RESPONSES TO RECOMMENDATIONS FROM THE CLIMATE WORKING GROUP RELATED TO THE CRM PROGRAM REVIEW

AS OF OCTOBER 2010

Climate Research and Modeling Program Review
March 24-26, 2008
Hyatt Regency
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The CRM program would like to note that a response to the CRM program review was presented by Program Manager Ramaswamy during the Climate Working Group Fall 2008 meeting. There have been many significant developments since the Fall 2008 Climate Working Group meeting and these are included in this updated version of the review response.

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Executive Summary

Recommendation: CRM must develop a comprehensive and in-depth Strategic Plan that defines its vision, mission, goals, and objectives, and lays out clearly the roles and required interactions of the numerous laboratories, centers, institutes and grant programs engaged in CRM-related activities.

Response: NOAA's climate research and modeling, a core capability, will be responsive to the details of the NCS implementation strategy and NOAA's Next Generation Strategic Plan and will articulate the: Vision, Mission, Goals; Roles of Labs, Centers, Institutes; Roles of Grant Programs; Intramural and Extramural Interactions.

Panel 1: Understanding Climate Processes

Panel 1a: Climate Processes and Atmospheric Modeling

Recommendation: As stratospheric ozone continues to recover, related research should evolve away from the ozone hole per se. However, understanding changes in stratospheric water vapor continues to be important, and understanding how changes in stratospheric ozone relate to climate changes continues to be important.

Response: As a result of Montreal Protocol regulations, the net ozone-depleting capacity of atmospheric chlorine and bromine compounds is declining slowly; however, ozone depletion remains severe. Continued monitoring of ozone and ozone-depleting substances is essential for verification of ozone layer recovery as expected by about 2050, which hinges on the complete elimination of atmospheric ozone-depleting substances. Replacements for HCFCs, methyl bromide, and halons are still being sought, and studies of the new compounds must continue. ESRL's Chemical Sciences Division (CSD) and the Joint Institute CIRES, conduct chemistry investigations and modeling relevant to ozone depletion, test new ozone-depleting gas replacements, develop instruments and conduct process studies using aircraft instrumentation. CSD scientists also interpret global ozone measurements and their links to dynamical and radiative changes. GFDL researchers develop computer models of the atmosphere to address the physics, chemistry and transport of atmospheric trace gases and aerosols. These models are applied to many topics of great practical value, including stratospheric ozone depletion. CRM provides the Co-Chair for the Scientific Assessment Panel of the Montreal Protocol and CRM scientists were engaged in leading, authoring, reviewing, and communicating the current state of scientific understanding of ozone depletion (2010 report). While it may be premature to move away from research on the ozone hole per se, CRM scientists are actively engaged in water vapor research including developing, evaluating and deploying instrumentation for making highly accurate and precise measurements of water vapor within the upper troposphere and lower stratosphere. NOAA's water vapor research received a modest increase in funding in FY10 but remains under-resourced. NOAA scientists have also been active in research into the relationship between the changes in stratospheric ozone and changes in climate. See, for example: Fogt, R. L., J. Perlwitz, S. Pawson, and M. A. Olsen (2009), Intra-annual relationships between polar ozone and the SAM, Geophys. Res. Lett., 36, L04707, doi:10.1029/2008GL036627; : Perlwitz , J., S. Pawson, R. L. Fogt, J. E. Nielsen, and W. D. Neff (2008), Impact of stratospheric ozone hole recovery on Antarctic climate, Geophys. Res. Lett., 35, L08714, doi:10.1029/2008GL033317; and Lamarque, Jean-François, Susan Solomon, 2010: Impact of changes in climate and halocarbons on recent lower stratosphere ozone and temperature trends. J. Climate, 23, 2599-2611.

Recommendation: The relationship between observations and improvement of global models would benefit from a higher level of coordination as well as visibility within the program.

Response: Examples of existing programs that coordinate measurements and modeling include Carbon Tracker, which combines the maintenance of carbon observatories and carbon data assimilation into transport models; efforts at GFDL to assimilate ocean data from the ARGO float network into coupled climate models; partnerships among GFDL, ESRL and NCEP (CPC and EMC) on data assimilation, analysis and reanalysis spanning timescales from seasonal to interannual to decadal; contributions to the GEWEX/CEOP (Coordinated Energy and Water Cycle Observations Project) program by ARL; and extensive participation by NCEP/CPC, ESRL/CSD and ESRL/PSD in field campaigns including the North American Monsoon Experiment, the Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS), and the African Monsoon Multidisciplinary Analysis. Developments include the selection of a visiting scientist at GFDL to utilize DOE's Atmospheric System Research (formerly Atmospheric Radiation Measurement) program observations in the context of model development. Most of these activities are highly visible within the CRM program.

Recommendation: Emphasis on understanding basic processes should be balanced with improving the models.

Response: Model development in NOAA is inseparable from fundamental process understanding. While for planning purposes, CRM is divided into four core capabilities, Understanding and Modeling, Predictions and Projections, Integrated Service Development & Decision Support and Climate Analysis and Attribution, the execution of research in CRM almost always draws on more than one capability. As models evolve in resolution and complexity, it is possible to directly represent a larger number of basic processes. For example, GFDL's CM3 climate model includes interactive atmospheric chemistry, and GFDL's newly developed Earth System Models close the carbon cycle. These models will be contributing to IPCC AR5.

Recommendation: Advancing understanding should emphasize decreasing uncertainty in aerosol/cloud interactions and how to treat these processes within the global models, though improvement of the other processes needs to continue to be developed.

Response: IPCC AR4 identified aerosols as the leading source of uncertainty in climate forcing. Consequently, progress to reduce uncertainties for this difficult problem will require major scientific efforts. A major research activity aimed at improving the representation of aerosols and aerosol/cloud interactions in the GFDL global climate model has been undertaken with the development of CM3. A Climate Process Team, funded jointly by NOAA and NSF and including GFDL, ESRL, NCAR, JPL, and the Universities of Wisconsin and Washington, will investigate new approaches to modeling cloud-aerosol interactions in climate models. Comparisons of the model simulations to observations show that these model improvements are producing more realistic aerosol/cloud interactions, but that there are areas requiring further work. Our observational and process understanding research in aerosols and their roles in climate, as well as a very limited venture to ensure the accuracy of upper troposphere/lower stratosphere water vapor measurements are continuing. An attempt to launch a coordinated research effort on aerosols, clouds, cloud feedbacks and water vapor, which included field, laboratory and modeling studies and involved ESRL, GFDL, ARL, CPC and extramural grants programs, was not funded in the FY12 NOAA budget process. CRM recognizes the importance of these topics to fundamental climate understanding and predictability, and will endeavor to make progress using existing resources, albeit at a greatly reduced pace.

Recommendation: Management should emphasize better coordination between measurements and modeling and between small scale process modeling and large scale prediction. This will be crucial to improve parameterizations in large scale models.

Response: [*A portion here reiterates an earlier response – see page 2*]. Examples of existing programs that coordinate measurements and modeling include Carbon Tracker, which combines the maintenance of carbon observatories and carbon data assimilation into transport models; efforts at GFDL to assimilate ocean data from the ARGO float network into coupled climate models; partnerships among GFDL, ESRL and NCEP (CPC and EMC) on data assimilation, analysis and reanalysis spanning timescales from seasonal to interannual to decadal; contributions to the GEWEX/CEOP (Coordinated Energy and Water Cycle Observations Project) program by ARL; and extensive participation by NCEP/CPC, ESRL/CSD and ESRL/PSD in field campaigns including the North American Monsoon Experiment, the Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study

(VOCALS), and the African Monsoon Multidisciplinary Analysis. New developments include the selection of two visiting scientists at GFDL, one to utilize DOE's Atmospheric System Research (formerly Atmospheric Radiation Measurement) program observations in the context of model development and one to address large-eddy simulation-based stratiform cloud parameterization. ESRL/CSD has recently hired a GFDL alumnus to facilitate the LES cloud parameterization. Climate Process Teams (CPTs) selected and supported by CPO are aimed to speed development of global coupled climate models by bringing together theoreticians, field observationalists, process modelers, and the large modeling centers. CRM scientists are participating in four new CPTs: on cloud macrophysical parameterization and its application to aerosol indirect effects (lead by University of Wisconsin-Milwaukee, with Principal Investigators at GFDL, ESRL, NCAR, NASA JPL and the University of Washington); on development of shallow convection (led by the University of Washington with Principal Investigators at NCEP/EMC, NASA JPL and the University of California at Los Angeles); on internal-wave driven mixing (lead by Scripps Institution of Oceanography, with Principal Investigators from GFDL, NCAR, University of Alaska, Florida State University, University of Michigan, and Woods Hole Oceanographic Institution); and on ocean mixing processes associated with high spatial heterogeneity in sea ice (lead by the University of Alaska, with participation by UCAR and GFDL).

Recommendation: There needs to be a long range plan that emphasizes how the development activity will be integrated into an operational capability.

Response: An attempt to launch a coordinated research effort on aerosols, clouds, cloud feedbacks and water vapor, which included field, laboratory and modeling studies and involved ESRL, GFDL, ARL, CPC and extramural grants programs, was not funded in the FY12 NOAA budget process. This effort included explicit resources for transition of new physics into operational models through the Climate Test Bed. CRM recognizes the importance of clouds, aerosols, and water vapor to fundamental climate understanding and predictability, from global-to-continental-to-regional space scales, and will endeavor to make progress using existing resources, albeit at a greatly reduced pace. Further, GFDL and NCEP (EMC and CPC) have agreed to explore areas in which collaborative research in climate sciences can be pursued that will be mutually beneficial to each organization. The resulting collaborative work should accelerate improvements to climate modeling systems focused on a broad set of applications relevant to seasonal-to-decadal time scales, and facilitate the transfer of research developments into operations. Collaborative activities will be defined and tracked through the creation of an annual workshop, the first of which will be held in the second quarter of FY11. NCEP (EMC and CPC) and GFDL will host each other's scientists in their respective internal seminar series depending on the seminar schedules at the institutions; exchanges will be on topics of mutual interest, with nominally two exchanges from each institution per year. The CRM strategic plan will further address issues of integration.

Recommendation: There is a need for better connection of the chemical and physical sciences and the role of chemical science and air quality in NOAA.

Response: The CRM Strategic Plan will address issues of coordination across CRM. Examples of connections between chemical and physical sciences include Carbon Tracker, which combines the maintenance of carbon observatories and carbon data assimilation into transport models, and collaborative research between ESRL and GFDL on aerosols and ozone (in the stratosphere and troposphere), with work on model-observation comparisons that also include observations from other Federal partners, including NASA and the Department of Energy. The results from these collaborations influenced the scientific conclusions in the WMO/UNEP Ozone Assessment as well as other assessments. On the topic of chemical science and air quality in NOAA, NOAA is currently collaborating with the California Air Resources Board to lead CalNex, an air quality and climate change field study, with participation by DOE, NASA and numerous universities. By focusing on major air pollutants that are also climate change forcing agents, CalNex seeks to provide decision makers with the scientific basis for their development of "win-win" solutions to improve air quality and mitigate climate change. California can provide a test-bed for developing regional climate-air quality decision-making in the U.S. CSD and GFDL are also engaged in evaluating the climate forcing by soot particles, and parameterizing and verifying the physical properties of aerosols for use in climate models.

Recommendation: A Strategic Plan is needed, to define how the various activities fit together into a coherent whole.

Response: CRM is developing a Strategic Plan (SP) document that will be responsive to the details of the NCS implementation strategy and NOAA's Next Generation Strategic Plan and will articulate the: Vision, Mission, Goals; Roles of Labs, Centers, Institutes; Roles of Grant Programs; Intramural and Extramural Interactions.

Panel 1b: Ocean Processes and Carbon Cycle

Recommendation: The CRM Program needs to better integrate with NOAA observational and modeling efforts to improve the observing system, the models, and the predictions. NOAA's program represents a unique opportunity among climate research efforts in US to leverage national investments in observations, operational prediction, and predictive modeling by taking advantages of synergies among them. Past work with CLIVAR Climate Process Teams (CPTs) has been very productive. It has been a part of the integration strategy. The Panel recommends additional targeted CLIVAR CPTs to take advantage of the wealth of Earth

system observations to improve operational seasonal to interannual forecasting, initialization of decadal prediction, and climate projection. NOAA should continue to fund NOAA scientist participation in CLIVAR CPTs. Regular meetings among key NOAA CRM researchers from all supported labs (including GFDL, ESRL, PMEL, AOML) and related University research colleagues on specific topics (e.g. ocean carbon) would facilitate such interactions.

Response: [*Repeating response from pages 3-4*]. Examples of existing programs that coordinate measurements and modeling include Carbon Tracker, which combines the maintenance of carbon observatories and carbon data assimilation into transport models; efforts at GFDL to assimilate ocean data from the ARGO float network into coupled climate models; partnerships among GFDL, ESRL and NCEP (CPC and EMC) on data assimilation, analysis and reanalysis spanning timescales from seasonal to interannual to decadal; contributions to the GEWEX/CEOP (Coordinated Energy and Water Cycle Observations Project) program by ARL; and extensive participation by NCEP/CPC, ESRL/CSD and ESRL/PSD in field campaigns including the North American Monsoon Experiment, the Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS), and the African Monsoon Multidisciplinary Analysis. New developments include the selection of a visiting scientist at GFDL to address DOE's Atmospheric System Research (formerly Atmospheric Radiation Measurement) program observations in the context of model development. Climate Process Teams (CPTs) selected and supported by CPO are aimed to speed development of global coupled climate models by bringing together theoreticians, field observationalists, process modelers and the large modeling centers. CRM scientists are participating in four new CPTs: on cloud macrophysical parameterization and its application to aerosol indirect effects (lead by University of Wisconsin-Milwaukee, with Principal Investigators at GFDL, ESRL, NCAR, NASA JPL and the University of Washington); on development of shallow convection (lead by the University of Washington with Principal Investigators at NCEP/EMC, NASA JPL and the University of California at Los Angeles); on internal-wave driven mixing (lead by Scripps Institution of Oceanography, with Principal Investigators from GFDL, NCAR, University of Alaska, Florida State University, University of Michigan, and Woods Hole Oceanographic Institution); and on ocean mixing processes associated with high spatial heterogeneity in sea ice (led by the University of Alaska, with participation by UCAR and GFDL).

Recommendation: Ocean modeling science and algorithms developed in the larger community filter into the GFDL ocean models more slowly than they should.

Response: GFDL has developed two world-class ocean models, and both will eventually be operating from one code base. Many ocean modeling science, algorithms, and parameterizations developed by, or in conjunction with, the larger community e.g., CPT process and have been incorporated into the code, evaluated, and adopted. One application resulting from an improved isopycnal ocean model has been the first NOAA model simulation study of the underwater plumes of dissolved oil in the the DeepWater Horizon disaster (Adcroft et al,. *Geophysical Research Letters, 2010)*

Recommendation: NOAA should continue to push the resolution envelope, at least for decadal-scale modeling. Sensitivity experiments have already indicated that process-level realism can be improved by a transition to eddy-permitting resolution. The Panel encourages an exploratory investigation of the results obtained with an eddy-permitting ocean model coupled to a cloud-resolving atmospheric model. For physical and biological systems, improved resolution of coastal systems is vital.

Response: Increasing resolution is desirable, and will be achieved to some degree using new ARRA-funded NOAA computing resources at DOE/Oak Ridge National Laboratory (ORNL) when available in FY11, although this will not fill NOAA's gap in computational resources. GFDL has been using the much higher-powered computers at DOE Oak Ridge to run higher resolution versions of GFDL's coupled climate model, CM2.1: CM2.4 has a 1 degree atmosphere and a ¼ degree ocean, CM2.5 has a ½ degree atmosphere and a ¼ degree ocean (currently running at Oak Ridge) and CM2.6, scheduled to start running in August 2010, will have a ½ degree atmosphere and a $1/10^{th}$ degree ocean. These runs will be used to assess decadal predictability of the ocean-atmosphere system as well as the impact on climate change simulations of the use of significantly higher spatial resolution. Also running at Oak Ridge are 25km and 50km atmospheric models for use in "time-slice" mode to study regional climate change. ("Time-slice" means running the model with boundary conditions (SST and sea ice) from observations (for the control) and from lower resolution coupled climate models for future selected time periods.) These runs will be contributed to IPCC AR5 and should also be of value for the next National Assessment. Output has been used for studies of hurricanes and global warming, the first of which was published in December 2009. Access to DOE machines is enabled through a competitively awarded INCITE grant. Under that same INCITE grant from DOE, NOAA is using computer time at Argonne National Lab, Illinois, for research into the next generation of atmospheric model, with resolutions of 12 km and less. An initiative to support the development of two-way nesting of regional ocean models in global ocean models is included in the Earth System Modeling: Urgent Climate Issues request within the FY11 President's Budget.

Recommendation: The panel is concerned that the influence of water, nitrogen, and phosphorous cycles on the carbon cycle are not receiving enough attention within the ESM effort.

Currently in the LM3 land model, the carbon and water cycles are coupled on both short-term and long-term time scales. The ESM project in the FY11 President's budget is for modeling various aspects of the terrestrial carbon cycle, including nitrogen and phosphorous cycles, and will include soil-vegetation modules, and biogeochemistry models for wetlands, surface waters and rivers.

Recommendation: The state of understanding of the interactions among coastal upwelling, advection, nutrient cycling, river inputs, and estuarine biogeochemistry and sedimentation remains poor. Progress in this area will likely require experiments at very high resolution in collaboration with experimentalists and data from field campaigns.

Response: A key uncertainty impeding our ability to predict how these systems will change in the future is our inability to represent these coastal systems in models of global climate change. Such representation is a critical focal point of future research. An initiative to support the development of two-way nesting of regional ocean models in global ocean models is included in the Earth System Modeling: Urgent Climate Issues request within the FY11 President's Budget. A more ambitious collaborative research proposal on linkages between climate, coastal, and ocean ecosystems, which included a collaboration with estuarine researchers at NOAA NCCOS, did not receive support in the FY12 NOAA budget process.

Panel 2: Reanalysis and Data Assimilation and Carbon Tracking

Recommendation: The CFSRR needs more connections to its customer base, and should survey the community as part of a process to define the product streams.

Response: The development of the NCEP Climate Forecast System Reanalysis (see Saha et al., The NCEP Climate Forecast System Reanalysis, Bull. Amer. Meteor. Soc. 2010, e-View doi: 10.1175/2010BAMS3001.1) was already underway at the time of the March 2008 CRM Review. Project design had been guided by a CFSRR-established science advisory board and NCEP's many years of experience with providing and using climate reanalyses since the release of NCEP/NCAR Reanalysis 1 (described in Kalnay et al.,The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470, 1996). The CFSRR Science Advisory Board was chaired by Jeff Anderson (NCAR) and members were: Saki Uppala (ECMWF), Gabriel Lau (GFDL/NOAA), Eric Wood (U Princeton), Gil Compo (CDC/NOAA), Mark Serreze (U Colorado), Rick Rosen (CPO/NOAA), Huug van den Dool (CPC/NCEP), Jim Carton (U Maryland) and Lars Peter Riishojgaard (JCSDA/NCEP). In advance of the development cycle for CFSv3 (and the next round of reanalyses and reforecasts), NCEP will hold a community workshop in the summer of 2011 that will serve as a jumping off point for development and planning by NCEP and potential community partners. The workshop will help NCEP articulate its prioritized goals for CFSv3 (e.g., increased accuracy and/or lead time and/or regional detail), its expected resources and constraints (likely computing capability, forecast "window" in operations etc.), and its desires for products and capabilities from the research community (upgraded dynamical cores, upgraded physics, new data assimilation techniques, new coupling strategies, and ensemble generation strategies). The workshop output will help to set priorities for the CPO Annual Announcements of Opportunity. The workshop will be open to interested members of the climate community and a summary will be made available for public comment and subsequent revision. Additional resources would be required to sponsor the workshop and prepare reports.

Recommendation: The CFSRR should undertake a validation to demonstrate the performance of the system and should involve external community early in the evaluation rather than relying entirely on the internal monitoring of the system.

Response: A major advance in the development of the CFSR, compared to earlier NCEP reanalyses, was the real-time monitoring that took place during the execution of the CFSR. Thousands of graphical plots were generated automatically at the end of each reanalyzed month, and displayed on the CFSR website in real time. Many scientists from both CPC and EMC monitored different aspects of the reanalysis during this two-year process. There were many times that the reanalysis was halted periodically to address concerns that something may have gone wrong, and many corrections, back ups, and restarts were then made to ensure that the process was executed correctly and homogeneously. This extremely large "atlas" of plots depicting nearly all aspects of the CFSR is open to the public at: http://cfs.ncep.noaa.gov/cfsr. A lower resolution reanalysis covering 1979 to present will be run in 2011 to provide improved continuity in the stratosphere, ocean, and land surface to meet CPC's requirements. A second lower resolution reanalysis to extend the coverage back to 1948 will begin in 2012. The Modeling, Analysis, Predictions, and Projections Program (MAPP) in NOAA's Climate Program Office funded one university-based research project on CFSR in 2009 (to assess the ability of the CFS reforecasts to predict hydroclimate of Pan America including drought/flood extremes) and is soliciting competitive proposals in 2011 for research to evaluate recently developed reanalysis projects including, but not limited to, CFS-Reanalysis and the 100-year Historical Reanalysis Project.

Recommendation: NCEP/EMC and NCDC should consider a distributed and incremental archiving of the reanalysis rather than waiting until the entire reanalysis is complete and shipping the end-product to NCDC for archival and distribution. Such an archival strategy would allow broad access to the products and support re-processing if and when problems are found within any portion of the first processing.

Response: The comprehensive monitoring by CPC enabled many problems to be mitigated before the final CFSRR data stream was completed. For public access at NCDC, the following data transfers were accomplished:

Feb 2010: Access to 10 TB of high-priority CFS-R data made available

Feb 2010 – June 2010: 235 TB of CFS-R data archived on CLASS disk through NCDC, NCEP partnership

June 2010: NCDC, NCEP partnership archive 245TB of CFS-R data (full suite) on CLASS.

August 2010: All reanalysis gridded data have been transmitted to NCDC. Observations are being filtered to keep out restricted observations from reaching the NCDC publicly accessible database.

Recommendation: The project and users need to agree that the proposed estimates of biases and uncertainties are sufficient indicators of product quality, and how these or other quality estimates will evolve to reflect user experience.

Response: The release of the CFSR dataset enables users to compare the resulting fields with earlier reanalyses (e.g. R1 and R2) and with observations in order to perform an objective assessment of biases and uncertainties (see, for example, Higgins et al., Intercomparison of Daily Precipitation Statistics over the United States in Observations and in NCEP Reanalysis Products, accepted in Journal of Climate: doi/abs/10.1175/2010JCLI363.) Evaluation of reanalyses is the topic of an upcoming workshop sponsored by NOAA, NASA, NSF and U.S. CLIVAR (November 2010). Workshop objectives include: assessing strengths and limitations of the new recent U.S. reanalyses (including the CFSR) and suggesting where improvements of reanalysis products can be made; identifying additional studies necessary to further elucidate the fidelity and usefulness of recent U.S. reanalyses; and developing diagnostics to quantitatively assess needed improvements in Integrated Earth System Analysis (IESA) products.

Recommendation: The above recommendations also apply to the 20th Century Reanalysis.

Response: The recommendations are repeated below for the 20^{th} Century Reanalysis, with appropriate responses.

Recommendation: The 20^{th} Century Reanalysis needs more connections to its customer base, and should survey the community as part of a process to define the product streams.

Response: The 20^{th} Century Reanalysis project is an international collaborative project lead by NOAA and CIRES and is profoundly connected to other reanalysis efforts and user communities nationally through U.S. CLIVAR (Climate Variability and Predictability Program) and internationally through ACRE (Atmospheric Circulation Reconstructions over the Earth). ACRE was established in 2008 with five core partners: the Queensland Climate Change Centre of Excellence (QCCCE) in Australia; the Met Office Hadley Centre (MOHC) in the UK; the U.S. National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) and Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado; and the University of Giessen in Germany plus the University of Bern in Switzerland. With endorsement from organizations such as the World Meteorological Organisation (WMO), the Group on Earth Observations (GEO), the Global Climate Observing System (GCOS), wide international support and the aid of various working groups of GCOS and World Climate Research Program (WCRP), ACRE provides an umbrella that links together some 35+ projects, institutions, organizations, data rescue and climate applications activities around the globe. Through ACRE, the 20th Century Reanalysis Project is linked globally to users and their climate applications needs. An ACRE working group that explicitly addresses the concerns raised in this recommendation is the User Requirements and Applications Working Group chaired by Roger Stone of the University of Southern Queensland. The terms of reference for this Working Group include generating a clear user requirement document.

Recommendation: The 20th Century Reanalysis should undertake a validation to demonstrate the performance of the system and should involve external community early in the evaluation rather than relying entirely on the internal monitoring of the system.

Response: An ACRE working group that explicitly addresses the concerns raised in this recommendation is the Verification and Validation Working Group chaired by Gil Compo, University of Colorado/NOAA ESRL. As described in more detail below, the 20th Century Reanalysis Project released data from both version 1 (1908-1958) and version 2 (1871-2008) during their generation and benefitted from the findings of an ACRE working group concerning Australian observations prior to 1948. As a result, a re-run was made.

Recommendation: 20th Century Reanalysis project should consider a distributed and incremental archiving of the reanalysis rather than waiting until the entire reanalysis is complete and shipping the end-product to NCDC for archival and distribution. Such an archival strategy would allow broad access to the products and support re-processing if and when problems are found with any portion of the first processing.

Response: Via ftp, ESRL released data of both version 1 (1908-1958) and version 2 (1871-2008) during their generation. User-requested data were online starting in June 2008. The ACRE working group found initial problems in the assimilation of the time of Australian observations prior to 1948 and in the surface temperature field arising from a bias in some land surface pressure observations. These issues were addressed, the U.S. Dept of Energy provided additional computing time, and a re-run was made. Data release was then coordinated as the corrected data were being generated with ESRL <http://www.esrl.noaa.gov/psd/data/20thC_Rean/> and NCAR http://dss.ucar.edu/datasets/ds131.1/. NCDC will also ingest and distribute the data via NOMADS. Data from 1891-2008 were released and examined before 1871-1890 data were generated.

With ECMWF, NCEP, ACRE and NASA, the 20th Century Reanalysis team is forming an interactive website called Reanalysis Intercomparison and Observations to allow the evolving evaluations and quality indicators to be easily accessible and publicly available for comment at a website "*reanalyses.org*". The website is expected to launch in late 2010.

Recommendation: The project and users need to agree that the proposed estimates of biases and uncertainties are sufficient indicators of product quality, and how these or other quality estimates will evolve to reflect user experience.

Response: This recommendation has been addressed by the formation of the ACRE working group on Verification and Validation. The terms of reference for this working group include testing against independent data sources; best practice; inter-comparisons with other reanalyses and reconstructions; and feedback on the 20th Century Reanalysis Project. A paper invited to the Quarterly Journal of the Royal Meteorological Society describes substantial validation of the 20CRv2 output (see Compo et al., 2010: The Twentieth Century Reanalysis Project. Quart. J. Roy. Meteor. Soc., submitted. Available online at http://www.esrl.noaa.gov/psd/people/gilbert.p.compo/20CRv2_Compoetal2010.pdf). Other studies arising from the Verification and Validation working group focused on El Nino variations in the early part of the 20th Century (see Giese et al., 2010: The 1918/1919 El Niño. *Bull. Amer. Meteor. Soc.*, 91, 177-183, doi: 10.1175/2009BAMS2903) and on decadal hurricane variations (Emanuel, 2010: Tropical Cyclone Activity Downscaled from NOAA-CIRES Reanalysis, 1908-1958. J. Adv. Model. Earth Syst., Vol. 2, Art. #1, 12 pp., doi:10.3894/JAMES.2010.2.1)

Other publications that use the 20th Century Reanalysis data include:

- Baird, M.E., J.D. Everett, and I.M. Suthers, 2010: Analysis of southeast Australian zooplankton observations of 198-1942 using synoptic oceanographic conditions. *Deep Sea Res. II*, in press.
- Cook, B.I, R. Seager, and R.L. Miller, 2010: Atmospheric circulation anomalies during two persistent north american droughts: 1932-1939 and 1948-1957. *Clim. Dyn.*, in press, doi: 10.1007/s00382-010-0807-1
- Brönnimann, S., A. Stickler, T. Griesser, A. M. Fischer, A. Grant, T. Ewen, T. Zhou, M. Schraner, E. Rozanov, and T. Peter, 2009: Variability of large-scale atmospheric

circulation indices for the Northern Hemisphere during the past 100 years. *Meteorol. Z.*, 18, 365-368, doi: 10.1127/0941-2948/2009/0392.

- Whitaker, J.S., G.P. Compo, and J.-N. Thepaut, 2009: A comparison of variational and ensemble-based data assimilation systems for reanalysis of sparse observations. *Mon. Wea. Rev.*, 137, 1991-1999.
- Wood, K. R., and J.E. Overland, 2009: Early 20th century Arctic warming in retrospect, *Int. J. of Climatol.*, in press, doi: 10.1002/joc.1973.

Recommendation: NOAA management should determine if, when, and how the CDA should transition to CFS, and if not, why it should continue at GFDL.

Response: Data assimilation currently plays a key role in research into decadal-scale climate predictability at GFDL and will be a crucial component of any future decadal prediction system. Seasonal/interannual hindcasts obtained using the GFDL CDA (Coupled ensemble filter Data Assimilation) and CM2.1 have been performed at GFDL and given to NCEP for the MME evaluation. However, a data assimilation system designed to meet GFDL's climate research needs may not be ideally suited to NCEP's need for operational prediction at shorter time scales. NCEP is currently evaluating options for ocean data assimilation (ODA) with research and operational partners. As with its atmospheric data assimilation system, NCEP can support a single core method for its ODA work. At the present time, a hybrid variational-ensemble system looks to be the most promising approach. The ensemble part of this advanced ODA system would be an ensemble Kalman filter, similar to what is used in the CDA. This advanced ODA system would be used for a wide variety of applications, including ocean forecasts on weekly time scales, coupled atmosphere-ocean-land surface-sea ice forecasts on seasonal-to-interannual time scales, and a possible annual-to-decadal system. A plan is being written by involved partners, including NCEP, NASA/GMAO, GFDL, the Navy, and the University of Maryland. A draft plan should be available to all partners by the end of summer 2010.

Recommendation: The CRM Program should recognize that the predictability of the Atlantic Meridional Overturning Circulation will continue to be a research problem, rather than an operational problem, for the foreseeable future.

Response: The CRM Program agrees and recognizes that the predictability of the Atlantic Meridional Overturning Circulation (AMOC) will continue to be a research problem, rather than an operational problem, for the foreseeable future. GFDL's Climate Change, Variability and Prediction Group seeks to better understand the mechanisms of decadal climate variability and to assess whether such variability may be predictable through the use of both statistical tools and advanced computer climate models. In particular, major research efforts are underway to evaluate the mechanisms of decadal climate variability, including the AMOC, and their climatic impact; and estimate the inherent decadal scale predictability of the climate system in general, and the AMOC in particular. Decadal predictability research in NOAA is supported by NOAA's extramural grants programs and received an increase in funding in FY10.

Recommendation: CarbonTracker should receive rigorous scientific review, and it should be integrated more fully with other CRM projects.

Response: A collaborative effort between Carbon Tracker and GFDL ESM developers has been started. Carbon Tracker underwent a full scientific review in the Fall of 2008 and the response to that review is included as an addendum to this document. The review panel suggested specific model improvements and noted the need for increased resources. The Carbon Tracker team is exploring implementing FIM (Flow-following finite-volume Icosahedral Model) as the transport model in Carbon Tracker. The FY11 President's Budget Request includes increased funding for NOAA's Carbon Observing and Analysis System, which, if passed by Congress, would provide support for Carbon Tracker.

Recommendation: An effort should be made to include ESM component models in CT, at least as part of a "MME" for carbon. Rather than simple regional scaling factors, model state variables (e.g., woody biomass, ocean nitrogen) or parameters (e.g., carbon allocation, carbonate ballasting) could be improved over time as the models are repeatedly confronted with atmospheric observations. Such a collaboration within NOAA CRM would improve the Carbon Tracker analyses, might expose weaknesses in ESM, and would help initialize ESM components for decadal prediction.

Response: A first step in the effort to test ESM components in the CarbonTracker framework has started. There are a number of scientific issues that need to be addressed before an accurate evaluation can be made of the performance of the ESM components. If the ESM components perform well, an evaluation will be made as to whether to port the ESM components into the CarbonTracker framework.

Recommendation: Despite workshops that have articulated the need for an ongoing national program to produce periodic reanalyses, no such program has emerged. Since reanalyses have generally been conducted by numerical weather prediction centers/activities, the Panel recommends that NOAA take the lead in forging an interagency partnership to create a national program.

Response: The U.S. Climate Variability and Predictability Research Program (CLIVAR) is organizing a workshop on "Evaluation of Reanalyses – Developing an Integrated Earth System Analysis (IESA) Capability" to be held in November, 2010. Sponsors include NOAA, NASA, NSF and U.S. CLIVAR and objectives include developing definitions and identifying goals of U.S. efforts leading to the forthcoming generation of integrated earth system analyses. This nationally focused workshop will be immediately followed by the Third Atmospheric Circulation Reconstructions over the Earth (ACRE) Workshop. ACRE is an international initiative that is providing new and unique historical weather data and reconstructions for users and climate applications needs worldwide and is endorsed by the World Meteorological Organization, the Group on Earth Observations, and the Global Climate Observing System. These initiatives will lead to the intercomparison of reanalysis datasets with observations (including the 20th Century Reanalysis Project) and make these intercomparisons available on the web.

Panel 3: Earth System Modeling, Predictions, and Projections

Panel 3a: Modeling Overview

Recommendation: GFDL and NOAA management should reach a mutual agreement on the relative priorities of Climate Modeling and ESM development. Then the various critical climate problems should be prioritized, and resources allocated accordingly.

Response: GFDL's research priorities in Climate Modeling and ESM development are responsive to agency directives, including NOAA's Next Generation Strategic Plan, the NOAA Administrator's Annual Guidance Memorandum, the mission of NOAA's Climate Goal and the emerging requirements of NOAA's climate services. Priorities are also guided by GFDL's participation in national and international efforts including the U.S. Global Change Research Program and the Intergovernmental Panel on Climate Change and the Assessments thereof. Within GFDL, priorities are set by senior management and GFDL's Research Council. Execution of GFDL's priorities is reviewed periodically by a panel of experts convened by NOAA's Office of Oceanic and Atmospheric Research. The executive summary of GFDL's 2009 review is appended to this document for informational purposes.

Recommendation: GFDL needs to make a strategic decision as to whether or not it wants to take a leading role, nationally and internationally, in ESM development.

Response: GFDL is contributing two sets of Earth System Model simulations, using two different ocean models, to the Intergovernmental Panel on Climate Change 5th Assessment. GFDL recognizes that support and staffing for ESM development is subcritical. An alternative included in the FY11 President's Budget request for NOAA contains a significant funding increase for research into biogeochemical feedbacks for ESM development. Land-ice modeling, and particularly the contribution of melting land ice to future sea level rise, remains another key area requiring improvement. GFDL is making progress in this area through collaboration with a new Cooperative Institute in Climate Sciences researcher and a UCAR post-doctoral fellow. The FY11 President's Budget request includes significant funding to further enhance NOAA's expertise in ice sheet modeling. GFDL continues to draw upon the world-renowned expertise of CICS (Princeton) for the oceanic components of the biogeochemical cycle.

Recommendation: GFDL's land-model development activity does not appear to be at the cutting edge. Land-ice modeling is a crucial area for future development.

Response: GFDL's land modeling effort uses the latest science. There is now a paper on the land model (Shevliakova et al., Global Biogeochemical Cycles, June 2009). The new scheme is included in the GFDL climate model simulation streams for CMIP5 and AR5. The land-ice modeling is a key area requiring improvement. The FY11-15 ESM project in the FY11 President's budget includes funding to focus on ice sheet modeling.

Recommendation: Management should determine to what extent future IPCC obligations can be supported through current and new collaborations, partnerships, and linkages.

Response: The development of IPCC-class climate and Earth System models requires a committed and stable scientific workforce and, a scalable high performance computer system that provides critical computing, storage, and analysis capabilities, as well as model development infrastructure support and data services. Collaborations, partnerships and linkages can enhance but not replace these core capabilities. Model development at GFDL is enhanced by a strong partnership with Princeton University through the NOAA-supported Cooperative Institute for Climate Science, through formal and informal collaborations (for example, Climate Process Teams, universities, and institutions abroad) and through participation in national and international research reprograms (for example, the Coupled Model Intercomparison Project under the auspices of CLIVAR and the World Climate Research Program). In addition, meetings and exchanges with NCAR, NASA and DOE enhance the modeling and scientific accomplishments at GFDL. The partnership with CICS and NOAA's participation in CMIPs was reviewed as part of GFDL's 2009 Laboratory Review. The executive summary of the review findings is appended to this response.

Recommendation: GFDL and NCEP should collaboratively perform an evaluation of HYCOM's overall performance as an ocean model for use by NCEP.

Response: HYCOM works for NCEP for the real-time now-casting and short-term (up to 10 days) prediction problems but significant issues arise for the long-term climate simulations. A key challenge for the future is building a real-time data ingest and data assimilation system encompassing GFDL's new ocean modeling capabilities.

Recommendation: NCEP should give higher priority to understanding climate, as per the draft CRM charge. In particular, it should consider whether the empirical result that the MME has improved forecast skill has a satisfactory theoretical basis.

Response: In coordination with the NOAA Climate Program Office and the Climate Test Bed, NCEP has achieved a major advance in seasonal climate prediction by establishing an operational multi-model ensemble prediction system with European partners (NCEP, ECMWF, Meteo-France and UK Met Office). The IMME significantly improves the skill of seasonal outlooks (both over the US and Europe). A formal Memorandum of Understanding that makes NCEP an Associate Partner in the EUROSIP Project has gone forward.

Recommendation: NCEP should develop the automated metrics that are appropriate to measure the skill of climate predictions.

Response: NCEP has implemented plans for an improved metric of advances in climate prediction that incorporates the CPC extended range and seasonal outlooks and that leverages the next generation Climate Forecast System. This metric will evaluate both the progress and the value of CPCs official outlooks.

Recommendation: NCEP should develop more formal and persistent mechanisms for scientific interactions with the outside research community.

Response: NCEP accelerated implementation of a Customer Requirements Process for the strategic development of CPC that gathers input from customers and partners, analyzes it through a coordinated vetting process, and develops requirements for use in the CPC and NCEP annual planning process consistent with organizational goals. During FY10, NCEP pursued numerous stakeholder activities to implement the process, including (1) the 34th annual Climate Diagnostics and Prediction Workshop and the 7th Climate Prediction Application Sciences Workshop, (2) joint seminar series with the Climate Test Bed and Center for Ocean-Land-Atmosphere studies to improve coordination of research that accelerates improvements in the Climate Forecast System, and with the U.S. Department of Agriculture to coordinate exchange of climate data and products, (4) a CPC-RISA program to partner the national centers and intermediaries on regional user needs, (5) the CPC Website Redesign project to improve the web interface and manage content with color graphics and new products suitable for the vision impaired, and (6) the NCEP Annual Numerical Weather and Climate Modeling Workshops, co-organized by NCEP and CPO since 2009. The goal is to engage outside research community in NCEP model development. CPC also exceeded NCEP timeliness goals for on-time delivery of the CPC official product suite while increasing the number of products that are routinely tracked by more than 50%.

Recommendation: NOAA management should assess the success of the Climate Test Bed, and develop a strategy for it to reach its potential.

Response: In coordination with the NOAA Climate Program Office and the Climate Test Bed, NCEP achieved significant improvements in the Climate Forecast System, the quality of the CPC forecast product suite, and achieved a major advance in seasonal climate prediction by establishing an operational multi-model ensemble prediction system with European partners.

Recommendation: NOAA needs to lead and develop the national strategy for intraseasonal to interannual climate prediction inclusive of MME, data assimilation, forecast metrics.

Response: NOAA convened a meeting (organized by CTB) in November 2009 to discuss issues/challenges associated with development of a National Multi-Model Prediction System (NMME) and to establish next steps. Participating organizations included NCEP, GFDL, NSF, NCAR, NASA, COLA and CPO. A key action item from the meeting was for the CTB to lead the development of a "White Paper" to be completed in Fall 2010. This paper will address key organizational issues for the development of an NMME, including commitments, resources, standards for model performance, responsibilities, and other strategic and technical issues. In addition, CTB and COLA have a funded CTB proposal to evaluate the skill of an MME consisting of CCSM and CFS.

Recommendation: The computing requirements for a National MME should be included in the NCEP climate computing request for 2011.

Response: The CTB has been allocated 1/3rd of the NCEP R&D machine (Vapor). R2O activities for an NMME Prediction System would necessarily have to fit within this allocation. Activities, such as model development and preparing hindcasts, would be the responsibility of the participating institution. Resources for running the operational NMME prediction system have yet to be discussed.

Panel 3b: Model Development

A. Modeling

Recommendation: The high-resolution modeling activity provides a strong incentive for a major enhancement of computing resources.

Response: Agreed. NOAA has received $170M in ARRA funds to accelerate and enhance NOAA's high performance computing (HPC) capabilities, enabling significant improvements for climate modeling and climate change research and partially filling NOAA's R&D computing gap. In addition, high resolution model development by GFDL scientists and their partners is currently supported through an INCITE grant from DOE, enabling access to DOE supercomputers at Oak Ridge and Argonne.

Recommendation: The ongoing atmospheric dynamical core development is very promising. Developments at GFDL, NCEP, and ESRL should be more formally coordinated, however.

Response: The ESRL dynamical core development path is based in large part on innovations in finite-volume atmospheric modeling by GFDL's S-J Lin and by collaborators at NASA. But there has been some divergence, particularly with regard to the choice of grid, vertical coordinate system, and the advection operator. Discussions continue between Dr. Lin and counterparts at ESRL, including Sandy MacDonald, concerning the divergence between the codes that has occurred. The NOAA Environmental Modeling System (NEMS) developed by NCEP allows various model components to be executed within a homogeneous verification, initialization and coupling capability. The NEMS is based on the community-developed "Earth System Modeling Framework" (ESMF). ESRL, GFDL, and NCEP support NEMS as a coupling standard for sharing model components across different NOAA labs, and it will be implemented to the degree it advances the scientific and technical goals of NOAA's modeling activities. Currently, the NEMS admits, in a research configuration, the GFS spectral and the Non-hydrostatic Multi-scale Model B-Grid (NMM-B). The Flow-following finite volume Icosahedral Model (FIM) developed at ESRL is also being added to NEMS. An additional candidate dynamical core from GFDL (cubed-sphere finite volume) can also be added to NEMS and a collaborative effort may be undertaken as part of a strengthened relationship between GFDL and NCEP that will be launched with a first annual workshop to be held in the second quarter of FY11. The goal of the workshop will be to define areas in which collaborative research in climate sciences can be pursued that will be mutually beneficial to each organization.

Recommendation: The parallel development within GOLD of MOM and HIM based capabilities at GFDL is potentially wasteful, especially when moving into the eddy resolving regime and data assimilation. Clearly both models have merits, so a consensus plan is needed. One of the models might be officially recognized as primary, while the other undergoes development in the background as resources permit. Cross-fertilization between the two efforts, and also with the atmospheric dynamical core activity, should be encouraged.

Response: MOM and HIM are not being developed in parallel: MOM is in production mode and HIM is in development mode in GOLD. CM2M is MOM-based and CM2G is GOLD-based; both coupled climate models will be contributed to IPCC AR5, and comparisons between the two will offer insights into uncertainties about the role of the oceans in the climate system and the associated influences on carbon-ocean biogeochemical interactions, as well as inform prioritization of ocean model development.

MOM has existed since 1990 and remains the world's primary community ocean code, with over 500 registered users of MOM4. High resolution decadal predictability experiments at GFDL use a MOM-based ocean, and significant improvements have been made to MOM for IPCC AR5.

A prototype hierarchy of higher resolution isopycnal-coordinate global ocean model configurations (up to 1/8-degree) using GOLD has been developed, and has already resulted in a peer-reviewed publication on consequences of the Deepwater Horizon oil spill (Adcroft et al., 2010, GRL, doi:10.1029/2010GL044689).

Far from being wasteful, the simultaneous development of prototype eddy-resolving Z-coordinate and isopycnal coordinate global ocean models at GFDL will provide invaluable guidance for coming to a consensus on the most promising and widely applicable approach to eddy-resolving ocean modeling.

Recommendation: The coupled climate modeling activity is critical to future IPCC participation, and to other projects. A formal pathway should be defined for model components to move from the ESM to the coupled climate model. The merits of coordination between GFDL's ESM and other national efforts such as NCAR's CCSM should be reconsidered. NCEP's data assimilation and reanalysis activities are critically important for the study of the climate system and the evaluation of climate models. This needs to be placed on a more sound funding and scientific foundation (see the discussion in connection with Panel 2).

Response: We agree that coupled climate modeling activity is critical to future IPCC participation and to other projects. However, the formal development pathway for model improvements is not as stated in the recommendation: GFDL's Earth System Models sit at the top of a hierarchy of model development activities. The development pathway is for component models to be improved and tested, then coupled to other component models to form a coupled climate model, then for that model to provide the physical basis for the Earth System Model. The Flexible Modeling System (which is fully compatible with the Earth System Modeling Framework) provides the software infrastructure that enables the component models to be coupled and interoperable. Decisions about movement of model components between models, adoption of new model components, and other model design issues are jointly made by leaders of the model development teams at GFDL based on the performance characteristics, including model component maturity, the computation requirements of the various components, and science considerations (e.g., what science problem would be addressed with the proposed physics change?) including the fidelity of the simulations when components are coupled. So far, this approach seems to be working well for GFDL (GFDL contributed two of the top-performing climate models to IPCC AR4 and will contribute four modeling streams to IPCC AR5), so that additional layers of formal oversight are not necessary in our view.

There are considerable linkages between model development at GFDL and at NCAR. For example, NCAR is currently testing the finite volume atmospheric core code developed at GFDL, GFDL ocean model developers are collaborating closely with NCAR on the development of CORE ocean forcing, and many ocean model parameterizations have been exchanged between GFDL and NCAR. The CM2-era cloud parameterization efforts at GFDL affected model development at both GFDL and NCAR. As GFDL's ESM development efforts evolve, there is likely to be extensive collaboration with NCAR, particularly in the area of terrestrial biology. GFDL is part of the new data network based on the Earth System Grid, partly developed at NCAR, and scientists from both GFDL and NCAR are involved in designing the experiments that will form CMIP5 (the Coupled Model Intercomparison Project Phase 5) to address outstanding issues from IPCC AR4. New developments in NCEP's data assimilation and reanalysis activities include the recent release of a Climate Forecast System Reanalysis over the period 1979-2009, a period covering observations from satellites. This is the first-ever reanalysis with a coupled climate model that includes ocean, land and sea ice components in addition to the atmosphere and is likely to become an extremely useful product for the evaluation of climate models.

Recommendation: Care should be taken to maintain and enhance ties between GFDL and NCEP as the latter moves to the University of Maryland campus.

Response: GFDL and NCEP (EMC and CPC) have agreed to explore areas in which collaborative research in climate sciences can be pursued that will be mutually beneficial to each organization. The resulting collaborative work should accelerate improvements to climate modeling systems focused on a broad set of applications relevant to seasonal-to-decadal time scales. Collaborative activities will be defined and tracked through the creation of an annual workshop, the first of which will be held in the second quarter of FY11. NCEP (EMC and CPC) and GFDL will host each other's scientists in their respective internal seminar series depending on the schedules at the respective institutions; exchanges will be on topics of mutual interest, with nominally two exchanges from each institution per year. The CRM strategic plan will further address issues of integration.

B. Computing Needs

Recommendation: The Panel concurs in spirit and principle with the comments and recommendations in the letter of April 4, 2007 from David Fluharty to VADM Lautenbacher that focused on HPC.

There is a need for a more integrated NOAA approach to high performance computing. We emphasize that this does not imply that there should be a "centralized NOAA computer." In fact, the heterogeneous nature of the problems and the varying missions in the different organizational units virtually assure that a one-size-serves-all HPC environment does not best serve NOAA. Emphasis should be placed on end-to-end systems design anchored on the software of the research and applications suites and data system requirements. There are key financial gaps, and the needed computing upgrade will cost about $150 million, with sustained expenditures for the foreseeable future. NOAA's existing facilities cannot house the required computational systems. Given high-performance networking and the development of a resource management strategy, NOAA should consider a centralized facility. (Note: A centralized facility is not the same as a single computational environment.)

NOAA should develop a "core team of HPC expertise." NOAA needs to take primary responsibility for maintaining the computational viability of its critical software. This is not a problem of simple procurement of computational systems. Again, the emphasis should be on software and data; computational systems are ephemeral.

NOAA should establish stronger relationships with the other Federal agencies, as well as the vendor community.

Response: The acquisition and management of High Performance Computing is conducted at the agency level, not at the program level, so these recommendations are beyond the purview of CRM. However, we can report that NOAA has a High Performance Computing Strategic Plan and Roadmap that identifies a new Target Architecture for NOAA HPC**.** NOAA has received $170M in ARRA funds. This funding will accelerate and enhance NOAA's high performance computing (HPC) capabilities, enabling significant improvements for climate modeling and climate change research, although not at the level suggested in the recommendation. NOAA allocates HPC to high-priority projects that have demonstrated that they can effectively use it. In August 2009, NOAA signed an Interagency Agreement for High Performance Computing Collaborative Services for Climate Modeling with the Department of Energy (DOE). This agreement leverages the significant specialized expertise and unique capabilities of DOE's Oak Ridge National Laboratory to provide NOAA with access to unprecedented HPC capabilities. Thus, the first phase of the agreement has been implemented at ORNL in Tennessee. Through this collaborative investment in new HPC capability, the skill, resolution, and complexity of climate change research model projections will be dramatically increased in order to better support improved decision-making across levels of government and the private sector. NOAA has also acquired high performance computing through a systems-integration contract awarded to Computer Science Corporation in May 2009 to support the development of seasonal and inter-annual climate and weather model projections bound for operational implementation. This high performance computing will be located within a yet-to-be-determined facility space that will be leased through the General Services Administration. A Chief Software Engineer now resides in NOAA's Office of the CIO to lead the development of a NOAA-wide software architecture. These activities are producing a NOAA HPC configuration that closely aligns with the recommendation: an integrated NOAA approach, heterogeneous solutions, the development of HPC expertise, and partnering with other Federal agencies.

Recommendation: "System diagrams" that expose not only the need for cycles, but that also capture the requirements for memory, memory bandwidth, the data system, communication, degree of parallelism, etc. should be drawn up to define the computational environment more robustly and contribute to better strategic management and acquisition of computational systems.

Response: The acquisition and management of High Performance Computing is conducted at the agency level, not at the program level, so these recommendations are beyond the purview of CRM. However, we can report that NOAA is considering the types of approaches described in this recommendation as the agency refines its processes for acquiring and managing High Performance Computing capacity. A representative suite of applications was used to not only evaluate computational performance but also to also design the nationwide research network capable of supporting NOAA's new R&D computing environment. All of the aspects articulated in the recommendation were used in designing the system configuration for the NOAA system at ORNL and its connection to NOAA organizations and their networking, storage, and analysis requirements.

Recommendation: A work flow model for research activities and operations should be built to expose the need for research computing and help to define the requirements for the system. For a sustained, robust activity such as GFDL or NCEP, an operational environment using on the order of 15% of the total computational capacity is robust.

Response: NOAA followed this type of approach in its current acquisition of High Performance Computing for research and development. The resulting work flow is also being used to tune overall system balance (between computer, network, analysis, and storage) as the system is being installed.

Recommendation: Given that state-of-the-art climate models form a niche in an HPC community which is already a niche in the computational market as a whole, sustained relations with vendors are important for keeping software execution efficient, indeed, viable. The Panel recommends that NOAA investigate participation in RAPS or a RAPS-like consortium (http://www.cnrm.meteo.fr/aladin/meetings/RAPS.html). This would have significant impact for the U.S.'s HPC culture.

Response: NOAA (GDFL) is partnering with the Department of Energy (both Argonne and Oak Ridge National Laboratories) in a co-design proposal process. Co-design refers to a computer system design process where scientific problem requirements influence architecture design and technology and constraints inform formulation and design of algorithms and software. It is anticipated that this activity will not only better position the Federal sector for exascale computing, but it will strengthen the partnerships between NOAA and DOE labs. A recent (September, 2010) House R&D event featuring DOE-Argonne, IBM, and NOAA/GFDL showcased the value and need for exascale computing developments that could be highly beneficial to the climate modeling and science field.

Recommendation: The Panel encourages continued development of software frameworks and participation in the Federal and academic communities that are developing software infrastructure.

Response: Both GFDL and NCEP are participating in the development of the Earth System Modeling Framework (ESMF), whose goal is to increase software reuse, interoperability, ease of use, and performance portability in climate, weather, and data assimilation applications. ESMF is being developed and deployed by a multiagency collaboration that includes many of the major geophysical modeling and data assimilation efforts in the U.S. Support for ESMF development and application teams is provided by the NASA Earth Science Technology Office, the High-Performance Computing Modernization Program of the U.S. Department of Defense, and NSF. Staff from modeling centers at the U.S. Department of Energy, DOD, NASA, NOAA, NSF, and numerous universities have contributed requirements, feedback, and software to ESMF, and are now beginning to evaluate and adopt the framework. The NOAA Environmental Modeling System (NEMS) architecture is based on the ESMF and was developed primarily at NCEP, with collaboration at GFDL. NEMS will be used in the National Unified Operational Prediction Capability (NUOPC), a collaboration of modeling centers that are developing a new ensemble forecasting system for operational numerical weather prediction. NOAA's partners include the U.S. Navy and Air Force.

Panel 3c: Operational Predictions and Applications

A. Operational climate monitoring and prediction products and services, and the Climate Test Bed

Recommendation: NCEP is applauded for its efforts to contribute to an international MME. It should be more aggressive and provide leadership in developing a national MME. The path to improving the national (NOAA) climate forecasts will come from the transition of national research efforts to operations.

Response: NOAA convened a meeting (organized by CTB) in November 2009 to discuss issues/challenges associated with development of a National Multi-Model Prediction System (NMME) and to establish next steps. Participating organizations included NCEP, GFDL, NSF, NCAR, NASA, COLA and CPO. A key action item from the meeting was for the CTB to lead the development of a "White Paper" to be completed in Fall 2010. This paper will address key organizational issues for the development of an NMME, including commitments, resources, standards for model performance, responsibilities, and other strategic and technical issues. NCEP has been iterating with GFDL on a Letter of Agreement that includes activities related to development and testing of an NMME system for ISI prediction. In addition, CTB and COLA have a funded CTB proposal to evaluate the skill of an MME consisting of CCSM and CFS.

Recommendation: The CTB computer requests should include support for a national MME.

Response: The CTB has been allocated 1/3rd of the NCEP R&D machine (Vapor). R2O activities for an NMME Prediction System would necessarily have to fit within this allocation. Activities, such as model development and preparing hindcasts, would be the responsibility of the participating institution. Resources for running the operational NMME prediction system have yet to be discussed.

Recommendation: Selected CTB activities seem to reflect interest of internal staff (NCEP/CPC) rather than NOAA or CPO programmatic needs. The CTB advisory panel needs to look at how the CTB is being implemented and should report to the CWG.

Response: CTB has focused its research priorities (to address this concern) on three primary activities: (i) accelerating improvements in CFS, (ii) development of MME prediction systems, and (iii) developing climate forecast products based on user needs. All three of these priorities are consistent with CWG recommendations and with the emerging implementation strategy for the NOAA Climate Service (societal challenges and core capabilities).

Recommendation: NCEP should consider a strategy for supporting visitors who come to NCEP to work directly with the scientists there, with the expectation that developments should be transition to NCEP systems and also from NCEP to the community as a whole. Computer resource requests should include resources needed for this.

Response: CTB has plans to establish a Visiting Scientist Program in FY11. NCEP has been participating in Climate Process Teams and coordinating with Field Campaigns (e.g. NAME, VOCALS, DYNAMO), to accelerate improvements in NCEP climate models and help focus field observations. A community workshop for CFSv3 is planned, to help focus NCEP and the community on priorities for CFS in advance of the development cycle.

Recommendation: NOAA needs an implementation plan that closes the loop between research to operations to applications. There needs to be an objective measure of determining when research is ready for transition, and a plan that spans from basic research to applied research to pseudo-operations to full operational transition.

Response: This fundamental issue will be addressed by the NOAA Climate Services Implementation Strategy.

B. Role of Climate Prediction Program: Improvements to NCEP climate and hydrology forecasts; land-surface processes and their role

Recommendation: Each CPO program seems to have its own, idiosyncratic approach to identifying gaps in near-term priorities, and balances between program elements. A more unified strategy would improve effectiveness for coordination across programs. Input from the operational elements of NOAA should influence the priorities.

Response: The recent restructuring and consolidation of CPO climate research programs into an Earth System Science Program and a Modeling, Analysis, Predictions and Projections Program will improve coordination among the various ESS and MAPP program elements to ensure that they are mutually supporting and focused on CPO research goals.

C. Roles of the IRI, Applied Research Centers, Joint Institutes, and Cooperative Institutes

Recommendation: The CPO ought to take care to balance the funding of internal NOAA research groups and Cooperative Institutes with those of the external community to ensure that fresh ideas, perspectives and contributions can be brought forward for R2O transition.

Response: The CPO views the Cooperative Institutes and Joint Institutes as one of the mechanisms for interactions with the external community. Since September 2005, NOAA's Cooperative Institute program (which includes Cooperative Institutes and Joint Institutes) has been governed by NOAA Administrative Order (NAO) 216-107 which provides for review and re-competition of Cooperative Institutes as well as the creation of new Cooperative Institutes to meet agency needs. The restructuring of the CPO programs is expected to provide more efficient use of funding to the external community.

Recommendation: The successful CPC-RISA paradigm should be expanded.

Response: CPO and CPC have entered into discussions on how to provide sustained support of the CPC-RISA exchanges. The recent expansion of the number of RISAs will place a practical limit on CPC's ability to sustain such an effort without an increase in staff.

Recommendation: The ARCs, Joint Institutes (JI) and Cooperative Institutes (CI) need to be reviewed, re-considered, and recompeted in the context of the CTB, the more successful RISAs, and the fact that other NOAA elements and activities from other agencies should be brought together in a strategy for climate prediction products and services. Possible redefinition of these centers and institutes should be considered in context of the review and implementation of a NOAA and CRM strategic plan.

Response: The ARC program has been re-evaluated with a decision to retain two of the ARCs through the next cycle and to re-program the remaining resources to support MAPP and ESS goals. This process is on-going. Since September 2005, NOAA's Cooperative Institute program (which includes Cooperative Institutes and Joint Institutes) has been governed by NOAA Administrative Order (NAO) 216-107 which provides for review and re-competition of Cooperative Institutes as well as the creation of new Cooperative Institutes to meet agency needs.

Recommendation: CWG should respond positively to Dr. Ropelewski's request for help in formulating a review plan for the ARCs/JI/CI and a strategic plan for better directing their research activities and integrating the results into CRM program priorities. In a time of challenging budgets, the under utilization of these centers and institutes is a problem worth fixing.

Response: The ARC program has been re-evaluated with a decision to retain two of the ARCs through the next cycle and to re-program the remaining resources to support MAPP and ESS goals. This process is on-going. Since September 2005, NOAA's Cooperative Institute program (which includes Cooperative Institutes and Joint Institutes) has been governed by NOAA Administrative Order (NAO) 216-107 which provides for review and re-competition of Cooperative Institutes as well as the creation of new Cooperative Institutes to meet agency needs. CRM undertakes planning activities with the knowledge that success in program execution can be greatly enhanced by active participation of Cooperative Institutes and external researchers funded by CPO grants programs. The FY10 budget increase for decadal predictability research includes funding for grants and Cooperative Institutes, as does the FY11 President's Budget request for Earth System Modeling.

Panel 4: Integration Between and Across Programs and Synthesis of Research leading to Information, and Products and Services

A. Synthesis of Research

Recommendation: NOAA's leadership and support of policy-oriented scientific assessments should continue. In particular, NOAA should continue its strong support for the IPCC.

Diligence should be made to ensure that the necessary resources are allocated, so that key NOAA institutions (e.g., GFDL) don't suffer as a result of the tremendous effort that is required to meet these commitments.

Response: CRM is contributing four streams of climate modeling activities to IPCC AR5: Earth System Models that achieve a closed carbon cycle (ESM2M and ESM2G); a coupled climate model with more complex physics and interactive atmospheric chemistry and land vegetation (CM3); high resolution ensemble runs for decadal-scale predictions (based on CM2.1); and time-slice experiments with high resolution atmospheric models for research into regional climate projections and the impact of small-scale processes on climate (e.g. clouds and water vapor). NOAA has been the lead U.S Agency since the beginning of the IPCC climate science assessment process and is likely to maintain this leadership role in AR5.

Recommendation: The implementation process used in the ozone assessment and IPCC AR4 should serve as a model for future assessments. NOAA should work hard to support their participation with the funding that is required, particularly in terms of supporting the model development and analysis at GFDL

Response: We continue to support NOAA participation in assessments. Our participation is strengthened with the development of the NOAA Climate Services Implementation Strategy as well as the budget process. There is a key role for assessments in the NOAA Climate Service, with 3 key areas for assessments which are: 1) National and International Climate Science Assessments 2) Thematic Problem-focused Assessments 3) Climate Information Stakeholder Needs Assessments

In the FY10 budget, NOAA received $9M for assessments. The FY11 request is to provide a permanent capability to produce climate assessments at national and regional scales. The assessments will synthesize, evaluate and report on climate change research findings, evaluate the effects of climate variability and change for different regions, and identify climate vulnerabilities and uncertainties as part of an ongoing effort to understand what climate change means for the United States. NOAA will build permanent capacity for regional climate assessment service. This assessment services capability will serve as a cornerstone of NOAA's climate services. The request includes $7,000,000 for regional and sectoral assessments, which includes (1) $400,000 to staff interagency efforts for directing national assessment activities, (2) $4,300,000 for grants to conduct regional assessments through regional working groups and to build/sustain regional networks, and (3) $2,300,000 to support overall coordination, a technical and scientific support unit for provision of scientific and graphical expertise, data accessibility, stewardship, and visualization for observations and model output, communication expertise, and other scientific and technical support for regional assessments, as well as support for U.S. Global

Change Research Program (USGCRP)-led sectoral assessments. The request also includes $3,000,000 for regional downscaling modeling efforts, which includes: (1) $2,200,000 for grants to support regional downscaling/impact modeling efforts, including assisting with the development of a consistent downscaling approach for regional groups to apply, and (2) $800,000 to provide centralized regional downscaling expertise and coordination. These assessment services augment existing regional and sectoral focal points across the agency and with our Federal and non-Federal partners (states academia, user communities, etc) to begin to integrate, evaluate and interpret climate change related observations, models and projections, and evaluate the effects of climate variability and change for approximately 10 regions and 1 sector (water) covering the United States and coastal waters.

In addition, NOAA in the American Recovery & Reinvestment Act of 2009 received $170M for computing within NOAA. We have installed the first phase of this at Oak Ridge National Laboratory in Tennessee. This will be augmented over the next year. The second NOAA site in Fairmont, West Virginia, will be operational in 2011.

Recommendation: The CCSP assessment process is almost complete, and will continue to be impacted by political agendas. NOAA should strive to make the remaining process and reports as transparent and rigorous as possible. In the future, more clear and uniform demarcation between the assessment participants and the government (e.g., NOAA) leadership should be realized. More clear articulation of the targeted "users" of the assessment is required. NOAA and other government agencies should not both facilitate and author assessments; there must be a clear independence between these two roles. Conflict-free mechanisms should be worked out so that some NOAA scientists can serve as authors in future assessments.

Response: In support, NOAA has helped the OSTP take a leadership role in developing the next national assessment, which will occur in 2013, and is working with collaborating agencies of the USGCRP. In addition, NOAA supports the National Assessment through IPA Kathy Jacobs, who is on detail to OSTP, and serves as the assistant director to the National Assessment. She is developing a plan for the National Assessment, which we hope will lead to continuing the assessment process and broader participation and communication with users of the assessment process and we feel separates the role of government agencies and ownership and provides independence to address the conflict of interest.

Recommendation: All policy-influential reports like those produced by the CCSP should be reviewed by the National Academy of Sciences in order to remove any possible taint of political bias.

Response: In general, that is true. Documents are produced and will meet the criteria/demands of the Information Quality Act for Highly Influential Scientific Assessments & Influential

Scientific Information. The Implementation Strategy would follow IQA proceedings, some to be reviews by NAS for the National Assessments. Professor Jacobs has outlined a strategy for review that includes NAS review

Recommendation: Strong efforts should be made to avoid scheduling overlap between the IPCC assessments and any national effort. The CCSP, in particular, may have suffered because of the temporal overlap of the two processes and the inability of the scientific community to support both sufficiently with time.

Response: The schedule for IPCC and National Assessments are outside of the purview of NOAA. Requirements for National Assessments are part of the USGCRP and are conducted every 4 years. The IPCC requirements are set by the IPCC governing body

Recommendation: NOAA should explore ways to make their success in the policy-oriented scientific assessment process more of a vehicle for cross-CRM and cross-NOAA-climate-program integration. For example, it may be possible to prioritize NOAA climate funding and science on the basis of how well it meets the integrated objectives of the policy-oriented scientific assessment processes. NOAA might also create a more formal process to anticipate the science that will be needed for future assessments and the support of policy-making, e.g., as the nation starts to implement large-scale climate change adaptation and mitigation programs – both will require greater NOAA effort, and greater NOAA climate program integration. NOAA might benefit from greater engagement with policy scientists, as well as regional climate scientists in this effort to anticipate future assessment needs while at the same time meeting current needs.

Response: The implementation strategy for the NOAA Climate Service includes scientific assessments (National and International Climate Science Assessments) as one of the three major categories of assessment and includes needs assessments in the overarching assessment process. Before formal work begins on National and International Climate Science Assessments or Thematic Problem-focused Assessments, policy advisors and decision makers are engaged through the Climate Information Stakeholder Needs Assessments to help properly determine the issues of most relevance to the other two types of climate assessments. Theses assessments are also used to design specific services, products and/or tools for stakeholders such as policy makers, decision makers, and/or resources managers. The results of stakeholder Climate Information Needs Assessments also have immediate impacts on products and service development and delivery, which in turn impact local and regional decisions. Needs Assessments help identify what problems to focus on, by linking science to decision making. Nevertheless, the Climate Service Vision and Strategy Framework makes clear that not all priorities for Services are based on their applicability to the assessment process.

B. Integration Between and Across Programs

Recommendation: NOAA should lead an integrated multi-agency effort to provide climate services.

Response: OSTP has identified itself as the coordinating agency for establishing the multi-agency effort for climate services and has begun the process through multi-agency round table.

Recommendation: The federal government needs to develop an entity that serves as the "recipient" of climate information that is developed, in part, by NOAA.

Response: This is not a recommendation that NOAA alone can address but a recommendation that needs to be addressed across the Federal Government

Recommendation: Strategic planning and management is required at all levels in NOAA, to allow the development of integrating activities both internal and external to the agency, and to help fix the current, fragmenting budget process.

Response: We have welcomed comments on NOAA's Next Generation Strategic Plan. The public comment period is now closed. We hope that you have had an opportunity to comment.

Recommendation: Budget, reporting and incentive mechanisms need to be developed to orient performing organizations with Laboratory and Agency Goals.

Response: One of the purposes of the establishment of the NCS is to address this recommendation and facilitate mechanisms that will address this recommendation

Recommendation: NOAA cannot provide the best Climate Services without well designed partnerships with other Federal Agencies, the academic community, the resource management community, and commercial interests.

Response: NOAA has outlined its strategy to coordinate with other Federal agencies within its Vision and Stategic Framework for a NOAA Climate Service. In some cases the design for the partnership is accomplished through a bilateral Memorandum of Understanding, such as we have done with the Department of the Interior.

Recommendation: NOAA needs a clear understanding of who are its "climate customers" or "climate stakeholders". NOAA alone cannot define the stakeholders.

Response: NOAA has defined a process to conduct needs assessments in the NOAA Climate Service Vision and Strategic Framework. Before formal work begins on National and International Climate Science Assessments or Thematic Problem-focused Assessments, policy advisors and decision makers are engaged through the Climate Information Stakeholder Needs Assessments to help properly determine the issues of most relevance to the other two types of climate assessments. Theses assessments are also used to design specific services, products and/or tools for stakeholders such as policy makers, decision makers, and/or resources managers. The results of stakeholder Climate Information Needs Assessments also have immediate impacts on products and service development and delivery, which in turn impact local and regional decisions. Needs Assessments help identify what problems to focus on, by linking science to decision making.

Recommendation: The Panel suggests that NOAA develop a management strategy that is consistent with modern concepts of open innovation or open communities – a generalization of the open source software culture. (http://climateknowledge.org/figures/Rood_Library/vonKrogh_open_source_2007.pdf.) Success will require the development of community governance models, which include definition of process for building and modifying capabilities.

Response: Our management strategy for NOAA Climate Services is set up in the Climate Service Vision and Strategic Framework and has begun to be formulated and utilizing open source concepts and those items espoused in the article will be incorporated and taken into consideration as it is further developed

Recommendation: Recognizing the successful attributes of the Climate Process Teams, the Regional Integrated Sciences and Assessments Programs, and the Applied Research Centers, the Panel recommends that NOAA develop an agency-wide strategy that incorporates these middle-sized activities as key strategic elements. Specifically, integrating activities should be focused at the interface between organizations to realize strategic goals. A subset of these activities should be in the spirit of a project, with a finite lifetime to achieve specific goals, and chosen competitively.

Response: Within the development of the NOAA Climate Service, there is continued support for the RISA/Climate Process Teams etc. We see them as valuable mechanisms and will continue to utilize them.

Recommendation: In the spirit of the Climate Process Teams, NOAA should form ad hoc research teams. Funds should be set aside in advance of any team building to ensure that non-NOAA scientists will be part of any given team.

Response: We continue to utilize ad hoc research teams.

Recommendation: NOAA must recognize the importance of the information technology infrastructure necessary to support its science-based generation of products and services, including high-performance computing and communications.

Response: CRM certainly recognizes the importance of the information technology infrastructure necessary to support its science-based generation of products and services and was an active participant in the development of NOAA's High Performance Computing Strategic Plan and Roadmap

Recommendation: The CPO ought to take care to balance the funding of internal NOAA research groups and Cooperative Institutes with those of the external community to ensure that fresh ideas, perspectives and contributions can be brought forward for R2O transition

Response: The CPO views the Cooperative Institutes and Joint Institutes as one of the mechanisms for interactions with the external community. Since September 2005, NOAA's Cooperative Institute program (which includes Cooperative Institutes and Joint Institutes) has been governed by NOAA Administrative Order (NAO) 216-107 which provides for review and re-competition of Cooperative Institutes as well as the creation of new Cooperative Institutes to meet agency needs. The restructuring of the CPO programs is expected to provide more efficient use of funding to the external community.

CPO continues to develop its model for developing research that can be moved into operations and routinely has discussions with NWS and other agencies on coordinating research to support in operational model by other agencies.

Panel 5: Decadal Variability and Predictability

Recommendation: NOAA should undertake a strategic planning exercise towards (possible) operational decadal predictions.

Response: We agree with the panel that a key hurdle is to establish whether or not there is useful predictability at decadal scales. The evaluation of the CMIP 5 and IPCC AR5 decadal prediction experiments will be a near-term step for this evaluation. Planning for operational decadal predictions should be based on a solid foundation of fundamental research.

Recommendation: While the Atlantic Meridional Overturning Circulation is one of the most important foci for decadal variability and abrupt change studies, the Pacific, polar regions (including recent trends in Arctic and Antarctic ice), and southern oceans, should not be neglected.

Response: Agreed. The FY11 President's Budget Request includes support for a collaborative effort by GFDL and ESRL on Arctic sea ice variability and change and fundamental research at GFDL on land-ice dynamics.

Recommendation: Continental hydrological processes and considerations on cryospheric components of climate should also be focused. Especially, process modeling of the cryosphere should be of considerable importance in advancing the understanding of abrupt climate change.

Response: The FY11 President's Budget Request includes support for fundamental research at GFDL on land-ice dynamics.

Recommendation: Coordination is needed between GFDL, NCEP, and other research sectors on initialization and prediction systems development for decadal prediction.

Response: GFDL, NCEP/EMC and NCEP/CPC have agreed to partner on climate research activities that will be mutually beneficial to each organization. The resulting collaborative work should accelerate improvements to climate modeling systems focused on a broad set of applications relevant to Seasonal to Decadal time scales. Collaborative activities will be defined and tracked through the creation of an annual workshop, the first of which will be held in the second quarter of FY11. NCEP (CPC and EMC) and GFDL will host each other's scientists in their respective internal seminar series; exchanges will be on topics of mutual interest, with nominally two exchanges from each institution per year.

Further comments on CRM by the CWG at their Spring 2010 meeting:

Finding: The CWG noted a lack of SI climate forecasting and regional modeling in support of regional climate change assessments in the current activities as presented by the CRM Program Manager.

Response: *[See Responses on pages 12, 15, 20-21 for various facets of this issue. Here, we focus on the general challenge associated with the question.]* There are a number of fundamental scientific issues that need to be addressed as a prerequisite to producing reliable forecasts. These issues likely apply to all time-scales, not just SI timescales. The first issue to address is whether there is any predictability in the climate system, and how much arises due to natural variability versus climate forcing. The question of predictability on the seasonal-to-interannual-to-decadal scales is being researched in NOAA and must be resolved before reliable predictions can be made. This includes investigations into coupled atmosphere and ocean initializations and initialization techniques. A second issue concerns the physics of the processes involved e.g., it is well recognized that there is a fundamental scientific gap in our understanding of convection, moisture, and clouds. Progress on these topics will likely benefit climate research at all timescales. An effort to develop a major cross laboratory initiative to advance the understanding of clouds, cloud feedbacks, aerosols and water vapor was not funded in the FY12 NOAA budget process. CRM recognizes the importance of these topics to fundamental climate understanding and predictability, and will endeavor to make progress using existing resources, albeit at a greatly reduced pace. CRM continues to make progress at the regional scale through the development of global, high-resolution models. However, these models are currently running in only the atmosphere and in a time-slice mode. The coupling of these atmosphere models to the high-resolution ocean models to form the eventual high-resolution coupled model is still some years away. The IPCC AR5 report in 2013 will likely be the first-ever assessment of the regional-scale projections/predictions made by a suite of models from around the world on the interannual to decadal scale climate. Intercomparisons of these models on short timescales and on regional simulations should yield insights into our capabilities and remaining gaps. One focus will be in terms of important regional phenomena, and CRM will make some high-resolution model simulations available for this assessment. Thus, it is in the 2013 time frame (about 4 years from now) that we will get to learn more about the potential applicability of a number of such models for near-term and regional-scale climate studies.

There is one lesson to be had from the IPCC that may be of value for the ISI forecasting capability. Just like scientific uncertainties are carefully drawn out and highlighted at the end of the IPCC Assessments, so too it would be a significant benefit if an ISI Assessment, along the standards of the peer-reviewed IPCC Assessments conducted by experts in the field, could unravel the chief limitations (initialization, physics, ensembles etc.), and present the community with a prioritization of the governing factors, and propose practical solutions. A highly anticipated report in this context is the upcoming Academy report on this subject. CRM agrees that downscaling strategies should be tried, whether these happen within NOAA or in the external community, but these techniques must be carefully scrutinized especially in the light of criticism of downscaling techniques (e.g., IPCC AR4). Efforts to augment NOAA's capabilities and partnerships to make progress in regional climate modeling received favorable review (thus far) in the FY12 NOAA budget process.

Finding: Linkages between GFDL and EMC were not well identified.

Response: GFDL and NCEP (EMC and CPC) have agreed to explore areas in which collaborative research can be pursued that will be mutually beneficial to each organization. The resulting collaborative work should accelerate improvements to climate modeling systems focused on a broad set of applications relevant to Seasonal to Decadal time scales. Collaborative activities will be defined and tracked through the creation of an annual workshop, the first of which will be held in the second quarter of FY11. GFDL's MOM4.1 ocean model has been successfully transferred to NCEP for operational use. NOAA model runs are being routinely used in the seasonal forecasting applications by IRI and the results are disseminated, a commitment that has endured and will continue. NOAA has two sets of simulation runs going into the MME at NCEP, plus GFDL's CM2.1 coupled model has been run at NCEP. In each case, CWG's recommendations at the Spring 2008 review have translated into positive, proactive steps. On the model understanding and development side, some small steps for joint post-docs between NCEP and GFDL have been proposed but have not been explicitly funded by NOAA. All these efforts involve complex modeling and take time to mature and depend on the availability of resources.

Finding: It is unclear how priorities are being set.

Response: CRM has maintained the same criteria for prioritizing budget requests since its first planning cycle in the Fall of 2008 (for FY11-15). Criteria include: NOAA Annual Guidance Memorandum and relevance to agency's Mission; Climate Goal Guidance and CPO directives; consideration of the CRM charter elements; emerging NOAA Climate Service goals; consideration of IPCC assessment reports, USGCRP synthesis products and WMO/UNEP assessments and programs; scientific importance, relevance and urgency; value to IPCC AR5 and AR6; "maturity" of proposed science and how key "gaps" will be resolved; clarity of strategy and execution plans; meeting user needs (operational products, applications); high potential for practical gains in near future; links to other Programs within the Climate Goal; Cross-Goal synergies within NOAA; and previous budget decisions and justifiable augmentation. Planning for the next budget cycle (FY13-17) will be further complicated by the status of the NOAA Climate Service line office, a new NOAA strategic plan, the implementation of a new Strategy, Execution and Evaluation process that will replace the Planning, Programming, Budgeting and Execution System, and a profoundly constrained fiscal environment. FY13-17 priorities must also be responsive to the outcomes of FY11-15 planning (which won't become clear before Congresses passes the FY11 federal budget) and FY12-16 planning. Thus while CRM planning for FY13-17 formally began with a meeting in early April of 2010, it would be premature to set priorities much before the end of 2010.

Other reviews relevant to CRM

In response to a recommendation by the CWG, the CarbonTracker program was reviewed in September, 2008. The complete review and review response are included in this document as Appendix A.

While CRM exists in the current NOAA matrix structure for planning purposes under the Climate Goal, each sub-unit within CRM exists within a NOAA Line Office that is responsible for overseeing execution of that sub-unit's mandates and responsibilities. The following sub-units of CRM have been reviewed within the last four years: ESRL/CSD (January 2008), GFDL (June 2009), CPC and EMC (as part of a full NCEP review in December 2009), and ESRL/PSD (March 2010). The executive summary of each of these reviews is included in Appendix B of this document, with information indicating how the complete reviews can be found.

Appendix A: Complete CarbonTracker Review and Review Response

CarbonTracker Review

Background:

CarbonTracker was presented to NOAA's Climate Working Group (CWG) in March 2008, during the CWG's review of NOAA's Climate Research and Modeling (CRM) program. Although CarbonTracker is not formally associated with CRM, the CWG provided recommendations for CarbonTracker in the context of the CRM review. The overarching recommendation was: "CarbonTracker should receive rigorous scientific review, and it should be integrated more fully with other CRM projects."

CarbonTracker was reviewed on 16 September 2008. The review panel consisted of Professor Scott Denning from Colorado State University, Dr. Jeff McQueen from NOAA's National Center for Environmental Prediction, Professor Joseph Berry from Stanford University and the Carnegie Institution, Dr. Marian Westley from NOAA's Geophysical Fluid Dynamics Laboratory, Dr. Stan Benjamin from NOAA's Earth System Research Laboratory and Dr. Steven Pawson from NASA's Goddard Space Flight Center. The Panel benefited from interaction with Charles Miller from NASA's Orbiting Carbon Observatory project. The Panel nominated Professor Denning as Chair. Professor Denning summarized the panel's findings in an oral presentation to the CarbonTracker Team on 16 September 2008 and presented the review to the Climate Working Group on 25 November 2008. This report is the written version of the two oral presentations and represents the consensus view of the six panelists.

Scope of the review:

The review panel was charged with answering the following questions:
• Can CarbonTracker's goals and objectives be achieved? What is needed to make this happen?
• Is the scientific approach reasonable?
• Is anything crucial being omitted?
• Are important opportunities being missed?

About CarbonTracker:

CarbonTracker is an ensemble data assimilation system that optimizes multiplicative scaling factors on four model components to observed carbon dioxide concentrations from the ESRL network of greenhouse gas observatories. The model components are: fossil fuel emissions (using CDIAC data and the EDGAR system for distributing emissions data within a country), fire emissions (from Global Fire Emissions Database version 2), terrestrial photosynthesis and respiration (using the CASA model), and air-sea gas exchange (originally using Takahashi climatology, more recently using MOM3-based air-sea gas exchange estimates). Atmospheric transport is by the TM5 model and uses ECMWF reanalyses on a nested grid, using a five-week assimilation window. Flux optimization is performed at a time step of one week.

CarbonTracker's goals are:

- to improve the understanding of the carbon cycle, and
- to provide objective, policy-relevant information on the carbon cycle.

CarbonTracker's objectives are:

- to provide continually updated products;
- to develop a carbon-cycle modeling capability to complement the global observing system;
- to create a platform to evaluate mechanistic carbon cycle models; and
- to determine needs for evaluating mitigation efforts.

Overarching comments:

The review panel applauded the team for an excellent job of presenting CarbonTracker in a manner that was compelling and comprehensible to experts and non-experts alike. The written materials provided and the oral presentations to the panel were thorough and well-organized. The panel particularly appreciated the detailed and thorough presentation of the pros and cons of CarbonTracker as it exists now. The team and their presentations invited and facilitated rigorous scientific assessment.

CarbonTracker has emerged as a flagship program highlighting seasonal to interannual variability in the global carbon cycle as revealed by NOAA's atmospheric observing network. The data assimilation system itself is among a handful of similar analysis systems around the world that define the current "state of the science," each with its own strengths and weaknesses. But CarbonTracker is unique in both its visibility (due to the excellent website) and its tight integration with atmospheric CO2 observations. The initiation and evolution of CarbonTracker from GMD/ESRL's observational expertise was hailed by one panelist as a brilliant strategic move to integrate observations into a useful global gridded tool. The panel also praised the transparency of the system: all the data, model code, documentation and visualization are freely available on the internet and are backed up by technical support from the CarbonTracker team. The CarbonTracker website also contains excellent public outreach material. The ongoing and openly documented incremental improvements to the observations, models and data assimilation system are commendable. There are dependable and regular updates, on a published timeline. CarbonTracker has demonstrated success in documenting interannual variability in carbon fluxes. The insistence on rigorous, continued vigilance and detection of biases is a major strength of CarbonTracker and it was observed that this philosophy flows from the experience of implementing and maintaining NOAA's Greenhouse Gas Observatories.

CarbonTracker is critically understaffed: 3.6 FTEs at ESRL is barely adequate for producing annual updates and does not allow for the type of growth that would be necessary for including future space-based observations of CO2 into the system. The relationship between CarbonTracker and other NOAA carbon cycle, weather and climate modeling efforts should be strengthened. The lack of formal feedback to coupled models misses an important opportunity for improving predictions of future states of the Earth System. Collaboration and leveraging developments within other parts of NOAA and other U.S. Agencies is important for continued improvement of CarbonTracker.

Technical issues:

Given the coarse sampling of the atmosphere represented by the current observing network, weekly scaling of component fluxes is applied only after aggressive preaggregation into large "ecoregions." Preaggregation reduces the degrees of freedom to allow well-constrained estimates, but the assumption that very large areas behave uniformly may not always be justified and therefore introduces bias into the weekly estimates. Hourly fluxes are calculated by underlying component models on a 1° grid, but estimation is made only on a weekly basis over fewer than 20 regions for all of North America. The detail provided in visualizations (especially those using Google Earth) greatly exceeds the true resolution of optimized fluxes, leading to the potential for spurious interpretations by uneducated users.

Multiplicative scaling is applied to component fluxes using sensitivities calculated following five weeks of downstream transport in the atmospheric model. Five weeks is probably sufficient for fluxes in North America to be felt at observing stations at all longitudes of the northern middle latitudes, but the five-week transport window is not sufficient to "see" fluxes at remote observing sites (e.g., the South Pole). Fire and fossil fluxes are specified (not optimized in the system), meaning that the validity of CarbonTracker depends on the validity of the fossil fuel and fire fluxes input into the model. Any errors in distribution or timing of emissions from fossil fuel or biomass burning are misinterpreted by the system as biological or air-sea fluxes.

The propagation of model state and error covariance in CarbonTracker is reasonable, but the chosen implementation is not used to estimate error in the optimized weekly fluxes. Error estimation is not straightforward given the complicated system for combining hourly gridded component fluxes, weekly ecoregion scaling, and temporal and spatial covariance. CarbonTracker errors have been estimated by performing sensitivity experiments, but the communication of these uncertainty estimates to the public via the website is much less clear than the finely gridded fluxes reported there.

CarbonTracker suffers from computational limitations: it currently uses only 32 CPU cores, and could easily absorb an order of magnitude greater computational capacity. Parallelizing component models (especially TM5) might involve substantial software engineering, but the data assimilation system is inherently parallel at the level of ensemble members. It should be quite feasible to improve computational performance by allocating a separate processor core for each ensemble member. The current use of a "nested" atmospheric grid to emphasize North America reflects a compromise between the need for high-resolution transport and limited computational resources. Even a modest boost in resources would make it possible to run the system globally at the native resolution of the meteorological reanalysis.

Scientific concerns:

The panel noted that CarbonTracker should be considered a research and monitoring activity that makes brilliant use of the ESRL observing networks. However, the panel is concerned that CarbonTracker may be marketed as a fossil-fuel emission monitoring tool. The panel notes that fossil-fuel emissions are assumed in the model, and that fossil-fuel emissions monitoring is not feasible in the near-term given the present state of the observing system. The panel questions whether monitoring fossil-fuel emissions is a desirable goal, given other, much more accurate methods of tracking fuel use. One panelist also suggested that emissions monitoring could be more appropriately conducted under an international umbrella such as that of the World Meteorological Organization, and cautioned NOAA against moving forward too rapidly in this area without international coordination. On the other hand, CarbonTracker could be an excellent tool for testing, in model space, what additional observations will be necessary as we move towards a carbon-constrained economy.

CarbonTracker's use of "off-the-shelf" model components is practical but not optimal for improving prediction. The system is clearly designed to analyze and interpret ESRL's current atmospheric observations. The system is unable to use additional data constraints, such as flux towers, output from the FACE experiments, carbon stock inventories, sea surface temperature, or ocean color. A comprehensive NOAA effort to diagnose, understand, and predict changes in the carbon cycle should include optimization of model parameters and state variables that incorporates all available constraints. Integration with other NOAA efforts to develop prognostic Earth System Modeling Framework (ESMF) components would allow an unprecedented opportunity for model evaluation and enhance prediction of global change. Research and development efforts should be extended to managed components of the carbon cycle such as agriculture, commercial forestry, urban/suburban landscapes, electrical power generation, and transportation.

Flux maps generated by CarbonTracker look like biogeochemical reanalyses. However such a reanalysis should be a set of model states, boundary conditions and fluxes that provide the optimal match to 4D analyses of atmospheric CO_2 distributions. Adjusting flux multipliers without optimizing states and parameters in the underlying carbon cycle models used to generate those fluxes results in inconsistencies between the net CO_2 fluxes reported by CarbonTracker and the underlying models. While this prototype system for integrated Earth system analysis points to improved predictions of the carbon cycle, it does not optimize the "spun-up" model state or model parameters.

Recommendations:

1. NOAA should consider CarbonTracker a prototype for a vigorous investment in Integrated Earth System Analysis that integrates observations, climate process modeling, understanding,

and prediction in a formal way across its Climate Research and Modeling program. Predictive model development at GFDL and the initiative to produce decadal climate prediction, in particular, would benefit from a rigorous and ongoing evaluation against operational observations of the carbon cycle. Such a formal program linking observations, modeling, prediction, and dissemination could be a "poster child" for engagement of stakeholders and the public in a new NOAA Climate Service.

2. Near-term CarbonTracker development should include both increased resources and effort (both computing and personnel) and tighter strategic integration with the larger CRM program. The effort is critically understaffed for growth beyond the current prototype effort. Tripling the number of scientific and technical staff and expanding computing resources by an order of magnitude would be a reasonable target in the near term. CarbonTracker would benefit from the addition of personnel specialized in both CO2 and CH4 forward modeling. CarbonTracker could easily absorb up to 100 times its current computational capacity. With greater computing capacity, CarbonTracker should consider running the transport model at much higher resolution. NOAA should leverage its other resources to augment CarbonTracker, including computing resources available to the agency, models developed and maintained by NCEP, GFDL, and ESRL, and activities taking place at NOAA's Cooperative Institutes.

3. NOAA should pursue a major expansion of its greenhouse gas observation network to allow more effective data assimilation for CarbonTracker and further Earth system modeling efforts/data assimilation efforts that are evolving in NOAA. NOAA should also provide increased resources for the QA/QC and intercalibration exercises for greenhouse gas measurements that are necessary to bring non-NOAA observations into a coherent and high quality global database.

4. The panel identifies four important roles for CarbonTracker in NOAA:

a. Carbon cycle diagnosis and analysis.
This is envisioned simply as a continued ongoing assimilation of ESRL CO2 observations, but more frequently and with fewer system updates. We recommend that the production cycle be decoupled from the development cycle: there is no need to completely re-engineer the system each time a new suite of flux estimates is produced. It should be quite feasible to extend the existing flux analysis with monthly updates posted to the web, perhaps with interpretive text highlighting emerging regional anomalies. Annual or less frequent system updates and reanalyses would not be precluded, but should only be undertaken when justified by significant new developments. Routine and frequently updated flux analyses would facilitate change detection, source/sink attribution, and public outreach.

b. Rationalization of future observing system enhancements
With adequate staff and computing support, the marginal effect of new observations on land, in the oceans, in the atmosphere, or in orbit could be easily explored through a streamlined

CarbonTracker. Investments in new capabilities could be quantitatively evaluated against well-established metrics for source/sink estimation.

c. Development testbed for ESM components

As NOAA develops prognostic models of carbon cycle processes to be used for decadal or century-scale prediction (e.g., at GFDL and NCEP), these components should be tested against CarbonTracker reanalyses for consistency with historical observations. This is precisely analogous to the evaluation of a new convective parameterization or dynamical core by comparison with weather reanalysis.

Incorporation of the component modules within the Earth System Modeling Framework (ESMF) is strongly recommended to leverage alternative transport and flux modules such as the NOAA/NEMS. This will allow access to any additional fields (e.g.: cloud mass flux) not available in the current operational NWS model outputs. Linkages to biomass emission modules being integrated into NEMS could also be leveraged.

A comprehensive observational testbed for biogeochemical components of Earth System Models should include assimilation of a much wider range of data as well as model state and parameter estimation. The optimization system should be generalized to include constraints by multiple atmospheric tracers (e.g., CO, CH4, COS, δ13C, δ 18O, O2/N2) as well as other types of observations such as eddy covariance flux towers, FACE experiments, physical ocean state, ocean color, ARGO floats, and biometric inventories. Serious development and routine use of an observationally based system for Integrated Earth System Analysis would also serve as a rational platform for initialization of decadal prediction efforts at NOAA under the CRM program.

d. Platform for research on the changing carbon cycle

Future development of CarbonTracker should also be a focus area for NOAA carbon cycle research. Priority should be given to development of component models that represent important aspects of the human-managed carbon cycle: fossil fuel emissions, agriculture, managed forests, and urban/suburban landscapes. Ocean components should include links to assimilation of the physical state of the ocean using remote sensing of sea surface temperature and height, with biogeochemistry and ecosystem models constrained by ocean color.

Changes in carbon cycling are one of the leading sources of uncertainty in projections of future climate, and CarbonTracker should provide a window into understanding these changes. An active research program investigating responses of regional land and ocean carbon to interannual variations in climate can be pursued using flux estimates from the system. Future research and development of carbon cycle processes for CarbonTracker should be conducted in collaboration with the very impressive constellation of related work within NOAA and in the larger community. One opportunity for collaboration would be through extramural programs (NOAA's Global Carbon Cycle program). Another would be to engage the Community Climate System Model community.

NOAA Earth System Research Laboratory
Global Monitoring Division
August 18, 2010

1. Background

The review of NOAA's Climate Research and Modeling program in March 2008 concluded that a detailed, scientific review specific to the CarbonTracker program was warranted. In direct response to this conclusion, the NOAA Earth System Research Laboratory convened a panel of carbon cycle and modeling experts on 16 September 2008 to conduct a scientific and technical review of the CarbonTracker (henceforth, CT) program. The review panel delivered its report on 28 September 2009 (http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/review_files/CT.review%2020090928.pdf). This document details the CT response to that review.

2. Review findings and recommendations

The review panel was gracious in its praise of CT's progress to date. In addition to their compliments, the major findings of the review panel were:

> ***F1. CT is understaffed;***
> ***F2. CT should expand its use of computing resources;***
> ***F3. CT should benefit from other NOAA modeling efforts, specifically the prognostic carbon models of GFDL and the meteorological state estimation of NWS;***
> ***F4. The presentation of CT results should emphasize its native scale of estimation instead of higher-resolution 1°x1° maps;***
> ***F5. CT should assimilate other CO2-relevant data such as eddy covariance fluxes and remote observations of the sea-surface;***
> ***F6. The CT inversion system is limited by a 5-week estimation window, by its use of assumed fossil fuel emissions, and by difficulty in estimating true uncertainties; and***
> ***F7. CT should not be oversold as an emissions verification tool.***

The panel made three broad recommendations for the CarbonTracker program:

> ***R1. NOAA should consider CT as a prototype of an integrated earth system analysis that links observations, modeling, prediction, and dissemination of results;***
> ***R2. In the near term there should be an increase in personnel (3x) and computing resources (10x) for CT, and this expansion should include efforts to integrate with and benefit from other NOAA carbon, climate, and weather modeling programs; and***
> ***R3. NOAA should pursue a major expansion of its greenhouse gas observation network.***

Finally, the panel identified four perspectives from which to view CarbonTracker's role within NOAA:

> ***P1. As a device for carbon cycle diagnosis and analysis;***
> ***P2. As a platform for rationalizing enhancements to the observation network;***
> ***P3. As a development testbed for earth system model components; and***
> ***P4. As a tool for research into the changing carbon cycle.***

3. NOAA/ESRL response

The response by NOAA/ESRL and the CT team to comments by the CarbonTracker review panel and the CRM review panel comprises specific enhancements in the CT2009 and upcoming CT2010 releases of the CarbonTracker product, ongoing developments of the CT program, and two broader initiatives: the creation of a NOAA Carbon Cycle Research Plan, and attempts to increase the CT budget.

NOAA Carbon Cycle Research Plan. In February, 2009, representatives from NOAA's PMEL, AOML, and GFDL gathered at ESRL to begin work on a coordinated plan for observations, analysis, and modeling for NOAA carbon cycle research. This emerging document is seen as a way of directing NOAA carbon cycle research, by coordinating observational programs, sharing modeling resources, and collaborating on analysis efforts. This plan should help to address panel findings **F2**, **F3**, and **F5** above, by providing a framework for sharing analysis products like the *p*CO2 air-sea flux maps being generated at AOML and PMEL, and by sharing model products between GFDL and ESRL. Furthermore, it promotes the across-laboratory vision for using contemporary atmospheric CO2 observations to evaluate and constrain climate models (**P3**, above), and recommendation **R1** involving the creation of an integrated earth system analysis. A draft of the plan is being circulated among the authors this summer, with broader circulation within NOAA anticipated for this fall.

FY11 Budget Increase. A funding alternative including a significant increase for greenhouse gas observations and modeling at ESRL was proposed to NOAA for FY2011. This alternative as successful through the entire planning process at NOAA and the Department of Commerce, and was included in the FY2011 President's Budget. The additional funds, pending Congressional approval, will be devoted to increased atmospheric CO2 observations, to data management efforts, and to increased manpower for CT modeling. This is a direct response to **F1**, **R2**, and **R3** above.

Collaborations with academic institutions. We have a vigorous program of active collaborations with academic institutions. We have trained researchers from U Wisconsin, U Michigan, Colorado State University, UC Irvine, Berkeley, Oregon State, and Penn State University to work with CT results and models. Numerous proposals have been generated with several notable successes already leading to postdoctoral position advertisements. The increased scrutiny of CT results has proven invaluable for identifying CT strengths and weaknesses (**F6**), and in the absence of direct funding increases, these collaborations are essential for addressing the finding **F1** of personnel shortages. It should be noted that these collaborations do not directly address NOAA's CT development priorities, since they are generally funded to use the existing CT platform as an analysis tool.

Collaborations within government. The CarbonTracker effort is seen as a notable success for the North American Carbon Program (NACP), and CT team members are strongly involved with NACP activities. The Department of Energy has shown significant interest in collaborating on CO2 modeling, and CT members have active accounts on supercomputers at Sandia National Labs and Oak Ridge National Labs. The current CT implementation does not scale well to using large numbers of CPU cores, but establishing the ability to exploit expanded computing resources is a high priority for CT development (*cf*. recommendation **R2**).

International collaborations. In addition to the domestic partners from academia and government mentioned above, the CT program has generated significant interest from international collaborators. Due to its use of regional high-resolution transport, the CT framework lends itself to other implementations. To date, the CarbonTracker Europe (Wageningen University) and CarbonTracker Asia (Korean Meteorological Agency) efforts have been most prominent. Regional CT simulations for China, Canada, New Zealand, and Brazil are all currently underway. This community of collaborators is promoted by the philosophy of complete openness within the CT project at NOAA, and having these partners indirectly addresses panel findings **F1** and **F6**.

CT2009 release. The October 2009 release of the CT product incorporated several significant changes in response to review panel concerns. We emphasized the ecoregion-scale estimation scheme by presenting "patch" flux maps as the primary visualization tool; we developed documentation pages specifically aimed at describing the ecoregion flux estimation scheme, and rolled out several documentation upgrades on uncertainty estimation and the effects of design decisions in our inversion scheme. These enhancements address finding **F4** directly, and begin to address finding **F6**.

OGP – GCC sponsored research. Two research proposals for CT development were funded by NOAA's Global Carbon Cycle program. The first, led by Wouter Peters, Kevin Schaefer, and John Miller of the University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES), Wageningen University, and the National Snow and Ice Data Center, aims to introduce a new terrestrial model into the CT framework, and to explore the direct assimilation of eddy covariance data. This effort directly addresses finding **F5**, and by entraining external partners (Peters and Schaefer), helps to address recommendation **R2**. The second piece of sponsored research is led by Andy Jacobson, also of CIRES, and is an attempt to create a new air-sea flux model driven by *p*CO2 observations extrapolated using remote observations of the sea surface. This product begins with GFDL ocean modeling and an air-sea flux inversion generated at the Princeton-GFDL cooperative institute. It builds on observations collected by AOML and PMEL, as well as analyses and modeling efforts at those institutions, thus addressing findings **F3** and **F5** above.

CT2010 efforts. A major revision to the CT inversion scheme is planned during FY2011. The CT product will be generated using a multi-model ensemble of two land models and two ocean models. The ocean models both use *in situ p*CO2 observations to drive flux variability, and one of them uses GFDL assimilated ocean currents. The land models are both tuned to eddy covariance flux observations and other terrestrial carbon cycle constraints. This variety of input data being used to generate prior fluxes goes a long way towards addressing finding **F5** above. The creation of a multi-model ensemble also requires a review of CT's parameter model, and will most likely involve an improvement to the current scheme of estimation scaling factors in a 5-week estimation window. By including multiple land and ocean models, a fuller picture of the true uncertainty should emerge. Both of these developments address finding **F6**.

FIM. We are beginning to evaluate the new NOAA FIM (Flow-following, finite volume icosahedral model) for use in global tracer studies. This model platform is strongly tied to NWS model development, and includes GFS model physics packages and uses GFS analyses as initial conditions. In collaboration with other divisions at ESRL, an ensemble Kalman filter for weather data assimilation has been ported to the FIM, and the exciting possibility of joint carbon-weather assimilation is now conceivable. This model bridges ESRL and NWS efforts, giving a direct means of addressing finding **F3** and recommendation **R2**. As a potential platform for integrated weather-CO2 analysis, it addresses recommendation **R1**. Its online tracer transport also provides a means of dramatically increasing the resolution of atmospheric modeling—potentially to 15km scales—and provides a way of better exploiting NOAA computing resources (finding **F2**). By involving a larger NOAA community, this effort also helps to address the personnel shortage identified in finding **F1**.

We take issue with finding **F7**. While CT is currently far from a tool that can be used to verify emissions at a regional scale, we strongly believe that global carbon analysis of this sort is required to identify shortcomings in our understanding of the carbon cycle, including the role of anthropogenic emissions, especially on subcontinental scales. Indeed, at the largest of scales, CT is already a tool for demonstrating (in)consistency of fossil fuel emissions estimates and surface CO2 exchange with observed atmospheric growth rates. As our models of fluxes and atmospheric transport improve, and as the observational network becomes more complete, the scales at which atmospheric inversions provide constraints on emissions will become smaller. Our belief is that atmospheric verification of CO2 emissions will be crucial to mitigation efforts, and we need to have tools like CT now to identify modeling and observational shortfalls which limit the utility of the atmosphere to inform policy.

4. Summary

By vigorously pursuing external collaborations with federal, academic, and international partners, the CarbonTracker program is ensuring that there will be increased resources available in the future. While these resources are not dedicated to CT development, this diverse set of collaborations provides a base for improving models and assimilation techniques. At the same time, we are working hard to justify increased direct funding and to coordinate carbon cycle research across NOAA laboratories and have succeeded so far in getting such funding included in the President's FY2011 budget. CarbonTracker continues its program of annual product releases, with incremental improvements to observations and modeling techniques. We remain committed to openness, with the conviction that scrutiny of our product by a wide community will provide the feedback necessary to understand the limitations of our analysis and guide its improvement.

Appendix B: Summaries or overviews of laboratory reviews relevant to NOAA's Climate Research and Modeling Program.

B1: Summary and synthesis of specific reviewer comments from the January 2008 ESRL Atmospheric Chemistry Review[1]*:*

Clearly the ESRL's Atmospheric Chemistry Research has an outstanding and exceptionally productive scientific staff that has contributed to a greatly improved scientific understanding of important environmental issues, including stratospheric ozone, air quality, and climatically important gases and aerosols. Several ESRL atmospheric chemistry scientists are recognized internationally as being among the most talented and respected of the world wide scientific community addressing these important societal issues. In addition to their high scientific research productivity, these scientists have also played a major (perhaps even a disproportionately large) role in major international efforts aimed at developing policy-relevant scientific assessments of these issues (e.g., IPCC and stratospheric ozone). Another major contribution of the ESRL Atmospheric Chemistry research includes the international leadership role it has played in the calibration and standardization of the global efforts to document the changing nature of the atmospheric composition.

With respect to the requested evaluation topics, reviewer input was essentially unanimous and consistent across all the groups evaluated.

Quality: ESRL's atmospheric chemistry researchers constitute one of the top atmospheric chemical sciences groups in the US and rank among the very best in the world. The overall quality of the atmospheric chemistry science being conducted at ESRL is outstanding in most respects.

Relevance: The ESRL atmospheric chemistry research activities were also judged to be especially relevant to both national an international environmental priority areas of importance to society. They have played a leading role nationally and internationally in documenting and understanding climate change, stratospheric ozone, and local and regional air quality.

Performance: The scientific leadership and planning is outstanding and has been a hallmark of this group for the last three decades. The performance of the ESRL atmospheric chemistry scientific staff has been outstanding and has provided many major scientific contributions for major national and international assessments that are of use to society and policy makers around the world. All in all, ESRL's atmospheric chemistry research is a remarkably effective and

[1] Complete review available from Michael Uhart, Executive Director, Office of Labs and Cooperative Institutes: Michael.Uhart@noaa.gov

efficient, although the efficiency of the effort would be improved with increased technical, engineering and IT support staff. This effectiveness might also be increased if it were better linked to the fuller set of NOAA research (see item two below).

There are two major issues of concern that reviewers identified that seem to be common to the various groups within ESRL atmospheric chemistry. The first is the observation that the demographics of the scientific staff is skewed perhaps too much toward senior personnel, and this raises the question of whether of not ESRL will be able to maintain the exceptional scientific and leadership quality and reputation for excellence in the longer term. The second deals with the relationship of ESRL atmospheric chemistry with other related NOAA activities both internal and external to OAR.

The issue of demographics concerns the health and durability of the scientific work force in ESRL's atmospheric chemistry activities. This group has a number of extraordinarily talented scientists that are recognized around the world for their scientific productivity and creativity. However, this is reflected in mostly the more senior staff of the laboratory with a number of these individuals now at a mature stage of their career with many now (or soon will be) eligible to retire. A common observation in the discussions and individual reviews comments was a concern that there may be an inadequate infusion of highly talented younger scientists to ensure the maintenance of the scientific stature of the ESRL chemical sciences research in future years. It is recognized that new or open positions have been tight and management is limited in what can be done to obtain this new talent. This problem is addressed somewhat through the use of non-government positions in CIRES, however, the very brightest and most desirable young scientists are opting for positions in academia or other government labs when it appears there may not be a position in ESRL in the near future.

A somewhat related point, as mentioned above, concerns the availability of technical support (i.e., technicians, engineers, IT, etc.) for the different scientific groups. In several cases it appeared that the scientific leaders had to spend more time than desirable on activities that could be handled by technical support staff. This means that there is less time for the scientists to spend on the more scientifically challenging issues being addressed by the ESRL atmospheric chemistry scientists.

A second concern that was common to the activities being reviewed was the nature of the relationship of the ESRL atmospheric chemistry research to other NOAA groups both internal and external to OAR. It was clear in some cases that very effective partnerships are at play with international and other agency organizations but reviewers felt that it was not clear how effectively ESRL interacted with other NOAA groups doing related and complimentary work. This may simply be the result of an oversight in preparing the materials for distribution and the presentations, but the near total lack of attention to this subject was of significant concern to the reviewers. This is an issue that should be explicitly addressed by both ESRL and the review panel in future evaluations.

In summary, ESRL atmospheric chemistry research is one of the crown jewels in NOAA and the nation in addressing several of the most pressing environmental issues facing the country and world today. NOAA and OAR management should do everything possible to maintain the position of prominence that it currently enjoys. Possibly the two most important are to allow the recruitment and retention of young new ESRL staff that will become its future scientific leaders and to be able to demonstrate the value of ESRL's research to a broad range of NOAA's activities.

B2: Summary report of the review of the Geophysical Fluid Dynamics Laboratory, June 30 – July 2, 2009[2]

Introduction

The Geophysical Fluid Dynamics Laboratory (GFDL) deserves enormous credit for its conduct of this quadrennial review. The high level of thought and preparation that went into every presentation was readily apparent, and was greatly appreciated by the panelists and myself. The extent to which the entire GFDL staff cares passionately about the future of the lab is heartening, and offers great hope that GFDL will maintain and enhance its prominence within the National Oceanic and Atmospheric Administration (NOAA) and the scientific community. I was equally impressed by the dedication of the panelists involved in the review, who have all shown a genuine desire to help the lab succeed. Their constructively critical evaluations and recommendations are eloquent and perceptive, and clearly demonstrate their generous investment of time and effort to the review process. The high level of commitment on the part of the panelists, the GFDL staff, and NOAA administrators resulted in an extremely productive review process.

In accord with NOAA guidelines, the panelists did not seek consensus in their evaluations of the lab. Nevertheless, a number of common themes emerge in their recommendations, which I have attempted to summarize below. Some of the panelists' recommendations are quite specific, but many are open ended, encouraging GFDL to think strategically about its future and come up with its own answers. The panelists' comments also go beyond internal recommendations to GFDL and address broader questions regarding GFDL's role within the Office of Oceanic and Atmospheric Research and NOAA, and NOAA's expectations of GFDL.

Any recommendations for GFDL's future development must be prefaced by an acknowledgement of the remarkable accomplishments of its recent past. Panelists were unanimous in their praise for the excellent quality of the lab's research on the underlying dynamics of climate variability and climate change, arguably the core disciplines of the lab. The lab's most visible accomplishment is its coupled climate model, which was described by two panelists (Marshall and Hurrell) as among the best, if not the best, climate model in the world today. Hartmann notes further the "very high technical and scientific standards" which GFDL applies in its modeling efforts, and mentions, as does Kasibhatla, GFDL's role in advancing the representation of aerosol forcing and aerosol-cloud interaction in climate models. Panelists also expressed enthusiasm for the work presented on high-resolution model simulations of hurricanes, and their implications for forecasts of the severity of hurricane seasons as well for assessments of changes in tropical storm frequency associated with global warming.

Perhaps the most encouraging aspect of the modeling effort is the extent to which it demonstrates a high level of performance in tackling lab-wide projects. Marotzke and Marshall characterized the model development of the past 10 years as a "turnaround", Marotzke noting that GFDL has

[2] Complete review materials are available at: http://www.gfdl.noaa.gov/2009review

“come back in style” after falling behind around the turn of the century. The collaborative performance is evident from the wide variety of contributions that led to the success of the model, including the development of physical parameterizations, finite volume dynamics on the cubed sphere, software infrastructure for scalability, and diagnostic comparisons against observations.

Reviewers are equally enthusiastic in their assessment of GFDL’s relevance to NOAA’s mission and to the nation’s scientific enterprise. They note in particular GFDL’s role in developing global coupled climate models, which are essential to developing a predictive understanding of climate variability and change. As Marotzke puts it, “GFDL is the only lab within NOAA that is capable of comprehensive climate model development. Thus GFDL fulfills a critical strategic need.” This sentiment is echoed by other panelists, for instance in Marshall’s claim that “model development at GFDL is very relevant and essential to NOAA and national needs.” Hartmann notes in particular the value of MOM (Modular Ocean Model), the ocean model developed at GFDL, which is “used by many operational and research organizations throughout the world.”

Panelists also praised the lab for its relevance to U.S. and global efforts to understand and anticipate physical climate change. Cox points out that GFDL’s work on physical climate change contributes strongly to NOAA’s stated climate goal, which is to “understand climate variability and change to enhance society’s ability to plan and understand.” Hurrell notes the “leading role GFDL scientists play in community service activities such as Intergovernmental Panel on Climate Change (IPCC), Climate Change Science Program (CCSP) assessment reports, National Academy of Sciences panels, editorships, etc.” He also applauds GFDL’s contribution in enabling community involvement in the IPCC process by making thousands of years of climate change simulations available to the public. This is just one example of GFDL activities that have had a huge impact in “facilitating community involvement in climate variability and change science.” He argues that “NOAA should recognize this, and take pride in it”. Likewise, Marotzke notes the value of the lab’s work on global warming mechanisms and their consequences. More generally, he points out that “GFDL is the only lab within NOAA that is capable of fundamental work on climate dynamics, as well as on developing predictive capabilities.”

Assessments of the lab’s work in the area of carbon, biogeochemistry, and climate, and the effort to develop an Earth system model (ESM) were mixed. Panelists noted that carbon cycle modeling is not a traditional strength of the lab, and that the lab relies on its collaborators at Princeton and elsewhere to fill the gaps. Marotzke characterizes the situation by saying that “GFDL is still building up its biogeochemistry capability”, an impression reinforced by his inability to see “clearly defined and passionately debated scientific goals from this area.” Kasibhatla notes the reliance of the ESM effort on external collaborations, writing that progress in ESM development has been “built on GFDL’s expertise in physical climate modeling, Princeton’s expertise in land vegetation modeling, United States Geological Survey contributions related to hydrology and water resources, and the combined GFDL-Princeton expertise in ocean modeling.”

Cox notes further that “the translation of Princeton University expertise into GFDL models has been slow to date, as the relevant biogeochemistry was developed [at Princeton] in the early to mid 1990s.” As a result, GFDL is “10 years behind the leading climate modeling groups in carrying out their first coupled climate –carbon cycle simulations, and has quite a bit of catching up to do.” Hartmann offers a counterpoint to this assessment, noting that GFDL has always emphasized quality, rigor, and depth over complexity. He characterizes GFDL’s approach as “limiting the scope of the model to those elements that are most critical or basic, before increasing complexity with components of what will be called an Earth System Model.” He argues that this is “good scientific method and returns better value to the taxpayer and greater scientific understanding than a more complex model in which the components are of lesser quality.”

In sum, the reviews paint a very positive picture of GFDL as a lab with considerable strengths in core areas of vital relevance to NOAA’s goals. Nevertheless, panelists see significant challenges ahead for the lab, and they have given careful consideration to the steps GFDL should take to maintain and enhance its scientific standing and its value to NOAA and the nation. Among the major challenges are decadal prediction, Earth system modeling (ESM), and defining GFDL’s role in a National Climate Service (NCS).

B3: Executive summary of the December 2009 Community Review of the NCEP Environmental Modeling Center[3]

The University Corporation for Atmospheric Research (UCAR) was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to facilitate a thorough and thoughtful community review of the nine centers that comprise NCEP, as well as the NCEP Office of the Director. This report summarizes the review of the Environmental Modeling Center (EMC) that was conducted by the panel that also reviewed NCEP Central Operations (NCO).

For the NOAA numerical weather and climate prediction endeavor to serve the nation adequately and be comparable to those that are the best in the world, NOAA must ensure that EMC and NCO work to:

- Create a culture and work environment that attracts an extraordinary cadre of talented scientists skilled in various aspects of numerical weather and climate prediction. This will require innovative personnel policies, a much greater fraction of civil service positions, opportunities for advancement based on scientific and technological contributions, and systematic mechanisms and commitments for ensuring cooperation and collaboration with the national and international modeling communities.

Deploy computer capabilities that are comparable to or better than those of other major international centers. This will require a substantial increase in computer power and data management and storage facilities;

- Provide adequate human resources to meet the stated operational mission;
- Employ data assimilation capabilities that are significantly advanced beyond those now used. This will require a careful examination and comparison of next-generation possibilities, including four-dimensional variational analysis (4D-Var) methods and ensemble Kalman filter approaches as well as a hybrid variational-ensemble approach; and
- Embrace an entirely new approach to model development and implementation. This will require a substantial effort to focus on creating a single, powerful, flexible, multi-scale atmosphere-ocean-land surface modeling approach that can be specialized to specific resolutions and time scales. It should be an effort that involves the entire national weather modeling community and engages partners from other agencies, academia, and the private sector. It will require a substantial commitment from NOAA and it is both urgent and absolutely essential to begin today in order to advance U.S. capability to an acceptable level in the decade to come.

[3] Complete review available from EMC Director Stephen Lord: Stephen.Lord@noaa.gov

B4: Executive summary of the December 2009 Community Review of the NCEP Climate Prediction Center[4]

A review of the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) was conducted in June 2009 as part of a comprehensive review of the National Centers for Environmental Prediction (NCEP). The CPC review panel was asked to examine the Center's mission to determine its relevance, appropriateness and alignment with NCEP's strategic plan, in addition to assessing the quality, relevance and impact of its operational products and services, and the productivity and quality of its scientific activities.

The review found that the Climate Prediction Center continues to serve as a national and global asset for providing climate predictions, analyses and assessment products. CPC's products and services target time scales ranging from weeks to about a year and are vital for NOAA's stewardship of life, property, and the economy. CPC is recognized as a global leader in climate monitoring, development and dissemination of reanalysis products and intra-seasonal prediction, and CPC stakeholders see CPC as an 'honest broker' of climate information. The vibrancy, commitment and talent of the staff are clearly evident and contribute to the productivity, value and relevance of CPC.

Below are the key findings and recommendations as arranged by the themes of NCEP's Strategic Plan. These findings and recommendations are related to each other and should not be considered in isolation. Additional findings and recommendations are in the body of the report.

Mission and Vision

CPC's mission is clearly articulated with its products vital to the NOAA Climate Services (NCS) activity and to the nation. Under its current director, CPC has embraced strategic planning, and its implementation plan is wholly consistent with the NCEP strategic plan. Overall, the shared strategic planning and vision by CPC provides a consistent framework for the Center personnel to carry out research and development that should allow for an evolution of its products and services over time.

The panel is concerned that CPC appears to have a low priority in the National Weather Service (NWS) mission planning and in the NCS initiative, which manifests in a sense of uncertainty about the Center's future mission. This is similar to the situation found in the 1998 CPC review ("It is a consensus concern of the Panel that CPC and its components of Climate Studies and operational Products and Services are vital but appear to be a low priority for the National Weather Service.")

[4] Complete review available from CPC Director Wayne Higgins: Wayne.Higgins@noaa.gov

Recommendation: The panel believes that CPC must play a critical and essential role in any future NCS activity, and recommends that ongoing NCS planning fully engage and involve CPC management. This will ensure that CPC's mission objectives, products and services, and expertise are represented.

Customers and Partners

CPC has a long history of proactively reaching out to the research community, e.g. hosting the annual Climate Diagnostics and Prediction Workshop, and interacting with the community in its scientific developments. By necessity, CPC also interacts with other NCEP centers, groups within NWS and NOAA (examples include the NWS/Office of Hydrologic Development (OHD), the NOAA/Office of Oceanic and Atmospheric Research (OAR)/Climate Program Office (CPO), and the Regional Integrated Sciences and Assessments (RISA) centers). This reflects the quality of CPC scientists and the importance of their work to the community.

By necessity, they also have collaborations and relationships with other NCEP Centers. While CPC and the Hydrometeorological Prediction Center (HPC) appear to have a mutually productive relationship, the panel is concerned that there is an apparent lack of balanced, mutually respectful and productive relationships with some centers within NCEP. This situation is impeding CPC from better executing its mission and developing its products and services. Specifically, the relationships between CPC and the Environmental Modeling Center (EMC) and CPC and the NCEP Central Operations (NCO) need to be improved if NCEP is to reach its potential in climate products and services. CPC requires cooperation with EMC for necessary Climate Forecast System (CFS) model improvements and the development of a National Multi-Model Ensemble (NMME) system, and CPC is dependent on NCO in transitioning to operations forecast products and services developed at CPC. The panel is aware of examples of successful EMC-CPC collaborations, including the recent work on high-resolution CFS-based seasonal hurricane outlooks and monitoring of the production of CFS Reanalysis in real-time. Such successes must be expanded. This means having an effective mechanism whereby EMC and NCO establish relationships with CPC in which roles, mission priorities, and intra-center roles and responsibilities must be clarified and clearly articulated.

Given CPC's critical dependence on CFS for many of its key products, and its unique role with respect to EMC, it is to the benefit of both organizations that it play a more integral role in the development of CFS – this includes (as examples) access to intermediate model versions for assessing and diagnosing climate variability and predictability, and the capability to do sensitivity experiments that can provide feedback to EMC regarding model development priorities, which could be facilitated by having CPC rotators in EMC and vice-versa.

Recommendation: It is recommended that effective mechanisms be developed that address center roles, mission priorities, and intra-center activities and responsibilities. This will lead to true partnerships between EMC and CPC in facilitating needed improvements to CFS and the development of a NMME system, and between NCO and CPC in the transition from research to operations (R2O) of CPC products and services that are ready to be made operational.

Products and Services

CPC has established itself as a world leader in the development of climate products. As examples, CPC has had a pioneering role in the development and dissemination of reanalysis products for climate monitoring and analysis, they have a leadership role in El Niño Southern Oscillation (ENSO) monitoring and prediction as well as for drought assessment and prediction products. CPC, in collaboration with EMC, is also taking a leading role in the development of new high-resolution CFS-based seasonal hurricane forecast products. The number of CPC products has greatly expanded over the years, and it's a testament to CPC and its scientists of their wide usage. But the review found that CPC faces the challenges of maintaining its current portfolio of products, and developing new, desired products and services, within its budget. CPC needs to determine what its essential climate products and services are, and what information is needed by the nation and decision makers, so CPC can generate and deliver its essential products and climate information effectively.

Recommendation: CPC needs to implement formal mechanisms for assessing its products and services with the goals of identifying those that are essential and must be maintained, those which can be retired, with their users transitioned to similar products that fulfill their needs, and those that need to be improved or developed.

Advancement and improvement of seamless weather-to-climate forecast products is an important example where product development is needed and can be achieved by partnering with HPC in developing unified week 2 and weeks 3-4 forecast and guidance products. Week-2 prediction is a major challenge for techniques traditionally associated with deterministic weather prediction. Similarly, the probabilistic techniques traditionally employed by climate science contribute to forecast skill at week 2. Providing a consistent, unified week-2 product would be useful for both CPC and HPC stakeholders (as discussed in section 5.3). A joint HPC-CPC effort, in consultation with EMC, stands a far better chance to generate products and services of importance and relevance to a wide range of stakeholders in need of information at this range. Similarly, at climate scales, there are opportunities to partner with the Geophysical Fluid Dynamics Laboratory (GFDL) modeling developments to evaluate climate products at the decadal-to-century scales that would be responsive to user needs identified in the NCS vision.

Recommendation: It is recommended that the development of improved forecast skill at week 2 be a high priority for NCEP. Thus, CPC and HPC should create a week-2 development team (W2DT) to develop and evaluate a unified CPC-HPC forecast product. As recognized by co-sponsorship of the Observing System Research and Predictability Experiment (THORPEX) Program by the World Meteorological Organization (WMO) and the World Climate Research Program (WCRP), W2DT should apply the methodologies and metrics of the extended range weather prediction community together with sub-seasonal predictions of the short-range climate community.

Information Systems

Over the last decade CPC has recognized and has been proactive and effective in developing web-based product delivery systems (e.g., Extensible Markup Language (XML), Geographic Information Systems (GIS) and KML (formerly Keyhole Markup Language) outputs), and must be commended for these developments, which will likely continue with their website redesign. However, more transformative improvements in product generation and delivery capabilities will require a more expansive paradigm in the design of products, the interface for user access, and the underlying technological systems for delivering products. CPC relationships with NCO and the inability of CPC to hire information technology (IT) software personnel can hinder its plans for R2O transitions and product delivery mechanisms. A current "valley of death" even exists now between the CPC development and operations branches.

Recommendation: NCEP should establish policies, processes, and practices that will foster interoperability among products and tools within CPC, NCEP, NWS, NOAA, and beyond. This includes a process of active engagement with NCO and other external groups that are developing new tools for users (public, academic, and private sector), and having easy access to explicit technical information, e.g., metadata. Engagement with the Earth Science Information Partners (ESIP) Federation, Earth Observing System Clearinghouse (ECHO), and similar groups is encouraged, with participation by CPC IT staff. CPC needs full access to IT software engineering personnel and an approach to R2O that prioritizes entrainment of software developed elsewhere rather than redevelopment of functionalities in-house.

Science and Technology

CPC maintains a world-class research and development program, with outstanding scientists that have a successful track record in attracting extramural, competitive funding and actively publishing in high-quality, refereed scientific journals. CPC has a very good track record of developing and providing important climate products and engaging the climate research community. The Climate Test Bed (CTB) was established as a mechanism for science and technology infusion related to model improvements, NMME development, forecast product development and R2O transition by leveraging resources in coordination with the CPO and through additional partnering with outside researchers. This has largely failed because of resource limitations and organizational issues documented by its Science Advisory Board (SAB). The CTB, while organizationally part of the Development Branch (DB), does not have an integrated relationship with DB and is relatively autonomous without clear lines of authority as discussed in the report (see sections 5.2 and 6.5). The roles of CTB and DB can and should function in a harmonious and mutually reinforcing manner, including complementary activities, undertaken by design. The current structure of the CTB hinders CPC in developing a unified organizational culture needed to meet its mission and strategic plan goals. Additional partnering with the other research agencies and universities (the National Science Foundation (NSF), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA)) would bolster science infusion by leveraging resources.

Recommendation: CPC needs to clarify the current structure of the CTB to make sure that it addresses its needs for research, product development and R2O transition in support of CPC's (hence NOAA's) mission and strategic plan goals. As part of this effort, CPC should move forward with plans to establish a model test facility, presumably as an effort that combines activities of the CTB, NCEP and CPO that gives the external research community (and CPC) access to the CFS with the aim of influencing and accelerating improvements to CFS, as discussed earlier.

People and Organizational Culture

The personnel of the CPC are very talented and committed people who are well versed with the current state of the science. They have exhibited an extraordinary amount of activity and passion for their work. Under its current Director, CPC has gained an appreciation for the value and need for strategic and implementation planning. This has led to an overall appreciation of staff roles and the contribution of CPC to NCEP.

Within CPC, the roles of the DB and the Operations Branch (OB) in the research and development of new products and services, which appears to occur in both branches, are unclear, resulting in overlapping development activities. The panel found insufficient coordination and interaction between the branches leading to less effective transitioning of DB research products to operations. A contributing factor may be CPC's organizational structure that relies heavily on contractors and "soft money" for the generation of its products and services. In part, this is a resource issue, and the observation about resource constraints is similar to that found in the 1998 review.

Development Branch personnel should be familiar with the challenges involved with operational product generation, and devote energy towards research that improves the operational product suite as called for earlier. An example of a mechanism for enhanced interactions would be to include in each research project an operational liaison who would provide suggestions and feedback. Also, the CTB must provide a more effective bridge between the operational and developmental activities at CPC.

Recommendation: Mechanisms must be developed for clearly delineating research and development activities for the two branches, increasing the coordination of activities between the DB and OB, and minimizing overlapping activities. Additionally, mechanisms are needed for reducing the reliance on contract personnel for mission-critical operational product generation (perhaps by reducing the number of products as called for in the 'Products and Services' recommendation and / or by establishing more formal decision making processes involving NWS Headquarters), while at the same time creating opportunities for enhanced interactions between the Operations and Development branches.

B5: Overview of the draft summary report of the Earth System Research Laboratory Review: Physical Sciences Research, March 9-12, 2010[5]

This Physical Sciences Review covered the broad range of activities in the Physical Sciences Division (PSD) and the Global Systems Division (GSD) in the Earth System Research Laboratory (ESRL). The vast majority of the presented materials, as well as useful background information, were provided in advance of the meeting, allowing the panel a welcome opportunity to preview even the posters. This was certainly very helpful as the review schedule was very intense with the many exciting activities and results that the Divisions were obviously proud to display. The materials can be found at: http://www.esrl.noaa.gov/research/review/. Additional information, such as a draft PSD Strategic Plan and the report on the *Attribution of the Mid-Atlantic Snowstorms*, was provided at the review. ESRL senior management and PSD and GSD staff are to be commended for their hard work and preparation for the review, for their openness, and for their willingness to provide additional information requested during the review. The care given to preparing presentations and posters was very apparent, as was the enthusiasm of all the science staff for their research and the pride they take in contributing to NOAA's mission in both advancing science and serving society's needs. Every review panel member gave expression to being overwhelmed and generally impressed by both the high quality of all we saw and the breadth of activities across the two divisions.

The review was organized along five themes:

1. Climate, Weather and Water Science
2. Modeling, Data Assimilation and Advanced Computing
3. Climate, Weather and Water Services
4. Technology Transfer and Outreach Activities
5. Earth System Observations and Analysis
    - 5a. Weather Systems Observations and Analysis
    - 5b. Climate Systems Observations and Analysis

A summary of reviewers' evaluations and recommendations for each theme is presented below, with focus on the three areas of our charge:

> **Quality:** Assess the quality of research over the last four years, and whether appropriate approaches are in place to ensure high quality work will be performed in the future.
>
> **Relevance:** Assess the degree to which research and development is relevant to NOAA's mission and of value to the nation.

[5] Complete draft review report available from ESRL PSD Director William Neff: William.Neff@noaa.gov

Performance: Assess the overall effectiveness with which the laboratory plans and conducts its research and development.

Consistent with the charge to the panel, we attempted to limit ourselves to research and development and technology transfer over the last four years, although it wasn't always apparent if accomplishments belonged to an earlier time. In accord with FACA rules, the review panel did not seek consensus in our evaluations. Nevertheless, there was a lot of agreement in the high level view of the two divisions and the relevance of their research to NOAA's mission. Since it is relevant across all themes, this view is summarized next, followed by the summary for each theme. The report closes with a summary of key recommendations including some thoughts on these two divisions *vis a vis* the emerging NOAA Climate Services (NCS), and on the NOAA-wide environmental modeling program.