences in the areas of severe weather warning/communication systems, improving forecast/warning reception, and decision-making with uncertainty. Some of these efforts are strategic (e.g., new hires) and other efforts are informal, including building relationships across the lab that could help improve the ways NSSL as a whole frames its research problems and methods for tackling complex societal problems. Social scientists and physical scientists with WAS*IS training are leading the way in the interdisciplinary areas, advising students, and cross-training staff.
- The SPC Stakeholder comments on timelines, external collaborations, and funding partners were revealing. There is amazing work going on, but there seems to be variability in terms of assessment and deliverable products. There appears to be "getting products over the finish line" issue that some stakeholders identified. Is a quasi-"academic" model with a Cooperative Institute (highlighting publications, professional society awards, etc.) optimized for product / services delivery? This is a broader question, by the way, than just for NSSL.
- Covid adaptations for R2O training opened the door for participation for more women and greater numbers of participants in virtual format, instead of having to travel, which

also reduced travel costs. Perhaps some future trainings should be held virtually even after the pandemic is over to continue these positive outcomes.

Transition of Research to Applications

- There is a commitment to continue to reach out to the various stakeholder communities through specialized conferences and meetings and to partner with NWSH and NWS regional/field offices to broaden engagement and further integrate with other existing outreach and training efforts. Some of these efforts are enhanced by more focused initiatives related to decision support at NWSH. The Lab has actively coordinated with these efforts and has invited leaders from those initiatives to attend NSSL monthly meetings to update partners on the latest research efforts.
- Deep Core Partners are rightfully and initially identified by NSSL as the NWS, EMAs, and the Media. However, it seemed there was an unintentional lack of a tangible plan to expand the sphere of partners in the very short term to include the private sector (outside of the government). Private sector has a huge stake in the great work NSSL is conducting. Examples are transportation (beyond DoT) and utilities. Utilities have government entities such as TVA and BPA as well as non-government entities that are considered "critical commodities" and as such are regulated for maintaining their services to the nation. Impact weather (fire, wind, convection) is a huge focus in utilities and requires the latest findings in scientific advances, such as those being worked on by NSSL, to be employed in its (utilities) impact-weather related operations to ensure services (gas, electric, water) are not interrupted.
- It would be helpful if there were a way to further promote or advertise HWT experiments. Although there is a link on NSSL page, it might increase visibility if it were mentioned in some of the meteorological list servs (example MAP). Also, it would be helpful to add a "Want to Participate" type link on the HWT page (hwt.nssl.noaa.gov) which might include a "qualifications to participate" to screen "just anyone". The use of virtual methods may help with accommodating such participants while not sacrificing the participation of deep core partners.
- There exists a level of reliance on NWS partners to share the information on NSSL's research and products. The Lab provides the needed subject matter expert support to develop training and outreach materials. This is currently adopted by NSSL as the most effective process for communicating this information. Survey responses and conversations with some of the partners and other stakeholders indicated that at times there is a lack of communication on the developments, status of projects and final products.

Recommendations:

Note- Recommendations for the Engagement of Customers, Stakeholders, and Users research area are noted with an E.

E1. NSSL should ensure they have quality assurance procedures for their research products for Lab and CIWRO projects. End user feedback should be gathered and reviewed by management. Problems should be identified and remedied based on that feedback.

E2. It is recommended that NSSL consider mechanisms to enhance and improve the level and methods of communication with stakeholders. There was a common theme in the survey responses and in both meetings with stakeholders that the process and frequency of communications of new developments, projects, research outcomes (including social science research) and plans needs to be improved. Development of a well-defined strategy for both interaction and communication with these groups would be beneficial, not only for NSSL, but in providing these groups with a stronger sense of inclusion and collaboration throughout the process. Even though, as was explained during the review process, feedback from stakeholders is only obtained for the purpose of the five-year review, it is recommended that NSSL conduct one additional survey or provide another formal opportunity for feedback between the formal Lab reviews to maintain better communication with all stakeholder groups.

E3. It is recommended that the Lab develop a well-defined engagement strategy for better communication, collaboration, and integration across agencies and the broader Weather, Water, Climate enterprise. NSSL might consider expanding on the existing strategy for the engagement of the emergency management community by forming an advisory committee (it was not clear if one was in the process of being developed or already exists with the new hire in BIU) that broadens the participation and deepens the inclusion of the emergency management expertise. The new partnerships through VORTEX-SE will certainly aid in this effort. This is important given the complexity of the emergency management community in terms of their diverse needs based on the geographic regions and the communities they serve

E4. NSSL should continue to find ways to innovate and expand engagement in the ongoing pandemic and in the future post-COVID workspace. This includes facilitating virtual, in-person, and hybrid experiments, especially including participants from geographically underrepresented areas and outside of CONUS and creating regional breakout groups for more in-depth and nuanced feedback.

E5. Recommend continuing expansion of open data/open science priorities by identifying datasets of value and increasing usability and accessibility of these datasets for the GIS community for broad societal benefits.

V. Numerical Modeling and Forecast / Warning Applications

Summary of Themes:

The Numerical Modeling and Forecast / Warning Applications research/activity area received *Highest Performance* score from three panelists and *Exceeds Expectations* from one panelist.

NSSL is a world class leader in the development of forecast and warning applications, fulfilling its mission in this space.

As with other research /activity areas, the incorporation of social/behavioral science methods (e.g., Warn on Forecast (WoF) product development and communication) has yielded significant benefits.

Support of open science (e.g., NOAA Big Data) and increased data and software availability has increased but still has room for more improvement.

Findings

Quality: Rated *Highest Performance* and *Exceeds Expectations*

- When it comes to the development of forecast and warning applications concerning severe storms, NSSL is a class apart: There is no awareness of any other institution worldwide that comes even close to what NSSL is doing. There is a good pipeline set up between this research and development activity, the basic science upstream, and the delivery of products and tools downstream. Research excellence in absolute terms has been recognized by several awards.
- Great coordination between in-house expertise and outside partners; including strong involvement of graduate students. The breadth of expertise is impressive, including radar algorithms, winter weather forecasting, numerical modeling, communication.
- The research teams are commended for recognizing the needs and expertise of stakeholders. Too often, end users are not fully recognized for their specialized skills; it was terrific to see how stakeholders are considered and valued in decision-making by NSSL staff. This was particularly apparent in discussions with the Observation-based Severe Convective Tools presenters and team (e.g., emergency managers = "knowledge brokers").
- There are some really important flood/extreme precipitation activities ongoing within NSSL. It is important to see these amplified even more as we move into this area of more frequent and/or intense hydrometeorological extremes.

Relevance: Rated *Highest Performance* and *Exceeds Expectations*

- The relevance of research work on forecast and warning applications is obvious when considered as a whole, and overall, NSSL succeeds in its mission.
- The work by the WSR-88D team in instrument and algorithm development makes the United States the international standard in radar networks for both research and operations.

- The MRMS product (and MYRRORS) is already incredibly useful to so many users. It has the potential to be even more impactful in research and operations with increased and more consistent support. The work done already with such a lean staff is amazing.
- The WoFS team are leaders in modeling hazardous weather and in object-based verification strategies. This is demonstrated by the material presented and further bolstered by the extensive WoFS publication list provided to the panel.
- The Advanced Radar Techniques (ART) team does excellent work, but it would benefit from having its focus gradually trend towards including current and future meteorological needs in how it approaches data quality improvement. NSSL is at the epicenter of a shift from a paradigm of human-centered detection of severe storms to one of algorithm-driven forecasts of storms and their threats. This paradigm shift does not seem to have yet influenced how ART thinks about its activities. Humans and algorithms deal differently with data quality deficiencies: With some training, humans can deal with artifacts and biases, yet cannot stand missing data; algorithms, especially data assimilation, often have little problems with missing data, but fail if errors in data are poorly characterized, especially if they are systematic or have long correlation distances. Much of ART's focus appears to be on trying to fix bad data as best as can be. While recovering perfect data would be ideal for everyone, it remains a never-ending quest, and imperfect corrections will remain. Yet the imperfect corrections we can achieve often introduce spatially correlated errors, often imperceptible to people, but fatal to algorithms (as an example, both clutter-affected and clutter-filtered data are notorious in that respect). And such error characterizations are rarely done. To further complicate matters, each change in data processing also changes those errors characteristics. Alternatively, simply identifying questionable data would be particularly valuable information for algorithms. Once this issue is recognized and assimilated by ART, occasional exchanges with WoF and observation-based severe convective tools will hopefully help better shape future directions to better serve those communities. Note that this effort or thinking is also needed for future radar designs; hence, introducing PAR groups to this issue and including PAR groups in these discussions would be beneficial to all.
- The work on facilitating the assimilation of "polarimetrically interesting signatures" will be hampered by similar limits in error characterization: Between the uneven quality of polarimetric radar data, models' inability to simulate many of the signatures given that the needed information is not simulated, and the highly correlated errors in observation simulation that arise from assumptions on non-simulated processed data, significant limits can be expected in our ability to assimilate polarimetric data. While assimilating data in liquid precipitation should be achievable, in melting and solid precipitation, a more indirect approach of assimilating signatures themselves ("there is a high ZDR column here", or "the bright band is there"), while not cannon in assimilation circles, may provide less misleading information to the model than directly using data that the model cannot accurately simulate.
- Shifting the focus from on warning on detect to on forecast is an appropriate response to the current lack of progress of warning times for severe weather phenomena, especially for those whose warning times are much less than an hour (e.g., tornadoes, wind gusts,

hail). In response to this challenge, the Warn-on-Forecast project (WoF) was born and was presented to this review committee with fanfare. Yet there is currently a temporal and spatial scale mismatch between the identified problem (the limited warning times of detected small-scale threats) and the response (WoF, which in its current implementation targets the 1-6 hr forecast window with 3-km resolution modeling). While there are plans to move to 1-km resolution, it is not clear how the current effort will improve warnings of events in the first hour, and some phenomena simply cannot be forecasted reliably on theoretical bases beyond that time window. For the foreseeable future, this effort will also be hampered by the limited quality of initial conditions, current and planned remote-sensed and in-situ data being insufficient to accurately measure the atmospheric fields that drive storm evolution at the needed resolution. For these reasons, it is hoped that WoF will not steamroll other research activities such as observation-based severe convective tools and new flavors of probabilistic nowcasting: these can also provide warning on forecasts of a different kind that may better serve the 0-1 hr window so critical to help save lives. In its current incarnation, WoF remains valuable for warnings of larger-scale convective patterns and associated threats such as flash floods, and perhaps for "heads-up" notices in between the current "watches" and "warnings" for faster-evolving phenomena.

Performance: Rated *Highest Performance* and *Exceeds Expectations*

Research Leadership and Planning

- The performance in numerical modeling and forecast and warning applications is very good overall. Excellent work by all groups. A lot is being accomplished and there are bigger challenges ahead in the next five years. With so much happening, a clear prioritization process is needed. While this prioritization process may exist, it was not clearly communicated.
- Great to see the strong support of open science and data/software accessibility, which should continue to be prioritized. Coordination with partners can inform best practices and collaboration on support (e.g., containerization strategies).

Efficiency and Effectiveness

- The damage projections being developed with the automated impacts guidance (slide 26 in the Storm-scale Probabilistic Hazard Information (PHI) presentation) will provide valuable information for emergency managers and other stakeholders. It is not clear if the research team is aware of and/or interacting with the SPC team developing something apparently similar for FEMA and the NIST-funded Center of Excellence for Risk-Based Community Resilience Planning at Colorado State University that has developed a comprehensive disaster impact and resilience modeling system, including tornado hazards. Communication and information sharing with these other related efforts can benefit all parties and make sure to avoid duplication of effort.

Transition of Research to Applications

- The research to identify intense downbursts has potentially valuable applications to engineering, in terms of potential for development of a climatology that can be used for creation of improved probabilistic wind speed maps for design of buildings. Engagement with wind engineering stakeholders to understand the needs of that community could expand the user base for this work.

Recommendations:

Note- Recommendations for Numerical Modeling and Forecast / Warning Applications research area begin with N. Recommendations for OAR and NOAA are designated with O.

N1. The strong integration between models and observations in verification, DA, and plans to merge PHI with WoFS is commendable. Prioritization of this integration across all areas (including model development) is recommended.

N2. It is great to see the development of sub-hourly HCA products. Coordination with modeling centers for sub-hourly model output to test possible improvements of these sub-hourly products is recommended. It may not yield sufficiently significant (and verified!) variation in environmental parameters to impact HCA in a substantive way, but valuable to test. Additionally, such coordination between observation and model teams is itself valuable.

N3. MRMS products are essential to NWS operations and of significant value to researchers. MRMS should prioritize level 2 radial winds. This is a high priority for DA applications. This was highlighted by one of the stakeholders who indicated that "current QC is dated."

O3. NOAA is encouraged to provide more base funding for both MRMS and MYRRORS.

N4. Development of a clear strategy to transition products more efficiently to end-users in the broadcast-communication sector is recommended. This needs clarity because some of this process seems rather ad-hoc.

VI. Additional Comments on Conduct of the Review for Use in Future Laboratory Reviews

Summary of Themes:

The review materials were of excellent quality, well organized, and provided in a timely manner. Coverage of key data to help evaluate quality and performance, such as lists of publications, patents, awards, and citations, was inconsistent and often anecdotal in nature. Success metrics were not always clearly defined and often documented anecdotally.

The Evaluation Worksheets don't *specifically* address Workforce and other non-technical issues, minimizing the perceived importance of these issues.

While staff went to extraordinary effort to make the best of the situation with the virtual review format necessitated by the COVID-19 pandemic, much was lost by not meeting in person.

Findings

Review Materials

- All review materials were of excellent quality and being able to see pre-recorded presentations / slides ahead of time was very helpful. The reviewers were very appreciative of the significant level of effort involved in preparation of these materials, particularly the very professionally done videos.
- The written stakeholder questionnaires provided very valuable feedback from user and customer perspective. A minor point, but it would have been helpful for stakeholders to self-identify which research/activity area(s) their response encompassed, and have that information summarized in a table provided to the panel members (along with stakeholder name and organization).
- The efficiency of the different activity areas and especially of their individual components proved difficult to evaluate. Perhaps because of the remote and presentation-oriented nature of the review, it was often hard to gauge both a) the amount and quality of work performed towards a given activity, as well as b) the size of the group working on that activity.
    a. While occasionally information on number of publications and other outputs were provided, and limited information on citations, awards, and patents, it was not done systematically; for some presentations/groups, reviewers could not easily capture the magnitude of the 5-yr work we were tasked to evaluate. One reviewer remarked "…this is the first scientific review I have been involved with where a list of publications was not provided as part of the review package, the very-detailed but Laboratory-wide bibliometrics information being a poor surrogate."
    b. Little indication was given on the 5-yr FTE workforce focused on any given component, and the expected sharing of human resources among different components did not allow reviewers to make that assessment easily. The resulting review hence lacks much of the component-level granularity that might have been helpful to managers. Without adding too much to the review preparation, providing information in one standardized slide/table on the 5-yr output of an activity and on the 5-yr averaged FTE scientific and perhaps support workforce involved would considerably help performance evaluation.

- It would be helpful for a given project or initiative that is presented to understand its status relative to completion. Along with this it would be helpful to have a list of projects that have been completed since the last Review.
- Success metrics were not always clearly defined; they were often documented anecdotally. Example – screenshot of forecaster using Satellite Based Lightning Jump to help with a warning process was impressive but, it seemed it was lucky that the forecast happened to know about this by method through attendance at the HWT.

Review Process and Execution

- The two-step format of the remote review with pre-recorded material and a live portion remarkably achieved its goals of providing both the depth of information required as well as the opportunity for exchanges in a structure that accommodated the strengths and weaknesses of the video-conference medium.
- The review process and the efforts by all management and research staff were outstanding, especially given the virtual nature of the review. The management and research staff are to be commended for their impressive level of involvement and openness to answering questions and providing additional information throughout the review process to respond to individual reviewer comments and questions.
- The opportunities for discussions with the different groups from staff to stakeholders were very valuable.
- The communication throughout the Review about the process was very good.
- The COVID-19 pandemic limited the "immersion" of the reviewers into the culture of the Laboratory, which made it more difficult to examine the innerworkings of the Laboratory.
- The lunches with young scientists didn't work that well in the virtual meeting format, but there was support for keeping the lunch component for future in-person meetings.
- While the Evaluation Worksheets did have a catch all section for review comments on topics not specifically covered elsewhere ("Additional comments for OAR and Laboratory management"), they didn't specifically address Workforce, diversity and other non-technical issues, minimizing the perceived importance of these issues.
- The Evaluation Worksheet sections don't quite align with the required organization of the Summary report (per the Guidelines for Review Panel Members). For example, the Worksheet collects comments for OAR and Laboratory management in the same section, but these are required to be reported separately. Improved harmonization between the Worksheets and report requirements would aid in preparation of the Summary Report.

Recommendations

Review Materials

R1. Recommend including lists of publications, patents, number/percentage of products successfully transitioned to operations, citations, awards, and other indicators of outputs and recognitions, to enable better assessment of the full range and quality of research. These materials should be grouped per review area or perhaps at a lower level (e.g., linked to each presentation). They can be touched on in the presentations to emphasize a point, but it may be easier to provide these details and statistics in a written report. It would be helpful if the list of publications could identify research and work with external partners, stakeholders, and users, to better demonstrate the nature and extent of the collaborative and integrated partnerships. This will enable reviewers to gain a deeper understanding of the extent of these collaborative and partnership efforts.

R2. Recommend having the Stakeholders indicate which Research/Activity Area(s) they believed they fell under in their response to NSSL and providing this information to the reviewers, to aid Panel Members when conducting their reviews.

Review Process and Execution

R3. Recommend return to in-person reviews as soon as safe to do so.

R4. Recommend that addition of an explicit review area on workforce and diversity issues should be considered, on the same level of the Science, Stakeholders, and Modeling. Otherwise, these topics will continue to be perceived as “extra” or “secondary” issues.

VII. Summary of Recommendations

This section contains a numbered list of all recommendations in the report, grouped by topic area.

Lab-wide; Relevant to the Entire Laboratory

L1. The Laboratory should develop a strategy for prioritization of projects and for cross-collaboration and for the various teams within NSSL that can help break down silos and encourage further collaboration and integration of research initiatives and can also provide an opportunity for more enhanced external research partners, stakeholder, and user engagement.

L2. NSSL should add social scientists to the Federal staff as well as the CIWRO. This will enable better long-term research and development planning and improved program continuity.

L3. The FOFS mini-division should have a staff size commensurate with its responsibility to "support the entire Lab's observational needs and develop and deploy innovative technologies". Development and implementation of formal safety plans and training should be a high priority.

L4. Recommend to engage the wind and structural engineering stakeholder community to learn more about their unique science needs, so these could be considered for incorporation into NSSL research plans, and to learn about windstorm research in engineering that could benefit current and future Laboratory projects. A workshop at NSSL for key engineering stakeholders such as ASCE, FEMA, NIST, NSF, academia, the National Storm Shelter Association, National Association of Home Builders, and others would be one possible step in this direction.

L5. Recommend additional oversight for interactions with external stakeholders, to assure adequate levels of communication and information sharing, and more careful coordination with internal stakeholders prior to external announcements of projects, products, and other results.

L6 Recommend continuing to push forward on Diversity, Equity, and Inclusion (DEI) and look to partner with other agencies and institutions working on similar issues. We can learn from each other across the scientific community on what works and what doesn't

L7. NSSL should update the existing NSSL Diversity & Inclusion Plan to be better aligned with the OAR DEIA plan to specifically address equity and accessibility and to expand on existing initiatives through engagement with external groups focused on DEIA efforts.

L8. Participation in mentoring opportunities should be encouraged. A formal mentoring strategy for early career scientists would be beneficial and should include an element that connects to NSSL strategy for cross-collaboration across research areas both internal and external to NSSL, promotion and retention. This may also address some of the different experiences of employees based on their affiliations and internal networks and create a more equitable and accessible environment for everyone.

OAR and NOAA

O1. OAR should be working as a whole to support scientists' careers from the beginning, in order to advance diversity. This includes more K-12 education and outreach that can reach students from all socioeconomic backgrounds, targeting students at minority-serving undergraduate institutions with fellowships and internships, as well as underrepresented students at traditional universities, targeted graduate fellowships, and guiding these students into careers at federal labs. It really takes an "all of the above" approach to enact long term, sustainable change in this area.

O2. There is a mismatch between NSSL's research recommendations and actions at the NOAA level on some boundary layer processes. For example, NSSL continues to show the value of Wind Profilers, yet there has been a reduction in operational profilers in recent years. It is recommended that this inconsistency needs to be rectified at the Agency level.

O3. NOAA is encouraged to provide more base funding for both MRMS and MYRRORS.

Observations and Understanding

U1. Recommend looking for ways to get even more visibility for instrument simulators (and continue to share that technology). There is a lot of potential for better integration of observations and models both pre- and post-campaign. Promoting, sharing, and supporting that work is another way that NSSL can be a leader in the broader community.

U2. Recommend that the successes of the VORTEX-SE program and the paradigm of basic research – operations – social impacts can be duplicated for other phenomena and hazards across the nation.

U3. NSSL (and NOAA) should consider taking social science integration with atmospheric/earth system science to the next level by supporting routine data collection for social science. This support would need to be for the data collection itself (technology and staff) and for full-time staff to support and analyze these data. As was pointed out by several staff, our current understanding of human responses is limited to the most extreme events, which is possibly skewing the findings in significant ways.

U4. Recommend a greater focus on connections between severe storms and climate change within the research portfolio.

U5. It is recommended that an internal and/or external review of the Phased Array Radar activity be conducted. This should include a more holistic assessment of what radar data will be most beneficial to forecasting. For example, do faster scans provide more value than increased low-level coverage?

U6. Recommend better communication of current progress and issues concerning the PAR effort should be initiated with key stakeholders.

U7. In the near term, NSSL should consider performing research on other possibilities for increasing radar scan timing, especially in areas where radar coverage by NEXRAD is poor. Continue to research the use of gap-filling radars for severe weather operations, either using a network of fixed radars in high-risk areas, or through the use of deployable C- or X-Band radars based on convective outlooks.

Engagement of Customers, Stakeholders, and Users

E1. NSSL should ensure they have quality assurance procedures for their research products for lab and CIWRO projects. End user feedback should be gathered and reviewed by management. Problems should be identified and remedied based on that feedback.

E2. It is recommended that NSSL consider mechanisms to enhance and improve the level and methods of communication with stakeholders. There was a common theme in the survey responses and in both meetings with stakeholders that the process and frequency of communications of new developments, projects, research outcomes (including social science research) and plans needs to be improved. Development of a well-defined strategy for both interaction and communication with these groups would be beneficial, not only for NSSL, but in providing these groups with a stronger sense of inclusion and collaboration throughout the process. Even though, as was explained during the review process, feedback from stakeholders is only obtained for the purpose of the five-year review, it is recommended that NSSL conduct one additional survey or provide another formal opportunity for feedback between the formal Lab reviews to maintain better communication with all stakeholder groups.

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R2. Recommend having the Stakeholders indicate which Research/Activity Area(s) they believed they fell under in their response to NSSL and providing this information to the reviewers.

R3. Recommend return to in-person reviews as soon as safe to do so.

R4. Recommend that addition of an explicit review area on workforce and diversity issues should be considered, on the same level of the Science, Stakeholders, and Modeling. Otherwise, these topics will continue to be perceived as "extra" or "secondary" issues.

VIII. References

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