2017 TROPICAL CYCLONE OPERATIONS AND RESEARCH FORUM
71st INTERDEPARTMENTAL HURRICANE CONFERENCE

SUMMARY REPORT

The Federal Coordinator for Meteorological Services and Supporting Research (OFCM) hosted the 2017 Tropical Cyclone Operations and Research Forum (TCORF)/71st Interdepartmental Hurricane Conference (IHC) for the Federal stakeholder agencies, together with representatives from the academic research community, and other user stakeholder communities.

137 registered participants convened at the Rosenstiel School for Marine and Atmospheric Science (RSMAS) on March 14-16, 2017 to review the Nation's hurricane forecasting and warning program and to make recommendations on how to improve the program in the future. Tropical cyclone research continues to be a part of the forum in the context of operational imperatives. The agenda comprised a combination of themed sessions, a poster session, and the Working Group for Hurricane and Winter Storms Operation and Research (WG/HWSOR) meeting. A summary of those agenda elements follows.

Opening Session. Dr. Bill Schulz, Federal Coordinator for Meteorology opened the forum by welcoming the participants and reviewing the agenda. He thanked RSMAS for hosting the Forum on its beautiful campus; the Office of Naval Research, the National Science Foundation, and NOAA's Office of Oceanic and Atmospheric Research for generosity in funding the forum; and those agencies and the National Hurricane Center for helping plan the agenda.

Dr. Schulz provided information on the efforts to revise the Federal Plan for Meteorological Services. The proposal calls for a Strategic Plan for Meteorological Coordination to be published every four years and a streamlined annual report limited to simplified past and future budget information and brief agency commentary on important budget initiatives and contributions toward the strategic goals and objectives. He reviewed the proposed strategic goal, noting that one of the goals was based on an action item from the last year's TCORF.

Session 1: Tropical Cyclone Operations: Challenges in 2016; New Products and Services Planned for 2017; New/Revised Requirements for Research. The National Hurricane Center noted that overall track and intensity forecasts were quite good with the exception of Matthew, where the model guidance helped forecast genesis but did poorly on track and intensity. The GFS overall is getting better but still has a long way to go. It had problems forecasting storm genesis in both basins, and mid-level vertical wind shear errors affected intensification forecasts. NHC will provide three new products for the 2017 season: Storm Surge Watch/Warning, Potential Tropical Cyclones, and an experimental Time of Arrival of tropical storm winds graphic. The Central Pacific Hurricane Center reported that their mean track and intensity errors were close to the five-year mean. Both NOAA and the 53rd flew surveillance missions during the season. CHPC is updating their webpage to mimic NHC's. CPHC plans to add a 5-day tropical weather outlook, a 2 and 5-day graphic, and potential TC watches and warnings. The Joint Typhoon Warning Center implemented TC Wind Radii capability improvements which decreased radii forecast errors by 20%-30%. This capability enables improved resource protection decisions and increases operational maneuver space. TC intensity change, particularly rapid intensification, is still the top forecast improvement priority. OMAO: The AOC Facility was moved during the "off-season" to Lakeland, FL. Only a single P-3 was available in 2016 because of the rewinging schedule. A corrosion problem kept the G-IV out of action for two weeks at the peak of

hurricane season. For 2017, there will be tail Doppler radar upgrades, a new 5-year contract in place for dropsonde purchases for use by NOAA and AF, and continued NOAA-AF collaboration on SFMR issues. The 53rd Weather Reconnaissance Squadron (53rd WRS) flew a near-average number of NHOP tasked hours with 91% reliability. Challenges for 2017 include airplanes nearing 20 years old, maintenance manning issues, pilot retention problems, and ARWO inexperience. The observing systems hardware upgrade has been delayed. Broadband will be tested in August 2017.

Session 2: Improved Capability to Observe the Tropical Cyclone and its Environment to Support Forecaster Analysis and Model Initialization. NOAA NWS NCEP/EMC conducted Observing System Experiments (OSEs) for supplemental observations from Global Hawk and found that dropwindsondes reduced 4-5-day average track forecast errors by about 30%. Most of the OSEs show varying degrees of small, positive improvements on track forecasts and an overall improvement on a global scale. Data are currently not assimilated in the GFS at NCEP, but positive results from these experiments justify their inclusion. A broader discussion on past Global Hawk operations and potential applications focused on strategies for planning missions and using data. Last season the National Hurricane Center used data from five of the nine Global Hawk flights for input into forecast discussions, advisories, and warnings. Dropsonde data are used in models operationally by HWRF (regional) and ECMWF (global). NASA reported on the Cyclone Global Navigation Satellite System (CYGNSS) which consists of 8 microsatellites, each with a 4-channel GPS bi-static radar receiver. The driving science objective is rapid sampling of ocean surface winds in the inner core of tropical cyclones. The first public release of Delay Doppler Maps and wind speed data products will be in mid-May 2017. NCEP/EMC reported on methodologies to relocate tropical cyclones in complex, high-resolution models. Results of a pilot study on Hurricane Joaquin and a season-long experiment show that relocation techniques are a work in progress.

Session 3: Techniques to Improve the Utility of Microwave Satellite and Radar for Tropical Cyclone Intensity and Location Analysis. (Pt 1) A study by FIU is investigating the use of passive microwave satellite observations to estimate TC intensity, building on earlier smaller studies that showed promise. Results suggested that the technique can provide TC intensity estimates that are at least comparable to, if not better than the Dvorak method. Further, because this techniques is independent of visible, IR, and microwave sounder observations, it provides additional information that can be used in conjunction with other techniques. Work is proceeding on real-time implementation of the technique. A presentation from RSMAS highlighted the usefulness of ocean heat content (OHC) vis-à-vis sea surface temperature in forecasting TC intensity. OHC was determined from a combination of profilers, floats, and satellite altimetry. Particularly interesting results were shown for Hurricanes Matthew and Patricia. NOAA/ESRL contractor ProSensing Inc discussed data from the Wide Swath Radar Altimeter (WSRA), which has operated routinely during NOAA WP-3D reconnaissance flights over the past decade. WSRA processing software estimates directional wave spectra, rain rate, and the mean square slope of the sea surface. Several yet to be operationally implemented refinements have been made to improve determination of the general direction of the ocean wave field. NASA introduced the Time-Resolved Observations of Precipitation structure and storm Intensity Constellation of Smallsats (TROPICS) mission, which will complement CYGNSS, GPM, and GOES-16 by making rapid-refresh, direct measurements of temperature, humidity, and precipitation. This observing system will be launched in 2019 to provide one year of high-

temporal resolution science operations data measuring environmental and inner-core conditions for tropical cyclones.

Session 4: Techniques to Improve the Utility of Microwave Satellite and Radar for Tropical Cyclone Intensity and Location Analysis. (Pt 2). CIRES/ESRL has been using ground-based dual polarization radar data to study ice particle types, sizes, and amounts in landfalling tropical cyclones. Iced crystal properties are important to TC structure through the radiation budget. Because the size and thickness of a modeled TC anvil depends on the microphysics scheme, observational data are key to improving TC models. The radar observations provided basic information and particle type and movement that can be used to improve model results. NASA presented results of a study comparing the surface wind retrieved from Hurricane Imaging Radiometer (HIRAD) data to surface wind projected from dropsonde data. Using data from the B-57 flights into four 2015 hurricanes, authors found a RMS difference of 4-5 m/s with very little bias when dropsonde surface wind speed error estimates and spatio-temporal mismatches were taken into account.

Session 5: Enhancement to the Operational Environment. NOAA/NWS/CPHC highlighted the increasing amount of real-time data available to operational tropical cyclone forecasters, as well as the diversity of sources, products, and data/image types. A number of useful resources are on web sites where they be accessed and downloaded. However, this type of "bookmark meteorology" doesn't lend itself to integration and flexible analysis of data. The need to efficiently assimilate and evaluate these diverse data sets requires improved data visualization methods and enhanced software capabilities. Storm Center Communications demonstrated a network service that permits real time data sharing and collaboration across an unlimited number of disparate web maps. This enables a "common picture" among multiple users in real time using map-based data and current technologies for a display of geospatial intelligence products on their interactive maps. JTWC briefly addressed AWIPS plans. The center is moving forward with AWIPS accreditation, expecting delivery next fall and IOC next year. Their plan is to collaborate with the NHC on migration to AWIPS-II. However, they will continue their current ATCF strategy for use and enhancements until AWIPS provides equivalent or better capability.

Session 6: Guidance for Tropical Cyclone Intensity Change. NHC introduced this topic by showing model performance during Hurricane Matthew's rapid intensification. The challenge was obvious. Studies by HRD and others looked into real-time quasi-operational ensemble prediction systems to provide a new source of probabilistic guidance for TC intensity change. Verification of the ensemble-based guidance indicates that output from some systems, including the HWRF and COAMPS-TC systems, have comparable reliability to the statistical SHIPS RI index. Plans for the 2017 season are to investigate an "over confidence" problem ant to expand the technology to multi-model ensemble-based probabilities. The first of two HRD presentations on this topic addressed performance of the new operational multi-lead time SHIPS RI model forecasts. The model exhibited a small amount of skill in the Atlantic and a modest degree of skill in the eastern Pacific during the 2016 season. New versions of the SHIPS Logistic Regression, and Bayesian RI models are currently being evaluated for potential implementation for the 2017 season. The second HRD presentation investigated intensity change sensitivity to the environmental vertical wind shear. Whether or not a TC intensifies in this shear environment is dependent on characteristics of the environment as well as the TC vortex. Intensifying TCs have more deep convection upshear, with stronger updrafts that peak at a higher altitude with

higher echo tops than non-intensifying TCs. Knowledge of the structure of the precipitation on the upshear side of the TC can provide an indication of the potential for intensification.

Session 7: Regional Model Advances and Plans. NRL reviewed COAMPS-TC developments and plans. After reviewing past performance of the model, projected performance of the 2017 model based on testing was presented. The 4 km model tested showed improvement in intensification forecasts. Studies indicated, however, that deterministic models may not be able to reliably predict RI. Further, multi-model ensembles may do better than single-model ensembles by better accounting for forecast uncertainty. HRD presented results of tests on the impact on HWRF performance of improvements in the Hurricane Ensemble Data Assimilation System. Addressing dropsonde data assimilation, they compared results of model runs when dropsonde location near the hurricane core was and was not taken into account. While taking location into account improved results, this issue will go away when BUFR is implemented for dropsondes. EMC presented results of HWRF data assimilation and testing. Changes to blending to address spindown and other issues and a new data assimilation system (including new data) showed encouraging results in intensity forecasts, but little improvement in track forecasts. Planned tests include hourly cycling to improve inner core balance and ingesting tail Doppler radar data from the G-IV. Long term plans call for further addressing spindown and bias, and ingesting more data. EMC followed with a second presentation on detailed plans for HWRF implementation for the 2017 season, addressing system, resolution, initialization/data assimilation, and physics enhancements. Combining all these enhancements produced both track and intensity forecast improvement in the North Atlantic Basin. The EMC hurricane team has been developing another non-hydrostatic hurricane model in the NOAA Environmental Modeling System (NEMS) framework known as HMON (Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic) Model which is being prepared to replace the GFDL hurricane model in operations this year. HMON is faster, scalable, and employs improved physics. Operational implementation is planned for June 2017. NOAA/AOML/PhOD presented results of experiments on three storms to show the impact of errors in ocean initial conditions on hurricane forecasts. The Blanca experiment illustrated the importance of correctly depicting the thickness of the upper warm layer. The Gonzalo experiment compared model performance when all ocean observations were denied against performance when all observations were used. There was little difference in track accuracy, but a significant difference in minimum pressure and max wind speed in the data-denied case. The Edouard experiment illustrated the effects of the year-to-year variability in upper-ocean hear content, leading to the conclusion that climatology is inadequate for ocean initialization.

Session 8: Global Model Advances and Plans. NHC introduced this session with a quick review of their historic forecast performance using global model guidance. EMC presented plans for implementing NOAA's the newly selected non-hydrostatic dynamical core based on the GFDL Finite Volume on Cube Sphere (FV3) model. Completion of initial operational implementation is expected by the end of FY 2019. GFDL followed with a presentation on performance of the FV3 dynamical core forecasting 2016 Atlantic hurricanes. Results showed improved track and intensity performance compared to the current GFS, and new GFDL microphysics lead to improvements in both storm structure forecasts. A second GFDL presentation provided additional evaluation of FV3 performance in forecasting tropical storms. Results showed track performance comparable with GFS, but improved intensity and genesis guidance. ECMWF reviewed recent and planned changes to their model and discussed a variety

of issues, including improvements derived from coupling and challenges forecasting the structure of the center of tropical storms. JMA addressed improvements in TC forecasting, applying a variety of techniques that reduced the uncertainty cone 10 – 20 % and showed enhanced intensity and genesis performance. Also addressed were the use of Himawari data and longer term genesis predictions. University of Hawaii briefed work on extended-range TC forecasting. Focusing on Sandy and Haiyan, application of their technique showed that the genesis of both TCs were predictable with a lead time of 11 days. Longer range predictions depend on models' capability to forecast circulation changes associate with the MJO.

Poster Session. Eleven posters were presented and reviewed. Abstracts for the posters are provided at the IHC 2017 presentation website.

Session 9: Research Supporting Operations (Pt 1) JHT Projects. The NHC/HRD team introduced the 8th round (FY15-17) JHT projects that were evaluated during the 2016 hurricane.

- JHT Project 1: "Transition of the Coastal and Estuarine Storm Tide Model to an Operational Model for Forecasting Storm Surges"
- JHT Project 2: "Improved Eyewall Replacement Cycle Forecasting Using a Modified Microwave-Based Algorithm (ARCHER)"
- JHT Project 3: "Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins
- JHT Project 4: "Probabilistic Prediction of Tropical Cyclone Rapid Intensification Using Satellite Passive Microwave Imagery"
- JHT Project 5: "Improvements to the Tropical Cyclone Genesis Index (TCGI)"
- JHT Project 6: "Improvements in Operational Statistical Tropical Cyclone Intensity Forecast Models"
- JHT Project 7: "Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage"
- JHT Project 8: "Further Studies of Observational Undersampling of the Surface Wind and Pressure Fields in the Hurricane Inner-Core"

Session 10: Research Supporting Operations (Pt2) forum (Presentations and Discussion): Current Research and Plans for the Future. Frank Marks and Fred Toepfer reviewed the HFIP charter, performance goals, 2016 issues, and priorities for 2017. Budget constraints have stretched out HFIP plans, but goals are still in sight. Ron Ferek reviewed tropical cyclone research sponsored by the Office of Naval Research. Looking to the future, he noted that 1) R&D is needed in observations and mesoscale models; 2) longer range genesis forecasting is dependent upon improvements in global models; 3) near term improvements and help in communicating uncertainty could be achieved through multi-model ensembles. Scott Braun summarized NASA satellite and airborne data and applications related to tropical cyclones, briefly touching on Cyclone Global Navigation Satellite System (CYGNSS), time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS), Temporal Experiment for Storms and Tropical Systems (TEMPEST), and In-Space Validation of Earth Science Technologies (InVEST), as well as field campaigns TCI, SHOUT, and EPOCH. Chungu Lu discussed where hurricane related core science programs fit into NSF sponsored research, the geosciences Prediction and Resilience to Extreme Events (PREEVENT) effort (which part of a larger NSF Risk and Resilience Research Initiative), and new facilities, including the A-10 Storm Penetrating Aircraft, and Airborne Phased Array Radar.

Final Plenary Session. Ed Rappaport, chair of the Working Group for Hurricane and Winter Storms Operations and Research, reported on the working group's meeting on Wednesday. Eighteen action items were reviewed, but time limitations did not allow for resolution of all issues. A follow-up meeting will be scheduled in the next few weeks to allow for completion of work and publication of the 2017 NHOP by May 1st. Harry Jenter, co-chair of the Working Group for Disaster Impact Assessment and Plans: Weather and Water Data briefed the results of the group's meeting the day before the Forum. OFCM briefed the action items from the conference, of which there were five:

1. Reorganize WG/HWSOR to function like a working group on a continuing basis. (OFCM)

2. Investigate the possibility of establishing requirements for targeted high resolution 3D atmospheric observations. (WG/HWSOR)

3. Investigate the possibility of establishing requirements for 3D ocean observations. (WG/HWSOR)

4. Plan a session in next year's TCORF/IHC on "guidance on guidance." (OFCM)

5. Publish 2017 NHOP by May 1, 2017. (OFCM)

In addition, the following high-interest research subjects were identified:

- Tropical cyclone genesis
- The Madden-Julian Oscillation and long range tropical cyclone prediction
- Automated tropical cyclone analysis techniques
- Observations, depiction, and forecasting of moisture fields
- Atmosphere/ocean coupling

To acknowledge the legacy of the GFDL hurricane model as it is being retired this year, a brief retrospective was presented by Sundararaman Gopalakrishnan after which certificates were presented to Dr. Morris Bender and Dr. Isaac Ginis recognizing their work on the model. Federal Coordinator for Meteorology Dr. Bill Schulz presented the Richard H. Hagemeyer Award to LtCol Jonathan Talbot, USAF (Ret), and former chief meteorologist with the 53rd WRS.