Geophysical Fluid Dynamics Laboratory (GFDL)
Science Review
October 29-31, 2019

GFDL Response to Panel Review Recommendations

Submitted by:

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Introduction

The Science Review of the Geophysical Fluid Dynamics Laboratory (GFDL or "the Lab") was held on site and at Princeton University on 29-31 October 2019. The Review Panel (hereafter, "the Panel") assessed three research themes of GFDL activities for the period 2014-2019: Theme 1 (*Modeling the Earth System*), Theme 2 (*Understanding Earth System Phenomena*), and Theme 3 (*Earth System Predictions and Projection*). The Panel was charged by NOAA Research leadership with addressing the quality, relevance, and performance of each theme and asked to provide recommendations as needed.

Link to Review website: https://www.gfdl.noaa.gov/2019review/

Below, we consider each of the Panel's Recommendations and its contents. We respond to the points raised, and describe actions that will be undertaken to advance the mission. The responses for each Recommendation comprise a narrative directly addressing the points in the Recommendation. Summary Action/s is/are stated. Timelines are given for those instances where it is possible to be quantitative. The responses are meant to be understood as deliverables in the 3-5 year period unless stated otherwise; in some cases, it could become a 5-10 year time frame depending on the complexity of the challenge and its evolution. We note that there were no remedial or rectification actions indicated by the Panel for the Lab.

The responses follow the line of GFDL's vision for contributions to NOAA, namely: advancing Earth System Modeling for scientific understanding, predictions, and projections; innovating global-to-regional-scale impacts quantification, including extremes; and seamless modeling from the weather to climate timescales. [See GFDL 5-10 year Strategic Science Plan; GFDL Charter].

Fully addressing several of the Panel's Recommendations will require additional, sustained resources for personnel and high performance computing. As suggested by the Panel, GFDL will work with OAR's Leadership to formulate initiatives to secure the necessary resources for accomplishing the NOAA/OAR goals. Further, NOAA/OAR resourcing and facilitation will significantly augment the partnerships suggested by the Panel within and external to NOAA.

The process followed at the Lab to compile this Response document is described at the end of the document.

Recommendations, Responses, and Action Plans

In this report, each actionable recommendation provided by the Science Review Panel is italicized and followed by GFDL's response. A table summarizing the major actions with timelines for completion is included below. Detailed responses and additional actions can be found in the Appendix. Implementation of and status of actions will be tracked internally at GFDL and will be presented at the next regularly scheduled laboratory review.

Recommendation	Action	Champion	Target start & Completion Dates
R1: Strengthen internal collaboration within GFDL/Princeton	Explore mechanisms to grow collaborations, and work to eliminate barriers to Princeton-GFDL collaborations.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R1: Strengthen internal collaboration within GFDL/Princeton	Improve the onboarding process for Princeton graduate students, postdocs, and visiting scientists.	GFDL Science Board and Research Council	Start: FY21 Complete: FY22
R2: Promote a culture of diversity, equity, and inclusion	Develop a GFDL DEI Strategic and Implementation Plan	GFDL DEI Committee	Start: Summer 2020 End: Summer 2021
R3: Be ready to reach out to outside entities	GFDL will pursue strategic opportunities in the enhancement of its models through community involvement. This will include attempts to identify additional funding streams in OAR and elsewhere to pursue new collaborations with external entities to benefit NOAA mission.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25

R3: Be ready to reach out to outside entities	A plan focusing on stratospheric chemistry, dynamics, and radiation, and their interactions, will be undertaken and used to guide GFDL's future modeling work in the understanding and predictability of weather and climate.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R3: Be ready to reach out to outside entities	GFDL will finalize and publish Fair Use Policy for GFDL model configurations, code, and data to provide clear guidance for collaborators.	GFDL Science Board and Research Council	Start: FY20 Complete: FY21
R4: Increase engagement with other NOAA efforts	Outreach and collaboration with other NOAA efforts, including workshops, will continue to be an ongoing effort.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R5: Define appropriate scope toward model development	Future model development will be based on the recently developed GFDL Science Plan focused on NOAA/OAR objectives and will target key areas, including those articulated in the Review comments, while cognizant of resource and personnel constraints.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R5: Define appropriate scope toward model development	GFDL will continue to contribute our model components to the UFS as well as weather- and climate- forecast-oriented innovations.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R6: Incorporate existing observational data toward GFDL model improvement	Incorporate new satellite data on vertical structure of water content in the atmosphere (including clouds and other hydrometeors) at high space-time resolution to provide quantitative evaluations of clouds, precipitation, and radiation simulated by the FV3-based models including high-resolution ones. This includes	GFDL Science Board and Research Council	Start: FY21 Complete: FY25

	testing for feasibility and seeking additional resources as needed.		
R6: Incorporate existing observational data toward GFDL model improvement	Use existing diagnostic packages and develop new methods for process-oriented evaluations of clouds, boundary-layer physics, convection, precipitation, and radiation, including augmentation of resources to automate process-oriented packages so that new data can be used to inform model parameterization development and testing.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R6: Incorporate existing observational data toward GFDL model improvement	GFDL will enhance the upgrading and expansion of model evaluation tools and datasets in various aspects of Earth System Modeling, which will include increased interactions with NOAA-internal and external communities.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R7: High Performance Computing (HPC) challenges and opportunities	GFDL will continue to optimize the utilization of current HPC assets via: Code optimization, workflow analysis and improvement, resource management (allocations, quotas), and exploration of new and novel platforms, architectures, and technologies.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25
R7: HPC challenges and opportunities	Creation of a new initiative at GFDL to explore the use of machine learning and artificial intelligence in enhancing GFDL's mission.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25

R7: HPC challenges and opportunities	GFDL will explore and invest (pending funding availability) in HPC assets outside of NOAA R&D HPCS, to facilitate external collaborations.	GFDL Science Board and Research Council	Start: FY21 Complete: FY25

Appendix

Recommendations

R1: Strengthen internal collaboration within GFDL/Princeton

The Panel commends GFDL for its close collaboration with CIMES and Princeton. The Panel noted existing robust collaboration with Princeton. This is evidenced by co-authored papers with each one of the four Faculty members from Geosciences and Princeton Environment Institute who are in the AOS Program. In addition, there are collaborations and regular scientific meetings with Faculty from each one of the following Departments: Applied Mathematics, Princeton International Institute for Regional Studies, Civil Engineering and Water Resources, Woodrow Wilson School of Economics (now the Princeton School of Public and International Affairs)*, History, Ecology and Evolutionary Biology. Finally, there are collaborations with 2 Faculty members from Rutgers, the other neighboring main University. The Panel encourages the Lab to continue to foster and further strengthen such collaborations in addition to sustaining strong internal cohesiveness. This is essential to success.*

R1 Response:

We thank the panel for their recognition of the vibrant GFDL-Princeton partnership. Its 2018 renewal through the Cooperative Institute for Modeling the Earth System (CIMES), together with the long-standing Program in Atmospheric and Oceanic Sciences (AOS), provide a firm foundation for this partnership to strengthen and evolve to meet new challenges. The CIMES and GFDL missions are closely aligned, ensuring that we can strike the panel- recommended balance between collaboration and cohesiveness. The synergies between GFDL's long-lead climate and earth system research and model development with Princeton's exceptional faculty, graduate and postdoctoral programs, and nimble academic enterprise remain compelling. To ensure these are realized, GFDL will, jointly with CIMES and other Princeton partners, explore innovative mechanisms to grow collaborations and entrain a new generation of Princeton researchers. These could include a) short symposia on high priority topics of mutual interest, with networking events, held as precursor to annual calls for CIMES proposals, b) co-hosting 1-2 week summer schools that include tutorials on GFDL models, Coupled Model Intercomparison Project (CMIP) analysis, and cover themes that enable novel connections between GFDL science and global challenges (e.g., climate impacts in disease, energy, water, etc.), and c) formation of cross-disciplinary postdoctoral fellowship groups, similar to the Princeton Energy and Climate Scholars program for graduate students, subject to resources. GFDL will also work to eliminate barriers to Princeton-GFDL collaboration. We will explore making GFDL models and data more accessible outside the NOAA firewall with the Princeton Institute for Computational Science and Engineering (PICSciE). We will finalize the Fair Use Policy for GFDL models configurations, code, and data, and we will work to improve the on-boarding process for Princeton graduate students, postdocs and visiting scientists.

R1 Action Plan:

Actions:

1. Explore innovative mechanisms to grow collaborations and entrain a new generation of Princeton researchers.
2. Work to eliminate barriers to Princeton-GFDL collaboration.
3. Explore making GFDL models and data more accessible outside the NOAA firewall with the Princeton Institute for Computational Science and Engineering (PSCSciE).
4. Finalize the Fair Use Policy for GFDL models configurations, code, and data.
5. Work to improve the on-boarding process for Princeton graduate students, postdocs and visiting scientists.

Group Responsible: GFDL Leadership, Science Board and Research Council will coordinate.

Timeline: Initiatives to begin in FY21.

R2: Promote a culture of diversity, equity, and inclusion

In closed sessions with GFDL leadership, it was clear that the Lab management is aware of issues that the Panel heard expressed during closed sessions. GFDL leadership is working on these issues, within the constraints of federal rules. The Panel acknowledges the complexity of managing the GFDL workforce comprising feds, Princeton staff and contractors. In discussions with staff, there seemed to be a lack of understanding on how leadership has taken steps to navigate through issues to the best of its ability. The Panel suggests lab-wide communications through periodic town hall meeting, onboarding processes so misconceptions are alleviated.

The Panel realizes that GFDL adheres to federal practices related to paid leave, hiring, security and data management. Nevertheless, on behalf of its employees, GFDL leadership as well as OAR could internally advocate for the improvement of support for new parents, expediency in hiring practice, and improved computing/data access. In addition to listening to concerns, proactive support groups can be formed to explore creative internal solutions and formulate contingency plans. For example, providing time-limited, secured access to GFDL computing and data archival outside the NOAA HPC firewall might be explored.

R2 Response:

GFDL appreciates the reviewers highlighting Diversity, Equity, and Inclusion (DEI) as a recommendation for GFDL to pursue, and acknowledges their reflections on the associated elements in the federal context. OAR has also recognized the importance of promoting a culture of DEI and undertook an organization-wide health and culture assessment in 2019. We will increase the number of Lab town hall meetings to eliminate misconceptions and confusion, and disseminate more clearly the manner in which the Lab is tackling various issues. We will take steps to explicitly recognize and acknowledge the importance of the contributions of Feds and non-Feds to the NOAA/OAR successes, and improve performance by providing important decisional information as rapidly as possible. We agree with improving support for new parents, in accord with the Federal Employee Paid Leave Act signed into law mid-December, 2019. This will grant federal employees 12 weeks of paid time off for birth, adoption or foster of a new child (scheduled to be effective October 2020). GFDL will work to improve internal communications across the Lab, improve the transparency on processes including onboarding, and work with OAR for improving the high-performance computing and data access. GFDL will also work to ensure that DEI is incorporated into other recommendations where improving computing/data access and onboarding are discussed. Finally, GFDL will work towards, as well as encourage OAR to advocate for, increased equity, consistent with Federal statutes, across all employee types (including, but not limited to, federal employees, contractors, UCAR, and Cooperative Institute employees).

R2 Action Plan:

DEI Strategic and Implementation Plan: GFDL will take the input from this recommendation along with the results and recommendations from the OAR Organizational and Culture Assessment to develop a GFDL DEI Strategic and Implementation Plan. This plan will be developed through researching similar plans at external institutions and organizations, and also by examining policies, processes, and practices throughout GFDL to identify and strive to address barriers and enhance diversity, equity, and inclusion (including, but not limited to, hiring, proactive support groups, listening to concerns, lab wide communications, secured access to NOAA Research and Development High Performance Computing Systems, and data archival outside the NOAA firewall) consistent with institutional, structural, budgetary, and facilities constraints.

Group Responsible: GFDL DEI Committee interfacing with the Lab Director, Deputy Director and Associate Director. GFDL will also assess the feasibility of bringing on a DEI specialist in coordination with OAR and NOAA organizational efforts. Commitment and engagement by lab leadership and all employees, as well as support from OAR, will be key to developing and implementing practicable initiatives and actions, with measurable improvements and steadily growing successes.

Timeline: Summer 2020 - Summer 2021. This plan will serve as the first official GFDL DEI plan, but will be an ongoing effort by the GFDL community, requiring regular review and development after initial implementation.

R3: Be ready to reach out to outside entities

GFDL should avoid duplicating efforts in Earth System model developed elsewhere like National Center for Atmospheric Research (NCAR), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), United Kingdom Meteorological Office (UKMO), and Max Planck Institute (MPI) to the extent possible and appropriate. For example, some redundancy and duplications already exist in land and biogeochemical model components as well as in activities in atmospheric boundary-layer turbulence, clouds and aerosol/cloud interactions. The Panel recognizes there is considerable risk in the proposed approach since borrowed components may not be readily transferable. Likewise, GFDL should be aware of missing or inadequate efforts that might hinder its strategic plan, e.g., the role of stratospheric processes in atmospheric predictability beyond two weeks.

In topics where GFDL lacks personnel or expertise, the Panel highly recommends GFDL to make tactical partnerships with appropriate external groups within the U. S. and international scientific communities and to welcome collaboration with other U.S. research groups outside of Princeton.

The Panel urges OAR to consider additional funding to pursue such proposed new partnerships and community outreach activities that will eventually benefit NOAA mission. Currently, the collaborator network favors people who have worked or studied there or at Princeton. The Panel also noted the current firewall in computing environment does not facilitate cross-fertilization with external collaborations. Improved model documentation and facilitating sharing of model simulations will be a step in the right direction.

R3 Response:

Toward advancing NOAA’s mission, GFDL leverages collaborations with other agencies and academic institutions, including Princeton University, to efficiently develop weather and climate model components. Our view is that redundancy or duplication in these critical areas is minimal. We agree with the Panel that borrowed components would most likely not immediately work within our modeling system. Such components would require substantial development to ensure they interact correctly with other parts of the model and to give the best results. This speaks to the importance of GFDL’s decades-long experience and success in integrating and synthesizing model components. We agree with the Panel that tactical partnerships with the external community are critical. GFDL is actively leveraging external expertise through a variety of community activities including the Coupled Model Intercomparison Project (CMIP), several Diagnostics efforts, several NOAA testbeds/task forces, US Climate Modeling Summit, and case-by-case project level external collaborations including 4 ongoing multi-agency Climate Process Teams to develop cloud, land, and ocean parameterizations. Another example is in land-atmosphere interactions which is utilizing knowledge from partnerships with NASA and DOE. Besides the above, there are several (many tens) of collaborations/partnerships which make use of observations and basic knowledge derived at other agencies for GFDL's model development. Some examples of these, benefiting from expertise elsewhere, are evident in GFDL's recent publications.

We share the Panel's assessment that stratospheric modeling and research needs to be further enhanced. We agree with the Panel that OAR could consider additional funding for GFDL to pursue new partnerships and the collaboration with external entities to benefit NOAA missions, building upon the 100+ collaborations developed over the past five years in mission-related activities, papers, applications, and assessments. One way is for OAR to set up matching funds (e.g., 'seed' funding as in 2013-14) to encourage GFDL to collaborate with national and international outside entities, which could include going beyond CIMES. As the Panel noted, the current NOAA firewall in computing environments does not facilitate cross-fertilization with external collaborations. A few modeling centers support multiple platforms for their models, but GFDL realistically only supports NOAA's internal R&D HPCS. We agree that these limitations can hinder external collaboration.

R3 Action Plan:

Actions:

1. While importing external components still requires local expertise for vetting, integration, and support, GFDL will continue to pursue strategic opportunities to enhance its models with community involvement when those efforts reach sufficient maturity. GFDL will also attempt to identify additional funding streams in OAR and elsewhere to pursue new partnerships and collaborate with external entities to benefit NOAA missions (e.g. GFDL has begun collaborating with: NCAR and NASA to enhance our stratospheric aerosol modeling capability as part of a new NOAA initiative on Earth's radiation budget; NASA on atmospheric modeling; WMO/WCRP on climate and Earth System Model evaluation and assessments; Vulcan philanthropy on use of machine learning to improve atmospheric process representation in climate models and code adaptation to GPU architecture). **Timeline:** Ongoing
2. GFDL will develop a detailed plan focusing on stratospheric dynamics, physics and chemistry including the polar vortex, aerosols, and stratospheric sources of predictability. GFDL will use this plan to guide future work in this regard.
3. GFDL will finalize and publish Fair Use Policy for GFDL model configurations, code, and data to provide clear guidance for collaborators. **Timeline:** Underway
4.

Group Responsible: GFDL Science Board and Research Council will perform the oversight.

R4: Increase engagement with other NOAA efforts

The Panel encourages GFDL to advance its working relationships with other groups within NOAA. Current physical embedding of EMC and NMFS scientists at GFDL has brought meaningful collaborations and promoted cross-fertilization of ideas. The Panel noted that GFDL's efforts in modeling the Earth System and resulting products are particularly relevant to NOAA, specifically citing the adoption of FV3, MOM6, and cloud microphysics for operational use by EMC and the NWS, and collaborations with the NMFS on coastal ecosystem modeling as 4 notable examples. The Panel suggests that GFDL be more involved in EPIC and take on more of a leadership role to further support NOAA. Given the outstanding progress related to high-resolution FV3, continued collaboration with NCEP for the operational modeling should be considered.
Again, the Panel suggests OAR provide additional funding for such participation, since this will eventually benefit NOAA mission goals.

R4 Response:

We intend to continue the efforts at GFDL that the panel highlighted that address well-defined stakeholder or mission needs at NOAA NWS, NOS, NMFS and NESDIS. Having embedded scientists from EMC and NMFS has facilitated meaningful collaborations on specific topics/goals, as does the open model development paradigm that GFDL has adopted for some components, including MOM6 and the FV3 dynamical core (as facilitated by 'GITHUB). Research that is additionally shared with EMC via meetings, through NOAA testbeds such as the Hazardous Weather Testbed, and through embedded scientists, will help efficiently drive future developments and operations at both institutions. Seasonal predictions will continue to be provided to NCEP for the NMME, with a new system (SPEAR) being transitioned in the next year. Model components have also been contributed to UFS and will continue to be contributed as they are developed. Accelerated development of regional MOM6 for coastal applications is a critical part of NOAA's recently endorsed Climate and Fisheries Initiative. GFDL is involved with designing and implementing EPIC. Since the laboratory review, Dr. Whit Anderson has joined the EPIC Board to further develop the initiative and work towards its implementation (work in progress). Through the NOAA Executive Committee (Dr. Ramaswamy is OAR representative) formulation of machine learning and artificial intelligence (ML/AI) initiatives in 2020, GFDL is actively pursuing the use of ML/AI techniques in earth system modeling. GFDL will also explore creatively to tap outcomes from its Climate Impacts Initiative (a lab-wide effort) into NOAA efforts.

GFDL recognizes the value of collaborations provided they fall within reasonable constraints of scientific capabilities, NOAA interests, and available resources. GFDL will encourage its scientists to identify and pursue collaborations with other NOAA line offices and laboratories to develop new projects consistent with the OAR Strategy. As mentioned by the panel, additional funding is needed for new projects or operational transitions. We will pursue competitive calls for funding as they align with the NOAA/OAR goals to facilitate this work.

R4 Action Plan:

Actions:

1. Virtual workshop with AOML. **Timeline:** Completed August 2020.
2. Outreach and collaboration with other NOAA efforts will continue to be an ongoing effort. Examples: global-nested hurricane modeling (AOML); Climate-Fisheries initiative; satellite data assimilation of cloud microphysics (NWS, NESDIS); Climate Process Teams (oceans, land); Climate Model Diagnostic Taskforce; Sea-level changes, weather and coastal inundation (NOS).

Group Responsible: GFDL Leadership will perform the oversight. A committee from multiple GFDL divisions jointly organized the AOML virtual workshop. Individual scientists are responsible for their outreach efforts on several specific projects or tasks. Lucas Harris leads efforts with FV3. Tom Delworth leads efforts with SPEAR. Robert Hallberg leads efforts with MOM6. Three GFDL scientists are currently participating in NOAA's Model Diagnostics Task Force.

R5: Define appropriate scope toward model development

GFDL should strategize how to approach its model configurations. Not all problems are best addressed using a fully coupled ESM. GFDL should not lose sight of the inherent values of simplified models (or lighter versions of recent model configurations) to investigate foundational processes and accommodate wide usage especially in academia. In maintaining its NOAA/OAR missions, based on the talent pool available and provided NOAA budget, GFDL should self-impose realistic expectations and focus on a targeted set of its modeling systems suitable for operations and applications. Reiterating the Panel's recommendation for Theme 1, GFDL must exercise care to ensure its preeminence in research and its core strength in climate physics. The Lab should leverage its core strength and address these self-imposed expectations from a scientific perspective.

The Panel is aware there is much more to do in the area of clouds-convection-microphysics-radiation to improve understanding of climate forcings, feedbacks and sensitivity. Nevertheless, GFDL scientists have made substantial contributions on these issues during the past five-year period. The GFDL community publishes approximately 200 papers/year. The Panel applauds GFDL scientists for their world-class contributions towards advancing the state-of-the-science on clouds-convection-microphysics-radiation. For example, the 2016 paper in the Journal of Climate by Zhao et. al was the recipient of the 2017 OAR Outstanding Paper award.

R5 Response:

Model development since the 2014 Review has been unified across the Lab, with all models now sharing common components, as articulated in the 2012 Science Plan. Future model development will be designed to meet the needs of the recently developed GFDL Science Plan [2019; see Attached] focused on NOAA/OAR objectives. We will continue to contribute our model components to the UFS (such as FV3 and MOM6) as well as forecast-oriented innovations. Future model development will support the goals articulated in the recent GFDL Science Plan, while cognizant of resource and personnel constraints. The new Science Plan was created consistent with up-to-date GFDL, OAR and NOAA mission statements and plans. The Plan builds upon the successful previous generation models (e.g., FLOR, HiFLOR, Hurricane model, HiRAM, AM2.1, CM2.1, AM3, CM3, ESM2M/G etc.).

GFDL's model developments take into account advances in fundamental climate sciences coming from theory, observations, and limitations diagnosed in prior model versions. This will continue with increased emphasis on areas called out in the Review. The Cloud-Climate Initiative will be the main mechanism for organizing research on clouds-convection-aerosols-microphysics and related topics. A balance is essential when incorporating the latest information on advancement in one area of the Earth System with the need to obtain a good simulation of the system as a whole. Progress is best obtained by carefully optimizing the latest scientific information, with a goal to advance the simulation characteristics in every aspect of the earth system subject to high quality observations over all space-time domains. Scientific perspectives and realism, together with realization of core strengths and the need to sustain NOAA/OAR pre-eminence, will guide the Lab's path forward.

The fully coupled Earth System Model (ESM) represents the full range of comprehensiveness incorporated in our model codebase. Models of varying complexity and resolution are developed and deployed to meet the scientific and computational requirements for research applications. GFDL's fourth-generation models (SHiELD, SPEAR, CM4, and ESM4) demonstrate the range of possible model configurations, with components forming inputs into UFS. The SPEAR_LO model has a relatively low resolution and can be seen as a particular example of a "light, fast model". The code is publicly available and could be used by the broader community. GFDL will consider carefully the construction of simpler, faster-running models for targeted purposes, subject to resourcing and collaborative interests in conjunction with the Weather, Climate, and Ocean Portfolios.

R5: Action Plan

Actions:

1. Future model development will be designed to meet the needs of the recently developed GFDL Science Plan [2019; see Attached] focused on NOAA/OAR objectives, while cognizant of resource and personnel constraints. Model development will target key areas, including through the Cloud-Climate Initiative and taking advantage of advancements achieved through Climate Process Teams. An improved representation of the stratosphere will be one focus of efforts, the need for which is articulated in the Review comments.
2. We will continue to contribute our model components to the UFS (such as FV3 and MOM6) as well as forecast-oriented innovations.

Group Responsible: GFDL Science Board and Research Council will coordinate.

R6: Incorporate existing observational data to GFDL model improvement

Some of the land modeling effort would benefit from the extensive observations being made elsewhere (like NEON). Efforts to analyze satellite data for evaluation and comparison of model results should be strengthened, particularly as related to clouds, precipitation, and radiation. Direct comparison of the cloud fields between models (like DYAMOND) and satellite observations on weather time scales is possible. GFDL should strategize how to use satellite data and observation networks in new ways for model evaluation and improvement."

R6 Response:

GFDL makes extensive use of a broad range of observations -- from deep ocean hydrography to stratospheric chemistry, including *in situ* and remote sensing data -- for parameterization development, model initialization, and model assessment. Continuous adoption, adaptation and application of new observational data sets is considered a high priority activity for GFDL model development. We have been routinely using gridded satellite data for evaluating modeled top-of-atmosphere and surface radiative fluxes, cloud radiative effects, aerosol optical depth, trace gas column abundance, and surface precipitation. Some new specific planned and potential activities using satellite data for evaluation and comparison of model results include: utilizing new satellite data products, developing/implementing process-oriented diagnostic methods, and automating diagnostic packages. New satellite products contain vertical structure information on cloudiness, water content, and hydrometeors at high spatial and temporal resolution (e.g. CloudSat, CALIPSO). One target area for the systematic and quantitative evaluations of clouds, precipitation and radiation properties using satellite observations includes the FV3-based global cloud-system-resolving simulations (e.g., DYAMOND).

There are numerous examples of GFDL land models (e.g., LM3 and LM4) making extensive use of global, regional, and site-level hydrological, ecological and biogeochemical observations, including remotely sensed data. GFDL is a member of the two land Climate Process Teams (CPTs) on land-atmosphere interactions. To understand how observations from the NSF National Ecological Observatory Network (NEON) could benefit GFDL land R&D, communication between GFDL land scientists and NEON will need to be established. This may require additional resources at both institutions as many NEON land observations are short-term, discontinuous, and at a different scale than a typical climate model.

Concerning strategies for using satellite and other observation networks in new ways for model evaluation and improvement, GFDL has many ongoing relevant projects destined for further expansion. Examples include: the Cloud-Climate Initiative; empirical statistical downscaling; earth system data assimilation/initialization; sea ice concentration and thickness assimilation; Biogeochemical Argo data assimilation; Climate Process Teams (CPTs); process-oriented diagnostic packages (contributing to CPO); atmospheric composition data (gases and aerosols); and Atlantic PIRATA array for ocean model evaluation. GFDL routinely produces a monthly ocean data assimilation product that incorporates *in situ* and satellite ocean data for use as initial conditions for seasonal-to-decadal predictions and verifications (e.g., contributions to NOAA coupled model development, hurricane predictions, National MultiModel Ensemble, Arctic summertime sea-ice predictions, and decadal predictions). Newer approaches to all of these projects will involve prioritization which in turn will depend on directions of new resources. A strategic question is whether GFDL should have a more organized effort to upgrade/develop/expand model evaluation tools and relevant datasets for broader long-term use across the lab.

R6 Action Plan:

Actions: The following lists key steps to address this recommendation. While many of these will go forward with existing resources, the scope of these efforts will depend on new resources becoming available.

1. Incorporate new satellite data on vertical structure of water content in the atmosphere (including clouds and other hydrometeors) at high spatial and temporal resolution (e.g. CloudSat, CALIPSO).
2. Use existing diagnostic packages and develop new methods for process-oriented evaluations of clouds, precipitation, and radiation so that new data can be used to inform model parameterization development.
3. Provide infrastructure, and possibly augmented resources, to automate process-oriented diagnostic packages. This is key for the data to be routinely used to inform model development.
4. Provide systematic and quantitative evaluations of the clouds, precipitation and radiation simulated by the FV3-based global cloud-system-resolving simulations (e.g., DYAMOND) using satellite observations.
5. Establish communications between GFDL land scientists and NEON scientists to explore how observations from NEON could benefit GFDL land R&D.
   Timeframe: FY21.

6. Decide whether GFDL should have a more organized effort to upgrade/develop/expand model evaluation tools and datasets for broader long-term use. **Timeframe:** FY21.

Group Responsible: GFDL Science Board and Research Council.

R7: High Performance Computing (HPC) challenges and opportunities

HPC crosscuts all three themes. The Panel anticipates that the Lab will face several challenges on the HPC front. In particular, GFDL will need sustained HPC resources to address issues such as code conversions, alternate architectures, machine learning and production runs for the climate assessment efforts on IPCC, WMO, and NCA. GFDL scientists have taken a leadership role in past assessments. The Panel believes GFDL will make significant contributions to the assessments that are useful to the agency as well as the nation.

GFDL is the go-to lab in NOAA for modeling needs and to maintain its top-notch stature. The Panel urges NOAA OAR leadership to provide adequate HPC resources. Some of the above recommendations hinge on NOAA resource and accommodations. To this end, the Panel makes the following recommendations to NOAA and OAR leaderships. The Panel strongly recommends that NOAA consider making additional investments in computational resources, software engineering, and building infrastructure to help GFDL address the goals set out in its strategic plan. Additional capacity for GFDL model output archival and analysis and for computation with GFDL models outside the NOAA HPC firewall would greatly facilitate GFDL collaborations with researchers not just at Princeton and CIMES, but elsewhere around the country as well. NOAA leadership could work with CIMES and Princeton University to explore creative and viable options for facilitating this investment.

R7 Response:

GFDL accepts and agrees with the statements and recommendations made by the panel on HPC matters. To address the needs and challenges stated by the reviewers for all the activities referenced requires the financial support of OAR and NOAA. While there has been continued (and appreciated) growth in the available HPC at GFDL it is still far below the projected and required curve. Private and academic institutions suggest that a healthy ratio of research and development to operational HPC resources is somewhere in the range of 7:1 to 9:1 (as often stated by NOAA Acting Administrator Dr. Neil Jacobs). OAR R&D HPC is currently significantly less than that of NWS operations. Being the leader of HPC-centered research in OAR on weather and climate modeling, GFDL is well poised to lead the communication of HPC needs and gaps as well as providing guiding technology and acquisition pathways.

R7 Action Plan:

Actions: GFDL will facilitate the acquisition of the above mentioned HPC, optimize current resources and look for internal and external HPC opportunities. Much of what is listed below has already begun.

1. GFDL will quantify current and projected HPC levels and identify gaps, shortcoming or imbalances. Impacts of these on missions and strategic plans will be communicated regularly to OAR leadership.
2. GFDL will continue to optimize utilization of current HPC assets via
    - Code optimization,
    - workflow analysis and improvement,
    - resource management (allocations, quotas),
    - and exploration of new and novel platforms, architectures and technologies. Planning, execution and information gained will be done with consideration and involvement of other OAR entities (e.g. EPIC).
    - creation of an new initiative at GFDL to explore the use of machine learning and artificial intelligence in enhancing GFDL's mission
3. GFDL will explore and invest (pending funding availability) in HPC assets outside of the trusted network, to facilitate external collaborations while adhering to DOC security structures on internal NOAA HPC access. Key considerations in where and how are GFDL's expected levels of control, responsiveness and longevity (in terms of assets being available and supported).
4. GFDL will position itself and lend guidance on/to HPC related boards and committees (ex. HPC Board, HPC Allocation committee, Cloud Strategies, EPIC, NOAA AI Committee) and monitor HPC policy and actions taken higher up in the Federal system.

Group Responsible: GFDL Leadership and Research Council will coordinate and have oversight.

Process for Drafting Review Response:

The Review was discussed at an All-Hands meeting, and in separate meetings with the GFDL Science Board (SB) and Research Council (RC). Two co-chairs were solicited from the SB and RC to lead Writing Teams for constructing the Responses to each of the 7 Recommendations. At the All-Hands meeting, early comments on responses to the Review were noted. A spreadsheet was implemented to obtain anonymous comments from the GFDL Community (Feds and non-Feds). At the All-Hands, solicitations were made for persons to join the Writing Teams to compose the Response. The Writing Teams so formed drafted the responses. They are acknowledged here. The Responses were examined collectively by the Science Board, Research Council, Writing Teams, and at an All-Hands Lab review. After those steps, the final editing was undertaken, culminating in the formal Response to OAR.

Writing Teams for the Responses:

R1: Co-leads [Rong Zhang, Charles Stock]; Robert Hallberg, V. Balaji, Sonya Legg, Gabe Vecchi

R2: Co-Leads [Lauren Koellermeier, Jasmin John]; John Dunne, Larry Horowitz, Sarah Kapnick, V. Balaji, Sonya Legg, Aparna Radhakrishnan, Matthew Harrison, Stefan Jonsson, Charles Stock, Thomas Robinson

R3: Co-Leads [John Dunne, Yi Ming]; Lucas Harris, Rong Zhang, Michael Winton

R4: Co-Leads [Sarah Kapnick, Robert Hallberg]; Charles Stock, V. Ramaswamy, Tom Knutson

R5: Co-Leads [Tom Delworth, Elena Shevliakova]; Larry Horowitz, Yi Ming, V. Ramaswamy, Alistair Adcroft, Baoqiang Xiang

R6: Co-Leads [Tom Knutson, Ming Zhao]; Elena Shevliakova, Whit Anderson, David Paynter, Keith Dixon

R7: Co-Leads [Whit Anderson, Lucas Harris]; Jeff Durachta, Tom Delworth, V. Balaji