2016 TROPICAL CYCLONE OPERATIONS AND RESEARCH FORUM
70th INTERDEPARTMENTAL HURRICANE CONFERENCE
SUMMARY REPORT

The 2016 Tropical Cyclone Operations and Research Forum (TCORF)/70th Interdepartmental Hurricane Conference, marked a return to a focus on operations. Tropical Cyclone Research continued to be a part of the forum in the context of operational imperatives. The meeting of the Working Group for Hurricane and Winter Storms Operation and Research (WG/HWSOR), which supports the annual update of the National Hurricane Operations Plan, was re-incorporated into the conference.

127 registered participants convened at the Rosenstiel School for Marine and Atmospheric Science (RSMAS) on March 15-17 2016, for the conference hosted by the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM). The agenda comprise a combination of themed sessions, panel discussions, and the 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 guests and reviewing the agenda. He then introduced the keynote speaker, VADM Manson K. Brown, USCG (Ret), Assistant Secretary of Commerce for Environmental Observation and Prediction and Deputy Administrator for the National Oceanic and Atmospheric Administration (NOAA). VADM Brown acknowledged the participation of international partners (UK Met Office, ECMWF, and Environment Canada) in this forum and emphasized the need for greater collaboration of this type to meet environmental challenges. For environmental observations this will include commercial interests along with government and the international community. He warned that in this context, some data issues will present serious challenges. He closed by thanking the participant for their on-going efforts to toward greater skill and accuracy in tropical cyclone forecasts.

Session 1: Tropical Cyclone Operations: Challenges in 2015; New Products and Services Planned for 2016 and 2017; New/Revised Requirements for Research. The National Hurricane Center highlighted problems with track uncertainties in the ensemble forecasts for Joachim, poor handing of shear in model forecasts for Erika, and underdone intensity for Patricia. This year the National Hurricane Center (NHC) used their web site and Twitter feed to inform users when initial advisories would be issued. They expect to add storm surge guidance next year and may start issuing watches and warnings before formation in 2017. They are also experimenting with a graphic depicting time of arrival of tropical storm strength winds. The Central Pacific Hurricane Center suggested that the super El Nino may have been responsible for their hyperactive season, which included a record 15 tropical cyclones, more days with multiple tropical cyclones than all other years combined since 1970, and the most reconnaissance flying time ever in the AOR. Challenges included workload, poor model forecasts with weak/disorganized systems, and IT security requirements impeding communications. The Center listed changes expected over the next two years, including a variety of new product and forecast points, and highlighted some very specific research needs. The Joint Typhoon Warning Center dealt with lower than average activity, noting lower track errors but little improvement in intensity forecasts. The center has encountered serious satellite reconnaissance problems.

Forecast challenges besides intensity issues include storm structure (size/shape important for ships) and data visualization and fusion. Research needs and priorities have not changed. The 53rd Weather Reconnaissance Squadron (53rd WRS) flew a near-average number of NHOP-tasked hours with 99% reliability. They reviewed last year's CHAT missions and the plan for this year's missions as well as the joint (with NOAA's Aircraft Operations Center(AOC)) 2016 Hurricane Awareness Tour. Planned technological improvements include software and hardware upgrades/refreshes, satphone upgrade, and broadband capability. The AXBT test program, which began in 2011, has been extended through 2016 (see further discussion on this program in the WG/HWSOR section). AMAO challenges related mostly to the heavy flight schedule (including non-hurricane research missions) and the unavailability of a P-3 due to re-winging. Hurricane hours flown were down by about a third. Upcoming challenges include re-winging of the second P-3 in 2017, MacDill AFB runway closure this fall, and the requirement to vacate MacDill Hangar 5 by July 2017.

Session 2: Critical Operational Information Technology: Ongoing joint development. This session focused on current and future operational IT systems in the tropical cyclone forecast centers: the Automated Tropical Cyclone Forecast (ATCF) system and the Automated Weather Information Processing System (AWPS2). ATCF has been available for some time, and was built specifically for tropical cyclone applications; AWIPS2 supports NWS operations at all sites, and is being adapted for tropical cyclone applications. DoD Plans for ATCF include continued use and some development in the future. For example, Navy systems will add 64 bit applications and new functionality related to wind radii in 2016. The system is funded for the foreseeable future, and the Navy has no plans to replace it. NWS Plans for ATCF include on-going development on an annual cycle focus on having new capabilities in place near the start of each hurricane season. A team at NHC is responsible for this work. However, as explained in the NWS and NHC Plans for AWIPS2 presentation, NHC considers ATCF to be a difficult to manage, "mash-up" project (6 scripting languages, minimal coding standards, little version control) that has been evolving organically for 30 years. The NHC solution is to merge ATCF into AWIPS2. The functional requirements specification document has been approved, initial funding is available and contractors have been hired. The project is expected to take 5 years. JTWC Plans for AWIPS2 include completing an MOU and transferring funds (imminent) supporting system roll-out at JTWC in January 2017. AWIPS2 will be used for data visualization, interrogation, fusion, and similar tasks, but it cannot as delivered replicate ATCF tasks. Hence, ATCF will remain the cornerstone of JTWC operations and research to operations (R2O), while AWIPS is expected to compliment ATCF with state of the art tools. While eventual integration of ATCF into AWIPS2 is the desired end state, no specific plans exist to achieve that at JTWC. The Hurricane Research Division is focused on development of applications. HRD eventually would like to implement this application work on their own AWIPS2 system for transition to NHC. However, HRD is not programmed to receive an AWIPS2, and the version of the platform they would need does not yet exist (it is under development at NHC). The plan then is to work with NHC to get a copy of the NHC AWIPS2 capability, which would support R2O and could allow HRD to serve as a back-up site for HRD.

Session 3: Research to Operations (R20) Activities, Part 1: Key Federal Research and R2O Intended to Improve Forecasts. This session provided organizations the opportunity to provide an update on relevant research to operations initiatives. NOAA Hurricane Research Division reported on work related to four programs: the Hurricane Forecast Improvement Program, the

High Impact Weather Prediction Project within the context of the Next Generation Global Prediction Program, the Quantitative Observing System Assessment Program under which OSSEs and OSEs (observing system simulation experiments and observing system experiments, respectively) are conducted, and the Joint Hurricane Testbed. The Office of Naval Research (ONR) presented the R2O process (where the proverbial "Valley of Death" resides), showed their approach to mitigating the associated risks, listed necessary attributes to successful transition processes, and detailed the COAMPS-TC development as an example of successfully progressing from basic research to operations. The ONR brief ended with the presentation of results of the National Aeronautics and Space Administration (NASA) WB-57 flights over hurricanes Joachim and Patricia as part of the Tropical Cyclone Intensity experiment. The National Science Foundation supports a variety of tropical cyclone related research initiatives, from basic research to field programs, as well as rapid response projects, some of which are collaborative with other agencies. Airborne observing is receiving emphasis with the acquisition of an A-10 for storm penetrations and continuing work on the Airborne Phased Array Radar. The National Environmental Satellite, Data, and Information Service (NESDIS) continues its preparation for the upcoming launch of GOES-R with an ambitious array of proving ground products, some of which are specifically focused on hurricane forecasting. Other efforts involved exploiting JPSS, Jason-3, Sentinel-3A products, and data from other satellites. NASA supports a number of programs that facilitate transition of research to operations, including the Global Modeling and Assimilation Office (GMAO), the Joint Center for Satellite Data Assimilation, and Short-Term Prediction Research and Transition (SPoRT). GMAO is working on relevant applications of GPM Microwave Imager data, which SPoRT is working on integrating that data into AWIPS-2. NASA's Research Opportunities in Space and Earth Sciences (ROSES) program, while not specifically focused on R2O, has provided grants for R2O work.

Session 4: Research to Operations (R20) Activities, Part 2: Joint Hurricane Testbed. The NHC/HRD team kicked off this session with an overview of Joint Hurricane Testbed (JHT) successes over the years. Eighty-one projects have been completed by JHT, with 46 implemented and another seven undergoing implementation. The seven projects that were recently evaluated for implementation were briefly described, and eight new projects were covered in separate briefings:

JHT Project 1: Guidance on Observational Undersampling over the Tropical Cyclone Lifecycle

JHT Project 2: Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage

JHT Project 3: Improvements in Operational Statistical Tropical Cyclone Intensity Forecast Models

JHT Project 4: Improvements to the Tropical Cyclone Genesis Index

JHT Project 5: Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins

JHT Project 6: Probabilistic Prediction of Tropical Cyclone Rapid Intensification Using Satellite Passive Microwave Imagery

JHT Project 7: Improved Eyewall Replacement Cycle Forecasting Using a Modified Microwave-Based Algorithm (ARCHER)

JHT Project 8: Transition of the Coastal and Estuarine Storm Tide Model to an Operational Model for Forecasting Storm Surges

Panel 1: Observing Systems: What should our operational airborne "fleet" comprise in 2030? AOC, chairing the session, opened the discussion with a few slides showing what the fleet looked like 50 years ago. The National Hurricane Center presented NOAA's needs for their area of responsibility stretching from the coast of Africa to the International Date Line. Needs for current reconnaissance data will continue, including center position, intensity, and dropsonde data. Future needs include improved temporal and spatial resolution of eyewall data, and 3-D depiction of wind, temperature, and humidity in the storm and environment. NHC sees a potential application for unmanned aircraft in monitoring a specific area, but is concerned about the drawbacks of their slower speed—particularly the time it takes to survey a storm and the impact of that on data assimilation systems. NHC closed by emphasizing that advances must be deployed on all aircraft in the reconnaissance fleet, not just the NOAA birds. The Hurricane Research Division addressed aircraft reconnaissance from the perspective of the structure of a hurricane, considering three regions: the lower region—the boundary layer, ocean surface, and subsurface; the middle region of deep convection; and the high region of outflow. Current aircraft are not capable of sampling any of these regions in the detail needed. The lower region would be best sampled using primarily unmanned aircraft and deployable/expendable systems from manned or unmanned aircraft. Manned aircraft would be used primarily in the middle region, along with some unmanned systems. The higher regions would be best sampled using high-altitude, long-endurance unmanned aircraft. The 53rd Weather Reconnaissance Squadron reviewed their current instrumentation before suggesting capabilities that could be deployed by 2030. Those capabilities include transmitting radar imagery (being tested now), and systems similar to Airborne Phased Array Radar, Hurricane Imaging Radiometer, and Coyote Unmanned Aircraft System (UAS). They suggested that Air Force Reserve airborne reconnaissance capability could be better applied to research projects. The Office of Marine and Air Operations provided a detailed brief on the planning for replacing the aging P-3 aircraft by 2030. An analysis of alternatives workshop held last October focused on better understanding of how to improve tropical cyclone forecasts. This process generated lists of what currently measured variables need to be measured better and what new variables should be measured. Also considered was the potential for transitioning the collection of data to unmanned systems and the associated capacity and capability differences between manned and unmanned systems. Flexibility for rapidly changing sensor technology would need to be accommodated, but it emphasized that one platform should not be expected to meet all observational needs. The NOAA UAS Program briefing focused on the Sensing Hazards with Operational Unmanned Technology (SHOUT) program, which involves conducting feasibility studies and evaluating/benefit analyses. The NASA Global Hawk was used to conduct a satellite gap mitigation study. The variety of sensors available for deployment on that platform was discussed, including a number of sounders. Other systems considered include the aircraft-launched Coyote and a low-altitude sensor network that will exploit vertical takeoff/landing and small fixed wing systems. The National Center for Atmospheric Research briefed on a number of their current research efforts that could be deployed as operational systems by 2030. These include the Airborne Phased Array Radar (to be deployed for research in 2022 on a C-130); High-performance Instrumented Airborne Platform for Environmental Research, a pod-based nadir/zenith pointing cloud radar, which is deployed on NCAR's Gulfstream V; the High Spectral Resolution Lidar (HSRL),which is also mounted on the NCAR Gulfstream V and senses aerosol backscatter cross-section and depolarization ratio and supports derived estimates of cloud

optical depth, aerosol optical depth, scattering cross-section, and extinction cross-section; and the next generation Water Vapor Differential Absorption Lidar (WVDIAL). NASA provided information on their fleet of Earth science research capable aircraft. These aircraft carry a variety of research sensors that could be deployed operationally by 2030, including the Hurricane Imaging Radiometer (HIRAD), the High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), and the Advanced Microwave Precipitation Radiometer (AMSR).

Panel 2: Observing Systems: New satellite data and applications for tropical cyclone operations by 2025: Agency and Interagency plans. Air Force Weather is currently exploiting data from 14 satellites, but is planning on operating with a "fragile constellation" in 2025—possibly just two low-earth and four usable geostationary operational orbiters. Industry has been touting cube or small satellites, and the AF Space and Missile Center is considering that possibility in the context of data restriction issues. However, Air Force Weather is planning to adapt to accomplishing their mission with limited metsat data as needed. NOAA NESDIS provides on-orbit satellite operations for the geostationary (GOES), polar orbiting (POES, DMSP, S-NPP), Jason, and DSCOVR satellites and is acquiring the next generation systems GOES-R, JPSS, and COSMIC 2. The conference was updated on schedules and timelines for existing and planned GOES and polar orbiter missions as well as the sensors on the GOES-R and JPSS and the advances in applications they will support. The Naval Research Lab, citing the challenges mentioned earlier with satellite observations in the future, recognizes the need to exploit the wider variety of satellite systems, including foreign satellites, smallsats and cubesats, and research-based satellites. Focusing on R&D leading toward providing better forecast guidance, implementation would emphasize agility to allow rapid transition to exploit different sources of data and the capability to apply objective/automated metrics for forecasting tropical cyclone intensity and for analyzing structure of storms. NASA continues technology development, including launch of the Cyclone Global Navigation Satellite System (CYGNSS) smallsat constellation later this year to measure ocean surface wind speed, and deployment of the Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats (TROPICS) in ~2019, a cubesat constellation to measure thermodynamic and precipitation structure. NASA's In-Space Validation of Earth Science Technologies (InVEST) program, testing new technologies on orbit, will launch cubesats testing microwave radiometers and a precipitation profiling radar.

Panel 3: What are the most promising short-term and long-term steps we can take to improve operational tropical cyclone forecast models? NOAA's National Centers for Environmental Prediction reviewed the deterministic model forecast capability (HWRF, GFDL, and GFS) and the ensemble guidance from GEFS. Changes to the GFDL model for the 2016 season are expected to significantly reduce track error or the earlier GFDL model based on forecasts for 2015 hurricanes. Several changes to GFS, most importantly implementation of Hybrid 4-D En-Var, and the impact of the changes on track and intensity forecasts (based on 2012-2015 hurricanes) was presented. Going forward, unified representation of clouds, convection, PBL and microphysics is planned for the 2017/2018 version of the model. Plans for the Next Generation Global Prediction System were presented along with results of recent changes to the GEFS. The US Navy proposed six steps to improve model performance. The final step was to implement a next generation global model run on a limited area for tropical cyclone application to allow for resolving clouds. The first five steps were applicable to current models,

and involved advanced data assimilation, improved treatment of air-ocean interaction, advanced model physics, multi-model ensembles for probabilistic intensity prediction, and exploiting high-resolution observation for model verification and evaluation. The European Center for Medium-Range Weather Forecasts (ECMWF) opened by presenting an extensive list of model upgrades just completed. Impacts of model changes presented included 1) effect of higher resolution and coupling on Western Pacific storm forecasts, 2) changes in dynamics on depiction of tropical cyclone structure, and 3) challenges with assimilating wind observations from dropsondes. Proposed future developments (10-year strategy) included more integrated, coupled earth system modeling (atmosphere, land surface, oceans), integrated ensembles at high resolution (5km), scalability in the dynamical core, scale awareness in the model physics to address partially resolved features, hybrid 4DVAR and ensemble applications in data assimilation, and improved diagnostics. In a broader sense, forecast targets for 2025 include ensemble prediction of high impact weather out to 2 weeks and predictions of large scale patterns and regime transitions out to four weeks. The UK Met Office started by reviewing recent upgrades to their models and the impact of those upgrades on tropical cyclone forecasts. These included a significant overall model upgrade in 2014 and a new scheme for initialization of tropical cyclones in 2015. Upcoming changes include satellite data usage this year, a major science and resolution upgrade in 2017, and a further upgrade focused on tropical performance in 2018. Beyond that, the focus would be higher resolution and improved atmosphere-ocean coupling. The presentation closed with a discussion of the challenge of forecasting rapid intensification.

Final Plenary Session. The meeting of the Working Group for Hurricane and Winter Storms Operations and Research was re-incorporated into the forum this year. Working Group chair, Dr. Ed Rappaport, briefed the results of that meeting to the entire forum. Three current and three legacy action items were closed. Two action items remain open, a new item related to a "Next Generation" Vortex Data Message and an on-going item related to continuing field work with the AXBT. The latter item was modified to direct the formation of a team to explore operational implementation. The Working Group for Disaster Impact Assessment and Plans: Weather and Water Data met the day before the Forum. Co-Chair Dr. Harry Jenter briefed on the results of that meeting and USGS plans for data collection during hurricanes. Forum host OFCM briefed the action items from the conference, of which there were two:

> *1. Coordinate an effort to establish an interagency process, sanctioned by FCMSSR, to define observational requirements to support tropical cyclone forecasting. (OFCM)*
>
> *2. Begin work on a final assessment of achievement of the goals of the Interagency Strategic Research Plan for Tropical Cyclones. (WG/TCR)*

Federal Coordinator for Meteorology Dr. Bill Schulz presented the Richard H. Hagemeyer Award to Dr. Lynn "Nick" Shay of the RSMAS. Finally, Dr. Schulz moderated a panel discussion amongst representatives of the organizations joining the Forum on the new format of the event. Most of the comments were positive, and the renewed focus on operations was endorsed. There was some discussion, however, on how to balance the emphasis on operations and research from year to year. Several comments on conference logistics were noted for future application.

The Forum closed with an optional tour of the National Hurricane Center.