2018 TROPICAL CYCLONE OPERATIONS AND RESEARCH FORUM 72nd INTERDEPARTMENTAL HURRICANE CONFERENCE SUMMARY REPORT

The Federal Coordinator for Meteorological Services and Supporting Research (OFCM) hosted the 2018 Tropical Cyclone Operations and Research Forum (TCORF)/72nd Interdepartmental Hurricane Conference for Federal agencies, together with representatives from the academic community, and other user communities.

119 registered participants convened at the Graham Center, Florida International University on March 13-15, 2018 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 panels and presentations along with the Working Group for Tropical Cyclone Operations and Research (WG/TCOR) meeting. A summary of each of these agenda elements follows. (*Slide presentations used by panelists and other participants are available on the OFCM website.)

Opening Session.

Dr. Bill Schulz, Federal Coordinator for Meteorology opened the forum by welcoming the participants and reviewing the agenda. He thanked the National Weather Service, the National Science Foundation, and the Office of Naval Research for assistance in funding the forum.

Panel 1: Tropical Cyclone Operations: Challenges in 2017; New Products and Services Planned for 2018 and 2019

The National Hurricane Center noted that having three Category 4 hurricane landfalls in the U.S. was unprecedented and resulted in the costliest year on record with more than $250 billion in damage. Overall track and intensity forecasts were quite good and continued to improve for all forecast periods compared with past seasons. The GFS performance was better but still had problems forecasting genesis of storms in both basins. Vertical shear errors in mid-levels of the storm were identified as a complicating factor when forecasting storm intensification. Beginning in 2018, NHC will provide 48-hour hurricane-force (64 knot) wind radii forecasts (in quadrants) and the Time of Arrival graphics will become operational.

The Central Pacific Hurricane Center reported that the number of TCs was below normal for the Central Pacific and near normal for the Eastern Pacific. CHPC will be incorporating some new forecast tools and introducing changes to their products and services for the 2018 TC season. These will include Time of Arrival graphics, TC public advisory discussion and outlook, and SLOSH guidance for the entire state Hawaii.

The Joint Typhoon Warning Center production included 6908 fixes, 762 forecasts on 69 TCs in their basins of responsibility. Their challenges are large track busts, rapid intensity changes and poor TD/TS intensity guidance. New products include a new website, an updated TC forecast graphic, “pre-invests”, and AWIPS-2 (to be USN accredited in early 2019). TC intensity change, and TC structure specification remain their top two R and D priorities.

The Aircraft Operations Center (AOC) facility moved to Lakeland FL in May and was in the direct path of IRMA in September 2017. The facility served as a safe haven for aircraft and other local assets. Only a single P-3 was available during the 2017 season because of the re-winging schedule, however, it flew 148% of its allocated hours. Changes for 2018 and 2019 include MMR replacement for LF Radar, improved GIV TDR, return of N43RF for the 2019 season, and improved RD-41 dropsondes and AVAPS system, new VORTEX Message, and transmittal of BUFR Data.

The 53rd Weather Reconnaissance Squadron (53rd WRS) flew 155 NHOP tasked hours (above average) with a reliability of 99%. Challenges for 2018 include airplanes nearing 20 years old, aircraft maintenance, pilot retention problems and SATCOM.

Panel 2: Recent and Planned Improvements in Modeling Capability

NOAA NWS NCEP/EMC reported on operational modeling plans at NCEP. The FV3GFS model has infrastructure and physics upgrades, data assimilation improvements and incorporates new data. This has increased the computational requirements 135%. Evaluations of the model performance in Harvey showed that during the first five days of each cycle, GFS and FV3 generally provided similar guidance with some subtle differences. FV3 suggested rapid intensification and a deeper storm at landfall before the GFS (which caught on in later cycles). The center of Irma forecasted by FV3GFS was shifted towards west of the GFS center and verified better against observations. Comparisons were also made with other models. For the Atlantic, the FV3GFS was generally more skillful than GFS, but worse than the operational HWRF. Potential FY18 HWRF upgrades include system and resolution enhancements, physics advancements, data assimilation and initialization improvements, coupling and other upgrades. There will be similar upgrades to the HMON.

NRL reported on COAMPS-TC status and plans. COAMPS-TC is a specialized version of COAMPS designed to predict tropical cyclone (TC) track, intensity and structure (wind radii) and has been operational at FNMOC since 2013. COAMPS-TC was much improved for track and intensity in 2016/17. Key gaps included the lack of TC observations, inadequate data assimilation methods in the TC, and uncertainties in physics. Plans are for physics and initialization upgrades in 2018 and using a 4D-Var/hybrid, improved physics, and waves in 2019.

UKMET reported on recent model improvements and planned changes to operational systems. Improvements include changes to data assimilation, increased resolution and increased ensemble size. Air-sea coupling in their global model has reduced track error and reduced the over-deepening bias.

ECMWF had a small reduction of forecast position errors at Day+3 and Day+5 last year compared with the previous year. On average the HRES (~9km) TC forecasts are too intense at Day+3 and beyond. There was significant improvement of TC intensity forecast errors when the HRES (~9km) was coupled with the ocean model. This configuration (45r1) should be in operations by this summer. The Seasonal Forecast System 5 (SEAS5) was successfully implemented last November. Lightning flashes density is a new product that will be available this summer. Work is underway to improve the scatter meter winds assimilation around TCs.

Panel 3: Ocean Model Impact on Hurricane Forecasting

URI (Isaac Ginis): Ocean state measurements under the hurricane's inner core are necessary to improve the ocean model physical parameterizations and evaluation. Sea state dependent effects are not currently included in the U.S. operational hurricane models. Momentum flux into ocean and the drag coefficient can be estimated from high-resolution current velocity profiles. Explicitly resolving sea state dependent processes in coupled hurricane-wave-ocean models will lead to increased accuracy in predicting the ocean response and hurricane intensity. Direct observations of ocean currents, waves and temperatures are necessary to fully examine the impact of sea state dependent processes under hurricane conditions and to evaluate coupled model results.

US Naval Academy (Elizabeth Sanabia): TC ocean observations are needed to resolve initial conditions and physical processes. Current TC observation programs include data from ships, on shore, satellite and air-deployed. Inter-annual differences in upper-ocean conditions have a large influence on predicted intensity. Accurate ocean model initialization is necessary, and assimilation of ocean observations is critically important for improving initialization. Emerging technologies include the Coyote UAS Air-Deployed Wave Buoy (ADWB), IR (SST)-Dropsondes and MASED - Combo Air-Ocean Sonde. Improving TC forecasts will require a coordinate comprehensive ocean sensing strategy and a commitment to funding.

MSU (Pat Fitzpatrick): Hurricane Nate weakened rapidly as it translated over the continental shelf of the Louisiana and Mississippi Sound. On the continental shelf as well as over the deep-water environment, it's crucial to bridge the understanding of coupling processes to obtain proper surface fluxes and intensity responses.

AOML (George Halliwell): Inter-annual differences in upper-ocean conditions have a large influence on predicted intensity. Assimilation of subsurface ocean observations to correctly initialize heat content and 3-D eddy structure is important to improve intensity prediction. Additional resources are needed, both to design improved ocean observing strategies and to support collection of the required observations.

NCEP/EMC (Hyun-Sook Kim): Observations are needed to validate and improve physics and model skill in the EMC operational coupled HWRF/HMON models. Current requirements for initial conditions include SST, mixed layer and mesoscale features. Future requirements include observations of surface and internal waves and freshwater in the surface. Improving forecasts will require observations of air-sea interaction processes and ocean mixing processes.

UM (Benjamin Jaimes): Numerical models must correctly represent ocean eddies to correctly simulate upwelling and down welling responses, sea surface cooling, and ensuing air-sea moisture disequilibrium, enthalpy fluxes, and tropical cyclone intensity.

This is largely a problem of model initialization, for which direct measurements of the pre- and in-storm ocean states (T, S, V) are critical.

AOML (Jun Zhang): The boundary layer recovery of low-entropy air through surface fluxes may be a key mechanism for TC intensity change, while the hurricane intensity is correlated to the entropy of the inflow more than the surface fluxes. Ocean structure and SST are crucial for determining enthalpy fluxes.

Session 4: Satellite Advancements

NHC (John "Jack" Beven): GOES-16 data had an immediate positive impact on NHC operational decision making. Examples of this included analyses of TC structure, analyses of the TC environment, center location, and existence of a circulation. GOES-16 imagery subjectively allowed for better center locations on weak systems, although no quantitative data on the exact impact is currently available.

CIRA/CSU (Stephanie Stevenson): The GOES-16 Geostationary Lightning Mapper shows that TC lightning peaks in the inner core and outer rain bands, with minima in between. Many recent studies link increased lightning to TC intensity change, showing promise for including lightning in intensity forecasting. Lightning shows promise for statistical TC intensity guidance. Experimental tests are planned for 2019 with transition into operations in 2020.

JTWC (Bob Falvey and Brian Strahl): Exclusively uses remotely sensed data from satellites and radars. Infrared/Visible imagery fixes via Mark IVB are done every 3 hours and microwave/scatterometer fixes are done whenever those sensors are available. JTWC uses microwave imagery from: DMSP, NOAA, JPSS, GPM, GCOM-W1, Coriolis, METOP A&B and scatterometry from

USN (Coriolis WINDSCAT), ISRO (ScatSat1 OSCAT) and EUMETSAT (METOP A&B ASCAT).

CIRA/CSU (Mark DeMaria): The CIRA/RAMMB JPSS operational application is the Hurricane Intensity and Structure Algorithm (HISA). HISA provides satellite-based TC intensity estimates that are global, objective, and independent of Dvorak. Real-Time/transitioning applications to operations include the Satellite Eye-Detection Routine (SEDR), which objectively determines the probability of the eye existence from IR imagery (GOES or VIIRS). The Moisture In-flux Storm Tool (MIST) (real-time planned for 2019) helps to detect and quantify dry air intrusions. VIIRS TC-centered imagery is especially useful for night-time center-fixing. Proxy-visible imagery allows forecasters to see low-level clouds at larger ranges of background surfaces and SSTs compared to existing products. The CIMSS SATCON application provides objective estimates of TC intensity in near real-time and compliments the current subjective Dvorak estimates.

Florida Public Hurricane Loss Model (Invited Presentation)

Shahid Hamid, PhD, CFA, Chair and Professor, Department of Finance, College of Business, Florida International University, noted that Florida ranks #1 in total insured property value exposed to hurricane wind and #1 in coastal property exposed to storm surge. Florida has $4 trillion in insured properties of which about $2.18 trillion are residential, and all are exposed to hurricane risk. In 2001, the Florida Office of Insurance Regulation funded Florida International University to independently develop a public hurricane loss model to assess hurricane wind risk and predict insured losses for these residential properties. The model was first activated in March 2006. The hurricane wind loss model has been used over 1,100 times by FL-OIR to evaluate insurance rate filings. The model simulates and predicts how, where and when hurricanes form, their wind speed and intensity and size, their track, how they are affected by the terrain along the track after landfall, how the winds interact with different types of structures, how much they can damage house roofs, windows, doors, interior, contents, how much it will cost to rebuild the damaged parts, and how much of the loss will be paid by insurers. Lessons from past hurricanes

indicate that the part of the house most vulnerable to hurricane wind is the roof and roof to wall connection. There has been much improvement in building codes and roof design and connection, but houses are still very vulnerable to major hurricanes. A wood roof is not suitable for a hurricane prone area whereas the concrete roof is preferable. Engineers at FIU have patented a 1.5inch thick lightweight but strong concrete roof that can stand up to 200 mph wind and is cheap to build and install.

Session 5: JHT Project Status: (Part 1).

Six projects started 1 July. 2017 (FY17-19: 9th round.) and are underway:

- Update on the JHT – Jason Sippel (NOAA/HRD), Christopher Landsea (NWS/NHC). Mark DeMaria (NWS/NHC)
- JHT Project 1: Evolutionary Programming for Probabilistic Tropical Cyclone Intensity Forecast - Paul Roebber and Clark Evans (UW-Milwaukee)
- JHT Project 2: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors - Galina Chirokova (CSU/CIRA), John Kaplan (AOML/HRD)
- JHT Project 3: Improvements and Extensions to an Existing Probabilistic TC Genesis Forecast Tool Using and Ensemble of Global Models - Bob Hart and Dan Halperin (FSU)

Session 6: JHT Project Status: (Part 2)

- JHT Project 4: Estimation of Tropical Cyclone Intensity Using Satellite Passive Microwave Observations - Haiyan Jiang (Florida Intl Univ.)
- JHT Project 5: Improvement and Implementation of the Probability based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins - Yongxian Pei and Haiyan Jiang (Florida Intl Univ.)
- JHT Project 6: Transition of Machine-Learning Based Rapid Intensification Forecasts to Operations - Andrew Mercer and Kimberly Wood (MSU)
- JHT Project 7: Ensemble-based Pre-genesis Watches and Warnings for Atlantic and North Pacific Tropical Cyclones - Russ Elsberry (UC-CS)

Session 7: Hurricane Forecast Improvement Project (HFIP) Update

Frank Marks, (HRD), provided an update on NOAA's HFIP. He summarized the vision and goals of the project from 2009-2018. He noted that HFIP achieved ~20% decrease in average hurricane track and intensity forecast errors, reaching the 5-yr goals, and for track very close to the 10-yr goal. The keys to success were partnerships, diversity of manpower, outreach and community participation, computing resources, and integrated use and support of testbeds. The modeling highlights for 2017 included improvements in intensity and track forecasts, new products and services for NHC, and other regional and global model developments. Modeling priorities for 2018 and beyond will address storm genesis, rapid intensification, and reducing uncertainty in prediction products.

Nicole Kurkowski, (NWS), presented the proposed new goals, objectives, and strategies developed in response to Section 104 of the Weather Act. The Weather Act directs the following: "The Under Secretary, in collaboration with the United States weather industry and such

academic entities as the Administrator considers appropriate, shall maintain a project to improve hurricane forecasting. The goal of the project shall be to develop and extend accurate hurricane forecasts and warnings in order to reduce loss of life, injury, and damage to the economy." The related HFIP science and R2O challenges include:

- Reduce track and intensity errors
- Improve initialization and physics impacting RI
- Extend forecast guidance to 7 days
- Improve model guidance of pre-formation
- Improve forecast and communication of storm surge
- Incorporate risk communication into product suite

The key strategies to address these challenges are:

- Advance operational hurricane analysis and forecast system (HAFS)
- Improve probabilistic guidance
- Enhance communication of risk and uncertainty
- Increase HPC capacity
- Research to Operations (R20) Enhancements
- Broaden expertise and expand interaction with external community

The strategic plan is under review and is expected to be sent to Congress in about two weeks.

Working Group for Tropical Cyclone Operations and Research (WG/TCOR) Meeting

The Working Group for Tropical Cyclone Operations and Research provides a forum for interagency coordination and collaboration on operations and research activities related to tropical cyclones. The WG/TCOR typically meets in person in conjunction with the annual TCORF to finalize changes to the (National Hurricane Operating Plan (NHOP).

Session 8: Advances in Airborne Observing Systems, Infrastructure, and Product Improvement

NHC (Eric Blake): initiated and coordinated enhanced changes to the reconnaissance vortex message. As one example, there was no SFMR or outbound flight-level winds in the original message format unless it was added in remarks. Also, center dropsondes wind needed for pressure estimates was only in remarks. This change in the vortex message was needed to make the data more uniform and able to be parsed. The changes for 2018 clarifies data reported for the center group, inbound group, outbound group, temperature group, fix statistics group.

NHC (Mike Brennan): is determining what the next advances in NHC's tropical cyclone products and services over the next 3 to 10 years should be? They are considering potential product enhancements in graphics and in forecasts and warnings, product enhancements such as in the TCM format, collaboration improvements, and developing new ensemble-based tools. The next step is to prioritize items, interact with users to determine details and involve social science for other changes.

AOC (Alan Goldstein): reported on airborne instrumentation now and in the future. Improvements are underway for the SFMR and an enhanced sensor on the RD41 dropsondes.

The multimode radar will be installed in May 2018 to help measure surface roughness and the GIV tail Doppler will help with real time accurate wind correction. Development ideas are being considered for APAR and WSAR and the new vortex message and BUFR reporting will start this coming hurricane season.

AOML/HRD (Jason Dunion): reported that the overall goal of SHOUT was to evaluate the potential ability of UAS like the Global Hawk to prevent the degradation of forecasts of high-impact weather events should there be a gap in polar-orbiting satellites. Three primary sensors were flown throughout SHOUT. The data were used in real time by forecasters and for operational assimilation in NWP forecast models and demonstrated the potential utility of Global Hawk observations for high-impact weather forecast improvement.

AOML/HRD and NCAR (Joe Cione): The Coyote UAS is a new tool to help better understand, evaluate and ultimately improve future forecasts of intensity change. The Coyote UAS Data collected in Hurricane Maria provided the type of highly unique data that have the potential to significantly enhance physical understanding of a rarely observed region of the storm, improve operational situational awareness and provide valuable insights related to (coupled) model evaluation and improvement.

53rdWRS (Kaitlyn Woods): is looking for better ways to meet their technology upgrade requirements in the future. Technological Improvements for 2018 include new hygrometers, software upgrades, new ground stations, an AXBT launcher and new mission computers. The radar transmission project is planned for implementation in 3-5 years. Three requirements in the NHOP are not being met. A process is needed to identify, validate and prioritize requirements for the long term. Once a requirement is made in the NHOP it will take approximately 5 years if not longer before it can be installed or implemented on the WC130. A long-range requirements list in the NHOP would help the 53rd obtain funding needed to develop and field new instruments/sensors. *A review and update of the requirements list could be done annually by a Working Group comprised of the 53rd, AFRC, NHC, HRD, and AOC.*

NHC (Chris Mello): The Automated Tropical Cyclone Forecast (ATCF) system is the primary software tool for NHC, CPHC and JTWC tropical cyclone product generation. NWS is working to integrate ATCF functionality into AWIPS2 over the next 5 years. NAWIPS and AWIPS2 are both used for satellite and model data display and product generation and migrating NAWIPS to AWIPS2 is a high priority for NWS. ATCF upgrades in 2018 for NHC are underway at NRL and NHC. Full capabilities of ATCF in AWIPS 2 are still 4-5 years away. AWIPS workstations will be installed on all HSU operations desks in 2018. *Setting up an operational AWIPS system is a difficult task with large hardware and support investments*.

AOML/HRD (Jason Sippel): presented a briefing on the value of extra dropsondes deployed by the AFRES. This study showed that dropsondes data improved track and intensity forecast skill. End/turn point dropsondes were requested this past season for Franklin, Harvey, Jose, Maria and Nate and increased intensity forecast skill by 10%. *It was recommended that end/turn point and environmental dropsondes be added to AFRES tasking this hurricane season. The added cost was estimated to be about $150,000 per year*.

Final Plenary Session

WG/TCOR Report:

Working Group chair, Dr. Mark DeMaria, briefed the results of the WG meeting. Two previous actions items were reviewed along with nearly two dozen new recommendations. A separate Record of Actions (ROA) covers this meeting and is available at https://www.ofcm.gov/meetings/TCORF/ihc18/2018presentations.htm.

Conference Action Items:

1. Recommended TCORF 2019 Sessions covering:
    - Implementation of AWIPS outside of NWS: Agencies expressed concerns about coordination of data access and product dissemination as JTWC and others implement AWIPS over the next few years.
    - Exploration of research efforts on sensing strategies (ocean in particular but could include atmosphere as well).
2. A process is needed to identify, validate and prioritize requirements for long term technology upgrades to reconnaissance aircraft. OFCM will inform the ICMSSR of this issue/concern and seek approval to form a WG or JAG to address the recommendation suggested during Session 8 of this Forum.
3. Publish NHOP 2018.
    - OFCM will coordinate publication by 1 May 2018.

Before adjourning, Federal Coordinator for Meteorology Dr. Bill Schulz presented the Richard H. Hagemeyer Award to Dr. Ed Rappaport, NWS National Hurricane Center (Acting) Director.

The **2019 TCORF** is tentatively scheduled for **March 12-14** at **Rosenstiel School for Marine and Atmospheric Science (RSMAS)** in Miami, Florida.