2009 Community Review of the Tropical Prediction Center (National Hurricane Center)

Carried out by the University Corporation for Atmospheric Research

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Executive Summary

The University Corporation for Atmospheric Research (UCAR) was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to conduct a thorough and thoughtful review of the nine Centers that comprise NCEP, as well as the NCEP Office of the Director (OD). This report summarizes the review of the National Hurricane Center-Tropical Prediction Center (NHC-TPC), which was conducted by a Review Panel that also reviewed the Ocean Prediction Center.

Overall, the Review Panel found that the NHC-TPC is an effective center, with a well-balanced portfolio of operational forecasting, research-to-operations transitions and outreach to stakeholders and the public. The current leadership deserves credit for improving staff morale, making necessary organizational changes, and re-focusing the center on its primary missions. The NHC-TPC staff deserves high praise for their job performance and dedication. The NHC-TPC is arguably the most highly visible of the NCEP centers and its products and services must remain credible in the public eye. A stakeholder survey revealed that the NHC-TPC is highly regarded by its customers and does have the nation's confidence that its forecasts and warnings can be counted on to help save lives and property during hurricane threats.

To build on this strong foundation, there are several overarching issues affecting the future success of the center that should be addressed by NHC-TPC, working with the NCEP OD and its partners. One is the recognition that the main driving force behind the significant increase in track forecasting skill over the years has been advances in environmental modeling, and continued increases in skill are possible through higher resolution, increased observations, improved model physics and advanced data assimilation methods. Development of complete observational, assimilation and modeling systems to address NHC-TPC needs for atmospheric, ocean, wave, surge and coastal forecasting, however, is a task beyond the scope of NHC-TPC's or even NCEP's mission. Thus this report recommends that a team be constructed involving NHC-TPC, the Environmental Modeling Center (EMC), the Ocean Prediction Center (OPC), the National Weather Service (NWS), the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service, the Navy, the research community (both national and international), as well as selected stakeholders to develop a strategic plan for an advanced, collaborative approach to coastal, surge and ocean observations and forecasting.

Another concern is that the increasing vulnerability of the expanding U.S. coastal populations to tropical storms has created an explosive growth of the need for ocean and coastal weather information and services and a concomitant growth in the number of NHC-TPC customers and partners, requiring greater outreach efforts and forecast improvement stewardship. Because the NHC-TPC has earned respect for its operational reliability, it should continue to leverage its high public visibility and positive image to improve public preparedness. Conflicting pressures exist from the emergency management community (which wants extended forecast lead times) and the reality of current forecast skill, especially of intensity. As forecast skill continues to improve, however, opportunities to further increase lead times should be strongly considered.

Specific recommendations to improve products and services include the addition of oceanographic expertise, more visibility and products for storm surge and inundation, employment of Spanish and French-speaking personnel, possible realignment of OPC and NHC-TPC responsibilities, working with the Federal Emergency Management Agency (FEMA) and the Department of Homeland Security (DHS) on joint national level training and exercise units, and improving communication with the World Meteorological Organization (WMO) Regional Association IV (RA-IV) countries in its area of responsibility.

On the science side, the NHC-TPC is encouraged to increase real-time verification and feedback, increase case studies of failed and successful forecasts, explore more sophisticated approaches to maximizing the information content from multi-model ensembles, determine the greatest observational needs for their mission, engage with partners on increased research on storm surge and inundation, and, via the Joint Hurricane Testbed (JHT) and Hurricane Forecast Improvement Project (HFIP) programs, engage in higher-risk research opportunities, especially for intensity forecasting.

1. Introduction

1.1 Purpose: Context and Summary of Charge

The University Corporation for Atmospheric Research (UCAR) was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to conduct a thorough and thoughtful review of the nine Centers that comprise NCEP, as well as the NCEP Office of the Director (OD). NCEP is organized under the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The nine centers include:

- Aviation Weather Center (AWC; Kansas City, MO)
- Climate Prediction Center (CPC; Camp Springs, MD)
- Environmental Modeling Center (EMC; Camp Springs, MD)
- Hydrometeorological Prediction Center (HPC; Camp Springs, MD)
- NCEP Central Operations (NCO; Camp Springs, MD)
- Ocean Prediction Center (OPC; Camp Springs, MD)
- Space Weather Prediction Center (SWPC; Boulder, CO)
- Storm Prediction Center (SPC; Norman, OK)
- National Hurricane Center and Tropical Prediction Center (NHC-TPC; Miami, FL)

This review is focused on the National Hurricane Center and Tropical Prediction Center (NHC-TPC). For the record, the NHC–TPC is presently known as the Tropical Prediction Center (TPC), but a name change to the more widely known National Hurricane Center (NHC) has been proposed by NOAA and is under consideration by the United States Government Executive Branch, so we are referring to the NCEP center in Miami as the NHC–TPC in our report.

The 2009 review of NCEP was undertaken because the centers of NCEP are viewed collectively as a critical national resource that delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its partners and external user communities. These products and services respond to user needs to protect life and property, enhance the nation's economy and support the nation's growing need for environmental information. As the centerpiece of the National Weather Service's science-based forecast enterprise, NCEP serves as the focal point for weather, climate and space weather modeling, analysis and dissemination of forecast products and services. As such, it is essential that NCEP be held to a set of high standards that define the quality, quantity, timeliness, impact and improvement over time of its products and services. An independent, external evaluation of the effectiveness with which NCEP is accomplishing its mission and realizing its vision was deemed necessary.

It has been over a decade since NCEP centers have been collectively assessed by UCAR. However, external reviews of each center occurred independently during the period 1996 – 2001. In particular, the complementary roles and interactions among the centers were not comprehensively reviewed in those singular reviews. The goal of the current UCAR review is to evaluate the entire range of NCEP activities, with particular emphasis on the way in which the various centers interact with each other, and in some cases rely upon each other, and with other NOAA, federal, academic and non-governmental entities.

This is a particularly appropriate time to conduct such a review insofar as many national and international challenges have arisen that require NCEP to operate at the highest possible level of scientific and technological excellence. Examples of challenges that the nation must meet for which NCEP's products and services are essential include the following:

- The growing threat of hazardous weather reached a new and staggeringly high level of severity in the 2005 hurricane season during which 28 named storms threatened the U.S. Atlantic and Gulf of Mexico coastlines, including Hurricane Katrina that caused massive damage and loss of life in New Orleans and along the Gulf coast.

- The 2007 Intergovernmental Panel on Climate Change released its fourth assessment report, stating unequivocally that the Earth's climate is changing at an unprecedented rate as a result, in part, of human activities. This recognition, along with the growing predictive understanding of the influence of El Niño and the Southern Oscillation, and a host of other climate factors and conditions, on climate-sensitive sectors of the U.S. population and economy, has led NOAA to begin planning for a suite of National Climate Services.

- Adverse weather continues to strongly affect the aviation industry, and the NWS' pledge of support to satisfy the weather requirements of the Federal Aviation Administration's (FAA's) new Next Generation Air Transportation System (NextGen) will place increased demands on NCEP services.

- Solar activity, in the form of flares and coronal mass ejections, has a profound influence on the Earth's atmosphere (causing beautiful auroral displays) and can project fluxes of high energy particles that can disrupt communications, navigation, satellites, electric power grids, and human space flight. Solar activity has an approximately 11-year cycle and has been at a minimum for the past few years, and is expected to rise to its next maximum in 2013. Given the increasing dependence of the U.S. and world economies on aviation, telecommunications, and the Global Positioning System (GPS), the coming Solar Maximum has the potential to be highly disruptive.

Because the threat to life and property from weather, climate and space weather anomalies has never been higher and continues to rise, the products and services of NCEP must be of the highest quality, timeliness and impact.

In order to provide a review that could be most useful to NCEP, the UCAR review was organized into five panels, each of which was asked to review two NCEP centers both individually and as a complementary pair. The five panels were asked to review:

- AWC and SPC
- CPC and HPC
- EMC and NCO
- OPC and TPC
- SWPC

In each case, the pair of centers was chosen specifically because the two centers in each pair are expected to work more closely together, having affinities of mission and/or stakeholder communities.

Each panel was asked to review the center's vision and mission to determine its relevance, appropriateness and alignment with NCEP's strategic plan. The review also assessed the productivity and quality of the scientific activities, and the quality, relevance and impact of operational products and services. Special emphasis was placed on the ability to gauge and meet customer demand and emerging requirements, the effectiveness of activities intended to support technology transfer based on research conducted either within or outside NOAA, and the effectiveness of collaboration with the academic research community or the private sector. The review evaluated the balance between operations and research and development and assessed the plans for evolving the suite of products and services. Finally, as indicated above, the interactions of each center with its "sister" center and the outside community were evaluated. The full charge to the review panels is provided in Appendix A.

1.2. Procedure

The review panel consisted of six members (see Appendix B) who were appointed by the President of UCAR. The NHC - TPC Review Team visited the NHC-TPC facilities in Miami on 16-17 June 2009. The Review Team had a planning dinner the evening of 15 June.

To prepare for the visit, a set of questions was provided to NHC - TPC leadership. In return, a comprehensive binder of material was provided to the review panel. This included responses to the panel's questions, NHC - TPC overview documents, and information on customers, products, and services; transition of research to operations; performance measures; budgets; strategic plan; etc. A web-based survey also was distributed to a variety of stakeholders.

During the on-site visit, NHC-TPC Director William Read presented highlights of NHC-TPC, including successes and challenges. Other presentations were given by branch chiefs James Franklin, of the Hurricanes Specialists Unit, Hugh Cobb of the Tropical Analysis and Forecast Branch and Jiann-Gwo Jiing of the Technical Support Branch and the Hurricane Test Bed, followed by discussions with center leadership and cross-cutting team representatives. Considerable time was spent conducting interviews with branch staff and teams on topics including administration, information technology and facilities, community engagement, and science/research. A preliminary briefing of the review panel's findings was provided to NHC-TPC leadership and Dr. Louis Uccellini (via conference phone) on the afternoon of June 17th.

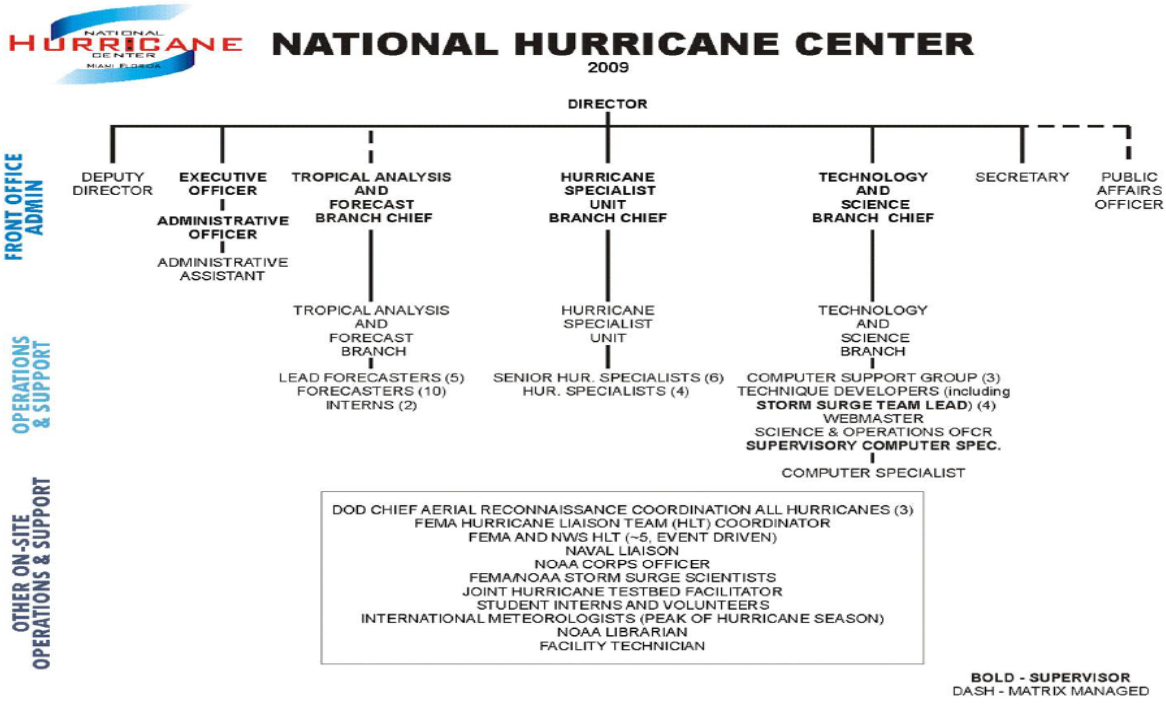
2. Overview of the National Hurricane and Tropical Prediction Center

2.1 Mission and Vision

The NHC-TPC's mission is: "*To save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, forecasts and analyses of hazardous tropical weather, and by increasing understanding of these hazards through global outreach*".

NHC-TPC's vision is: *"To be America's calm, clear and trusted voice in the eye of the storm, and, with our partners, enable communities to be safe from tropical weather threats.*"

2.2 Brief History and Organizational Structure



The present organizational structure of the NHC-TPC is shown in the schematic above. The center presently bears the name of the TPC. The TPC was previously known as the National Hurricane Center and, given consent of the Executive Branch of the United States Government, will reassume its former name. The organizational schematic shown below reflects the anticipated change. The NHC-TPC provides forecasts of the movement and strength of tropical weather systems and issues watches and warnings for the U.S. and surrounding areas. It is of note that hurricane forecasting in U.S. regional waters has a rich history with the first recorded forecast of an impending storm credited to Christopher Columbus. He was a perceptive sea captain who understood that the appearance of forerunner waves meant that a large atmospheric

tempest was on its way toward Santa Domingo, Hispaniola on June 29, 1502. He sought shelter in the lee of the islands and his ships were spared, thus producing the first successful hurricane forecast. The NHC-TPC has kept up this proud tradition.

Through international agreement, the NHC-TPC has responsibility within the World Meteorological Organization (WMO) to generate and coordinate tropical cyclone analysis and forecast products for more than twenty-four countries in the Americas, Caribbean, and for the waters of the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and the eastern North Pacific Ocean. Several years ago, the WMO shifted the eastern boundary of NHC's hurricane responsibilities from 35W to the coast of Africa, which added countries to NHC-TPC's responsibilities. NHC-TPC products are distributed through a close working relationship with the media and emergency management communities.

To meet its mission presently the NHC-TPC comprises three branches: The Hurricane Specialists Unit (HSU) maintains a continuous watch on tropical cyclones from 15 May in the eastern Pacific Ocean and 1 June in the Atlantic Ocean Basin through 30 November for both the Atlantic and the Pacific. The center prepares and issues forecasts, watches and warnings within text advisories and graphical products. Although many countries issue their own warnings, they generally base them on direct discussions with, and guidance from, the HSU. During the "off-season", nominally for December – May, the HSU conducts an extensive outreach and education programs, thereby training U.S. emergency managers and representatives from many other countries affected by tropical cyclones. They are also involved in research, summary reports and verification studies.

The NHC-TPC Tropical Analysis and Forecast Branch (TAFB) provides year-round marine weather analysis and forecast products over the tropical and subtropical waters of the eastern North and South Pacific and the North Atlantic basin. The branch also produces satellite-based weather interpretation and rainfall estimates for the international community. The TAFB provides support to the HSU during the hurricane season through tropical position and intensity estimates based on the Dvorak technique.

The Technical Support Branch (TSB) contains the NHC-TPC's Science Operations Officer (SOO) and a small Techniques Development and Applications Unit (TDAU). It also oversees the Joint Hurricane Testbed (JHT) effort that, together with the SOO and TDAU, develops tools for improved hurricane and tropical weather analysis and prediction. The TSB provides support for the NHC-TPC Computer Programming and Technical Support group, and Information Technologists. The TSB also has a storm surge group that provides information for developing evacuation procedures for coastal areas.

The NHC-TPC collaborates with universities, government research laboratories, international tropical weather centers, the private sector and other NWS and NOAA components to maintain its leading edge in forecasting hazardous tropical weather through coordinated operations, observing technology, research, and training.

NCEP centers that the NHC - TPC relies on for products and services and model output or interacts closely with include the CPC, EMC, HPC, OPC, SPC and NCO.

3. Progress Since the Previous Review

This section will assess (a) progress at NHC-TPC since the 1997 UCAR review; (b) degree of completion of the recommendations of the 2007 "Turner Report", and (c) changes in the social, science and technology environment applicable to the NHC-TPC over the past decade.

3.1 Progress Since the 1997 UCAR Review

The NHC-TPC, together with NCEP OD, has responded well to the recommendations made by the 1997 UCAR Review Panel. Staffing levels were maintained overall, a Branch Chief was added, and the number of Hurricane Specialists was increased from 6 to 10. The Public Affairs Officer continues to be funded and an Executive Officer was added. Improved communications between NHC-TPC and emergency managers and the media have occurred. The use of the Internet for product delivery has expanded greatly and a webmaster position was created by converting another NHC-TPC position when it became vacant. New observing tools were added (the Quick Scatterometer or QuikScat, the Tropical Rainfall Measurement Mission or TRMM, the Advanced Microwave Sounding Unit or AMSU, the Stepped Frequency Microwave Radiometer or SFMR, the Gulfstream IV or G4, and other systems) and are routinely used, although serious observing voids still exist in all US coastal waters including the Atlantic, Gulf of Mexico, and Pacific coastlines, Alaska, Hawaii and the Great Lakes.

During this period, the NHC-TPC increased its tropical cyclone forecasts from three to five days, introduced probabilistic wind speed products, and met their Government Performance and Results Act (GPRA) goals in every year. Track accuracy is currently at an all-time high. They engaged the research community with the formation of the JHT, and have already completed the research-to-operations transition for about two dozen projects. They helped develop and are strong participants in the new NOAA Hurricane Forecast Improvement Project (HFIP). They have strengthened relationships with both the international community and with Federal Emergency Management Agency (FEMA) emergency managers. Marine product services have improved as a result of working more closely with OPC and NWS Forecast Offices. They are now providing data to the National Digital Forecast Database. Finally, they have increased public outreach activities to engage stakeholders in hurricane awareness via conferences, workshops, tours and many talks around the coastal U.S. Budgets remain tight, however, for travel by NHC-TPC personnel for public outreach and professional development purposes.

3.2 Progress in Addressing the 2007 TPC Assessment Recommendation Implementation

The NHC-TPC Review Panel was asked to comment on the progress the NHC-TPC has made in addressing the recommendations of a report authorized by the NOAA Administrator in June 2007 to assess NHC-TPC's leadership and capabilities. The report, called the "Turner Report" after its leader, was issued just three weeks later, and resulted in the removal of the NHC-TPC Director and 10 additional recommendations. The Panel was provided with a June 2009 update document that showed that nearly all the recommendations had been completed by that time.

Extensive staff interviews were completed by a consultant and results shared with management and staff. Management and performance evaluation training has occurred. A Branch Chief was created for the HSU, and other re-organization efforts were completed. On the science side, a strategic plan has been completed and the HFIP effort was begun that will concentrate on the greatest scientific needs (intensity forecasting; improved modeling, surface wind data, etc.)

The NHC-TPC Review Team believes that NHC-TPC and NCEP OD have responded quickly and appropriately to the Turner report recommendations. A follow-on assessment was completed in late summer 2009 and only a few activities remain to be completed and are contained in the NHC-TPC annual operating plans. While the team did not do an extensive employee survey, it received the impression that staff morale has improved under the current leadership, and that the new administrative changes are working well. A sense of hierarchy across the branches appeared to linger, however, and may impede open communications; NHC-TPC will need to remain vigilant to sustain its progress. The NHC-TPC is now strongly focused on serving the public well and improving all aspects of their forecast products.

3.3 Changes in the Social, Science and Technology Environment Applicable to the NHC-TPC

The increasing vulnerability of the burgeoning U.S. coastal populations to tropical storms has created an explosive growth of the need for ocean and coastal weather information and services. A concomitant growth has occurred in the number of NHC-TPC customers and partners, requiring greater outreach efforts and forecast improvement stewardship. The panel believes that the NHC-TPC has responded well to these challenges. In addition, the NHC-TPC is arguably the most highly visible of the NCEP centers and its products and services must remain credible in the public eye. In the panel's view, the NHC-TPC is highly regarded by the public and does have the nation's confidence that its forecasts and warnings can be counted on to help save lives and property during hurricane threats.

Ensuring the highest quality products in response to evolving customer needs requires NHC-TPC to maintain strong customer interactions, have mechanisms to gather their requirements, and provide advice and education on the impacts of weather throughout the tropical coastal zone. While NHC-TPC has reached out to numerous customers to gain an understanding of their impacts and requirements, limitations in staff and budgets have led to gaps in the customer feedback and education process. To help bridge these gaps, NHC-TPC has tried to leverage the ocean and marine weather communities' capabilities and resources to meet customer requirements by developing and promoting partnerships; though as discussed below, more needs to be done.

The main driving force behind the forecast improvements mentioned above has been advances in numerical weather prediction (NWP) guidance through increased resolution, additional data, improved assimilation techniques, and upgraded model convective, microphysical and boundary layer treatments. Prior to the early 1990s, the best track forecast models were statistical or simple statistical-dynamic models. In recent years, however, dynamical models - both limited area, mesoscale tropical cyclone models such as the Geophysical Fluid Dynamics Laboratory

(GFDL) Hurricane Model and the Hurricane Weather Research Forecast (HWRF) model, and large scale, global models such as the Global Forecast System (GFS) and the Navy Operational Global Atmospheric Prediction System (NOGAPS), as well models from the United Kingdom Meteorology Office (UKMET) and the European Center for Medium-Range Weather Prediction (ECMWF) - have become the leaders in tropical cyclone (TC) track accuracy. Indeed, a simple consensus done by NHC-TPC that averages track forecasts from the GFDL Hurricane Model, UKMET, NOGAPS, and GFS has outperformed the best single model consistently over the last 6 years. The so-called super ensemble technique developed at Florida State University, where past forecast skill is used to determine how much weight certain models receive in the ensemble, has also shown skill in reducing TC track errors. Nonetheless, additional work is needed to determine which methods are best for continuing to improve multi-model ensembles and NHC-TPC is encouraged to continue exploring these options and to stay abreast of developments in the larger research community on this topic.

In stark contrast to TC track errors, TC intensity forecasts, at all lead times, have exhibited no trend over the last 15 years despite the overall improvements in the model guidance available to forecasters noted above. (We note that the HSU official intensity forecasts on average remain more accurate than the available model guidance.) This contradiction stems from the much lower skill demonstrated by models when forecasting TCs that undergo rapid intensification or weakening, and recent research that suggests atmospheric model resolutions on the order of 1 km or finer and ocean model resolution of order 0.5 km or finer, are needed to resolve the physical dynamic and thermodynamic processes involved in rapid intensity changes. This required resolution is much finer than the ~9 km being employed by EMC's current state of the art, mesoscale TC models, the GFDL Hurricane Model and the HWRF model. Required is a fully, interactively coupled model system, with an atmospheric numerical model component such as HWRF, and an oceanic numerical model, which itself has ocean waves interactively coupled to oceanic currents. The point is that the atmosphere and the ocean exchange mass, heat and momentum in real time over comparable spatial and temporal scales and these exchanges must be modeled in the deterministic numerical models.

In recognition of this challenge, NOAA, with input from stakeholders, the National Science Board (NSB), the Office of the Federal Coordinator for Meteorology (OFCM), and NOAA's Science Advisory Board (SAB) Hurricane Intensity Research Working Group (HIRWG), established the Hurricane Forecast Improvement Project (HFIP), a ten year effort to accelerate improvements in one to five day forecasts of hurricane track, intensity, and storm surge, and to reduce forecast uncertainty, with an emphasis on rapid intensity change. The major goals of HFIP are: 1) define and build an enhanced HWRF/GFS system capable of representing the physical processes responsible for rapid intensity change; 2) increase high-end computing (HEC) capacity and capability to allow for higher resolution models to be used in operations; 3) institutionalize and fully fund transition of research to operations to ensure an efficient process to get demonstrated research results in modeling and observing systems and platforms into operations; and 4) broaden and access the expertise of the operational NWP modeling and research communities.

4. Summary of Stakeholder Survey

An invitation was distributed to a wide spectrum of potential users of NHC-TPC weather information and products, requesting that they respond to an on-line questionnaire. Responses were obtained from 156 users. Of those indicating a profession, 53% were Research & Development, 25% were Public Safety/Emergency Management, and 19% were Media. Other users, ranked respectively by participation were: private weather industry, recreational fishing/boating, commercial shipping, oil & gas exploration/operations, US Navy/Coast Guard, and NOAA ship operations. Nearly half of the respondents rated their understanding of tropical weather as "Excellent".

Feedback from the user community was largely positive, with a few responses indicating suggestions for improvement. Below is a summary of the responses in which NHC-TPC received a majority of ratings in the "agree or strongly agree" category:

- NHC-TPC personnel sufficiently understand the mission of stakeholder organizations.
- Effectively communicates its mission to stakeholders.
- Mechanisms are effective for stakeholder organizations.
- Personnel are professional.
- Communicate updates of existing and new products and services effectively.
- Products and services are packaged adequately to meet stakeholder needs and are appropriate for NHC-TPC's mission.
- Products and services are:
    - readily accessible in a timely manner
    - reliable
    - effective
    - of appropriate quality
    - consistent from shift to shift and day to day
    - improved at an appropriate pace
    - represent state-of-the-art capability
    - include provision of archives of prior realizations
- Stakeholder activities would be negatively impacted without NHC-TPC products.

A very small number of responses suggested areas where improvements could be made by NHC-TPC or there was no basis for judgment; however, it should be noted that "no basis for judgment" most likely indicates that the question does not apply to the stakeholder or that the stakeholder has not interacted with NHC-TPC regarding the question's subject. The two areas where NHC-TPC received less favorable ratings or no basis for judgment were:

- NHC-TPC is responsive to stakeholder suggestions for improving products and services or developing new ones.
- NHC-TPC welcomes my suggestions for improving products and services or developing new ones.

Below is a summary of the most common themes in the responses to questions that required the stakeholder to provide written text responses:

Question #33 "List the most significant benefits provided to their organization by TPC".

- Official forecast track, watches & warnings, advisories, intensity, trends, graphical outlook,
- Timely forecast products and real-time data collection and communication to the stakeholders and public
- Hurdat and archival information

Question #34 "What are the most significant limitations or weaknesses of the TPC":

- TPC Forecaster collaboration with stakeholders and NOAA partners must improve. Increase track forecast, research, new product development collaboration.
- Become more open to new technology/ideas.
- Improve intensity and tropical wave forecasting
- Issue advisories and statements on a more media friendly cycle. Often advisories/statements are too late for broadcasts.
- Satellite resolution, images, and loop quality are poor.
- Short staffed to conduct outreach and collaboration with stakeholder community.
- Inconsistency in naming storms.

Question #35 "Have opportunities been missed by the TPC?"

- TPC rarely misses good opportunities and has a good core of experienced forecasters
- Modernize products similar to SPC and incorporate new scientific ideas
- Collaboration with external community stakeholders/partners
- NWS must incorporate behavioral sciences in product and advisory development
- An insular corporate culture that is reluctant to change.

Question #36 "What TPC products and services do you find most useful, least useful?"

- Most Useful:
  - Discussions
  - Track forecast & error cone
  - Advisories
  - Graphical Outlook
  - Storm Surge and Slosh runs
  - Intensity forecast
  - Advisories
  - Archival storm data
  - Surface analyses

- Least Useful:
    - High seas forecast
    - Easterly wave tracking
    - Sea state and wave period charts
    - NOAA seasonal outlook

Question #37 “What additional TPC products and services would benefit you most?”

- Storm Surge probability
- Probability forecasting for intensity
- Higher satellite resolution
- Expected storm impacts inland
- Improve wind field forecast data
- Incorporate new methods of communicating risk to public
- Incorporate more graphics into products
- Caribbean weather discussion
- Link HPC rainfall products to the NHC website
- Improve graphics for media use

Question #38 “What improvements of the current TPC offerings of products and services would benefit you most?”

- Increase resolution of storm surge graphics (Sea, Lake and Overland Surges from Hurricanes – SLOSH – runs).
- Simplify public advisories and terminology. Organize them to highlight the most important information.
- Improve intensity forecast and storm structure data (e.g., wind field radii)

Question #39 “How do you use any of the TPC’s products and what are the benefits to your organization?”

- TPC products serve as the basis for multiple stakeholder products and information
- Research
- Media on-air reporting
- Storm tracking and climatological studies
- Life safety evacuation and stakeholder mission decision making
- Tropical monitoring
- Quantitative Precipitation Forecasts (QPF) modeling

Question #40 “Do you feel research outcomes, including those produced within the TPC as well as those as brought in from external organizations and programs are translated into useful products and services in a timely fashion?”

- A majority of responses were “Yes”
- JHT received mixed reviews from stakeholders.
- Transitioning research into products and services is sometimes slow

Question #41 “How do you envision your needs changing during the next 5 years and how might they be met most effectively by the TPC?”

- Improved storm surge, intensity, and structure forecasting
- Transition to a Storm Prediction Center (SPC) model where the NHC provides guidance to Weather Forecast Offices (WFO) who then produce forecast/advisories/watches & warnings
- Promote products through the media and become more graphical
- The need for immediate information continues to grow
- Prepare for the age of the internet TV channels

Question #42 “How does TPC compare against comparable organizations with which stakeholders interact?”

- TPC is a top-notch/superior/non-comparable/top of the line/outstanding/unique/first rate/supportive/active/reliable organization
- Private weather companies are more responsive to fast breaking forecast changes than TPC.
- Business model could be upgraded to follow SPC.

Question #43 “Is TPC communication of vulnerability level adequate to be easily understood?”

- A majority of respondents indicated “Yes”
- The is a disconnect between the TPC advisory and what can be expected at the local level
- Communication of real risk could be improved for storm surge, storm structure to specific communities. (Ike exposed a lack of public understanding about storm surge vs wind intensity)
- Increase focus on storm societal impacts.
- Continue to build solid relationships with the Emergency Management community.

Question #44 “Are the TPC’s products and services packaged sufficiently to meet your specific needs?”

- A majority of respondents indicated “Yes”
- Increase graphical and computer visualization

- Improve risk and vulnerability communication methods
- End the use of CAPITAL FONT
- Improve storm surge products

Question #45 "Please provide other comments, suggestions and recommendations?"

- "Keep up the good work", "Excellent Organization", "Respected Source" etc.
- Forecasters tend to be too conservative at times
- Increase relationship with the media, and understand media cycle
- Lack of staff must be addressed.
- Improve intensity forecasting
- Become more open about collaboration internally and externally
- Products are lacking in hazard and threat level communication
- Standardize wind data and consider objective wind analysis

5. General Observations and Overarching Issues

Overall, the Review Panel found that the NHC-TPC is an effective center, with a well-balanced portfolio of operational forecasting, Research-to-Operations (R2O) transition and outreach to stakeholders and the public. The current leadership deserves credit for improving staff morale, making necessary organizational changes, and re-focusing the center on its primary missions. As noted earlier, the NHC-TPC is arguably the most highly visible of the NCEP centers and its products and services must remain credible in the public eye. In the panel's view, the NHC-TPC is highly regarded by its customers and does have the nation's confidence that its forecasts and warnings can be counted on to help save lives and property during hurricane threats. There are, however, several overarching issues affecting the future success of the center that should be addressed by NHC-TPC, working with NCEP and its partners. In no particular order, they are:

5.1 Interactions with FEMA, DHS and State/Local Emergency Managers

While NHC-TPC is well-engaged with FEMA, Department of Homeland Security (DHS) and the emergency management (EM) community, more can be done. Although NHC-TPC will go to a 48/36 watch/warning lead time for the first time during the 2010 hurricane season, that is still well short of the 72-120 hr lead time required by EM community services to begin their evacuation staging, purchase logistical support, etc. Moreover, there is a requirement for probabilistic information that would enable emergency managers to provide citizens with more reliable evacuation options that may be closer to the warning areas. The EM community (and the public) can see the 5-day forecasts on the NHC-TPC website but the latter will not respond until they see official watches or warnings. Pressure by the EM enterprise for longer watch/warning lead times is counteracted by the greater forecast errors at these times, especially for intensity, and by "Chamber of Commerce pressure" to not warn large segments of the population unnecessarily. Thus the NHC-TPC needs to continue its outreach and education efforts with the EM community and the public to inform them about the limits to forecast

accuracy while simultaneously educating them on the need to take seriously all impending tropical storms. At the same time, as forecast skill continues to improve, opportunities to further increase lead times should be strongly considered.

5.2 Research Activities

The NHC-TPC has a significant applied research program, primarily because (i) funding exists for the JHT to support research projects by external partners; (ii) funding also exists for the growing HFIP program which has been used to fund contracted support, and (iii) tropical storms are seasonal, so HSU forecasters also have time to contribute to research projects. NHC-TPC is justifiably proud that they have already completed the research-to-operations transition for more than two dozen JHT projects. The rate of success has increased in recent years. The Review Panel is concerned that the JHT may have become too focused on funding only those projects which are nearly completed and for which only implementation of a new product at NHC-TPC is needed. There should be a better balance between higher risk but potentially higher reward research projects that attempt to incorporate recent theoretical findings, such as those on hurricane dynamics, into intensity forecasting.

The HFIP program is NOAA-wide, with $17M for FY2009. However, only a fraction goes to NHC-TPC, which with existing personnel is participating in four of eight research teams in FY10, with the NHC-TPC Deputy serving as HFIP Management's Operational Lead. The NHC-TPC Director is on the HFIP Executive Oversight Board. HFIP funds that do go to NHC-TPC are used to support non-federal information technology (IT) and research support personnel. The Review Panel would like to see NHC-TPC more involved in HFIP projects, with more funding for research personnel. The panel notes that the official intensity improvement goals for HFIP seem overly optimistic (50% improvement in 10 years), as this is inconsistent with the accuracy that the initial hurricane wind field is measured, but this is probably beyond NHC-TPC control.

Despite these research activities, NHC-TPC personnel told the Review Panel that in general little opportunity existed to do retrospective studies of poorly-forecast (as well as well-forecast) hurricanes. Subsequent to the site visit, a HFIP contractor was hired in FY10 to conduct model diagnostic studies, mainly with HWRF. NHC is complimented for this pro-active action. Additional studies in kind would help NHC-TPC considerably by informing them about the sources of error in poor forecasts, under what conditions excellent forecasts are made, how to recognize the level of predictability in advance, etc. Knowledge of the impact of observational deficiencies is a closely-related topic, and there is a need for more observing system simulation experiments (OSSE) and observation system experiments (OSE). The computing resources at NHC-TPC preclude such experiments from being done there, so they would have to collaborate with EMC within NCEP or external research partners on such projects. This issue is related to the 3rd over-arching concern below.

5.3 Dependency on NWP and New Observations for Increased Skill

The state of the science of environmental modeling has advanced significantly over the past decade and is expected to continue to improve over the next decade. NOAA, National Aeronautics and Space Administration (NASA), Department of Defense (DOD), etc. observing systems, both remote and in-situ, are expected to collect more and overall better data, mostly from satellites, all of which should be used to improve diagnostic and prognostic model output via sophisticated data assimilation techniques. Thus, NHC-TPC should become direct beneficiaries of the improved numerical model output to improve and expand their product and service suite. There are, however, significant hurdles to be overcome to realize this vision.

Modeling support for NHC-TPC products and services is provided largely by EMC's GFS and HWRF model forecasts and by the Marine Modeling and Analysis Branch. The Meteorological Development Laboratory (MDL) of the NWS provides the storm-surge model (SLOSH) used for coastal flooding guidance. Although the ocean and surge models supported by EMC and MDL are computationally easy to use, they are two-dimensional, not fully physics based and are thus not state-of-the-science systems.

Because modeling and observations are dependent on one another to maximize their joint forecast utility, coordinated programs of observations and models are required regionally and locally. Unfortunately, the current suite of in-situ observations across and in the global ocean, the coastal ocean, and estuaries, harbors and lower rivers are presently inadequate to provide the essential network of data necessary to serve NHC-TPC needs. Further, the data assimilation systems used to update model projections of ocean and marine atmospheric variables are presently lacking. Therefore, the issues of data coverage and data assimilation into models must be improved if NHC-TPC products and services are to realize sustained improvement.

Development of complete observational, assimilation and modeling systems to address NHC-TPC needs for atmospheric, ocean, wave, surge and coastal forecasting, however, is a task beyond the scope of NHC-TPC's or even NCEP's mission. Thus this report recommends that a team be constructed involving NHC-TPC, EMC, OPC, NWS, NOAA's National Ocean Service (NOS), DOD, specifically the Navy, the research community (both national and international), as well as selected stakeholders to develop a strategic plan for an advanced, collaborative approach to coastal, surge and ocean forecasting.

Note that several of the findings and recommendations that are in the document, "Ocean Modeling" (2004)[1] which NCEP commissioned via the NOAA SAB, and which was provided to the NHC-TPC panel, are still germane today. That report recommended that NCEP rapidly develop two-way, interactively-coupled, state-of-the-science atmospheric, ocean, coastal ocean and land-surface models, driven by real-time data from smart buoys (and other sources) that are assimilated into the models. The implications of that study for this review are:

- EMC/MDL must take advantage of modern, well-tested numerical models of waves,

[1] Pietrafesa, L., D. Blaskovich, A. Blumberg, A. Busalacchi, J. McClean, C. Mooers, D. Rogers, R. Weisberg, 2004: **Review of National Centers for Environmental Prediction Ocean Modeling**. NOAA Science Advisory Board, 37 pages.

currents, surge, etc. that are better connected to academic advances, and which creates a pathway for continuous improvements via community engagement.

- EMC must employ four-dimensional data assimilation (4DDA) for ocean and coastal data

- NHC-TPC must push for the essential suite of in-situ data over the global and coastal oceans, and in estuary areas, derived from smart buoys using modern technology

- NHC-TPC should work with EMC in the conduct of OSE/OSSE tests to guide improvements in NOAA's ocean and coastal observation networks, including atmospheric and ocean state variables

- NHC-TPC should work with EMC to insure that there are sufficient staff personnel trained in global ocean, coastal ocean, and estuary science

- NHC-TPC should work with EMC and MDL to develop Model Output Statistics or MOS-type products for the oceans.

One tool that over the past decade has become important to the process of TC wind forecasting was Quick Scatterometer (QuikScat), a satellite based microwave scatterometer that could indirectly measure surface winds. QuikScat winds, which were available twice a day via descending and ascending passes, providing near sea surface wind vectors on a 12.5 km footprint, had become extremely useful to NHC-TPC staff, even given the caveat of the diminished quality of the measurements in the presence of precipitation. However QuikScat died in November 2009 with no replacement yet in place. Possible sources for the replacement of QuikScat winds include: (1) Use of winds from the ASCAT (Advanced Scatterometer) operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). ASCAT winds provide 60% of the QuikScat coverage at reduced (25 km) resolution. (2) NOAA is working with the Indian Space Research Organization (ISRO) on real-time access to its Oceansat2 scatterometer, which has similar coverage and quality to QuikScat. It is hoped that these data will be available in a year or two. (3) A Microwave Imagery Sounder was supposed to be on the National Polar Orbiting Environmental Satellite System (NPOESS), but uncertainties exist about its status. (4) NOAA is exploring the possibility of flying a scatterometer with capabilities superior to QuikScat on a Japanese satellite, but the funding for and timing of this are uncertain. It is also noted that the NRC Decadal Survey in 2006 recommended a scatterometer with capabilities far exceeding QuikScat, the Extended Ocean Vector Winds Mission (XOVWM). The Review Panel encourages NOAA to move forward on restoring or improving QuikScat capabilities, both for hurricane/marine analysis/forecast purposes and also to maintain the decade-long ocean surface vector wind climate record. It is also noted that a denser network of National Data Buoy Center (NDBC) marine buoys could provide additional real-time wind information, but never at 25 km spacing.

6. Findings and Recommendations

6.1 Mission and Vision

The NHC-TPC mission is focused entirely on "hazardous tropical weather". This singular focus on highly recognizable and potentially life-threatening weather phenomena, and the overall skill in which the center performs its mission makes the NHC-TPC arguably the most publicly visible NCEP center. The stakeholder survey confirmed that its performance is highly regarded by the public. NHC-TPC leadership has wisely taken advantage of this public respect over the past few decades by engaging in significant outreach efforts in coastal U.S. communities.

Finding MV1: NHC-TPC has earned high public visibility and respect, and thus good will, for its operational reliability. The NHC-TPC staff deserves praise for their job performance and dedication.

Recommendation MV1: NHC-TPC should continue to leverage its high public visibility and positive image to advocate for improved public preparation and mitigation of the negative effects of tropical storms and hurricanes, for the safety of lives and protection of property.

The Review Panel discussed two NHC-TPC areas of responsibility for which its mission could be adjusted. During hurricane season (6.5 months), the TAFB is tasked with many additional duties in support of the HSU such as Dvorak estimates, rainfall guidance, forecast preparation, media support, etc., while still producing its usual suite of forecasts and products. Since many of these products (high seas, wind waves, peak waves, sea state, etc.) are ones in which the OPC has expertise, mission realignments are theoretically possible. The second area was the need for the NWS-operated Central Pacific Hurricane Center (CPHC) in Hawaii, which typically handles one land-threatening storm per year, but which has to be staffed throughout the season.

Finding MV2: The OPC and TAFB have similar forecasting tasking over the open ocean, with the TAFB having responsibility south of 31° N. The TAFB is required to augment the HSU during hurricane forecast periods. It would appear that the OPC could assume regional forecasting responsibilities during these periods of increased NHC-TPC stress.

Recommendation MV2: NHC-TPC**,** OPC and the NCEP OD should assess the responsibilities and capabilities of the NHC–TPC, and OPC to develop a more cost-effective and beneficial distribution of duties. Possibilities to consider include OPC assuming regional forecasting responsibilities during the hurricane season, OPC taking over all TAFB high seas forecasts, etc. The TAFB could retain marine responsibility solely for the offshore marine forecasts. Such discussions should also ensure an improved continuity of operations among the centers.

Recommendation MV3: Consider assigning all U.S. open-water hurricane responsibilities to the NHC-TPC, freeing up forecasters and reducing training requirements at the CPHC.

6.2 Customers and Partners

The NHC-TPC interacts with a wide realm of customers and partners, ranging from its sister NCEP centers, to other parts of NOAA, other countries, other Federal entities (FEMA, Navy, etc.), the media, and the general public. As has been stated, NHC-TPC has done an overall excellent job in engaging with these partners. The findings and recommendations below are provided to foster additional collaborations.

Finding CP1: Despite having the responsibility for a vast part of the ocean, the only oceanographic forecasts discussed were waves and storm surge. Other potential ocean products include currents, temperature, salinity, heat content, harmful algal blooms, etc. It is not clear, for the regions they are responsible, how NHC-TPC is coordinating with OPC, the Navy, and the NOS on requests for these services.

Recommendation CP1: NHC-TPC needs to engage oceanographic expertise within NCEP, NOAA and the Navy to coordinate tasking for national oceanographic support; that is, to ensure marine, ocean and ecological forecasting southward of 31° N. Formal agreements with OPC (also see Recommendation MV-2), NOS and the Navy may be needed.

Finding CP2: NHC-TPC recognizes that storm surge, inundation (SS&I) and flooding is a very important part of hurricane forecasting and safeguarding the nation's citizens. Its initiatives to improve SS&I forecasting and convey these dangers to the public, and its participation in the Storm Surge Roadmap are commendable. NHC-TPC has partnered with FEMA for funding this program. There are 3.5 people consisting of an NHC lead, 2 FEMA funded positions, and a ½-time NOAA Corps officer available for surge forecasting. Also, NOAA has committed to funding an additional person that will bring the total group to 4.5 full-time equivalents (FTE). These personnel make the scenario runs and real time runs of SLOSH. .However, this past financial dependence is not assurance of future funding, which is required for the program to continue to meet NHC-TPC needs and requirements. Further, the financial dependence upon FEMA carries with it FEMA's perspective on what model architecture should be used and, since they do not have core in-house model development competency, they rely on the Army Corps of Engineers (ACE) and the NWS MDL for model guidance. While MDL, ACE and the EMC model guidance currently in use for storm surge prediction is computationally easy to apply, it is not physically complete nor fully four-dimensional.

Recommendation CP2: NHC-TPC should continue to partner with FEMA to support the needed storm surge, flood and inundation modeling but not be directed by FEMA on what models should be used for guidance. NHC-TPC should take advantage of advanced, tested, community models and also adopt a surge model ensemble forecast approach. Also, NHC-TPC should look for additional sources of funds to support this effort, and develop a contingency plan for the event that FEMA funds would decrease or be withdrawn.

Finding CP3: Close coordination with FEMA and DHS is vital to the success of the NHC-TPC mission, and we support the on-site presence of FEMA/DHS personnel. In addition, the

emergency management community has requirements for increased training exercises, in which the NHC-TPC can play a role.

Recommendation CP3: NHC-TPC and NCEP OD should develop a National Level Exercise and Training Unit to help support FEMA and DHS needs for periodic readiness exercises. This group could also develop emergency action plans for NCEP offices, conduct internal exercises and ensure continuity of operations.

Finding CP4: A continuing concern exists between the 36/24 hr watch/warning lead time provided by NHC-TPC and the 72-120 hr lead time required by emergency management services to begin their evacuation staging, purchase logistical support, etc. Moreover, there is a requirement for probabilistic information that would enable emergency managers to provide citizens with higher probability, lower risk shelter options closer to the evacuation warning areas. The CY10 goal to extend the times for watches and warnings from 36/24 hours to 48/36 hours is excellent.

Recommendation CP4: The 48/36 hr watch/warning time extension should be implemented. As forecast skill continues to improve, NHC-TPC should assess the merits of further extensions of watches and warnings.

6.3 Products and Services

The NHC-TPC provides a wide range of products for its customers. The HSU issues track and intensity forecasts for all tropical cyclones, including tropical depressions, every six hours (more frequently if needed) out to five days, and provides the "big picture" setting for all local NWS Forecast Office products. This information is conveyed via Tropical Weather Outlooks, Forecast/Advisory messages for the public and automated ingests, Discussions, and Surface Wind Speed Probability products. The TAFB provides tropical and marine forecasts and discussions for "offshore" (primarily Gulf of Mexico and Caribbean) and "high seas" regions. The primary distribution medium is the internet, with some radiofax and voice distribution as well. New products include storm surge probabilities and storm surge inundation graphics. A mailing list was introduced in 2001 and over 60,000 subscribers can receive up to a million messages per day during active tropical cyclone days.

An ongoing challenge is the communication of information to vulnerable regions outside the U.S. that have out-of-date technology and non-English languages. Because of their lack of sufficient Spanish (and much less French) speaking personnel, it is very difficult for NHC-TPC to properly address these media requests.

Finding PS1: Numerous requests come from Spanish-language media in the U.S., and from countries where the general population does not speak English. NHC-TPC's RA4 warning responsibilities, coupled with the growing U.S. Spanish speaking population, create a pressing need to provide an adequate Spanish language interface to the media. A Spanish language NHC-TPC media desk was created, and is managed by the NOAA Office of Communications. It is

manned on a part-time basis, but only for U.S. land falling hurricanes and often by visiting NWS staff, not fully immersed in NHC-TPC operations.

Recommendation PS1: NHC-TPC should ramp-up efforts to efficiently communicate with the non-English-speaking population in the U.S. as well as countries or dependencies in Central and South America and the Caribbean. This communication could be strengthened by noting that their WMO Area of Responsibility (AOR) includes these areas and thus these languages are essential in this role. As such, these efforts might include adding staff that can serve media requests in several languages, especially Spanish. The NHC-TPC Public Affairs office could have a trilingual (Spanish is essential, French is desirable) individual on staff who has excellent television (TV) and communications skills.

Finding PS2: Coordination with other countries in their area of responsibility is sometimes difficult. In addition to language issues, it appears that just getting timely information to the proper people can be impossible. Improved connections, possibly via more use of the Internet, should be investigated. In addition, the past requirements to read location, intensity, etc., values is time consuming and prone to errors. The plan to forward electronic pre-release worksheets to U.S. forecast offices is a good step forward.

Recommendation PS2: Convey tropical cyclone location data to local and international government customers electronically, allowing more time for discussion.

Finding PS3: Creating a designated webmaster in the Technical Support Branch has led to an excellent suite of web-based products. The creation of Graphical Information System (GIS) products is commended. The Graphical Forecast Editor (GFE) is impressive.

Recommendation PS3: Continue efforts in creating digital, graphical, and sophisticated web products responsive to customer requirements.

Finding PS4: The amount of money that emergency management agencies in coastal states have to spend staging supplies and transportation, starting 3-4-days before hurricane landfall, is significant. The Navy also needs at least a 72-hour notice to get ships out of harm's way. The emergency management community typically issues life safety warning guidance between 36 and 72 hours out (i.e. - before an official warning has been issued.) Despite this, FEMA post-storm behavioral analyses indicate that the public does not heed evacuation protective guidance until "Warnings" have been issued. In summary, emergency managers and coastal residents need longer lead times.

Finding PS5: The growing disparity between the ever-increasing skill of track forecasts and the slow rate of improvement of intensity forecasts causes problems for the emergency management community, as they may not fully appreciate or understand the intensity forecast skill limitations. For example, early in the 2009 hurricane season the Monroe County (Florida Keys) officials reported that they would no longer be issuing evacuation orders for systems classified as Category 1 or below. This presents the possibility of a nightmare scenario where a Category 1 storm spins up to Category 3 intensity overnight, as has happened in the recent past. A related

problem is categorizing intensity only by wind speed, since huge rainfall totals and storm surge damage are not just functions of wind speed.

Recommendation PS4: In concert with Recommendation CP4, a study should begin on the pros and cons of a further extension beyond 48/36 hours that not only assesses whether this is justified by current forecast skill but also includes the emergency management community, media outlets, and social science and communication expertise. Increase education outreach on tropical cyclone forecast skill, storm surge and associated flooding, and involve the private sector. Consider expanding the warning criteria to include rainfall and other destructive conditions.

Finding PS6: It appears that product verification during the hurricane season is minimal, as NHC-TPC personnel said they do not have the time to fully utilize available tools. Waiting until the end of the season to assess forecast skill does not allow for the possibility of important mid-stream corrections. Feedback to the model community is also important.

Recommendation PS5: Encourage a more deliberate use and tracking of a program that collects forecast skill indicators and feeds results back to forecasters in near real-time. The Hurricane Specialists do have and could use software that would provide real-time verification. These results could be used to improve the use of model guidance and to determine where corrections in models or products are needed.

Finding PS7: Storm surge is a very important part of hurricane forecasting and safeguarding the nation's citizens. The initiatives to improve forecasting and convey the dangers of surge to the public are to be commended. However, the existing models that drive NHC-TPC model output products may not represent the best available tools to reduce the loss of lives and property. Numerous advanced and tested community models are publicly available, suggesting the adoption of a surge and inundation model ensemble approach.

Recommendation PS6: NHC-TPC should take advantage of community modeling efforts and multi-model ensemble approaches to receive improved surge and inundation forecasts from tested, state-of-the-art models. Partners in this effort include EMC, NOS, ACE, Navy, FEMA and others. NHC-TPC should continue to actively participate in the national effort to improve public awareness of storm surge & inundation threats.

Finding PS8: NHC-TPC has recognized and advocated the need to improve storm surge products and services, and management has supported the efforts of the storm surge team leader to participate in the Storm Surge Roadmap and engage with other NOAA components, agencies, and the academic community to identify and transition vital improvements. Specific initial improvements to address inundation and lead time are scheduled for the FY09 season and beyond. The panel applauds these efforts to bring visibility to this issue. Large inconsistencies still exist, however. During the review, NHC-TPC stated: "*the greatest potential for loss of life related to a hurricane is from the storm surge,*" yet storm surge does not appear anywhere on the front of the NHC-TPC web page. In addition, storm surge is included in the official forecast in a very rudimentary way, and is handled by a skilled, but small storm surge team. This team is not given official forecaster status and may not be supported with the optimal suite of oceanographic and hydrodynamic/civil engineering expertise.

Recommendation PS7: Storm surge forecasts and products need more attention, visibility and support to enhance NHC-TPC's ability to effectively communicate actionable information on SS&I to a wide variety of customers to improve preparedness and decrease loss of life and property. Specific suggestions include: (i) playing a key role in the NOAA storm surge road map and interagency/ surge community plans currently in development; (ii) addressing storm surge requirements with JHT; (iii) exploring social science and media partnerships to improve public communication; (iv) investigate approaches to account for storm surge uncertainty similar to those used for hurricane track and intensity; and (v) establishing a formal plan to clarify relationships and roles with partners including agencies with related requirements, the academic and private sector.

6.4 Information Systems

IT systems support is provided within the Technology and Science Branch (currently the "Technical Support Branch" while TPC awaits the change to NHC) which maintains a myriad of computers, routers, etc. that provide data to the NHC-TPC, generate, display and disseminate all products, and provide IT security. Some of their recent accomplishments include developing a Graphical Forecast Editor and experimental GIS products, transitioning the tropical cyclone model forecast suite to the Power 6 computer at NCEP NCO, and responding to increased security mandates.

Finding IS1: Installation and maintenance of mandated security and other system updates are creating a drain on present personnel, at the expense of NHC-TPC core responsibilities. The relative roles of NHC-TPC IT staff and NCO security experts are not clear.

Recommendation IS1: NHC-TPC should team with NCEP NCO to come to agreements on NCO's role in increasing the centralized support of NHC-TPC in the areas of IT security, systems maintenance and upgrades, Advanced Weather Interactive Processing System, version 2 (AWIPS2) support and other tasks.

Finding IS2: The IT staff has a growing load of responsibilities. These include support of: (a) an increasing number of computer systems, (b) continuous new product and software additions without commensurate retirement of legacy programs, (c) continuing and new JHT projects as well as new HFIP research, and (d) AWIPS, NCEP Advanced Weather Interactive Processing System (NAWIPS) and the upcoming transition to AWIPS2.

Recommendation IS2: Increase IT support via a contractor approach, as is being done with HFIP funds. Work with the Office of the Director and NCO to reduce required documentation. Perform an inventory of operational programs and look for possible elimination of obsolete legacy products.

6.5 Science and Technology

Overall, the Review Panel found that the NHC-TPC is an effective center, with a well-balanced portfolio of operational forecasting based on the transition from research to operations (R2O) and outreach to stakeholders and the public. The NHC-TPC engages in applied research designed to assist their mission. Most efforts are organized in the TSB, as that unit contains the Science Operations Officer and a Techniques and Development Unit, and is also the focal point for the JHT and HFIP research projects. Owing to the seasonal nature of tropical cyclones, the HSU forecasters are also involved in research activities in addition to their post-season storm summaries and verification studies. There are, however, several overarching science and technology issues affecting the future success of the center, as discussed in Sec. 5, which should be addressed by NHC-TPC, working with its partners and the NCEP Office of the Director.

Finding ST1: The NHC-TPC has been and will continue to be extremely dependent on improvements in NWP products to improve tropical storm forecast skill. There are, however, significant hurdles to be overcome to realize this vision. A national effort to develop comprehensive observational, assimilation and modeling programs that address NHC-TPC needs for improved atmospheric, ocean, wave, surge and coastal forecasting is required. The review panel realizes this is a task beyond the scope of NHC-TPC's or even NCEP's mission.

Recommendation ST1: NHC-TPC and NCEP OD should promote the creation of a team involving NHC-TPC, EMC, OPC, NWS, NOS, DOD (specifically the Navy), the research community (both national and international), as well as selected stakeholders to develop a strategic plan for an advanced, collaborative approach to coastal, surge and ocean forecasting. Two-way, interactively coupled, state-of-the-science atmospheric, ocean, coastal ocean and land-surface models are needed.

Finding ST2: NHC-TPC is to be commended for having already completed the research-to-operations transition for more than two dozen JHT projects. The rate of success has increased in recent years. The Review Panel is concerned that the JHT may have become too focused on funding only those projects which are nearly completed and for which only implementation stage of a new product at NHC-TPC is needed.

Recommendation ST2: There should be a better balance between higher risk but potentially higher reward research projects in JHT that attempt, for instance, to incorporate recent theoretical findings on hurricane dynamics into intensity forecasting.

Recommendation ST3: As a corollary to Recommendation ST2, ensure that NHC-TPC continues to be a major participant in the HFIP process. The HFIP intensity forecast goals are very stringent and the NHC-TPC needs to be especially involved in assessments of research in that area and R2O transitions.

Finding ST3: HSU forecasters stated that there was no time to do case studies on poorly-forecast hurricanes and to evaluate what went wrong (or, conversely, to examine why some forecasts were so successful).

Recommendation ST4: NHC–TPC operational forecasters and TSB personnel should be involved in close collaboration with EMC, the Hurricane Research Division in NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) and perhaps other groups in studying "skill-dropout" (and successful) cases. This will result in a better understanding of data and model deficiencies and of NWP guidance, and permit an improved knowledge transfer across the center.

Finding ST4: The mechanism for the NHC-TPC to establish, submit, track, and transition requirements for product or capability improvement is poorly defined. It was not clear who is responsible for committing funds to Research & Development to specifically improve NHC-TPC forecasts, nor what the NHC-TPC role is in expressing their requirements to management, thereby ensuring research and development is working to meet their operational needs, monitoring progress, and completing the transition.

Recommendation ST5: Strengthen the requirements process and connection of NHC-TPC to larger programs through NCEP OD. Consider holding an annual exercise involving research, development and operational personnel to focus on key forecasting issues.

Finding ST5: The JHT is an effective vehicle to engage the research and development community. However, it was not clear that projects were based on requirements but rather were more likely a case of funding an investigator's interest with results that may or may not fit into the operational environment. Also, the good points of the JHT may not be used by the HFIP, with the inference that NHC-TPC may not have much influence on this program.

Recommendation ST6: NHC-TPC should continue to embrace partnerships with academia and the private sector in both the JHT and HFIP programs, guided by Recommendations ST1, ST2 and ST3 above.

Finding ST6: The introduction of probability forecasting procedures at NHC-TPC is to be commended although more needs to be done in this area. They have also developed many ensemble products to assist forecasters, but most are simple averages of various model combinations.

Recommendation ST7: NHC-TPC should explore more sophisticated approaches to maximizing the information content from multi-model ensembles. This, in turn, will lead to new and/or improved probability forecast products.

Finding ST7: NHC-TPC's suite of watches and warnings and information services rely on extensive observational needs, which are also required to drive numerical forecast models.

Finding ST8: Numerical model output of coastal storms and coastal processes, including physical and bio-geo-chemical models, has been shown to improve with the assimilation of in-situ and satellite data, and promises to improve coastal surge, inundation, flood and ecological modeling needed by NHC-TPC.

Finding ST9: To meet its present and future forecast challenges NHC could benefit from enhanced in-situ atmospheric and oceanic observations (in terms of density of coverage, suite of sensors, and real-time data assimilation into forecast models) and modeling enhancements being explored in the scientific community. However, NHC-TPC's ability to consistently articulate these requirements to the appropriate NCEP (EMC) or NOAA (Integrated Ocean Observing System or IOOS, Global Ocean Observing System or GOOS, HFIP, Naval Ocean System Center or NOSC, etc.) programs and to evaluate the success of new approaches seems limited.

Recommendation ST8: In order to provide the information, products and services and to drive the storm surge, inundation, flood and ecological models needed, the observational requirements of NHC-TPC must be met. NHC-TPC, working with EMC, and then NCEP OD, NWS and NOAA, needs to identify existing observational gaps, both atmospheric and oceanic, and to determine the essential and optimal suite of observations that are needed. The goal is that this will lead to the enhancement and build-out of the present NDBC network, and possibly to a meaningful engagement with GOOS and IOOS.

6.6 People and Organizational Culture

Finding POC1: NHC-TPC staff deserves high praise for their job performance and dedication.

Finding POC2: There is a NOAA public affairs officer on site who has an education in meteorology and numerous years of on-camera television experience, and thus has expertise in communications. However, NHC-TPC does not have professional social sciences communications expertise on staff.

Recommendation POC1: NHC-TPC needs to more actively engage and incorporate internal and external communication and in particular, professional social science expertise in product design, web design and public communications, broadly defined, to improve forecast effectiveness and public understanding.

Finding POC3: NHC-TPC does not have dynamical nor bio-geochemical oceanography expertise on staff.

Recommendation POC2: Determine NHC-TPC oceanography support requirements. Open communications with NOS, OPC, the Navy and other ocean support groups for mutual cooperation. Hire an oceanographer if required.

Finding POC4: Adequate bi-lingual, technically competent, media-comfortable personnel on the NHC-TPC staff are needed to deal with NHC-TPC's WMO Regional Association IV (RA4) warning responsibilities along with the increasing U.S. Spanish speaking population. Spanish is essential and French is desirable.

Recommendation POC3: NOAA should consider hiring hurricane specialists who are bilingual or trilingual so as to better serve the media and public. At a minimum, the Office of Communications at NHC-TPC should be staffed by a bilingual or trilingual individual with

excellent communications skills. Other alternate solutions might be explored although "flying-in" people without strong NHC knowledge or experience may not provide the needed communications.

Finding POC6: The Navy and NOAA officers both contribute to the NHC-TPC. The experience gained by young officers has to be invaluable. They also keep valuable lines of communication open with their respective organizations.

Recommendation POC4: NOAA and Navy billets are valuable and should be continued.

Finding POC7: Significant positive steps taken since the 2007 Turner report on NHC have resulted in improved morale and openness; however, it was evident that a few cultural issues will need to be continually monitored to avoid similar challenges in the future. The importance of the NHC mission to the nation, and the substantial success and recognition they have received for their work seems to create a very deliberate approach to change, and a hierarchy across the branches. These perceptions can lead to NHC seeming like a somewhat closed system where not everyone feels free to speak their mind.

Recommendation POC5: NHC needs to continue to explore safe mechanisms for resolving employee issues quickly and hearing all employees' ideas and feedback. Providing a strong team culture and balanced access to all units will be important tools for ensuring continued success. External assistance may be required.

6.7 Business Processes

Finding BP1: NHC-TPC is clearly built to withstand strong winds, yet may be vulnerable to communication outages, flooding, or social/political hazards (noted little perimeter security). Although procedures for Continuity of Operations (COOP), fire drills, moving operations, etc, are clearly established, it did not appear that substantive full-scale COOP exercises were routinely conducted.

Recommendation BP1: As a vital national resource, NHC needs to continue to ensure they are optimally prepared to provide continuity of operations and safety and security of employees. NHC should conduct annual exercises with realistic scenarios to improve preparedness.

Finding BP2: The current national response to hurricane threats may be misguided, i.e., a better response to land falling tropical storms may be weatherproof and surge-proof shelters near coastal cities rather than elaborate plans to evacuate large populations long distances inland. There is a growing concern that Emergency Management will not be able to adequately respond to rapidly intensifying storms just off the coast. Many operational time frames exceed H-120 hours; however, a significant number of storms are not predictable at this range.

Recommendation BP2: Use NHC-TPC's considerable influence as hurricane experts to improve the Emergency Management community's operational and evacuation timing considerations.

Increase training opportunities to the emergency management community. Consider leading a collective effort to provide citizens with shelter options closer to the evacuation warning areas.

Finding BP3: The NHC-TPC warning coordination area covers not only the United States, but also many countries in the WMO RA4. Media outlets are the biggest and most important partners when it comes to the dissemination of life saving hurricane warnings.

Recommendation BP3: NHC-TPC needs to ramp up their services to Spanish media inside and outside of the U.S., and to French-speaking media for the Caribbean countries where that is the primary language.

Finding BP4: National Weather Service policy is that WFOs may and do provide weather services directly to the media on unscheduled significant weather. The NHC Director also provides frequent interviews and briefings for significant weather events. What is not done is the provision of routinely scheduled weathercasts, which is deemed a private sector only service, and NHC-TPC refers such requests to the private sector. In addition, NHC-TPC provides outreach and educational services to the media year round.

Recommendation BP4: The NHC-TPC should, via web and in-person efforts, continue to educate its stakeholders on hurricane science, preparedness and response. In addition, NHC-TPC should include WFOs as preparedness/outreach focal points during hurricane threats. With the aim of establishing stronger bonds, the NHC-TPC partnerships with the media and private weather providers should continue to be strengthened, with respective roles clearly defined.

Appendix A

National Centers for Environmental Prediction Review
Charge to the Review Panels

Charge

The University Corporation for Atmospheric Research (UCAR) will carry out a review of the National Centers for Environmental Prediction (NCEP) in 2009 through a series of panels that will assess the individual Centers, their interaction with each other and with other NOAA, federal, academic and non-governmental entities to determine how effectively NCEP is accomplishing its mission and realizing its vision. In particular, for each Center and NCEP as a whole, the Review will assess:

- Statements of mission, vision and five-year plans.

- Productivity and quality of scientific activities and/or operational products and services with an emphasis on the progress since the most recent review.

- Relevance and impact of the research and/or products. Ability to meet customer demand and emerging requirements.

- Effectiveness of activities or specific plans for transition of research to operations (R2O), including research conducted outside NCEP within NOAA, within the federal research enterprise, and in academia or the private sector.

- Effectiveness of activities or specific plans for support of research by and/or joint efforts with program elements within NOAA that provide support for or conduct research as their primary mission and also with outside entities (academia; research laboratories) via the provision of operational products, services and in-house support (operations to research - O2R).

- Balance between operational responsibilities and research and development initiatives.

- Programmatic plans for new scientific activities and operational products and services, including plans for continuations and terminations.

In addition, the Review will address any specific other issues or questions raised in the course of the review.

Procedure

1. The Review will be organized under the leadership of an Executive Committee composed of two co-chairpersons, representatives of the operational environmental prediction and NCEP user communities, and each of the chairpersons of the individual Center Review Panels. Each Center Review Panel will have 5-6 members with diverse representation from academia, federal labs and users. The Executive Committee will develop a slate of panel members in consultation with the Director of NCEP. The Executive Committee will recommend a panel review slate to the President of UCAR, who will appoint the Review Panels.

2. The following documentation will be requested from each Center and NCEP OD:
    - Vision and mission statement (strategic plan, if extant)
    - Organization chart and list of present staff and visitors (staff turnover since last review)
    - Summary narrative of recent highlights and accomplishments
    - Summary narrative of R2O and O2R activities
    - Summary narrative of collaborative work
    - List of publications and/or reports since last review (with sample of reprints)
    - List of products and services, along with selected samples
    - Summary of budget, sources of support and expenditures
    - The NCEP and/or individual Center responses to the reviews conducted between 1996 and 2001.

3. Each Center will be asked to submit documentation, at least one month before the on-site visit, to UCAR for distribution to Review Panel members before the on-site visit.

4. An on-site review (typically 1.5-2 days) will be conducted at each Center. The date for each review will be fixed in consultation with the Center Director and the Director of NCEP.

5. Each Review Panel will provide a preliminary briefing to the Director of NCEP at the conclusion of each on-site review.

6. Each Review Panel will write a report of its findings. A draft of the review report for each Center will be shared with the Center Director to correct any factual errors.

7. The Executive Committee will write a final report, directed to the President of UCAR, that summarizes the findings of the reviews of the individual Center as well as NCEP as a whole, and will make recommendations for improvements.

UCAR will provide administrative help for the preparation of the individual Center Review Panel reports and the final report of the NCEP Review.

Appendix B

NHC-TPC Review Panel Membership

Dr. Len Pietrafesa (Chair)
North Carolina State University

Dr. Frank Bub
Naval Oceanographic Office, Stennis Space Center

Dr. Kristen Corbosiero
University of California Los Angeles

Ms. Mary Erickson
NOAA National Ocean Service

Mr. Brock Long
Alabama Emergency Management Agency

Mr. John Toohey-Morales
NBC-6 Miami

NCEP Review Executive Committee Members

Frederick Carr (Co-chair)
University of Oklahoma

James Kinter (Co-chair)
Center for Ocean-Land-Atmosphere Studies

Gilbert Brunet
Environment Canada

Kelvin Droegemeier
University of Oklahoma

Genene Fisher, Panel Chair
American Meteorological Society

Ronald McPherson
American Meteorological Society (Emeritus)

Leonard Pietrafesa
North Carolina State University

Eric Wood
Princeton University

Appendix C

List of Acronyms and Terms

ACE	Army Corps of Engineers
AMSU	Advanced Microwave Sounding Unit
AOML	Atlantic Oceanographic and Meteorological Laboratory
AOR	Area of Responsibility
ASCAT	Advanced Scatterometer
AWC	Aviation Weather Center
AWIPS	Advanced Weather Interactive Processing System
BP	Business Processes
COOP	Continuity of Operations
CP	Customers and Partners
CPC	Climate Prediction Center
CPHC	Central Pacific Hurricane Center
CY	Calendar Year
DHS	Department of Homeland Security
DOD	Department of Defense
ECMWF	European Center for Medium Range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EM	Emergency Management
EMC	Environmental Modeling Center
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
4DDA	Four-Dimensional Data Assimilation
FTE	Full Time Equivalent
FY	Fiscal Year
GFDL	Geophysical Fluid Dynamics Laboratory
GFE	Graphical Forecast Editor
GFS	Global Forecast System
GIS	Graphical Information System
GOOS	Global Ocean Observing System
GPRA	Government Performance and Results Act
GPS	Global Positioning System
G4	Gulfstream IV
HEC	High-End Computing
HFIP	Hurricane Forecast Improvement Project
HIRWG	Hurricane Intensity Research Working Group
HPC	Hydrometeorological Prediction Center
HSU	Hurricane Specialists Unit
HWRF	Hurricane Weather Research and Forecast Model
IOOS	Integrated Ocean Observing System
IT	Information Technology
IS	Information Systems

ISRO	Indian Space Research Organization
JHT	Joint Hurricane Testbed
MDL	Meteorological Development Laboratory
MOS	Model Output Statistics
MV	Mission and Vision
NASA	National Aeronautics and Space Administration
NAWIPS	NCEP Advanced Weather Interactive Processing System
NHC	National Hurricane Center
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NDBC	National Data Buoy Center
NextGen	Next Generation Air Transportation System
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Navy Operational Global Atmospheric Prediction System
NOS	National Ocean Service
NOSC	Naval Ocean System Center
NPOESS	National Polar Orbiting Environmental Satellite System
NSB	National Science Board (OFCM)
NWP	Numerical Weather Prediction
NWS	National Weather Service
OD	Office of the Director
OFCM	Office of the Federal Coordinator for Meteorology
OPC	Ocean Prediction Center
OSE	Observing System Experiments
OSSE	Observing System Simulation Experiments
OSVW	Ocean Surface Vector Wind
POC	People and Organizational Culture
PS	Products and Services
QPF	Quantitative Precipitation Forecasts
Quikscat	Quick Scatterometer
RA-IV	Regional Association IV
R2O	Research-to-Operations
SAB	Science Advisory Board
SLOSH	Sea, Lake and Overland Surges from Hurricanes
SMFR	Stepped Frequency Microwave Radiometer
SOO	Science Operations Officer
SPC	Storm Prediction Center
SS&I	Storm Surge and Inundation
ST	Science and Technology
SWPC	Space Weather Prediction Center
TAFB	Tropical Analysis and Forecast Branch
TC	Tropical Cyclone
TDAU	Techniques Development and Applications Unit
TPC	Tropical Prediction Center
TRMM	Tropical Rainfall Measurement Mission
TSB	Technical Support Branch

TV	Television
UCAR	University Corporation for Atmospheric Research
UKMET	United Kingdom Meteorology Office
WFO	Weather Forecast Office
WMO	World Meteorological Organization
XOVWM	Extended Ocean Vector Winds Mission