The Geophysical Fluid Dynamics Laboratory (GFDL)
RESEARCH REVIEW TEAM DATA REQUEST

1.) Please provide a copy of the most resent evaluation of the lab or center in pdf format .

Dave Evans' summary of the 1999 review and letters from each reviewer are provided separately on a CD.

a. Was this review internal or external?

This review was external.

2.) Please provide a brief history, and mission of your laboratory /center.

GFDL was formed in 1955 as the research branch of the U.S. Weather Bureau in Washington, D.C. In 1968, GFDL moved to Princeton, New Jersey, to pursue collaborative research with Princeton University through a memorandum of understanding (MOU). That arrangement continues to this day. GFDL encompasses a variety of disciplines (e.g., meteorology, oceanography, hydrology, chemistry, biogeochemistry) and focuses on topics of practical value (i.e., hurricane forecasts, El Nino prediction, stratosphere ozone depletion, and global warming). GFDL's research goal is to expand the scientific understanding of the physical, chemical, and biological processes that govern the behavior of the Earth System – with special focus on the development and utilization of computer simulations.

The mission of the Geophysical Fluid Dynamics Laboratory (GFDL) is to be a world leader for the production of timely and reliable knowledge and assessments on natural climate variability and anthropogenic changes and in the development of the required earth system models. GFDL works cooperatively in the National Oceanic and Atmospheric Administration (NOAA) to advance its expert assessments of changes in national and global climate through research, improved models, and products.

3.) Please provide a listing of major customers of the laboratory /center, with a one sentence description of what is being done for them.

- NWS – GFDL maintains and updates the GFDL Hurricane Prediction System and provides these updates to NCEP, and maintains and updates the ocean model and data assimilation system NCEP utilizes in their seasonal forecasting system
- DOD – The Navy uses GFDL's Hurricane Prediction System
- NASA – GFDL provides expertise toward establishing community standards for Earth System modeling infrastructures and model diagnostics packages
- IPCC – GFDL provides climate model output using IPCC scenarios
- Atmospheric research community – GFDL provides its latest atmospheric model (AM2) and research results
- Oceanic research community - GFDL provides its latest world ocean model (OM3, using MOM4 code) and research results
- Land processes research community - GFDL provides its latest land model (LM2) and research results
- Sea-Ice processes research community - GFDL provides its latest sea-ice model (Sea Ice

Simulator - SIS) and research results
- Climate Change research community, including those involved in the CCSP and CCTP - GFDL provides its latest coupled climate model (CM2) and research results

In the last three years, GFDL authors have published over 150 peer-reviewed papers in nearly 40 different scientific journals.

4.) Please provide a summary of research being conducted

- **Reducing the uncertainty of climate projections and increasing their scope of applicability (Climate Predictions and Projections Program)**

  A prototype Earth System model (ESM) is currently being implemented at GFDL. Ongoing research has lead to more accurate simulations of the physical climate system using CM2. Additional research is directed at the inclusion of interactive biogeochemistry, carbon and nutrient cycles. The ESM is capable of: simulating natural variability such as El Ninos; global change resulting from anthropogenic changes to radiative forcings by greenhouse gases and short lived species and land use; impacts of volcanic eruptions; impacts of changing nitrogen cycles. Hence it represents the platform for enhanced and new forecast products for ecosystems, air and water quality, and the impacts of land use change. Short to medium term research goals include:
  - Produce model-based scenario runs for the 2007 Intergovernmental Panel on Climate Change's Fourth Assessment Report
  - Assessments of global and regional impacts of latest global warming projections
  - CCSP Synthesis Reports (Temperature Trends; Model Uncertainties)
  - Assess the role of stratospheric changes in trace constituents on the climate system
  - Explore regionality, feedback processes, and changes in extreme events such as hurricanes using high resolution models
  - Experimental seasonal ecosystem and global and national air quality forecasts.

  Long-term research will focus on continuing the reduction of uncertainty and the enhancement of predictability in decadal-centennial climate projections with comprehensive, high-resolution Earth System models with fully interactive atmospheric chemistry and biogeochemical processes that can address both global and regional climate change.

  This research is primarily global in geographic scope, but will begin addressing regional scales in the medium to long term.

- **Assessment of decadal predictability and nowcasting when feasible (Climate Predictions and Projections Program)**

  Consistently the most skillful tool for the NOAA's seasonal temperature forecasts is an empirical estimate of recent decadal trends. The underlying mechanisms for the trends will be explored and this knowledge harvested to advance decadal predictions at the regional

scale. Model runs, using observed anthropogenic and sea surface temperature forcing, will enable trend forecasts the next decade. Short to medium term research goals include:

- Assessment and attribution of recent climate trends based on model simulations
- Development of next generation ocean data assimilation system for assessing oceanic uptake of heat, carbon, sea level rise, and initialization of decadal to centennial climate forecasts with MIT through NOPP ECCO-GODAE project
- Nowcasting climate trends and their use in seasonal predictions
- Assessment of predictability of decadal trends from uncoupled and coupled simulations

Longer-term research goals include using increasingly comprehensive Earth System models to improve trend forecasts and decadal predictability.

The geographic scope of this research is national.

- **Modernizing, improving, and extending operational seasonal forecasts (Climate Predictions and Projections Program)**

  Current seasonal forecasts are based primarily on empirical tools. Existing practices will be improved with an increasing reliance on information from ensembles of coupled atmosphere-ocean-land-surface-sea-ice dynamical forecast systems and advanced post-processing methodologies. GFDL will be contributing its new climate model and advanced diagnostics to this effort. Short to medium term research goals include:

  - Implementation of global coupled forecast system as part of a multi model ensemble at NCEP, including a new Ocean Data Assimilation system developed at GFDL
  - Development with NCEP, NASA(JPL & Goddard), Harvard of next generation ocean data assimilation system for seasonal forecasting through NOPP ECCO-GODAE project
  - Annual reports on seasonal climate variability and its attribution
  - Specification reports on the observing system required to improve seasonal forecasting

  Longer-term research goals include incorporating increasingly comprehensive Earth System models and additional sources of ocean data in the assimilation systems.

  The geographic scope of this research is global and national.

- **Advancing predictions of extreme events such as floods, droughts, and cold waves (Climate Predictions and Projections Program)**

  An important fraction of the seasonal climate anomaly is determined by the occurrence of intraseasonal extremes. Emerging research points to skill in predicting such events, with several weeks lead time in some cases. Upgrades of the existing capability will occur by creation of improved multi-model ensemble forecast systems and calibration procedures.

Integration of such "weather-climate connection" research results into operations will accelerate the implementation of the NOAA-NWS strategic goal to provide a seamless suite of forecast products. Short to medium term research goals include:

- Improve understanding of the relationship between extreme events, such as hurricanes and droughts, and interannual climate variability

Longer-term research goals again include using increasingly comprehensive Earth System models, particularly those with higher resolution than is anticipated to be available in the short to medium term, in the ensembles used to predict extreme events.

The geographical scope of this research is global, regional, and national.

- **Environmental Modeling (Environmental Modeling Program)**

GFDL has implemented its new coupled global ocean-atmosphere-ice model for climate variability and change studies. Short to medium term research with the external community will be directed into two areas: a) improving the model's physical parameterizations; b) implementation of an Earth System model (ESM) which extends the physical model through incorporation of interactive hydrologic, biogeochemical, carbon cycles, as well as, fully interactive atmospheric chemistry modules. The ESM would have the capability to simulate the delivery into the coastal zone of precipitation, various atmospheric constituents, and nutrients which are essential elements for a system capable of coastal ecosystem forecasting. The development of high-resolution ESMs will better represent critical processes such as cloud distribution and feedback, runoff, and chemical transport, as well as more accurately capture the impact of global change on extreme events such as hurricanes and severe weather.

This research would provide the foundation for the long-term goal of a seamless suite of forecast models for seasonal to multi-decadal timescales to enable reliable estimates of the impacts of climate on physical variables, ecosystems, and life resources. As noted in preceding research themes, this will require long term research to produce increasingly more accurate (capable) and comprehensive physical and Earth System models and linking these to regional and local processes which are based on a better understanding of climate variability, trends, physical and biogeochemical processes, and rudimentary abstractions of ecosystems.

More generally, NOAA's future products and services need models that extend from global scales down to regional and local scales, cover timescales from minutes to hours to centuries, and can couple physical models of the ocean, atmosphere, and land to biogeochemical cycles and ecosystems. The development and implementation of a future NOAA Integrated Environmental Modeling System (NIEMS) addresses this need. There is a multi-agency (including NOAA) effort underway to construct a software infrastructure that can help meet this goal: the Earth System Modeling Framework (ESMF). When complete, ESMF will serve as the basis for the NIEMS in the short-term. In the 2-5 year timeframe, the Weather, Research, and Forecasting (WRF) model will be merged into this framework. Long term, NIEMS will provide the infrastructure necessary for coupling and nesting models (e.g.

ecosystem, geo-chemical with ocean circulation models); accelerate advances in environmental prediction by eliminating software barriers to collaborations between organizations and facilitating development of new interdisciplinary collaborations, e.g. biogeochemical and ecosystems with weather and climate; facilitate the development and exchange of scientific codes between weather and climate communities, both inside and outside of NOAA; promote the reuse of standardized technical software while preserving efficiency; and allow specialists to handle computer architecture changes without diverting scientific resources.

The geographic scope of this research is global, regional, national, and local.

5.) Please provide a listing of 3-5 major accomplishments in the last five years.

(a) Release of FMS and participation in national ESMF

FMS is a software framework for supporting the efficient development, construction, execution, and scientific interpretation of atmospheric, oceanic and climate system models. FMS comprises a software infrastructure for constructing and running atmospheric, oceanic and climate system models. This infrastructure includes software to handle parallelization, input and output, time management, data exchange between various model grids, makefiles, and standardized run scripts. This infrastructure largely insulates FMS users from machine-specific details, a key goal for software infrastructures. FMS has been used in the development of ocean models (MOM and HIM), and the new atmospheric and coupled climate models at GFDL. The Galway version of the FMS infrastructure was released to the research community on March 28, 2002, the Havana version on October 21, 2002, and the Inchon version in September, 2003. FMS also serves as a working prototype framework for ESMF. Many of the software infrastructure concepts in FMS that have been successfully demonstrated in the construction of GFDL's new coupled climate model will be carried over into ESMF and eventually the ESMF-based infrastructure for the NOAA Integrated Environmental Modeling System.

(b) Ocean Model Development

Two new model codes of the world ocean have been developed and released by GFDL scientists. The Modular Ocean Model (MOM) is a three-dimensional, z-coordinate, B-grid, primitive equation ocean circulation model. It is designed primarily as a tool for studying the ocean climate system. The Hybrid Isopycnal Model (HIM) is a three-dimensional, isopycnal coordinate, C-grid, primitive equation ocean circulation model. HIM is designed as a tool for studying both the ocean climate system and more idealized ocean circulations. Both models are developed and supported by researchers at GFDL with significant contributions from oceanographers outside of GFDL. MOM4 is publicly released and is currently being used in GFDL's new coupled climate model.

(c) Hurricane Model Development

In May 2003, GFDL delivered a new hurricane model to NCEP to be used in its Hurricane Prediction System. The GFDL nested moveable mesh model is a primitive equation model formulated in latitude, longitude, and sigma coordinates, with 42 vertical sigma levels. It features

improved representations of cumulus and boundary layer processes. Since 1995, the Hurricane Prediction System has provided operational guidance for forecasters at the National Hurricane Center (NHC) in both the Atlantic and East Pacific basins. In addition, a version of the GFDL model has been used by the Navy to provide operational guidance for storms in most of the other ocean basins. The hurricane model has been coupled to a high-resolution version of the Princeton Ocean Model. It is anticipated that sustained model improvements will continue to make the model a valuable tool to the National Hurricane Center.

(d) Ocean Data Assimilation

GFDL has continued its significant activities in Ocean Data Assimilation (ODA). These accomplishments include an extension of a 20-year global reanalysis that will be continually kept up to date as an ongoing project. A software infrastructure has been developed for parallel computing environments. This has allowed for the integration of various methods for ocean state estimation and forecast initialization, including, ensemble methods, 4D-VAR and traditional OI. In particular, each of these methodologies is being developed with identical software for the handling of quality-controlled observational data streams, cost function evaluation, minimization and diagnostics. Current research is focused on the development of OI products for seasonal-to-interannual forecasting, including investigation of 3-dimensional prior variances, bias error modeling (with IRI and the University of Maryland) and reduced state space error models (with IRI). An assessment of the TAO moored observational network is being made in the context of seasonal forecast initialization using traditional OI methods as part of the ODASI partnership.

(e) Coupled Climate Modeling

GFDL has recently completed the configuration of its new atmospheric model and its new coupled climate model. Comprised of GFDL's new atmosphere, land, ice, and the new MOM4-based OM3 ocean model, this coupled model has significantly improved representations of the physical processes that govern the state of the Earth's climate. Its performance is competitive with the leading national and international models as measured by objective skill scores. In addition to several thousand model years of experiments performed in support of the next IPCC assessment, the new coupled model will be used extensively to support the goals of the Climate Change Science Program, which include producing climate projections for research and assessment based on emission scenarios developed through the Climate Change Technology Program (in addition to the IPCC). An analysis of the climate models' sensitivity, feedbacks, and uncertainty will also be undertaken. Moreover, these results can be used to supply the best scientific information on climate change to policymakers, including information on the consequences of different technological options for producing energy.

6.) Please provide a summary of legal mandates for the work in the laboratory/center.

- **U.S. Climate Change Science Program (CCSP) strategic plan**, some of the relevant CCSP focus areas include: Improve and harness the capability to forecast El Nino-La-Nino events and other seasonal to interannual cycles of variability; Increase confidence in the understanding of how and why climate has changes; Improve national capacity to develop and apply climate models; Improve capabilities to develop and apply emissions and related scenarios for conducting "if…, then…" analyses in cooperation with the CCTP.
- **Weather Service Organic Act (15 U.S.C. 313 et seq.)**: "The Secretary shall have charge of forecasting weather and issuing storm warnings for the protection of life and property and the enhancement of the Nation's economy. The Secretary shall monitor and record climatic conditions." NOAA has responsibility to issue operational intraseasonal to interannual climate forecasts and produce climate monitoring and application products.
- **National Climate Program Act (15 U.S.C. 2901 et seq.):** "Requires the establishment of a National Climate Program Office within the Department of Commerce to study Climate Change".
- **Global Change Research Act (15 U.S.C. 2921 et seq.):** "Establishes a comprehensive and integrated U.S. research program aimed at understanding climate variability and its predictability". NOAA is a major contributing member agency through NOAA Climate and Global Change (C&GC) program.
- **High-Performance Computing Act of 1991 (15 U.S.C. 5501-5528):** "the National Oceanic and Atmospheric Administration shall conduct basic and applied research in weather prediction and ocean sciences, particularly in *development of new forecast models,* in computational fluid dynamics, and in the *incorporation of evolving computer architectures and networks* into the systems that carry out agency missions"
- **FY 2004 House CJS appropriations subcommittee report on funding for IRI**: "The committee expects funding for the International Research Institute Climate Prediction program to be continued at no less than the current year level."
- **NOAA PRT#38**: "… NOAA commit to spending 50 percent of new research funds … within the external community … via competitive proposals and peer review. "
- **Department of Commerce Order 2-B (July 29, 1968):** "… the Geophysical Fluid Dynamics Laboratory is to conduct investigations of the dynamics and physics of geophysical fluid systems to develop a theoretical basis by mathematical modeling and computer simulation, for the behavior and propertied of the atmosphere and oceans."

7.) Attached in Excel format is the compilation of financial and staffing data that your laboratory or line office provided. Please verify that data are correct.

We have attached a spreadsheet with updates.

In your response please identify a contact person and a telephone number, in case clarifying information is needed.

Contact: Brian D. Gross (Brian.Gross@noaa.gov; 609-452-6504), GFDL Deputy Director