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Research & Development High Performance Computing System
Annual Operational Analysis - Calendar 2006

This annual operational analysis report is a status review of the Research & Development (R&D) High Performance Computing System (HPCS) program in terms of financial performance, customer results and performance measures. It details financial and technical performance against established baselines/requirements and evaluates customer results. The program continues to meet established cost, schedule and performance parameters and directly facilitates NOAA's strategic goals to "Serve Society's Needs for Weather and Water Information" and "Understand climate variability and change to enhance society's ability to plan and respond".

In 2006 the R&D HPCS operated as three distinct computational systems managed by the Office of Ocean and Atmospheric Research (OAR) and the National Weather Service (NWS). Starting in FY2007 these three systems have been consolidated into a single NOAA HPCS and are now being managed in an integrated manner. The program management support for this project is provided by the NOAA Office of the Chief Information Officer. For the purpose of this report the 2006 operational analysis for the three legacy systems have been integrated into this single report.

I. Customer Results

In 2006 the Weather and Climate Operational Supercomputing System (WCOSS), operated by the NWS, consisted of both the operational and R&D computational resources integrated into a single system. Some of the results reported here have also been reported in the operational analysis for the WCOSS. The WCOSS program is fully meeting the customer's needs and the program is delivering the services intended. During 2006 the WCOSS program directly contributed to the NOAA/NWS mission and was critical in supporting the issuance of weather watches and warnings that protect both life and property. The value of this program in terms of lives saved and property protected as well as service to the Public mandates a continued need for this investment.

Significant Accomplishments

During 2006 significant improvements were made to the following models that run only on WCOSS assets;

- ✓ Global Forecast System (improved science, improved data assimilation, improved database)
- ✓ North American Mesoscale (improved science, improved database)
- ✓ Real-Time Mesoscale Analysis (improved resolution)
- ✓ Short-Range Ensemble Forecast (improved science, improved timeliness)
- ✓ North American Ensemble Forecast System (improved science, improved database)
- ✓ Air Quality Forecast (expanded domain to CONUS)

- ✓ Rapid Update Cycle (improved resolution)
- ✓ Marine Wave Model (improved science, expanded domain to include Great Lakes)

The Geophysical Fluid Dynamics Laboratory (GFDL) High Performance Computing System (HPCS), operated by OAR, provides the computational capability and modeling/infrastructure support that is central to the mission of GFDL, which is focused on attacking long-lead-time problems associated with the physical processes that govern the behavior of the atmosphere and the ocean by means of mathematical models and complex computer simulations.

In addition to sustained contributions to the scientific literature, GFDL has transferred major technological innovations to a host of organizations collaborating on extremely difficult problems of critical importance to NOAA and the nation. The customers for GFDL computational research products (via an average of 70-80 research publications in peer-reviewed journals each year, extensive participation in climate assessments, scientific programs, and workshops, and extensive research activities involving climate/weather modeling research and computing resources) include: a broad portion of the academic climate and weather research community; close scientific collaborations with Princeton University, Columbia University, and others; the national and international assessment community; and users of climate/weather research findings within government and industry. An increasingly critical customer for the products of GFDL research is the community of policy makers considering the implications of, and possible ways to address, climate change.

The customers for GFDL models and modeling products (advanced hurricane forecast models, world and coastal ocean models, climate models, and the newly developed modeling infrastructure known as the Flexible Modeling System) include: weather forecast centers, including NOAA's National Centers for Environmental Prediction, the US Navy's Fleet Numerical Prediction Center, and others; the climate modeling community, including groups within government at NSF, NASA, DOE, and Department of Interior and within the academic community; climate and ocean modelers, both academic and in private industry; and public and private organizations requiring coastal ocean models. Release of codes improves quality through bug elimination, third-party critical evaluation, and collaborative development, all valuable contributions to NOAA's mission.

Significant accomplishments for 2006 on behalf of our customers include:

- The impact of land use change on climate has been evaluated in a new study with the GFDL climate model. It was shown that the conversion of native forests to agricultural crops and pastures has little impact on global mean quantities, but has significant local impacts, particularly in Eastern Europe and northern India. This study provides a crucial evaluation of the impact of land use change on past and present climate. (*Modeled Impact of Anthropogenic Land Cover Change on Climate" by Kirsten L. Findell, Elena Shevliakova, P.C.D. Milly and Ronald J. Stouffer. Accepted for publication in Journal of Climate on November 3, 2006.)*

- A prerequisite for making seasonal/interannual/decadal predictions starting from the observed ocean state is to have a suitable coupled model, network of oceanic observations, and an assimilation system capable of combining them for initializing models. One of the challenges for decadal prediction is that the variability (and hence prediction) may involve the deep ocean (perhaps several thousand meters), and both temperature and salinity. We have conducted preliminary experiments to evaluate what observational networks and assimilation systems are required to initialize prediction models for the meridional overturning circulation (MOC). (*Detection of Multi-Decadal Oceanic Variability within a Coupled Ensemble Data Assimilation System , S. Zhang, A. Rosati, M.J. Harrison - submitted to JGR oceans*).
- Simulations of the GFDL climate model with coupled stratospheric chemistry have been completed for the recent past (1960) to the end of the 21st century. The results showed a depletion of ozone from the late 1970s in accordance with observations and a subsequent recovery from about the current decade. Climate change was found to speed up ozone recovery in the Arctic by up to 25 years, but in the Antarctic full recovery of ozone does not occur until 2065, about 15 years later than previous indications. The GFDL simulations provided major contributions to the quadrennial report on ozone to the World Meteorological Organization to be published early in 2007 (*WMO/UNEP Scientific Assessment Of Ozone Depletion: 2006*)
- A regional high resolution atmospheric climate model has demonstrated very significant skill in simulating the statistics of the Atlantic hurricane season when relaxed to the large-scale observed atmospheric flow for that season. This success creates the opportunity to explore the dynamics of both interannual variability in Atlantic storm statistics and of the trends over the past decades. (*Knutson, T. et al, 2007: Simulation of the recent multi-decadal increase of Atlantic hurricane activity using an 18km grid regional model, BAMS, submitted*)
- A new integrated look at the global ocean carbon cycle has been completed. It starts with satellite-based surface chlorophyll and uses a suite of algorithms to follow the cycling of organic carbon from production through sinking out of the surface, through the water column and accumulation in sediments as it is coupled to the cycles of silicon, calcium carbonate and lithogenic material. We provide a demonstration of the importance of near-shore and shelf regions in the global context as well as the importance of mineral material, particularly river-derived lithogenic material on the preservation of carbon during transport to the sea floor. (*Dunne, J. P., A. Gnanadesikan, and J. L. Sarmiento (submitted) A synthesis of global particle export from the surface ocean, through the ocean interior, and on the sea floor. Global Biogeochem. Cycles*.)
- One reason that the atmosphere does not contain more carbon dioxide than at present is that phytoplankton take up carbon in the surface and sink into the deep sequestering carbon there. We recently showed (*Marinov et al., Nature, 2006; Marinov et al, submitted*.) that this process is largely controlled by the balance between vertical exchange and biological cycling in the Southern Ocean, and that this balance is strongly regionally dependent. The results have important implications for explaining why atmospheric carbon dioxide was lower during the

Last Glacial Maximum as well as casting doubt on plans to sequester carbon through ocean fertilization.

- Atmospheric deposition of mineral dust supplies much of the essential nutrient iron to the ocean. Our simulation produces a significant increase in soluble Fe deposition, particularly in remote ocean regions and may require more rapid biological and physicochemical scavenging of Fe than used in current ocean models. We further suggest that increasing SO2 emission alone could have caused significant "Fe fertilization" in the modern northern hemisphere oceans. (*Fan, S-M., W. J. Moxim, and H. Levy II, 2006: Aeolian input of bioavailable iron to the ocean. Geophysical Research Letters, 33, L07602, doi:10.1029/2005GL024852*.)

Significant accomplishments for 2006 on behalf of the customers utilizing the R&D HPCS operated by OAR's Earth System Research Laboratory Global Systems Division (GSD), located in Boulder, include:

- Development and implementation of a semi-operational data assimilation system to track global carbon emissions
- Extensive testing of the latest revisions of the Weather Research Framework (WRF) in support of the wider research community.
- The HPCS was used to help identify optimal parameters for a new microwave surface emission model that will be incorporated into the Joint Center for Satellite Data Assimilation Community Radiative Transfer Model.
- The HPCS has been used to perform calculations in support of the simulation of a geostationary microwave sounder/imager. This instrument is a pre-planned product improvement to the GOES-R series of spacecraft, and the work on the HPCS has been critical to assessing performance improvements expected from geostationary microwave sensors as well as developing the radiance assimilation techniques necessary to fully use the data when on-orbit.
- The NCCOS/CCMA/COAST team processed the entire CONUS seawifs 1km data set (approx. 17000 images) from L1 to a mapped product in support of the National Marine Sanctuaries management goals.
- Development of a configuration of an unprecedented high resolution ensemble for the Hydrometeorological Test Bed.
- Developed post processed data to develop calibrated and debiased probabilities for important precipitation thresholds.
- Support of 13km Rapid Update Cycle (RUC), sub-hourly RUC, and 13km RUC backup.
- Development of the chemistry component of WRF (WRF-CHEM).
- Extensive WRF/Rapid Refresh (RR) core testing for Rapid Refresh to planned to replace the RUC by 2009. Completed in Sept 2006, report written for NCEP. All testing completed for 4 one-month periods on the HPCS, each with 4 different versions of the WRF model. Extensive changes to WRF model repository made made on this testing conducted on Jet.
- Observation impact studies for TAMDAR and other aircraft data (20km dev and 20km dev2 cycles). Conference proceeding papers written, used as guidance for ongoing and planned NOAA and FAA observation acquisition activities.

II. Strategic and Business Results

The R&D HPCS supported these NOAA strategic goals:

- Weather and Water – Serves society's needs for weather and water information
- Climate – Understand climate variability and change to enhance society's ability to plan and respond

The WCOSS accomplishments in support of these goals are listed in section I.

Gaps in our understanding of climatic variations, particularly intra-seasonal and inter-annual trends, hinder efforts to address important societal issues including drought, human health, agriculture, sustainable living marine resources, and urban and coastal impacts from climate change. NOAA's Climate program supports the U.S. Climate Change Science Program, which integrates all federal research on global climate change, and other sources of national and international attention to climate change continue to elevate the need for improved climate predictions and more robust climate data and information tools.

GFDL's research emphasis has been in attacking these difficult, long-lead-time problems in order to expand scientific understanding and improve prediction of the physical processes that govern the behavior of the atmosphere and the ocean by means of mathematical models and complex computer simulations. Ongoing research will continue to refine our understanding of what is considered to be one of the "Grand Challenge" problems. Progress on reducing the uncertainties surrounding the complex physical processes underlying climate change will help to guide future decisions about what steps to take to mitigate potential consequences. A primary objective of the investment in NOAA/GFDL HPCS is to provide NOAA's 'Climate' and 'Weather and Water' programs with effective state-of-the-art computing capabilities through the ongoing maintenance to ensure a balanced system.

Research accomplishments for 2006 toward NOAA's strategic goals include:

- A regional atmospheric model has been used to study variations in Atlantic hurricane activity over the last several decades. When forced with observed SSTs and large-scale atmospheric conditions, the model is able to simulate the observed year to year and longer scale trends in hurricane activity. This study lays crucial groundwork to assess the factors responsible for changing hurricane activity in the Atlantic, eventually leading to enhanced credibility in projections of future hurricane changes. (*Knutson et al., submitted to BAMS*.)
- A new study clearly delineated the differing roles of increasing greenhouse gases and aerosols on Atlantic ocean circulation in the 20th century. While increasing greenhouse gases, in isolation, lead to a significant 20th century decrease in the Atlantic thermohaline circulation

(THC), increasing aerosols have largely counteracted that influence, leading to no net overall THC trend in the 20th century. As the impact of aerosols diminishes in the future, this study suggests a rapid rate of THC weakening. (*Delworth and Dixon, 2006, Geophysical Research Letters, Vol 33, L02606, doi:10.1029/2005GL024980*.)

- The causes for the wide range of modeled thermohaline circulation (THC) responses to freshwater perturbations in the N Atlantic Ocean have been investigated. In the past, large freshwater perturbation occurred when the ice sheets melted as the planet warmed after the past ice age. In the future, models show that the freshwater flux in high latitudes increases as the planet warms due to increases in the atmospheric transport. This understanding helps in the interpretation of past climate changes and reduces the uncertainty associated with the THC response in future projections. (*Stouffer et al., 2006, Investigating the causes of the response of the thermohaline circulation to past and future climate changes. Journal of Climate/, 19(8), 1365-1387*)
- An extensive suite of GCM experiments have been conducted to delineate the separate and combined atmospheric responses to the long-term SST warming trend in the Indian Ocean-Western Pacific (IWP) and the El Nino-related interannual SST variations in the eastern equatorial Pacific. Attention has been focused on the influences of these boundary forcings on the winter climate of North America. These model diagnoses indicate that, for both the 1951-2000 and 2001-2050 epochs, the SST conditions in IWP tend to amplify the atmospheric anomalies occurring in La Nina events, and attenuate the corresponding signals in El Nino events.
- The impact of increasing greenhouse gases on the tropical atmospheric and oceanic circulation has been assessed using a coordinated set of 21st century climate model experiments performed for the IPCC AR4. All models project a weakening of the atmospheric overturning circulation as the climate warms. This weakening occurs preferentially in the zonally asymmetric (Walker-type) rather than the zonal mean (Hadley-type) component of the circulation, and induces significant changes in the thermal structure and circulation of the tropical oceans. (*Vecchi, G., and B. J. Soden, 2007: Global warming and the weakening of the tropical circulation, J. Climate, submitted*).

The table below describes the contributions made to the Weather and Water goal by the R&D HPCS located in Boulder:

2006	Mission and Business Results	Information and Technology Management	>98% of legacy systems available at the end of FY06.	100% availability of legacy system for 6 months prior to delivery of replacement system (with funding)	Graceful degradation of legacy system though component cannibalization, maintaining minimum of 80% availability for entire year, due to lack of funding
2006	Mission and Business Results	Environmental Management	Testing accomplished as required (see section I above)	Simultaneous execution of a single WRF core and a single WRF-RUC	Simultaneous execution of two WRF cores and one WRF-RUC

2006	Mission and Business Results	Information and Technology Management	2.5 year data storage policy implemented. Media reuse of 250 tapes thus far.	Retain all data saved to the HSMS	Implement a data storage policy to age off data after 2.5 years in order to contain data storage costs due to lack of funding	
2006	Mission and Business Results	Environmental Management	>99% availability.	Support NCEP as secondary backup for the operational RUC in high-availability mode at 99% availability	Support NCEP as secondary backup for the operational RUC with best effort, targeting minimum 95% availability, due to lack of funding	

The R&D HPCS represents a cross Line Office effort within NOAA. There are no other organizations within NOAA that have the ability, computational resources and expertise to perform this type of work.

III. Financial Performance

The WCOSS financial performance for 2006 shows no variance, lease costs followed the contractual baseline exactly. The WCOSS lease packages hardware, software, maintenance, support (including on-site personnel, training and travel) costs under a single invoice.

Performance for the months January through September was tracked against the base period of performance as defined in the contract.

The GFDL HPCS project FY06 spending deviated from the original plan by $613K due to a $500K funding cut to the High Performance Computing and Communications (HPCC) budget and additional cuts to the CCRI program. The HPCS support contract was cut by this amount, taken from reserve funds and application engineering services. These budget cuts resulted in:

- A delay, until at least Q3 FY 2007, in the delivery of demand-driven scenarios as required under the President's Climate Change Science Program (CCSP).
- A delay of at least six months the integration of the carbon cycle into Earth System models for connecting climate (and weather), land use, air and water quality, coastal pollution, and ecosystems.
- A delay of at least three months in the completion of the CCSP Synthesis and Assessment report updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the Climate Change Technology Program.

The GSD HPCS project FY06 spending deviated from the original plan by $3M due to a funding cut to the HPCC budget. This budget cut resulted in a delay in making the R&D HPCS contract award. This budget reduction also resulted in a minimal maintenance option for the two legacy systems located in Boulder. As a result, a number of nodes of the oldest legacy system were lost during the year due to failures of equipment not under maintenance. Fortunately, the loss of nodes was less than anticipated.

IV. Innovation

A. Performance

1. Customer Results

FY	Measurement Area	Measurement Category	Indicator	Baseline	Planned Improvement to the baseline
2007	Customer Results	Timeliness and Responsiveness	Response Time	Escalation Levels : Level 0 = 1 business hour; Level 1 = 3 business hours; Level 2-3 = priority/issue dependant	These response times are specified in the HPC R&D contract. During first year of the contract the timeliness and effectiveness of escalation process will be monitored and adjustments made as necessary.

2. Strategic and Business Results

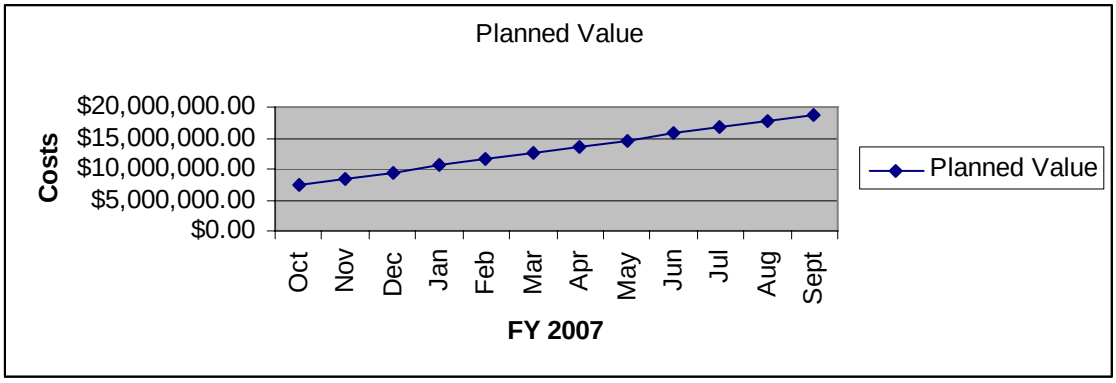
FY	Measurement Area	Measurement Category	Indicator	Baseline	Planned Improvement to the baseline
2007	Mission and Business Results	Environmental Management	Concurrent execution of atmospheric models on the NOAA R&D HPCS	Atmospheric models run on the NOAA operational HPCS	Atmospheric models (NMM, WRF-EM, GFS) to run concurrently on the NOAA R&D HPCS
2007	Mission and Business Results	Environmental Management	Implement at least one new or updated component into the Earth System Model	Uncertainty in climate model projections remains higher than desirable	Decrease uncertainty in climate system processes and long-term climate projections measured through improvements in Earth System models
2007	Mission and Business Results	Environmental Management	Decadal predictive skill in North America surface temperature	Quantification of climate model validation is insufficient	Measure predictive skill to validate the reduction of uncertainty in climate models
2007	Mission and Business Results	Environmental Management	Perform enhanced climate scenarios designed to address specific decision issues regarding climate change	Perform climate model scenarios with current physics-only climate models, as resources permit.	Simulate 7800 equivalent model years to clarify natural systems uptake of carbon and to provide climate information for assessment report

2007	Mission and Business Results	Environmental Management	Provide focused assessment reports based on climate scenarios	Contribute research findings to National and International climate assessments	Publish assessment report on a key climate impacts topic, incorporating climate scenario results
2007	Mission and Business Results	Environmental Management	20 km resolution RUC Hybcst code performance	Existing performance	2x increase
2007	Mission and Business Results	Environmental Management	Reduced Atlantic Hurricane Forecast 48 Hour Track Errors (model capability)	142 Nautical Miles	128 Nautical Miles
2007	Mission and Business Results	Environmental Management	Improved 3 Day Precipitation Forecasts (%Accuracy, model capability)	17% (forecast precipitation accuracy)	32% (forecast precipitation accuracy)
2007	Processes and Activities	Management and Innovation	Implementation of Integrated Management	Initial Integrated Management processes in place	Refined and more complete processes to be defined and implemented during FY07.
2007	Processes and Activities	Productivity and Efficiency	Benchmark suites	63,073 benchmark suites	146,066 accumulated benchmark suites
2007	Technology	Effectiveness	Weather and climate applications benchmark performance	Performance on existing GFDL and NCEP R&D systems	Successful acceptance of replacement systems for GFDL and NCEP that meet contracted availability and enhanced Benchmark Performance requirements
2007	Technology	Information and Data	Terabytes (TB) of storage	127 TB	Upgrade in FY07 to 830 TB of disk space
2007	Technology	Reliability and Availability	% available	96%	Vendor will deliver additional equipment to make up for any loss of availability below 96% or the Government will reduce its monthly lease payment by the % of time that the system was unavailable.

3. Financial Performance

R&D HPCS funding is managed in a more integrated manner involving the Environmental Modeling Program (EMP) Steering Group and NOAA HPC Board allowing for an increased optimization in both the acquisition and utilization of HPC computational resources to meet EMP requirements.

As with the rest of NOAA the Continuing Resolution (CR) situation has presented major difficulties in the implementation of the new R&D HPCS contract. The contract was severely under funded through the first quarter of FY07. The CR coupled with a 50% reduction in FY06 funding to the HPCC program has severely impacted our ability to meet contractual obligations. Second quarter funding has just been provided which will fund the contract until the end of February 2007. It is anticipated that the remainder of the funding required will be provided.



B. Alternatives:

1. For meeting Customer Needs:

Technical alternatives to improve the ease of use of NOAA's R&D HPCS resources include:

- Provide common software tools
- Improve the network connectivity between HPCS sites and for remote users
- Adopt a single R&D HPCS system authentication
- Implement a common scheduling system
- Increase the use of modeling frameworks (ESMF, WRF).

2. For meeting Strategic Goals

A major goal of the R&D HPCS is to obtain increased computational capacity for NOAA without the benefit of increased funding. Alternative approaches for accomplishing this goal include:

- Consolidation of all of NOAA's R&D HPC requirements
- Consolidation of the number of R&D HPC acquisitions from three to one
- Adoption of a lower availability rate for R&D systems (97%) then what is required for operational systems (99%), allows NOAA to purchase more R&D capacity for the same amount of dollars.
- Coordinate the mid-life upgrade for all of NOAA's R&D computational resources to take advantage of Moore's law
- Work more closely with EMP to better optimize the use of R&D HPCS resources and work to provide access to these resources to non-traditional users within NOAA.
- Seek advice from the NOAA Science Advisory Board in identifying other alternatives to close the existing gap that exists between the number of requirements and the available computational capacity that NOAA has available.
- Develop partnerships with other Federal agencies to obtain time on their systems for NOAA applications (i.e. NASA and DOE).
- Implement an integrated management approach for managing R&D HPCS resources.