Summary Report:
Earth System Research Laboratory
Global Systems Division Science Review 2015

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Review Panel:
Christa D. Peters-Lidard (NASA Goddard), Chair
Fred Carr (OU), Brad Colman (The Climate Corporation),
Tom Fahey (Delta Airlines), Oliver Fuhrer (MeteoSwiss),
Rebecca E. Morss (UCAR), Peter Neilley (TWC)

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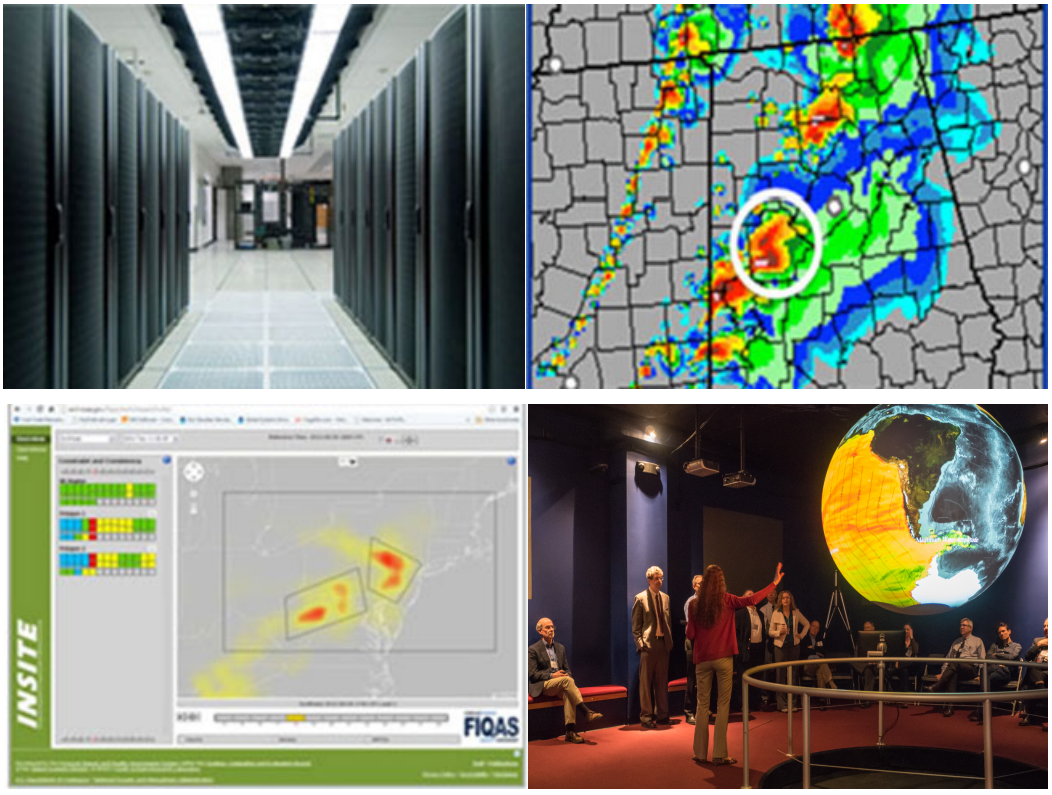

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A Overview

This review covers the research of the Earth System Research Laboratory's (ESRL) Global Systems Division (GSD) over the last five years (2010-2015). The members of the review panel attended the review in Boulder, Colorado November 3-5, 2015. Prior to meeting in person, the reviewers were furnished materials including the agenda, oral and poster presentations, preparation materials, guiding documents, previous review materials, and stakeholder surveys, via a web site: http://www.esrl.noaa.gov/gsd/research/review/2015/. This website was very well organized and easy to navigate, and facilitated the review process before, during and after the in-person review. Two pre-review teleconferences also helped clarify the charge, streamline logistics, and tweak the agenda to maximize in-person interactions. The management and support staff were highly effective and responsive in preparing and conducting the review. We commend all the GSD personnel for their commitment to and execution of a successful review process.

We were asked to evaluate the Quality, Relevance, and Performance of GSD in three topical areas:

1) Numerical Weather Prediction
2) Decision Support
3) Advanced Technology

In accord with FACA rules, the review panel did not seek consensus in our evaluations. However, there was substantial agreement on the general findings as well as on our specific findings in each topical area. Below, we present general findings and recommendations, followed by findings and recommendations in each topical area.

B General Findings

GSD has an impressive array of excellent-quality scientific and technological activities performed by a passionate, uniquely qualified staff with high relevance to NOAA and the Nation.

Prospects for continued and future success are high. Our general findings relate to organizational leadership, workforce, quality, relevance, and performance.

B.1 Organizational Leadership

In addition to a well-qualified, motivated workforce, one of GSD's greatest assets is a strong, competent senior leadership team, led by Kevin Kelleher and Jennifer Mahoney, which appears to be universally appreciated by employees and partners. In addition, there is a positive, inclusive relationship with Cooperative Institute staff. There did not appear to be any major issues between Federal and non-Federal (CIRES and CIRA) personnel. As one reviewer noted, "the latter felt well-integrated into lab activities and were not treated as second-class citizens." This is commendable and management should continue efforts to maintain this "seamless workplace".

The recent reorganization appears sound and provides further opportunities for GSD-wide coordination. Some of the activities have potential to be further improved by entraining additional expertise from other areas of GSD or ESRL. NWP data

assimilation, earth-system modeling, GOSA, renewable energy, and post-processing are particularly noted.

GSD's recent efforts to reduce the number of activities it is pursuing and to reduce redundancy in those activities are commended. There appears to be additional room for streamlining the GSD R&D portfolio. The issue of balance between basic research and R2O implementation work came up frequently. GSD does need to assist NOAA's mission agencies (e.g., NCEP), and always be aware of potential customers for its research, but there should be some fraction of effort devoted to research that might not pay off for 5-10 years.

Research computing insufficiency was seen as a major problem by many GSD researchers. Computer resource allocation across NOAA (and outside) systems should be reconsidered. One item to consider is whether real-time forecasting efforts should be taking up so many resources (HWRF, FIM, NIM, etc.)

B.2 Workforce

As noted above, we applaud efforts to support a "seamless workplace" with a good mix of Federal, cooperative institute and contractor employees. Diversity was a topic discussed in the previous review report, and it remains an issue that has not seen much improvement since the last review. Beyond diversity, the age demographics are worrisome, and succession planning is problematic with NOAA's hiring backlog.

Additional emphasis should be placed on developing a more diverse workforce, and developing explicit plans for Federal employee succession. In order to make significant progress, with the current aging workforce at GSD, and the increasing percentage of staff eligible for retirement, a structured approach with proactive strategies that encourage retirement as well as hiring of a diverse workforce could possibly be part of the solution. As one reviewer noted, and given well-known pipeline issues, we "realize that it is much easier said than done" particularly given the challenges of retaining and backfilling FTE slots of retired Federal employees.

B.3 Quality

Indicators of quality include publications, citations/H-index, awards, election to fellow in professional societies, editorships, and society/committee leadership, in addition to patents and successful operational transitions. Without clear targets and baselines in each area, it was somewhat difficult to assess quality in an objective way. Looking across the evaluation worksheets from each individual reviewer, quality scores were all in the highest two categories: Highest Performance: (43%) and Exceeds Expectations (57%). This resonates with our initial report-out where we stated, "Quality of the work is high. Publication rates are very low." Despite the focus on applied research and decision support, a target rate of about 1-2 publications per scientist per year is reasonable. Aside from publications, GSD has and tracks a number of reasonable metrics of success that measure many facets and direct impacts of its work.

B.4 Relevance

Relevance is determined primarily by assessing written customer surveys and interviews in addition to research products, information and services, models and model simulations, and an assessment of their impact by end users. In addition, relevance includes an assessment of the degree to which GSD research and development is relevant to NOAA's mission and of value to the Nation. Our discussions with stakeholders, which included reviewing their written input, were essential contributions to evaluating relevance. Looking across the individual evaluation worksheets, GSD did not receive scores for relevance as high as it did for quality, with (67%) Exceeds Expectations, and (33%) Satisfactory. One overarching finding that emerged is that there is opportunity for more strategic and tactical alignment between the R&D activities at GSD with modernization plans of the NWS. While most of the activities within GSD envision the NWS as the primary end user of the technologies, there are opportunities to improve alignment with NOAA as well as with other users such as FAA.

B.5 Performance

Performance evaluates research leadership and planning, efficiency and effectiveness, and transition of research to applications. Indicators of performance include strategic and implementation plans, interactions with stakeholders, funding portfolio, and assessment of technology impacts and transition by stakeholders. As noted in our report-out, it is challenging to strike a balance between prospective research and targeted development for stakeholders. Individual scores for performance were (9%) Highest Performance, (64%) Exceeds Expectations and (27%) Satisfactory.

We have commented above specifically on positive aspects of GSD organizational leadership, as well as on more troubling issues of demographics and succession planning. From a planning perspective, the horizon of the research portfolio is a bit short given that 60-70% of resources are devoted to projects with 0-2yr time frames. An effort to push the roadmap and strategy a bit further out with several more innovative projects would be beneficial.

For future financial competitiveness, efforts to continue reducing overhead should help GSD to maintain and extend partnerships.

B.6 Recommendations

- Continue to build on opportunities presented by reorganization for synergistic work in:
  - software engineering
  - end-to-end forecast improvement
  - re-usable core software components
- Seek, recruit, and train candidates for future hire (through graduate and/or postdoctoral fellowships) with particular attention of creating a pipeline of future employees with increased diversity.
- Continue to hire through Cooperative Institutes while pursuing conversion of qualified candidates to Federal positions
- Senior GSD management and project managers should continue to

    - improve good relationships with stakeholders (including private sector) and regularly re-align strategic research priorities
    - work closely with NWS to improve relationships and develop a clear, integrative partnership
- GSD should take a broader perspective on the users of its technologies towards achieving a more holistic realization of NOAA's Weather Ready Nation objectives.
- Coordinate a community effort on model validation and verification involving GSD with NCEP, DTC, MDL and others.
- Develop mechanisms (e.g. matrix alignments, cross-cutting programs) to foster greater symbiotic collaboration across thematic areas in GSD and ESRL, so that work in each area can take advantage of knowledge and expertise across the laboratory.
- Further consolidate and coordinate activities undertaken by GSD and ensure that all innovative initiatives with long-lead development horizons receive some base funding.
- Identify, track and embrace broader metrics of GSD's success even if those metrics are outside of GSD's direct or sole influence, with particular focus on measures of key stakeholder outcomes.
- Analyze problems / obstacles in previous R2O efforts (HRRR, MADIS, AWIPS, etc.) and define clear actions that can be taken in order to improve the effectiveness and efficiency of the process from which all R2O efforts of GSD will profit in the future. For example, consider a change in responsibility / personnel as developments transition down the TR-funnel (hand over from a research scientist to a project manager?).
- Establish a process to continually set / re-align priorities together at least every two years ideally involving key scientists, mid-level management and upper-level management.
- Actively pursue visiting scientist and engineer programs in order to continue to infuse external knowhow into GSD in key areas of research.
- Make continuous education and training of the workforce a priority of mid-level management in order to ensure that employees remain fully up-to-date in terms of scientific, project management and software engineering methods. Introduce GSD-wide standards for software engineering (e.g., agile development, code reviewing, unit testing, regression testing, automated continuous integration systems, transparent issue and feature tracking).

C Numerical Weather Prediction

GSD is well-known for its research, development, and transition of the hourly-updating Rapid Update Cycle (RUC), Rapid Refresh (RAP) and the High Resolution Rapid Refresh (HRRR) models. In a related effort, GSD researchers are performing in-depth Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs) to quantitatively evaluate the benefits of current and future observing systems for improving weather forecasts from numerical models. GSD has also been active in developing new global models (FIM and NIM) which participated in the recent NWS NGGPS dynamical core selection process.

C.1 Quality

GSD has a skilled, innovative staff that is making important scientific and technological advances and valuable, unique contributions to NWP science. The unique and powerful mix of modeling expertise, experience, and internal collaboration combine to create high quality results. One reviewer remarked, "the lab and its leadership within NWP clearly embrace a culture that encourages differentiating research." The regional modeling work, especially HRRR, has recently seen major success, and it is important for this effort to continue moving towards convection-permitting ensembles. In global modeling, GSD scientists have valuable expertise but it is not yet clear how GSD will utilize this expertise to contribute to NGGPS. As one reviewer noted "It is not clear to me that this necessarily represents any misstep or poor choices at the laboratory but rather may well be the general outcome of a diverse community. The critical outcome here is that the team must embrace an effort to realign in a way that will allow them to contribute wholly to the development of the NGGPS program." It is also not yet clear how GSD can most effectively contribute to ESRL's efforts towards developing an integrated physical-chemical-biological earth system model. That task is daunting, and OAR should ensure that NOAA-wide resources are effectively leveraged across labs (e.g., GFDL, ESRL) as well as through interagency (e.g., DOE, NASA) and international partnerships.

Publishing GSD modeling work can be challenging, due to the constraints of funded efforts and the R2O nature of the work. GSD scientists give many conference presentations and write conference papers, but journal publication rates (especially of articles on which GSD scientists are first or among the first few authors) are low. GSD's high-quality work would have more reach into the atmospheric science R&D community if more of the advances being made were formally documented in journal publications. Publications serve multiple purposes, including enhancing the science through feedback in the review process, promoting GSD work in the scientific community, and supporting scientific career development. Applied research and R2O work can and sometimes should be published. Even for experienced scientists, this can be challenging as FAA and/or NWS driven projects are on very strict timelines with tasks and deliverables that do not leave significant space for scientific exploration and thoroughness. Mentoring early career scientists on choosing what to publish and on writing journal articles is important, especially when the funding provided doesn't include all of the science or time needed to complete a publication. The conference presentations that GSD scientists frequently give are important and valuable, but it is less clear how active they are in giving longer seminars at universities and other institutions. Scientists with a strong track record of publications are often more successful in proposals, so investing in this area could be important for future funding.

C.2 Relevance

GSD efforts have made major contributions to operational NWP, in NWS and other organizations. GSD's interactions with NCEP have improved substantially during the last few years, but there is still significant room for improvement in the alignment of some of GSD's NWP efforts with NCEP and broader NWS and NOAA needs. For GSD NWP activities to realize their potential to benefit the nation, it is important to view the NWS – especially NCEP and other national level programs – as strong partners. This will also require commitments from NWS, NCEP and other outside institutions to partner

effectively with GSD. Nevertheless, continuing to improve how GSD navigates this space is key for GSD's continued success. The recent UMAC report offers relevant guidance to NCEP on these same issues.

The primary focus of GSD's NWP work is to advance NWP systems and improve predictions. There is less emphasis on incorporating current and future societal application needs into NWP plans. Incorporation of NWP users' needs into GSD R&D efforts is typically done implicitly, by incorporating high-level NOAA/NWS organizational goals and model developers' knowledge about user needs. Often, this works well, leading GSD NWP efforts to be relevant and beneficial. Sometimes, however, it works less well. More explicit consideration of applications and decision support needs could further enhance the societal benefits of GSD's NWP work.

In addition, GSD NWP efforts to improve probabilistic guidance have potential to play an important role in helping the NWS shift towards a less deterministic forecasting paradigm, with improved estimation and communication of uncertainty.

At times the modeling efforts did not appear to be aligned with other cross cutting programs that could benefit from a tighter collaboration, for example renewable energy or decision support. The renewable energy program is a forward-looking, potentially nationally useful program that would require strong inter-agency (e.g., DoE) coordination to avoid duplication of effort. The roadmaps did not reflect a tight business case linking the various efforts. This is not a necessity, but ultimately it would result in a better integration of research projects, and a more holistic story that will better resonate with funding agencies.

C.3 Performance

The strategy for many of GSD's NWP activities seems to be develop a new idea with potential benefits, prototype it, and then demonstrate it to motivate others to adopt it (with testing and improvement along the way). This approach has often been successful, especially for recent regional modeling efforts such as the HRRR. One reviewer observed that the relationship between GSD and EMC "remains fragile", and noted that the successes have come with "significant investment of resources and near heroic efforts by some (on both sides)." While coordinated applied research and transition activities with EMC are important for future success, having longer-term R&D program elements with a clear immediate pathway to operations is critical to the future success of GSD. Beyond GSD management, one reviewer suggested "both NWS and FAA should understand the importance of more long-term research and GSD should work towards increasing their awareness."

In addition to a strategic balance between R&D and R2O, GSD's NWP efforts would likely benefit from incorporating a more "end-to-end" approach to forecast system improvement. More strategic incorporation of decision support, application, and user perspectives could help GSD manage the NWP program to have even greater successes. It is also important for GSD to take advantage of its unique R2O niche within NOAA, and to develop and implement R&D plans in ways that are synergistic with NOAA's operational NWP needs. For example, GSD has considerable expertise in model verification and should work to better exploit this core capability, perhaps with other NCEP partners beyond EMC, e.g., DTC, MDL, and the National Water Center.

The OSSE/OSE effort is an important newer program that is growing rapidly. As the GOSA group continues to develop, it will be important to develop a strategy that takes advantage of GSD scientists' expertise while also coordinating effectively with the other US groups engaged in OSSE/OSE and observing system design efforts. This includes taking advantage of (rather than duplicating or competing with) the broader community's efforts and expertise, and building on existing relevant knowledge.

C.4 Recommendations

- The GSD numerical modeling program should identify its core competencies within NOAA and the broader community and develop a strategy for how it can best utilize this expertise (in collaboration with others) to improve the research and operational NWP suite.
- Build on the current success of HRRR as a basis to help develop a convection-permitting ensemble capability for the nation. One reviewer specifically recommends that "research efforts for convection resolving ensembles should focus on full-fledged ensembles as opposed to time-lagged ensembles." Achieving a good spread/skill relationship is key for a convection resolving ensemble system (and the associated ensemble data assimilation system).
- In global modeling: Finalize and implement a plan to contribute to NGGPS with selected NGGPS core, and develop a longer-term plan for GSD's global modeling efforts, including a reduction in FIM and NIM work, especially the hydrostatic FIM.
- To improve quality metrics, develop and implement concrete mechanisms within GSD to encourage and reward publications and other types of scientific engagement in the research community beyond GSD and ESRL. Develop and implement mechanisms to mentor scientists on how to publish R2O and applied work, given the constraints of funded efforts.
- Design strategies for prioritizing future GSD NWP efforts in a way that balances advancing the science and technology of numerical weather prediction with stronger operational partnerships and including more robust understanding of users' needs from early on in system planning and development.
- It is essential that a plan for National OSSE and OSE research be developed in collaboration with AOML, JCSDA, NASA/GMAO, NESDIS, perhaps via the QOSAP (Quantitative Observing System Assessment Program). Tested systems should include existing and possible ground-based remote sensing and in situ systems.
- Work to clarify and tighten GSD's roadmap; and make necessary efforts to ensure buy-in across NOAA. Incorporate a clearer understanding of who might be using the predictions, how, and why into NWP system development, from the beginning.
- Collaborate with the National Water Center. This seems like a natural fit and could lead to some productive and interesting innovation in the area of water forecasting.

D Decision Support

GSD is known for its leadership in developing innovative forecast tools, beginning with the Advanced Weather Interactive Processing System (AWIPS), to AWIPS II, FX-Net, and GFE, among others. These tools support issuing timely and accurate weather hazard information, forecast monitoring, collaboration between forecasters and decision-makers, and communication of weather uncertainty. A key partner in these efforts is the Federal Aviation Administration.

D.1 Quality

The specific decision support work that GSD undertakes appears to be of high quality following careful scientific principles and development methods. GSD has developed a unique niche in providing high-quality decision support for specific user applications that, in many cases, also contributes to the broader scientific community. For the most part, results appear sound and robust, although in some cases, the scientific quality of the work or its applicability beyond the current funded application was not clear, in part due to the emphasis on providing tools and technologies requested by funders. Most of this work has not been published in peer-reviewed literature, hence limiting the confidence in this quality assessment. GSD appears to be providing quality work in certain decision support niches, but as one reviewer stated "while the overall quality of this research area appears satisfactory, it is not on par with the quality or significance of the other GSD research areas assessed." This is partly a consequence of the nature of the work undertaken (largely very specific funded tool or capability development with limited core science research opportunities) but may also be related to the background and emphasis of the project team (which appears to have fewer researchers with PhDs than the GSD NWP area).

GSD staff members have an impressive, unique knowledge base in designing and implementing technologies and tools to improve NWS WFO forecasters' capabilities and support aviation weather verification needs. In longer-term, strategic areas such as hazard services, it was not clear whether progress was being made in going from broad concepts and programmatic frameworks to more specific R&D plans leading to implementable science and technology.

D.2 Relevance

Most of the individual decision support activities are highly valued by funders and users. Within the constraints of their funding environment, GSD efforts also have well-developed plans for how GSD will continue to contribute to decision support for key stakeholders into the future. GSD scientists have excellent relationships with NWS forecasters and other key stakeholders that significantly enhance the relevance of the decision support work.

The decision support tools being developed are highly specific, and an opportunity exists to consolidate this into a set of common core capabilities that could be leveraged more broadly. Due to the current portfolio of work, most of the decision support activities within GSD envision components of the NWS or FAA as their primary users. However, NOAA's and GSD's strategic objectives and service to the nation would benefit from GSD taking a broader perspective on who are and could be the users of its technologies

and should include non-governmental entities. This includes conceptualizing decision support beyond serving the current customers. It also includes going beyond the largely successful current efforts to serve individual users in the field and improving the incorporation of broader agency strategies and programs into decision support activities.

GSD's expertise in decision support has potential to contribute to ESRL's planned development of an integrated earth system model in a way that goes beyond the current integrated physical-chemical-biological system plan towards one that more fully incorporates societal systems. Doing so, however, would require additional resources.

With its unique mix of expertise, GSD has an opportunity to help design the forecast office and the forecast and warning system of the future. GSD can also help define and make important contributions to the NWS's and NOAA's longer-term decision support goals. However, meeting the needs of NWS forecasters requires substantial engagement from requirements to design and testing, and despite GSD's best efforts, this is not always effective. As one reviewer noted "the fact that the forecast update process tool has relatively low engagement and use by NWS forecasters (as a GFE add-on) is somewhat concerning. Low use typically indicates some fundamental flaw, such as it doesn't meet a need or is hard to use."

The aviation program appears to be more successful at delivering production capability than the NWS program. While it is hard to tell, it appears to benefit from a more clearly stated development path and roadmap created and shared by both GSD and the FAA. A best practice appears to be the assessment reports, with methodologies being reviewed by both stakeholders and developers.

D.3 Performance

GSD's decision support efforts face significant challenges in striking a balance between prospective research and targeted development for stakeholders. GSD decision support projects, collaborations, and goals appeared to be primarily driven by current users and funding sources. As a result, short-term applicability and priorities are typically well addressed, and excellent, user-specific tools are being planned and generated. However, longer-term, broader strategies appear less well developed. This is understandable, given that the reorganization of GSD is still quite recent. However, in the coming years, the effectiveness and reach of GSD decision support efforts would benefit from developing a bigger picture strategy. This includes considering how tools may overlap or complement each other, within GSD and with related tool development elsewhere, and leveraging a set of common tools where possible.

In some cases, e.g., with parts of the NWS, weaker connections and partnerships seemed to contribute to less efficient R2O processes with slower progress. An example of this is the unified hazards tool, which has been in production for approximately six years, but has not successfully migrated any capability into the operational system. In this age of rapidly evolving technical capabilities, such a slow process cannot be tolerated. The focus and work appear on target and solid, but for some reason the commitment or process to get it into operations is lacking. Similarly, there appears to be some overlap and duplication with other Federally Funded Research and Development Centers (FFRDC) such as Mitre and MIT Lincoln Lab in the aviation area. Perhaps pursuing

either formal or informal collaborations with these groups would help better position GSD in this arena.

Given how the funding environment is evolving, improved training of GSD staff in project management skills would be helpful, to enhance skills in developing and implementing project plans to meet operational goals with a given amount of resources in a specified time frame.

Finally, an critical area of work that GSD should additionally invest in, is developing effective communication of the uncertainty in forecasts. We applaud and encourage GSD to work in this critical area of decision support, but acknowledge that there are many challenges, as noted by one reviewer "even simple differences like it being point-based versus area-based creates resistance and undermines its usability."

D.4 Recommendations

- Improve partnerships with National level programs, to complement current efforts to support forecasters in the field. Perhaps opportunities like FACETs or the Weather-Ready Nation Pilot Programs could serve as shared initiatives to better integrate the efforts.
- Begin incorporating social science perspectives and knowledge into decision support activities, to help realize the Grand Challenge goals.
- Develop a broader strategic direction for GSD Decision Support (or update existing strategic directions, if appropriate). This includes:
    - clarifying what "decision support" means for GSD;
    - considering the appropriateness of developing technologies that support broader sets of users and uses while maintaining current competencies;
    - balancing meeting the needs of current users with taking a more active role in offering capabilities and pursuing new opportunities that leverage existing work to serve broader sets of users; and
    - enhancing awareness of other public and private sector decision support activities to remain competitive and collaborate where beneficial.
- Seek opportunities to build a set of common core tools that can be leveraged across GSD.
- Utilize knowledge from Best Practices in aviation program: assessment reports, and methodology reviews by stakeholders and developers to guide other programs.

E Advanced Technologies

GSD has global recognitions for advanced technologies and outreach activities including advanced High Performance Computing, and Science on a Sphere. Recent efforts have focused on advanced visualization through the NOAA Earth Information System (NEIS), transitioning the Meteorological Assimilation Data Ingest System (MADIS), and developing the SOS Explorer.

E.1 Quality

MADIS has been undergoing operational transition, and the 2015 NOAA Administrator's Award to Kevin Kelleher, John Schneider and Greg Pratt for their work on MADIS is a tangible example of the quality of work. Even though not complete, MADIS is a

successful program, which is serving a broad set of observational needs of the nation, including facilitating regional and storm-scale DA and NWP efforts.

The quality of Science on a Sphere (SOS) is evidenced by the dozens of installations worldwide, in addition to a large community of practice that supports this endeavor. Several reviewers noted that they were "very impressed with the quality of the SOS work and display capability". The development of SOS Explorer as a means to further bring SOS content to the public without having to visit an installation is a great idea to multiply the impact of the SOS effort. These technologies represent a major success of GSD and constitute an important service to the nation and our sciences.

The more recent developments of NOAA Earth Information System (NEIS) and TerraViz are innovative and impressive in a live demonstration. It is difficult to assess their quality beyond impressions from the demonstration at the posters; however, leveraging gaming technologies is innovative and forward-leaning for the atmospheric sciences community.

The HPC activities are world leading, high-quality and essential to ensure return on investment in NWP. These activities have impacted vendors and standards to the benefit of the general NWP community. Activities in addressing fine-grain computing, performance portability and optimization are particularly noteworthy. As one reviewer commented, "while many labs are opting for a wait-and-see strategy the HPC group has taken an aggressive approach towards embracing future and emerging hardware architectures, which has paid off."

E.2 Relevance

MADIS has helped to support NWP efforts and operational forecast offices with its database and graphical user interface web site designed to display automated aircraft weather reports including water vapor, temperature, winds & turbulence. MADIS, now that it has been transferred to an operational system, has great, untapped potential to support the NWS operations as well as the broader private forecast community. As one reviewer notes, "display capability of the aircraft data in plan view as well as soundings from the surface to cruise altitude (30,000-40,000+ feet) have been very much appreciated by the aviation forecasting community." There is still a large amount of work remaining to ensure that the operational version of MADIS is relevant for operational purposes ranging from increased access and ease of operational forecaster use to operational NWP.

One of the keys to maximizing benefits of numerical weather prediction modeling and data assimilation efforts is to take advantage of advances in High Performance Computing (HPC). The high-performance computing initiatives are extraordinarily relevant and serve a national imperative. The team represents a unique national resource. and highly relevant to the NWP community through their impacts on vendors and standards. However, as noted in our initial findings, "it is unclear if these activities are adequate for current and future activities including NGGPS." One reviewer suggests that "it may be time to consider transferring more of these HPC responsibilities to the private sector in order to focus more resources on the actual development of the Next Generation Global Prediction System (NGGPS)," although other reviewers suggest that this is not an either-or proposition, and note that NGGPS can benefit from the unique expertise of the GSD HPC group.

The Science on a Sphere and related programs, while not core research programs, also represent unique global capabilities that serve NOAA, national and global interests. While NOAA has explicit goals related to "an engaged and educated public", at least one reviewer was "conflicted on SOS relevance" given that "there are many other pressing issues in the areas of NWP and DST." That reviewer wonders whether "SOS would survive a cost vs. benefits analysis." It was emphasized during the briefings on SOS that it is supported through deployment costs, so the funding is likely less of a concern than the strategic role that SOS plays in the overall NOAA and OAR education and outreach program.

Finally, the advanced visualization programs such as NEIS and TerraViz are creative and cutting-edge although the future application of some of these technologies is not clear.

E.3 Performance

From nearly all perspectives, performance metrics for the advanced technologies are exceptional. The reach of the SOS program is truly impressive, and the sustained funding, enhancement and leveraging through SOS Explorer and continued global deployments funded by partners are all indicators of exceptional performance.

The high-performance computing initiatives have focused largely on GSD affiliated models (FIM/NIM and perhaps HRRR), and the impact on compiler vendors and HPC acquisitions are further evidence of high performance. As noted above under Relevance, moving forward it is imperative that the HPC work inject itself and become integral to the NGGPS initiative and all NCEP operational modeling initiatives.

The transfer of MADIS into operations represents a significant accomplishment serving the nation. The advanced visualization initiatives, particularly the NEIS/TerraViz visualization programs, while creative in the use of some emerging visualization and compute technologies, overlaps in capability with many existing environmental visualization technologies and as such may only serve niche uses. For example, is NEIS integrated with or additive to NCEI capabilities?

E.4 Recommendations

- Continue to support, mature and support the highly successful SOS, MADIS and HPC initiatives including the use of base funding to ensure long-term sustainability of these programs.
- Work with NOAA operations to tighten the R2O process for GSD's role in the continued evolution of operational MADIS, including acquiring new data sets and improving data latency.
- Along with all of GSD's numerical weather prediction initiatives, become a contributor to, integral to, and tightly aligned with NOAA-wide strategic and tactical plans to develop next generation global and regional modeling capabilities, including establishing benchmarks for model optimization success and a program to reach those benchmarks. Work with NCEP/EMC to inject GSD's HPC talent and capabilities into the development of NCEP operational models and in particular in the NGGPS program, and expand the GSD HPS activities as necessary to support this national imperative.

- Rather than developing new visualization tools, consider how to integrate new GSD-developed visualization technologies into existing visualization tools to avoid creating niche applications with limited utility, but rather create capabilities that will have broad use and distribution.

F Final Comments

As noted above, the panel was impressed by the enthusiasm, openness and effectiveness of the top-level GSD management and their dedication to attack pressing GSD issues. Furthermore, the acceptance and support the workforce has for the recent changes and reorganization is impressive. Recent changes have addressed the top priority issues and first results (reduction of overhead, new organizational structure with three research branches) have been achieved rapidly.

Regarding the next review, it would be useful to dedicate some time in the introduction to summarize the findings/recommendations of the past review as well as the actions that have been taken, and some comments on their effectiveness. This would help set the tone for the next review, and set a baseline going forward. We also note that while FACA rules prohibited the creation of consensus findings and recommendations, that overcoming this limitation could strengthen the review outcomes, and GSD should consider options to enable such.

We want to express our appreciation to OAR, ESRL, GSD leadership and staff for facilitating what was an enlightening and productive review for all. The panel members enjoyed getting to know each other in addition to becoming much more familiar with all the excellent work at GSD.