2015 TROPICAL CYCLONE RESEARCH FORUM
69th INTERDEPARTMENTAL HURRICANE CONFERENCE

SUMMARY REPORT

With the support of the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) and the sponsorship of NOAA/OAR, the Office of Navy Research (ONR), and the National Science Foundation (NSF), the 2015 Tropical Cyclone Research Forum (TCRF)/69th Interdepartmental Hurricane Conference (IHC) was hosted and chaired by Mr. David McCarren, Federal Coordinator for Meteorological Services and Supporting Research (Acting), from March 2-5, 2015, at the Wyndham Jacksonville Riverwalk, Jacksonville, FL. During the 2015 TCRF/69th IHC, the following observations were highlighted:

- In addition to the on-site participants, the forum had a substantial "virtual" attendance, with attendees participating via the internet, using "GoToMeeting" and dial-in audio technology.
- There were 143 total registrants—83 attended in person and 60 participated virtually.
- It was pointed out by several participants that the face-to-face interaction at the forum was very valuable; lots of good discussions went on during the breaks.
- The session presentations were delivered in a timely manner and, in most instances, adequate time was available for questions from both on-site and virtual participants.
- The Hagemeyer Award was presented to Edward Fukada via video-link to the JTWC.

This document summarizes the results of the forum and includes the following sections:

- Section I – Overview
  - Purpose and Theme
  - Objectives
  - Abstracts and Presentations
  - Key Observations and Takeaways
  - Action Items
- Section II – Synopsis
  - Sessions Conducted
  - Key Events
- Section III – Summary Remarks

I. OVERVIEW

Purpose and Theme:
The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) annually hosts this event to provide a forum for the responsible Federal agencies, together with representatives from the academic community, industry, and other user communities, such as emergency management, to prepare for the upcoming tropical cyclone season and to make improvements to the Nation's tropical cyclone forecasting and warning program. The theme for the forum was: *Tropical Cyclone Operations and Research: Setting our Future Course*.

Objectives:
Forum sessions were structured to address the following objectives:
- Review and update the Nation's tropical cyclone forecast and warning program, to include a review of the 2014 season.
- Assess the progress in addressing the operational priorities of the operational centers (NHC, CPHC, and JTWC) and adjust research priorities moving forward based on the inputs of the centers.
- Receive updates on Joint Hurricane Testbed projects, assessing their readiness to transition from research into operations.
- Review ongoing tropical cyclone model development and evaluation initiatives within NOAA, Navy, and NASA.
- Explore ongoing and future developments in observation technologies for both the atmosphere and ocean that will promote improvements in the forecasting and understanding of TCs and their associated affects.

Abstracts and Presentations:
Abstracts for the presentations that were given at the 2015 TCRF/69th IHC can be found at: http://www.ofcm.gov/ihc15/final%20booklet.pdf. Presentation and poster preview slides, and available posters may be viewed at: http://www.ofcm.gov/ihc15/69IHC-Linking-File.htm.

Key Observations and Takeaways:
- An annual OFCM-sponsored meeting of the TC operations and research community is strongly supported.
- Partnerships are more important than ever; the ability of our TC community to work together keeps the TC forecast and warning enterprise moving forward.
- Funding from the Sandy Supplemental has had a big impact.
- Meteorology is becoming well integrated with emergency management. Florida has a Chief State Meteorologist who serves as a Deputy Operations Officer in the Florida Division of Emergency Management and gave a presentation on her activities in the opening session.
- It would be useful to invite the growing number of state meteorologists to the IHC to give state government views of TC impacts on their citizens, societal costs and issues, and ways to improve TC forecast information for integration in their decision processes.
- While NOAA AOC hurricane research flying hours were up in 2014, one WP-3D will be unavailable for the 2015 season for re-winging which will add 15-20 years to the service life of the aircraft.
- This is the 4th season that the 53 WRS and the U.S. Naval Academy personnel have worked together to provide airborne/air expendable bathythermograph (AXBT) data in and around hurricanes in an effort to better quantify ocean heat content. The objective of the ongoing AXBT demonstration project is to increase hurricane forecast accuracy by assimilating ocean observations from beneath tropical cyclones into coupled numerical models in near-real time.
- The Joint Hurricane Testbed continues to be healthy and productive. Since 2001, 81 projects were supported, 74 were completed, and 52 accepted for operational

implementation. To date, 45 projects have been implemented—14 numerical modeling projects at NCEP/EMC/NCO and 31 at NHC.

- Improved guidance on tropical cyclone intensity change remains the top priority of the operational centers.
- Genesis and rapid intensification were the focus of the lot of work presented at the forum.
- The NOAA/Navy multi-model ensemble will be expanded to all basins for FY15.
- Assimilation of dropsonde observations has a positive impact on model track forecasts.
- Model results were much improved for track and intensity in 2014.
- New (some on the horizon) observation technologies are extremely promising; e.g., HDSS, APAR, air-deployable profiling floats, wave gliders, Coyote UAS, GOES-R, and the CYGNSS satellite constellation.
- During a 5-week deployment in late August through September 2015, NOAA's SHOUT (Sensing Hazards with Operational Unmanned Technology) Program will use NASA's Global Hawk to test a prototype UAS concept of operations that could mitigate the risk of diminished high impact weather warnings in case of polar-orbiting satellite observing gaps.
- At the 5-year point of a 10-year project, NOAA's Hurricane Forecast Improvement Project (HFIP) is providing a good return on investment. Broader community participation and accelerated research to operations have been instrumental to HFIP's success to date.
- Research into outflow and aerosols may pay dividends in the future.
- The operational centers desire further development of forecaster guidance decision tools.
- Coastal and inland storm effects such as surge, inundation, flooding, etc., require continued attention.
- The presentations reflected excellent collaborations and partnerships in research and applications. The number of platforms and the data being shared are impressive. A considerable amount of R&D data is getting into operations.

Forum Action Items:
- The OFCM will post forum presentations and this summary on the conference web page.
- The OFCM will publish the annual National Hurricane Operations Plan (NHOP), to include changes recommended to and accepted by the WG/HWSOR, no later than May 1, 2015.
- The OFCM will work with NOAA and the Navy to secure the funding and support for the Automated Tropical Cyclone Forecast (ATCF) system.
- Through the OFCM infrastructure, a strategic plan for improved tropical cyclone reconnaissance and surveillance systems and observations (manned, unmanned, space-based, etc.) will be developed.
- The OFCM will complete and publish a mid-course assessment, to be conducted by the WG/TCR, on the *Interagency Strategic Research Plan for Tropical Cyclones: The Way Ahead* (FCM-P36-2007).

II. SYNOPSIS

Sessions Conducted: In addition to the opening, poster, and plenary sessions, the 2015 TCRF/69th IHC agenda included the following:

Session #	Title
1	The 2014 Tropical Cyclone Season in Review
2	Research Priorities of the Operational Centers
3a	Transitioning Research to Operations (JHT and DTC), Part 1
3b	Transitioning Research to Operations (JHT and DTC), Part 2
4a	Observations and Observing Strategies, Part 1
4b	Observations and Observing Strategies, Part 2
5a	Advances in Tropical Cyclone Model Development and Evaluation, Part 1
5b	Advances in Tropical Cyclone Model Development and Evaluation, Part 2
6	The Future of the IHC—Agency Perspectives
7	Products, Services, and Societal Impact
8	Tropical Cyclone Plan Mid-Course Assessment—Operational Needs and Research Priorities

Key Events:

- **Working Group for Hurricane and Winter Storms Operations and Research (WG/HWSOR) meeting:** The working group met on-site and virtually on March 2, 2015. The final working group results were presented during the final plenary session by the working group chair. Twenty-six new action items were addressed; all were closed. Nineteen required NHOP updates and seven were information items. Additionally, six items from previous IHCs were reviewed. Two from the 68th IHC are on-going; one from the 67th IHC is on-going; one from the 66th IHC was closed; one from the 65th IHC is ongoing; and one from the 62nd IHC is on-going (the MOA between AFRC and NOAA needs to be updated). It was reiterated that the WG/HWSOR meeting is best held during the IHC, and the intent is to hold this meeting during future IHCs.

- **Forum Opening Session:**
  o **Welcoming Remarks.** Mr. David McCarren, Federal Coordinator for Meteorological Services and Supporting Research (Acting) opened by noting that the forum goal is to meet annually to improve the tropical cyclone forecast operations and set priorities for research to address gaps in forecast capabilities. The forum will also evaluate progress in the 2007 Tropical Cyclone Forecast Research Plan.
  o **Perspectives from the Florida Division of Emergency Management.** Mr. Steven C. Woodard, Director, Emergency Preparedness Division, Jacksonville Fire and Rescue Department and Ms. Amy Godsey, Chief State Meteorologist, Florida Division of Emergency Management discussed the nature of the tropical cyclone threat to the Jacksonville area.
    - It has been 50 years since Jacksonville area experienced a hurricane (Hurricane Dora with 100 mph winds).
    - Emergency managers conduct an active awareness program annually to remind people of the threat and the need to be prepared for the many types of hazards associated with tropical systems.
    - Emphasized the need for specific messages to the public on the impacts associated with tropical cyclones.

- ▪ Importance of getting involved with the community in all four phases of emergency management; prepare, respond, recover and mitigate.
- ▪ Importance of surveys to better assess how people get and use information related to storm hazards.
- ▪ The use of color codes for storm surge warnings has helped the public to understand and respond to the storm surge threat.

- **Session 1: The 2014 Tropical Cyclone Season in Review.** Session Leader: Kathy Winters (Air Force/45th Weather Squadron) (see presentations)
  - o Review of the 2014 Central Pacific Tropical Cyclone Season and Preliminary Verification; Thomas Birchard (NOAA/NWS/CPHC)
    - ▪ The North Central Pacific experienced a near normal number of tropical cyclones during the 2014 Hurricane Season, with a distribution of four hurricanes and one tropical storm.
    - ▪ The second tropical cyclone, Hurricane Iselle, was the first tropical cyclone since 1992 to make landfall. One impact was the substantial damage to the papaya crop on the Island of Hawaii.
    - ▪ The remaining four TCs entering or developing in the North Central Pacific remained over the open ocean.
    - ▪ Research is needed to better understand the interaction of TCs with the topography of the islands and the effect on TC tracks.
  - o A Review of the 2014 Joint Typhoon Warning Center Tropical Cyclone Season; Robert J. Falvey (JTWC).
    - ▪ Below average year with 52 TCs in the 3 forecast basins: 23 tropical cyclones in the western North Pacific, 24 tropical cyclones in the southern hemisphere, and 5 tropical cyclones in the northern Indian Ocean.
    - ▪ Track forecast accuracy and track error reduction have not reached their goal.
    - ▪ Satellite reconnaissance is critical to forecasts and warnings.
    - ▪ Technique development includes track, intensity and genesis prediction.
  - o NOAA Aircraft Operations Center (AOC) 2014 Seasonal Summary and Future Plans; CAPT Harris Halverson (NOAA/AOC).
    - ▪ Sharp rise in tropical cyclone flight hours from 204 in 2013 to 460 in 2014 of the three NOAA aircraft that perform these missions.
    - ▪ The three aircraft flew missions into five named storms in the Atlantic, three in the eastern Pacific, and one in the central Pacific.
    - ▪ The G-IV and both P-3s participated in several HRD experiments during the season, notably the Model Evaluation Experiment.
    - ▪ First successful launch from a P-3 of a small, unmanned aircraft, the Coyote, into a hurricane.
    - ▪ Commencing in March 2015, NOAA will begin its Service Life Extension upgrades to both of the P-3s utilizing funds from a Sandy supplemental. Included will be the re-winging of the aircraft along with the upgrade of the P-3 engines.
    - ▪ Coincidental to the re-winging and engine improvements will be a $9+M upgrade to the aircraft avionics and instrumentation.
  - o 53rd Weather Reconnaissance Squadron/AFRC 2014 Hurricane Season Summary; 1st Lt Leesa Froelich (53 WRS).

- Completed 64 Atlantic and 33 Eastern/Central Pacific NHC fix requirements along with 14 other requirements (Invest, Surveillance, Buoy).
- A total of 74 missions and 915.4 hrs were flown in support of NHC.
- First season since the mid 1990's that the unit deployed significant resources to the Central Pacific region due to two hurricane threats.
- First season that the unit deployed ocean instruments ahead of a hurricane in the Central Pacific.
  - 2014 AXBT Demonstration Project: Operations Summary and Research Update; Elizabeth R. Sanabia (U.S. Naval Academy)
    - Fourth year of the hurricane AXBT demonstration project mandated at the 65th Interdepartmental Hurricane Conference Working Group for Hurricanes and Winter Storms.
    - Project goal was to increase hurricane forecast accuracy by assimilating ocean observations from beneath tropical cyclones into coupled numerical models in near-real time.
    - More than 250 AXBTs were deployed during 34 WC-130J flights over the Atlantic and Pacific Oceans, including 28 missions into 4 named storms over a 6-week period.
    - In addition, Air-Launched Autonomous Micro Observer (ALAMO) profiling floats were deployed during tasked reconnaissance missions for the first time.

- **Session 2: Research Priorities of the Operational Centers.** Session Leader Eric W. Uhlhorn (NOAA/AOML/HRD). Five supporting talks (see presentations).
  - Tropical cyclone reconnaissance and warning capability critical to resource protection, operations, and saving lives.
  - Must continue to work JOINTLY to improve analysis and forecast capability; significant improvement is needed in intensity forecasts.
  - Can use minimum Deviation Angle Variance Method within a disturbance to determine whether it is developing or not based on a pre-determined threshold value.
    - 50% chance of developing into a TD/TC/STC within X amount of time based on reaching certain threshold DAV values.
    - New strategy for providing probabilistic genesis forecasts based on the DAV is in current development, including how to exploit further the tendency in the DAV variance.
  - For TC genesis probabilities most important "environmental" predictors are mid-level RH and mixing ratio. Rain fractional area is good though less significant proxy.
  - The improvement in TC genesis skill over the last 6 years is attributable to the general advancements in NWP model resolution and physics. Future improvement in TC genesis forecasting will come from a deeper diagnosis of the model TC formation process that helps identify deficiencies in the key physical process – tropical rainfall.
  - TC genesis serves as a model diagnostic itself, revealing model performance characteristics, which can vary across basins.
  - The unique aspect of the tropical cyclogenesis satellite guidance product (TCGSatP) is the emphasis on passive microwave satellite overpasses to assess the convective and rainfall characteristics, and infrared cloud cluster tracking to quantify the longevity of organized deep convection.

- Knowledge of how quickly the outer rainbands become disorganized and center becomes exposed can help improve the spatial accuracy of rainfall forecasts. Research is needed to assess the accuracy of TC rain fields in the WRF model.
- Pre-establishment of fixed-place deployment locations will increase the efficiency of USGS storm-tide sensor deployment and recovery at selected sites in advance of land-falling hurricanes and other coastal storms. It also improves the timeliness of data analysis and delivery because such information is often needed as quickly as possible after these events.

- **Session 3a/b: Transitioning Research to Operations (JHT and DTC).** Session Leaders: Chris Landsea (NOAA/NCEP/NHC) and Shirley Murillo (NOAA/AOML/HRD). Eleven supporting talks. (See presentations).
  - Top 5 priorities for funding:
    - Guidance for tropical cyclone intensity changes, especially for the onset, duration, and magnitude of rapid intensification events, as well as over-water rapid weakening events.
    - Improved capability to observe the tropical cyclone and its environment to support forecaster analysis and model initialization.
    - Statistically based real-time guidance on guidance to assist in the determination of official track and intensity forecasts. This could include multi-model consensus approaches, provided in probabilistic and other formats.
    - Enhancements to the operational environment (e.g., ATCF, AWIPS-II) to increase forecaster efficiency by expediting analysis, forecast, coordination, and/or communication activities.
    - Techniques or products to support pre-genesis disturbance track, intensity, size, and wind speed probability forecasts.
  - 45 projects implemented since inception of JHT:
    - 14 numerical modeling projects implemented by EMC/NCO.
    - 31 projects implemented by NHC.
    - 5 projects accepted but not yet fully implemented by NHC.
    - 2 projects unable to be implemented after acceptance.
  - In addressing intensity forecast errors, multiple linear regression techniques are promising with 2007-2014 independent results showing percent improvement over climatology ranging from 6%-18% for average error and 8%-30% for bias.
  - One approach to creating more reliable TC intensity forecasts with the resources currently available is to create real-time skill predictions that help forecasters and end users know when a particular model forecast will be more or less skillful than average.
  - Improvements to the Monte Carlo model were made to improve the accuracy of the wind speed probabilities for exceptionally small or large (e.g., 2012's Hurricane Sandy) tropical cyclones.
  - Monte Carlo track improved results by 10%.
  - Despite considerable model improvements over the past decade, there remains a significant bias in NWP TC forecasting that varies with forecast hour.
  - The Automated Rotational Center Hurricane Eye Retrieval (ARCHER) Automated TC Center-Fixing Algorithm will be operational for the 2015 hurricane season.

- o The probability-based microwave ring RI index (PMWRing RII) is planned to be implemented not only in the Atlantic and Eastern & Central North Pacific basins, but also the JTWC forecast basins including the North Western Pacific, North Indian Ocean, and Southern Hemisphere.
- o Upgrades to the GFDL and GFDN models include an increase in the number of vertical levels from 42 to 60, minor modifications to the physics to account for the resolution change, improvements in the moisture initialization, a new specification of the storm size (Rb), and fixing of two bugs in the hurricane model that were found over the past year.
- o HFIP results are an increase in TC accuracy for track and intensity and more confidence in the forecast.
- o The NCAR TC modeling team develops new verification methods and tools for TC forecasts and the design and implementation of diagnostic verification experiments to evaluate the performance of tropical cyclone forecast models.

- **Session 4a/b: Observations and Observing Strategies.** Session Leaders: Scott Braun (NASA/GSFC) and Chris Velden (University of Wisconsin/CIMMS). Thirteen supporting talks. (See presentations)
  - o NOAA's Intensity Forecast Experiment (IFEX) for 2015 will focus data collection on the full lifecycle of a TC from development to extratropical transition or landfall for each storm to better understand the complete processes within the system. IFEX is a multi-sensor project. Aircraft observations had a positive impact on simulations of ISAAC (2013) with HWRF.
  - o Hurricane and Severe Storm Sentinel (HS3) conducted ten flights of the environmental Global Hawk (GH) and three of the WB-57. Four GH flights sampled Hurricane Edouard over much of its life cycle, including its early stage as a tropical storm, a period of rapid intensification, its mature stage, and its dissipation stage.
  - o The Stepped Frequency Microwave Radiometer (SFMR), installed in the WP-3D, WC-130 and G-IV, has greatly improved wind- field observation in storms, including the maximum wind, from reconnaissance aircraft. Algorithm adjustments will improve the real-time winds. In general, winds will be somewhat lower in weak to moderate wind speeds within heavy precipitation, and largely unaltered at hurricane wind speeds. Also, maximum rain-rate values (a bi-product of surface wind retrieval) will be greater than before, more consistent with the highest observed radar reflectivity values.
  - o High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) measurements from higher altitudes above storms provide higher spatial and temporal resolution than obtained by current satellites and lower-altitude instrumented aircraft. It measures ocean surface backscatter from which ocean surface winds can be derived through scatterometry techniques similar to QuikScat. HIWRAP can transmit data in real time.
  - o The Hurricane Imaging Radiometer (HIRAD), a four channel C-band water vapor sensing radiometer, made observations of Hurricane Gonzalo during three flights of a NASA WB-57 high-altitude aircraft during 15-17 October 2014. The wide-swath imagery from HIRAD clearly revealed a concentric eyewall structure before the hurricane hit Bermuda and improved radial wind profiles assimilated in models for hurricane Karl. More WB-57 sorties are planned.

o The High-Definition Sounding System (HDSS) is an automated system deploying the eXpendable Digital Dropsonde (XDD) designed to measure wind and Pressure-Temperature- Humidity (PTH) profiles plus Sea Surface Temperature (SST) within and around tropical cyclones and other high-impact weather events needing high sampling density. A test flight flown off the Texas Coast demonstrated excellent capability to obtain complete soundings from 19 km to the surface plus SST.

o The HDSS collection system was used in Hurricane Gonzalo to measure and determine the impacts of outflow layers above the troposphere. HDSS can assist in validating working hypotheses of pre-development based on outflow patterns while also measuring inner core features.

o Airborne Phased Array Radar (APAR), at C-band, will allow the measurement of 3-D kinematics of the inner core and rainband structures with less attenuation compared with current airborne Doppler radar systems. The unique combination of APAR capabilities as well as water vapor measurements using dropsonde and in situ measurements, and other remote sensing instruments such as cloud radar and wind lidar from a single airborne platform, will help scientists to examine the role of the hurricane eye with regard to intensity changes.

o RapidScat was launched and is on the International Space Station. It is a two-year mission to support global monitoring of ocean winds for improved weather forecasting and climate studies. The data are processed at JPL for ocean surface wind vectors and transmitted to NOAA who posts it on their research server NOAA-STAR. There are 25- and 12.5-km products sent to NWS.

o High frequency radars are operated in the southeast from Florida to North Carolina. These HF radars map surface processes such as surface currents, winds and waves in near real time with 16 passive beams via Bragg scattering. Using these real-time measurements has promise to improve surge models if radar sites can be hardened to withstand hurricane force winds for landfalling storms. The system is currently being expanded to add coverage of the southeast and Gulf coasts, providing data relevant to the behavior of the Loop current. Two or more receivers are needed to resolve currents.

o Air-Deployable Profiling Floats are a primary source of ocean data temperature and salinity.

o Wave Gliders (WGs) provide dynamic environmental monitoring in the maritime environment with long- duration deployments of continuous real-time meteorological and oceanographic data collection, using solar panels to power sensors and satellite and cell communication channels for data delivery. The WGs have also demonstrated robustness in harsh maritime conditions and a monitoring capability for data-void regions.

o The NASA Cyclone Global Navigation Satellite System (CYGNSS) is specifically designed to study the surface wind structure in and near the inner core of TCs. CYGNSS consists of a constellation of eight small observatories carried into orbit on a single launch vehicle and is expected to provide unprecedented temporal resolution and spatial coverage, under all precipitating conditions, and over the full dynamic range of wind speeds experienced in a TC with a mean revisit time between three and six hours. The planned launch date is October 2016.

- **Session 5a/b: Advances in Tropical Cyclone Model Development and Evaluation.** Session Leaders: James D. Doyle (NRL/Monterey) and Vijay Tallapragada (NOAA/NCEP/EMC). Twelve supporting talks. (see presentations)
  - o HWRF will be upgraded in 2015 to run at 2km resolution near the storm region with advanced physics improvements, and for the first time, HWRF will run operationally for all global tropical cyclones throughout the year in support of NHC, JTWC, CPHC and National Weather Service (NWS) Pacific Region.
  - o Improvements in predicting the rapid intensity changes, development of advanced inner core data assimilation techniques, and application of scale-aware and stochastic physics remain as the high priority areas of research.
  - o Based on the 2014 HWRF system that includes the operational initialization scheme and recent upgrades to physics, the Hurricane Research Division (HRD) of the Atlantic Oceanographic and Meteorological Laboratory (AOML) with its partners at Environmental Modeling Center (EMC), National Centers for Environmental predictions (NCEP) have created a basin scale HWRF system that can operate with multiple moving nests spanning at resolution down to 3 km.
  - o Ocean impacts on storm intensity are broadly understood, but detailed quantitative understanding of the impacts on intensity forecasts produced by operational prediction models is limited.
  - o Initial results indicate that the enhanced Atmospheric Motion Vectors (AMVs) (derived from sequences of visible and infrared satellite images) can have a beneficial impact on both track and intensity during the first 24 to 48 hours relative to a control which assimilates only radiosonde observations. The impact on the intensity bias is robust and is positive at all lead times.
  - o An evaluation of a large sample of real time forecasts for 2014 in the Atlantic, E. Pacific and W. Pacific basins reveals much improved COAMPS-TC track and intensity predictions, and in many regards on par or in some aspects better than the established operational dynamical forecast models.
  - o For track, the COAMPS-TC ensemble has an average spread that is very similar to the average accuracy of the ensemble mean prediction, and an exceptionally good correlation between track spread and track accuracy. The multi-model ensemble also shows good consistency between track spread and track accuracy. For intensity, both the COAMPS-TC ensemble and the multi-model ensemble lack sufficient spread and have biases that degrade the reliability of the forecast.
  - o In-situ ocean observations such as the Airborne eXpendable Bathy Thermograph (AXBT) provide vital information on the upper-ocean sea temperature changes that arise beneath the tropical cyclone. Assimilation of these AXBT sea temperatures data has a positive impact on the TC intensity and track prediction.
  - o The Coupled COAMPS-TC Prediction optimal sampling case study suggests observations in the northern quadrant in front of the TC have the greatest positive impact on modeling.
  - o Simultaneously assimilating data from HIWRAP and the other Global Hawk compatible instruments results in further analysis and forecast improvements including ocean surface winds, TC intensity, and TC size.
  - o Improved understanding of boundary layer processes, through targeted, enhanced and continuous observation using low altitude unmanned aircraft systems (UAS) will be

essential in order to significantly improve scientific understanding and future predictions of hurricane structure and intensity.
   o The JPL Tropical Cyclone Information System (TCIS) is being developed to facilitate the inter-comparison of models and observations by bringing them into a common system and developing online tools for joint analysis and visualization.

- **Session 6: The Future of the IHC—Agency Perspectives.** As the new Federal Coordinator for Meteorological Services and Supporting Research (Acting), Dave McCarren expressed his desire to get some honest feedback from the 2015 TCRF/69th IHC attendees on how future IHC's should be conducted. The following summarizes that feedback:
   o The IHC is particularly valuable because it provides a forum for the TC operations and research communities to meet face-to-face. The operations folks can identify where they need help from the research community, and the researchers can let the operators know what they're working on and how they can possibly adapt their research and focus future research to help the operators.
   o The research to operations piece is very important. The Joint Hurricane Testbed (JHT) presentations are and should continue to be part of the IHC agenda, and the IHC should bring the JHT investigators together with the National Hurricane Center (NHC) points of contact to facilitate the interactions between the two. Presenting part of the JHT talks virtually from NHC and part from forum site in Jacksonville was less than ideal.
   o The general consensus was that south Florida is the best location for the IHC. Because this is a Federal interagency forum, it should be conducted where we can bring the most operators and researchers together face-to-face in the most cost-effective way to the government. However, JTWC and CPHC would like to see the IHC in Hawaii occasionally, possibly in conjunction with a DOD/WESTPAC Tropical Cyclone Conference.
   o Moving forward, the IHC organizing committee will have to address a number of issues discussed during the session, to include:
      ▪ Selecting a date. NHC and HRD, in particular, discussed the numerous TC-related meetings that they have to support, in addition to the IHC.
      ▪ Developing a robust agenda (possibly around themes like intensity or storm surge) that allows for lots of interaction between operators and researchers and deciding on the nature and extent of participation by Federal agency senior leadership.
      ▪ Selecting a location. South Florida is the preferred location for the next IHC.
   o The bottom line—there is a continued need and desire for an annual OFCM-sponsored IHC.

- **Session 7: Products, Services, and Societal Impact.** Session Leader: CDR Elizabeth Sanabia (Navy/U.S. Naval Academy). Four talks. (see presentations)
   o Determining the vulnerability of societies can improve prediction of level of TC impact. To isolate key individual factors, vulnerabilities can be segmented geographically.
   o The potential for impacts due to landfalling TCs will be assessed based on factors including storm size, precipitation rates, wind speed at landfall, storm surge damage, and the recurrence of landfalling events within a geographic region. The goal is to quantify the level of vulnerability and resiliency of each impacted region.

- o The Satellite Proving Ground was established to provide forecasters with advance looks at new satellite data and products using proxy information, and to obtain user feedback for the product developers. Fourteen GOES-R products and 1 NPP product were chosen for demonstration at NHC during most of the 2014 Hurricane Season (1 Aug to 30 Nov). Three of these products were new in 2014: an alternate Red-Green-Blue (RGB) dust product, a RGB nighttime microphysics product and a lightning density product with more coverage in the Pacific and Atlantic. The emphasis in 2014 was on evaluating these new products. Several GOES-R products already made the cut for the NHC satellite product suite.
- o NRL's TC web page uses data fusion by combining data sets from both operational and R&D sensors (SSM/I, SSMIS, WindSat, TMI, AMSU, and MHS). More recently, they have brought online the DMSP F-19 SSMIS with up to 5-km resolution, after successful cal/val program approval and the NASA Global Precipitation Mission (GPM) Microwave Imager (GMI) via NASA/GSFC. They also now include NASA's RapidSCAT wind vectors.
- o In general, even familiar users do not seem to understand the risks associated with storm surge or hurricane advisories. An interactive website is now active that combines SLOSH estimated surge with elevation and tidal data and then simulates the level of surge on photographs of a thousand landmarks throughout the Charleston SC metropolitan area. The intent of the surge visualization model is to allow anyone to find a landmark near a location of their choosing, and then to see approximate water depths on photographs of that location for a variety of hurricane scenarios. The intent is for the public to use the model while no hurricane is present to improve their understanding of hurricane surge while also assessing which areas are particularly vulnerable to surge. NHC has separated Saffir-Simpson categories from storm surge products to better emphasize evacuation zone extent and risks. This will assist in land use planning, home construction and other uses.

- **Session 8: Tropical Cyclone Research Plan Mid-Course Assessment—Operational Needs and Research.** Panel Moderator: Mr. David McCarren (OFCM). Panelists: NHC: Dr. Richard Knabb, CPHC: Mr. Thomas Birchard , JTWC: Mr. Robert J. Falvey, Dr. Frank Marks, Jr., WG/TCR Co-Chair and Director, Hurricane Research Division (NOAA/AOML), and Dr. Ronald J. Ferek, WG/TCR Co-Chair and Program Officer, Marine Meteorology Program (ONR). In preparation for the development of a mid-course assessment for the 2007 *Interagency Strategic Plan for Tropical Cyclone Research: The Way Ahead* by the Working Group for Tropical Cyclone Research (WG/TCR), the operational centers—NHC, CPHC, and JTWC—provided input on new product development and on how their operational priorities have changed. The results are summarized as follows:
- o National Hurricane Center (NHC)
  - New products include an experimental 5-day graphical tropical weather outlook which depicts the chance of genesis in 5 days; with a target date of 2016, begin issuing watches/warnings before TC genesis; in 2015, an experimental prototype storm surge watch/warning graphic; and a wind arrival timing uncertainty product is under development.
  - Provided revised list of 14 Forecast Improvement Priorities for use by the WG/TCR; guidance for TC intensity change remains the #1 priority. Forecast needs are channeled through JHT to better align improvements with operational needs.

- o Central Pacific Hurricane Center (CPHC)
  - ▪ Priorities are linked with NHC's priorities, but expressed a need to expand the tropical weather outlook to 5 days and for improved wind arrival products, and for an objective Dvorak-type technique for satellite microwave data to evaluate intensity change. Dvorak technique may not handle eyewall replacement cycles very well near landfall. Microwave data will be coming into AWIPS and there are issues with microwave-derived tropical cyclone intensities.
  - ▪ Commented that this forum provides a unique opportunity for CPHC to get plugged into the TC research community and provides a lot of valuable information for CPHC's annual TC training.
- o Joint Typhoon Warning Center (JTWC)
  - ▪ A key role is to evaluate products that are being developed for JTWC's operational use and provide feedback to the researchers and developers working on the products. HWRF has been helpful to JTWC.
  - ▪ Intensity remains #1 priority, but the need for improved satellite reconnaissance has been elevated to #2. Specifically, there is a need for techniques or products that improve the utility and exploitation of microwave satellite, ocean surface wind vectors, and radar data for fixing TCs, or for diagnosing RI, ETT, ERC, etc. (e.g., develop a "Dvorak-like" technique using microwave imagery).
  - ▪ Priority #9—enhancements to the operational environment—has been elevated to #5 because JTWC cannot put out a forecast without the Automated Tropical Cyclone Forecast (ATCF) system. ATCF must be maintained/sustained and enhanced.
  - ▪ A revised list of 18 R&D priorities includes two new ones:
    - - #8. Guidance to diagnose and predict the formation of TCs via tropical transition.
    - - #10. Development of a confidence-based error swath derived from model spread.

In summarizing the work of the WG/TCR to date, Dr. Frank Marks and Dr. Ron Ferek highlighted the following:
- o The snapshots that were conducted in 2008, 2010, and 2012 revealed that we were spending about $50 million dollars and averaging 220 man-years of labor per year on TC research and development and that research was influenced by the centers' operational priorities.
- o These snapshots have allowed us to effectively communicate a success story to Federal senior leaders that fund the research (NOAA, Navy, NASA, and NSF), but we need to improve our communication down to the operational level and have more focused discussions at the working level.
- o With the updated priorities provided by the centers, the WG/TCR will be able to assess and evaluate how research is contributing to those priorities as the group prepares the mid-course assessment which will allow research managers to make informed decisions for future investments.
- o Moving forward, there is a need to develop a strategic plan for TC observations. The tropical cyclone warning program and education, outreach, and work-force development also require continued review and attention. JHT and HFIP priorities need to be written in a way that better links research and the management of those activities.
- o Tropical Cyclone Genesis (TCG) products need further development to show mission planning impact. ONR has a Defense Research Initiative for large-scale atmospheric

oscillations (e.g. NAO, MJO) some of which may relate to improving TCG through 10-km models. There is a need for external assessors and plan review to better identify which problems should be addressed. Leveraging field research through partnerships requires dialogue and communication.

- **Forum Luncheon Talks.**

  o The Hurricane Forecast Improvement Project (HFIP): Progress and Accomplishments. Mr. Frederick Toepfer (NOAA/NWS/OST).
    ▪ <u>HFIP at the 5-Year Point</u>. Charter was to improve hurricane forecast system and global forecast systems track and intensity forecast guidance to NHC; make better use of existing observing systems and define future observing system needs; and expand and improve forecaster tools and applications to support NHC.
    ▪ HFIP accomplishments
      - Public-private partnership teams established to significantly broaden scientific approach to the problem.
      - Improved flows of research into operations.
      - Improved data assimilation and modeling technologies (global and hurricane scale) for improved track and intensity forecasts.
      - Better use of aerial reconnaissance to improve model initialization.
      - Improvements in numerical guidance appear to be showing up in NHC official forecast for track and intensity.
    ▪ HFIP <u>operational</u> priorities
      - HWRF upgrades for 2015 hurricane season and future plans.
      - Increased horizontal resolution from 27/9/3km to 18/6/2km.
      - Improved physics packages for 2km resolution.
      - HWRF Data Assimilation System to include GFS EnKF driver and assimilation of P3 TDR and P3/G-IV/AF/GH dropsonde output.
      - HWRF transitioning towards unified NMMB/NEMS infrastructure (2016-2017).
    ▪ HFIP <u>research and development</u> priorities
      - Further development and testing of HFIP Multi-model Regional Ensemble System (20-member HWRF, 10-member COAMPS-TC and 10-member GFDL).
      - Continue to improve physics packages.
      - Improve use of satellite datasets focusing on hi-res AMVs and microwave.
      - Real-time demo of three-way coupled HWRF-POM/HYCOM-WAVEWATCH-III modeling system.
      - Continued Basin-scale HWRF development - couple to ocean and advance DA system.

  o Understanding and Predicting the Impact of Outflow on Tropical Cyclone Intensification and Structure. Dr. Ronald J. Ferek (Navy/ONR)
    ▪ Background
      - Since 2003 in WPAC, there has been little improvement in TC track prediction.
      - Since 1990 in WPAC, there has been very little improvement in TC intensity prediction.
      - 2009 New USPACOM "Goals for Tropical Cyclone Forecasting" letter.

- 2012 ONR held a TC science workshop to identify next set of basic research questions.
- Problem: Upper-level outflow associated with tropical cyclones may be the key link between the environment and TC intensification; processes remain largely unexplored.
  - Key science issues and approach.
    - Understand the coupling between all the branches of the secondary circulation (and the relationship of this coupling to intensity changes).
    - Observe the evolution of outflow in relation to the environment.
    - Employ state-of-the-art numerical modeling.
  - Observation strategy:
    - WC-130J or P-3 to monitor the TC intensity and structure.
    - Global Hawk or WB-57 to observe the outflow and environment.
  - Expected Payoff: This effort will have two primary benefits:
    - First-ever comprehensive observations of the upper-level outflow structure will provide a unique dataset that will be critical to improving our scientific understanding of the outflow evolution as well as the associated interactions with TC intensification and structure change.
    - Improved understanding of the relationship between upper-level outflow and the TC vortex, along with new techniques to assimilate field campaign observations using emerging tropical cyclone modeling systems will lead to much improved TC intensity and structure predictions (particularly for rapid intensification and rapid weakening).

- **Richard H. Hagemeyer Award.** The award is presented annually to honor the memory of the longtime Director of the NWS Pacific Region and patriarch of the IHC until the time of his death in 2001. It is awarded to dedicated supporters of the IHC who have made substantial and long-standing contributions to our Nation's tropical cyclone forecast and warning program. The winner of the 2015 award was **Mr. Edward Fukada** (USN LT Retired), Technical Advisor, Joint Typhoon Warning Center, Pearl Harbor, Hawaii. The conference connected to JTWC by video-link where RDML Gallaudet (CNMOC) presented the award to Mr. Fakada.

III. SUMMARY REMARKS:
- The tentative dates and location for the next IHC/TCRF are still to be determined. Based on discussions during the forum, the likely location will be south Florida.
- In-person conferences/forums remain the preferred option by the OFCM. While future OFCM conferences/forums will likely include a "virtual" component to allow for participants who would otherwise be unable to attend, there is simply no substitute for face-to-face interactions and conversations at scientific meetings as part of the peer review process.
- Finally, to the OFCM staff and the UCAR staff, a note of deep gratitude for their dedicated and tireless efforts which significantly contributed to the success of the forum.