Tropical Cyclone
Research Forum

March 3-6, 2014

March 3, 2014

Dear Colleagues,

Welcome to the 2014 Tropical Cyclone Research Forum/68th Interdepartmental Hurricane Conference! We are looking forward to a very productive and informative four days.

The theme of this year's forum is: *Tropical Cyclone Research: Assessing the Past—Planning for the Future*. The goal of the forum is to roll up our sleeves and conduct a thorough assessment of the progress we have made in implementing the 2007 *Interagency Strategic Research Plan for Tropical Cyclones: The Way Ahead*. The opening session on Tuesday morning features a panel of senior Federal leaders, discussing to their individual agency's perspective on the contributions they have made to our Nation's tropical cyclone forecast and warning program in terms of both operations and research.

Other topics on the forum agenda include:

- The meeting of the Working Group for Hurricane and Winter Storm Operations and Research
- The 2013 Tropical Cyclone Season in Review
- Tropical Cyclone Observations and Observation Applications
- Tropical Cyclone Numerical Modeling Initiatives
- Research Priorities of the Operational Centers
- Applications of Social Science to Tropical Cyclone Forecast and Warning

Thank you for joining us as we seek to enhance our ability to improve our Nation's hurricane observing, forecasting, and warning system as we prepare for the upcoming tropical cyclone season and beyond. This is our second experience with conducting a forum of this magnitude where over 50 percent of the attendees will participate "virtually" over the web. We hope to build upon last year's success, and your participation and continued support are key to that success!

Sincerely,

Samuel P. Williamson
Federal Coordinator for Meteorological Services and
Supporting Research

Department of Agriculture • Department of Commerce • Department of Defense • Department of Energy • Department of Homeland Security • Department of Interior
Department of State • Department of Transportation • Environmental Protection Agency • Office of Management and Budget • Office of Science and Technology Policy
National Science Foundation • National Transportation Safety Board • Nuclear Regulatory Commission • National Aeronautics & Space Administration

Agenda

2014 Tropical Cyclone Research Forum (TCRF)/68th IHC
Tropical Cyclone Research: Assessing the Past—Planning for the Future

AGENDA

DAY 1 – Monday, March 3, 2014		
1:00 PM	Working Group for Hurricane and Winter Storm Operations and Research (WG/HWSOR) Meeting	*Edward Rappaport (NCEP/NHC), Chair*

DAY 2 - Tuesday, March 4, 2014		

8:00 AM   Registration *(7:00 AM-12:30 PM)*

Opening Session

9:30 AM	Forum Opening	Mr. Samuel P. Williamson Federal Coordinator for Meteorology
9:45 AM	Setting the Stage/ Introduction of Panel Moderator	Mr. Samuel P. Williamson Federal Coordinator for Meteorology
10:00 AM	**Senior Leader Panel** **Moderator:** Dr. Ronald Ferek, Program Officer, Marine Meteorology Program, Office of Naval Research **Panelists:** ● RADM Jonathan W. White, Oceanographer and Navigator of the Navy ● Col John Engetowich, Air Force Director of Weather ● Dr. Louis Uccellini, Director, National Weather Service ● Dr. Jack Kaye, Associate Director and Research and Analysis Lead, Earth Science Division, National Aeronautics and Space Administration ● Dr. Michael C. Morgan, Division Director of Atmospheric and Geospace Sciences, National Science Foundation **Discussion and Q&A**	

12:00 PM   Lunch on your own *(12:00- 1:00 PM)*

Afternoon Coordinator: Mark DeMaria (NOAA/NWS/NHC)

Session 1:   The 2013 Tropical Cyclone Season in Review

Session Leader Jim McFadden (NOAA/AOC)		
1:00 PM (S1-01)	Review of the 2013 Central Pacific Tropical Cyclone Season and Preliminary Verification	*Tom Evans* (NWS/CPHC)
1:15 PM (S1-02)	A Review of the 2013 Joint Typhoon Warning Center Tropical Cyclone Season	*Robert J. Falvey* (JTWC)
1:30 PM (S1-03)	53rd Weather Reconnaissance Squadron/AFRC 2013 Hurricane Season Summary	*Lt Col Jonathan Talbot* (53 WRS)
1:45 PM (S1-04)	NOAA Aircraft Operations Center (AOC) 2013 Seasonal Summary and Future Plans	*Jim McFadden,* Alan S. Goldstein, Devin R. Brakobb (NOAA/AOC)

Session 2:   Transitioning Research to Operations (JHT, DTC, and FNMOC)

Session Leaders Christopher Landsea (NOAA/NHC) and Shirley Murillo (NOAA/AOML)		
2:00 PM (S2-01)	An Update on the Joint Hurricane Testbed (JHT)	*Christopher Landsea* (NOAA/NHC) and Shirley Murillo (NOAA/AOML)
2:15 PM (S2-02)	Improvement to the Satellite-based 37 GHz Ring Rapid Intensification Index	*Haiyan Jiang*, Margie Kieper, Yongxian Pei (Florida Intl Univ), and John Kaplan (NOAA/AOML)

2:30 PM (S2-03)	Predicting Tropical Cyclone Intensity Forecast Error	*Kieran T. Bhatia*, David S. Nolan (Univ. of Miami/RSMAS), and Andrea B. Schumacher (CSU/CIRA)
2:45 PM (S2-04)	Upgrades to the Operational Monte Carlo Wind Speed Probability Program: A Year 1 Joint Hurricane Testbed Project Update	*Andrea Schumacher* (CSU/CIRA) and Mark DeMaria (NOAA/NHC)

3:00 PM   Afternoon Break *(3:00-3:30 PM)*

3:30 PM (S2-05)	Optimized Multi-Sensor Application in the ARCHER Automated TC Center-Fixing Algorithm	*Anthony Wimmers* and Christopher S. Velden (Univ. of Wisc./CIMSS)
3:45 PM (S2-06)	Upgrades to the GFDL/GFDN Operational Hurricane Model for 2014	*Morris A. Bender*, Matthew Morin, and Timothy Marchok (NOAA/GFDL); Isaac Ginis, Biju Thomas, and Richard Yablonsky (Univ. of Rhode Island); and Robert Tuleya (Old Dominion Univ)
4:00 PM (S2-07)	Improving HWRF and GFDL/GFDN Hurricane Models by Advancing the Air-Sea Interaction Components	*Isaac Ginis*, Richard Yablonsky, and Biju Thomas (University of Rhode Island); Morris Bender (NOAA/GDFL); and Vijay Tallapragada (NOAA/NCEP)
4:15 PM (S2-08)	Verifying Historical Forecasts and Developing a Statistical Model from NWP Output	*Daniel Halperin*, Robert Hart, Henry Fuelberg, and Joshua Cossuth (Florida State Univ.)
4:30 PM (S2-09)	AdcircViz: A Visualization and Analysis Application for Distributed ADCIRC-based Coastal Storm Surge, Inundation, and Wave Modeling	*Brian Blanton*, Renaissance Computing Institute, and Rick Luettich (Inst. of Marine Sciences, Univ. of N. Carolina at Chapel Hill)
4:45 PM (S2-10)	Developmental Testbed Center (DTC) Activities in Support of Transition of Research to the Operational Hurricane WRF Model	*Ligia Bernardet* (NOAA/GSD, CIRES/CU, DTC), Vijay Tallapragada (NOAA/EMC), Timothy Brown, (NOAA/GSD, CIRES/CU, DTC), Mrinal Biswas (NCAR), Samuel Trahan (NOAA/EMC/ IMSG), Donald Stark and Laurie Carson (NCAR)
5:00 PM (S2-11)	Testing and Evaluation of the GSI-Hybrid Data Assimilation and its Applications for HWRF at Developmental Testbed Center	*Hui Shao* and Chunhua Zhou (NCAR); Ligia Bernardet and Isidora Jankov (NOAA/ESRL); Mrinal K. Biswas (NCAR); Brian Etherton (NOAA/ESRL); Mingjing Tong (NOAA/EMC); Jeff Whitaker (NOAA/ESRL); and John Derber (NOAA/EMC)
5:15 PM (S2-12)	The Development of COAMPS-TC, Transition to Navy Operations, and Future Plans	*James D. Doyle* (NRL/Monterey), R. Hodur (SAIC), J. Moskaitis, S. Chen, E. Hendricks, Y. Jin, A. Reinecke, and S. Wang (NRL/Monterey)
5:30 PM (S2-13)	Recent Tropical Cyclone Modeling Transitions to Operations at Fleet Numerical Meteorology and Oceanography Center	*Charles E. Skupniewicz*, Carey Dickerman, and Raymond C. Lee (Fleet Numerical Meteorology and Oceanography Center)

5:45 PM   Adjourn for the day

<div style="background:#c6d4e4; font-weight:bold; text-align:center">DAY 3 - Wednesday, March 5, 2014</div>

9:25 AM   Opening/Administrative Remarks—Bob Dumont (OFCM/STC)

Morning Coordinator: Col Gary Kubat (Air Force/OFCM)

Session 3a: Tropical Cyclone Observations and Observation Applications, Part I

Session Leader Scott Braun (NASA/GSFC)		
9:30 AM (S3a-01)	Hurricane and Severe Storm Sentinel (HS3): Results from the 2013 Deployment	*Scott A. Braun* and Paul A. Newman (NASA/GSFC)
9:45 AM (S3a-02)	HIWRAP Global Hawk Status and Future Plans	*Gerald Heymsfield* (NASA/GSFC), S.Guimond (NASA/ORAU), M. Mclinden and L. Li (NASA/GSFC), J. Carswell (Remote Sensing Solutions, and L. Tian (Morgan St. Univ)
10:00 AM (S3a-03)	HIWRAP Observations from the Hurricane and Severe Sentinel (HS3) Campaign: Comparing Retrieval Techniques	*Anthony C. Didlake, Jr.*, Gerald M. Heymsfield, Lian Tian, and Stephen Guimond (NASA/GSFC)

10:15 AM (S3a-04)	Ensemble Kalman Filter Assimilation of HIWRAP Observations of Hurricane Karl (2010) from the Unmanned Global Hawk Aircraft	*Jason A. Sippel*, Fuqing Zhang, Yonghui Weng, Lin Tian, Gerald M. Heymsfield, and Scott A. Braun (NASA/GSFC)
10:30 AM (S3a-05)	High Definition Sounding System (HDSS) for Atmospheric Profiling	*Peter Black* (NRL/Monterey/SAIC); Lee Harrison (Univ of Albany/SUNY); Mark Beaubien and William Jeffries (Yankee Environmental Systems, Inc); Robert Bluth, Haflidi Jonsson, and Andrew Penny (Naval Postgraduate School); and Robert W. Smith (NASA/JSC)
10:45 AM (S3a-06)	Extreme Wave Height Reports from NDBC Buoys during Hurricane Sandy	*Richard H. Bouchard* (NOAA/NDBC), Robert E. Jensen (USACE), David W. Wang (NRL/Stennis), George Z. Forristall (Forristall Ocean Eng, Inc), Oceana P. Francis (Univ of Hawaii Manoa), and Rodney E. Riley (NOAA/NDBC)
11:00 AM (S3a-07)	Progress on Upper Ocean Measurement Strategies during Hurricane Passage: AXCP and AXCTD Profiling	*Lynn K. Shay*, Benjamin Jaimes, and Jodi K. Brewster (RSMAS/ Univ of Miami); Eric W. Uhlhorn (NOAA/HRD); and George R. Halliwell (NOAA/AOML/POD)
11:15 AM (S3a-08)	The AXBT Demonstration Project: Implementation, Impact, Collaboration, and Outlook	*Elizabeth R. Sanabia* (USNA) and Peter G. Black (NRL/Monterey/SAIC)
11:30 AM (S3a-09)	Upper-Ocean Thermal Structure Variability during Hurricanes Ernesto and Isaac (2012)	*Ellen K. Deckinga*, William J. Schulz, Elizabeth R. Sanabia, and Bradford S. Barrett (USNA)
11:45 AM (S3a-10)	Impact of AXBT Ocean Observations on the COAMPS Prediction of Tropical Cyclones	*Sue Chen* (NRL/Monterey), James Cummings (NRL/Stennis), Jerome Schmidt (NRL/Monterey), Elizabeth Sanabia and Bradford Barrett (USNA), and Peter Black (NRL/Monterey/SAIC)

12:00 PM   Lunch on your own *(12:00 - 1:00 PM)*

Afternoon Coordinator: CAPT Erika Sauer (Navy/OFCM)

Session 3b: Tropical Cyclone Observations and Observation Applications, Part II

Session Leader Robbie Hood (NOAA/OAR)		
1:00 PM (S3b-01)	Observing Upper Ocean Structure Changes in Hurricane Conditions using Profiling Glider Technology	Walt H. McCall (NOAA/NDBC), *Hyun- Sook. Kim,* (NOAA/NCEP), and L. Brzuzy, (Shell Upstream Americas)
1:15 PM (S3b-02)	Impact of Simple Parameterizations of Coastal Upper Ocean Heat Content on Modeled Hurricane Irene (2011) Intensity	*Greg Seroka*, Travis Miles, Yi Xu, Oscar Schofield, and Josh Kohut (Rutgers University)
1:30 PM (S3b-03)	The 2013 Satellite Proving Ground at the National Hurricane Center	*Mark DeMaria*, Jack Beven, Michael Brennan, and Hugh Cobb (NOAA/NHC); John Knaff (NOAA/NESDIS), Andrea Schumacher (CIRA/CSU), Christopher Velden (CIMSS/UW), Jason Dunion (NOAA/HRD), Gary Jedlovec (NASA/MSFC), Kevin Fuell (Univ of Alabama, Huntsville); and Michael Folmer (UM/CICS)
1:45 PM (S3b-04)	Exploiting SNPP VIIRS Day Night Band (DNB) for Tropical Cyclone Monitoring	*Jeff Hawkins*, Jeremy Solbrig, Mindy Surratt, and Kim Richardson (NRL/Monterey), Steve Miller (CIRA), Charles Sampson (NRL/Monterey), John Kent (SAIC), and Tom Lee (NRL/Monterey)
2:00 PM (S3b-05)	Satellite-Derived Oceanic Heat Content Estimates in the North Pacific Ocean Basin For Typhoon Intensity Forecasts: ST Haiyan	Claire McCaskill, *Lynn K. Shay,* and J. K. Brewster (RSMAS/ Univ of Miami)
2:15 PM (S5b-06)	Forecasting Flossie: A Look at Using the Most Progressive Satellite Technology	*Tom Evans* (NOAA/CPHC)
2:30 PM (S5b-07)	Sensing Hazards with Operational Unmanned Technology (SHOUT) to Mitigate the Risk of Satellite Observing Gaps	*Robbie Hood* (NOAA/OAR), Michael Black (NOAA/A OML), Gary Wick (NOAA/ESRL), , Philip Kenul (TriVector Services Inc.), and John Coffey (Cherokee Nation Technologies LLC)

2:45 PM   Afternoon Break *(2:45-3:00 PM)*

Note: Presentation abstracts can be found in the conference booklet   3

Session 4:   **Tropical Cyclone Numerical Modeling Initiatives**

	Session Leaders Jessie Carman (NOAA/OAR) and Vijay Tallpraganda (NCEP/EMC)	
3:00 PM (S4-01)	Evaluation of Experimental Models for Tropical Cyclone Forecasting in Support of the NOAA Hurricane Forecast Improvement Project (HFIP)	*Paul A. Kucera*, Barbara G. Brown**,** Louisa Nance, and Christopher L. Williams (NCAR/Research Applications Laboratory)
3:15 PM (S4-02)	Significant Improvements in Hurricane Intensity Forecasts from NCEP/EMC Operational High-Resolution HWRF Modeling System	*Vijay Tallapragada*, (NOAA/NWS/NCEP/EMC)
3:30 PM (S4-03)	The Physics Suite Upgrades of the Operational HWRF Model for 2014 Implementation	*Young Kwon* (NOAA/EMC/IMSA), Vijay Tallapragada, and Qingfu Liu (NOAA/EMC), Zhan Zhang, Samuel Trahan, Weiguo Wang, and Chanh Kieu (NOAA/EMC/IMSG)
3:45 PM (S4-04)	Real-Time HWRF Forecasts for the Joint Typhoon Warning Center	*Sam Trahan* and Chanh Kieu (NOAA/EMC/ IMSG), Vijay Tallapragada (NOAA/EMC), Brian Strahl (JTWC), Bob Gall (NOAA/HFIP/CIMAS), Lee Cohen (NOAA/ESRL/GSD/CIRES), and Thiago Quirino (NOAA/AOML)
4:00 PM (S4-05)	Experimental Real-Time Forecasts for the 2012-2013 Northwestern Pacific Season with the NCEP Operational HWRF	*Chanh Kieu*, Vijay Tallapragada, Samuel Trahan, Zhan Zhang, Qingfu Liu, Young Kwon, Weiguo Wang, and Mingjing Tong (NOAA/NCEP/EMC)
4:15 PM (S4-06)	Application of Coupled HWRF-HYCOM System for the Northwestern Pacific Typhoon Prediction	*Hyun-Sook Kim*, Sam Trahan, Chanh Kieu and Vijay Tallapragada (NOAA/NCEP/EMC/Marine Modeling and Analysis Branch)
4:30 PM (S4-07)	HWRF-based Ensemble Prediction System using Perturbations from GEFS and Stochastic Convective Trigger Function	*Zhan Zhang* (NOAA/NCEP/EMC/IMSG), Vijay Tallapragada (NOAA/NCEP/EMC), Chanh Kieu, Samuel Trahan, and Weiguo Wang (NOAA/NCEP /EMC/IMSG)
4:45 PM (S4-08)	Coastal Storm Modeling System (CSTORM-MS)	*Chris Massey* (USACE Engineer Research and Development Center/Coastal & Hydraulics Laboratory)
5:00 PM (S4-09)	Verification of Tropical Cyclone Genesis Prediction in a Suite of Operational Global Numerical Weather Prediction Models	*Mike Fiorino* (NOAA/Earth System Research Lab)
5:15 PM (S4-10)	New Challenges and Expectations of Dynamical Seasonal Prediction of Tropical Cyclones	*Jan-Huey Chen* and Shian-Jiann Lin (NOAA/GFDL)

5:30 PM   Adjourn for the day

DAY 4 - Thursday, March 6, 2014

9:25 AM   Opening/Administrative Remarks—Michael Bonadonna (OFCM)

Morning Coordinator: Christopher Landsea (NOAA/NWS/NHC)

Session 5: Research Priorities of the Operational Centers

	Session Leaders James Franklin (NOAA/NWS/NHC) and Jason Dunion (NOAA/AOML/HRD)	
9:30 AM (S5-01)	Multi Lead-time Statistical Rapid Intensification Guidance	*John Kaplan* (NOAA/HRD), Christopher M. Rozoff (CIMSS/UW-Madison), Charles R. Sampson (NRL), James P. Kossin (NOAA/NCDC), Christopher S. Velden (CIMSS/UW-Madison), and Mark DeMaria (NOAA/NESDIS/NHC)
9:45 AM (S5-02)	Real-Time Verification of a Passive Microwave Imagery-Based Statistical Model of Tropical Cyclone Rapid Intensification	*Christopher M. Rozoff* and Christopher Velden (CIMSS/UW-Madison), John Kaplan (NOAA/HRD), Anthony J. Wimmers (CIMSS/UW-Madison), and James P. Kossin (CIMSS/UW-Madison/NOAA/NCDC)

10:00 AM (S5-03)	Tropical Cyclone Genesis Ensemble Forecasts	*Jiayi Peng* (NOAA/NCEP/EMC/IMSG), Yuejian Zhu (NOAA/NCEP/EMC), and Richard Wobus (NOAA/NCEP/EMC/IMSG)
10:15 AM (S5-04)	Analysis Tools for Online Evaluation of the Operational Hurricane Forecasts Using Satellite Data	*Svetla M. Hristova-Veleva* (NASA/JPL), Mark Boothe (NPS), S. Gopalakrishnan (NOAA/HRD), Ziad Haddad, Brian Knosp, Bjorn Lambrigtsen, and Peggy Li (NASA/JPL), Michael Montgomery (NPS), Noppasin Niamsuwan (NASA/JPL), Vijay Tallapragada (NOAA/EMC), Simone Tanelli and Joseph Turk (NASA/JPL), and Tomislava Vukicevic (NOAA/HRD)
10:30 AM (S5-05)	Outer Vortex Wind Structure Changes during and following Tropical Cyclone Secondary Eyewall Formation in the Atlantic	*Robert A. Stenger* and Russell L. Elsberry (Naval Postgraduate School)
10:45 AM (S5-06)	MDL Research for Hurricane Storm Surge	*Amy Fritz* and Arthur Taylor (NOAA/NWS/MDL); Bobby Louansaysongkham, Huiqing Liu, Ryan Schuster, and Dongming Yang (NOAA/NWS/ MDL/Ace Info Solutions, Inc.); and Jindong Wang (NOAA/NOS/Coast Survey Development Laboratory/Earth Resources Technology, Inc.)
11:00 AM (S5-07)	Rapid Evaluation of Hurricane-driven Storm Surge using Pre-computed ADCIRC Solutions	*Rick Luettich* (Institute of Marine Sciences, Univ. of North Carolina-Chapel Hill), Brian Blanton and Jesse Bikman (Renaissance Computing Institute, Univ. of North Carolina-Chapel Hill), and Alex Taflanidis and Andrew Kennedy (Dept. of Civil and Environmental Engineering and Earth Sciences, Univ. of Notre Dame)

Session 6:   **Applications of Social Science to Tropical Cyclone Forecasts and Warnings**

Session Leader Bryan Norcross (The Weather Channel)		
11:15 AM (S6-01)	Enhancing the Timeliness of Tropical Cyclone Watches and Warnings: Issuance of Watches/Warnings Prior to Genesis	*Daniel P. Brown*, Todd Kimberlain, James Franklin, Ed Rappaport, and Rick Knabb (NOAA/NHC)
11:30 AM (S6-02)	Progress over the Past Five Years on a Hurricane Surge Visualization Model and Future Plans to use the Model to Assess Public Understanding of Risks due to Storm Surge	*B. Lee Lindner*, Stephen Duke, and Janet Johnson (Physics and Astronomy Department, College of Charleston) and Frank Alsheimer and Robert Bright (NOAA/NWS/Charleston SC)
11:45 AM (S6-03)	Improving Local Hurricane Forecast Communication	*Betty Hearn Morrow* (SocResearch Miami) Linda Girardi, Gina Eosco, Stephanie Fauver, Chris Ellis, and Vankita Brown
12:00 PM (S6-04)	Linking New Technology and User Behavior	*Brenda Philips* (Univ. of Massachusetts, Amherst)

12:15 PM   Lunch on your own *(12:15 PM-1:15 PM)*

Afternoon Coordinator: Daniel Melendez (NOAA/NWS)

Hagemeyer Award Presentation	
1:15 PM	Announcement and Presentation of the 2014 Hagemeyer Award Frank Marks (NOAA/AOML/HRD)

Invited Presentation	
1:30 PM (I-01)	Real-Time Geospatial Sharing Between Agencies—An Update *Dave Jones* (StormCenter Communications)

Final Plenary Session

	Session Moderator John Murphy (NOAA/NWS)	
1:45 PM	**Summary of Assessment Results—Agency Perspectives** **Panelists:** ● John Cortinas (NOAA/OAR) and Frank Marks (NOAA/AOML/HRD) ● Ron Ferek (Navy/ONR) ● Michael C. Morgan (NSF) ● Ramesh Kakar (NASA) **Discussion and Q&A**	
3:45 PM	WG/HWSOR Meeting Action Item Review	Edward Rappaport (NCEP/NHC) Chair, WG/HWSOR
4:00 PM	Final Wrap-up	Mr. Samuel P. Williamson Federal Coordinator for Meteorology
4:30 PM	Adjourn	

Session 1
The 2013 Tropical Cyclone Season in Review

Review of the 2013 Central Pacific Tropical Cyclone Season and Preliminary Verification

Tom Evans
(Tom.Evans@noaa.gov)

NOAA/NWS/Central Pacific Hurricane Center

The North Central Pacific experienced an above normal number of tropical cyclones during the 2013 Hurricane Season, with a distribution of one hurricane, four tropical storms and one tropical depression. The first tropical cyclone crossing into the Central North Pacific, Tropical Strom Flossie, was the only one to impact land. The remaining five tropical cyclones entering or developing in the North Central Pacific remained over the open ocean. This talk will provide a review of the hurricane season and associated verification.

A Review of the 2013 Joint Typhoon Warning Center
Tropical Cyclone Season

Mr. Robert J. Falvey
(robert.falvey@navy.mil)

Joint Typhoon Warning Center

 In 2013, there were 33 tropical cyclones in the western North Pacific, 24 tropical cyclones in the southern hemisphere and 6 tropical cyclones in the northern Indian Ocean. JTWC will present a summary of the 2013 activity across these areas, including preliminary forecast verification.

53d Weather Reconnaissance Squadron/AFRC 2013 Hurricane Season Summary

Lt Col Jonathan Talbot
(Jonathan.talbot@us.af.mil)

53d Weather Reconnaissance Squadron

The 53d WRS completed 30 Atlantic and 1 eastern Pacific NHC fix requirements along with 11 other requirements (Invest, Surveillance, Buoy) during the 2012 hurricane season.   A total of 34 missions and 325.4 hrs were flown in support of NHC. During the 2013 hurricane season, the 53WRS flew the least amount of hours than in the past 23yrs.

NOAA Aircraft Operations Center (AOC)
2013 Seasonal Summary and Future Plans

Jim McFadden, Alan S. Goldstein, Devin R. Brakobb
(Jim.D.Mcfadden@noaa.gov)

NOAA Aircraft Operations Center

While the 2013 hurricane season was a bit of a disappointment from the standpoint of aircraft hours flown and reconnaissance and surveillance tasking, there were som interesting highlights in the research area as well as TDR missions. The downside of the season was that only 204 hours were flown by all aircraft for research, reconnaissance and surveillance with there being zero hours for NHC tasked missions and only 7.9 hours for G-IV surveillance – an historic low in NOAA aviation history.

On the up side a number of TDR and IFEX research missions were flown into several storms including Hurricane Ingrid and T.S. Karen along with a few Ocean Winds IWRAP flights. On one of these missions the NOAA P-3 N43RF (Ms. Piggy) joined up with the NASA Global Hawk 871 over the Atlantic east of Florida to perform a series of coordinated stacked runs to compare the GH HIWRAP with the P-3 IWRAP. Finally, on the last flight into TS Karen the TDR data from one of the P-3s was used operationally in model runs

AOC is looking forward to the 2014 season with a large number of flight hours available for all facets of hurricane work, be it surveillance, operations or research. With both P-3s fully operational, they with the G-IV are prepared to fly round-the-clock EMC TDR or NHC tasked recco and surveillance missions with double crews. Given storms in accessible locations, AOC is prepared to perform these operational missions along with IFEX research flights tasked by the Hurricane Research Division of NOAA's AOML.

Beginning in January 2015, NOAA will begin its upgrades of the P-3s utilizing funds from a Sandy supplemental. Included will be the re-winging of both aircraft along with the upgrade of the P-3 engines to Series 3.5. The latter will result in increased efficiency and fuel savings, allowing for an increase in endurance to approximately 12 hours.

Coincidental to the re-winging and engine improvements will be a $9+M upgrade to the aircraft avionics and instrumentation. Some of the upgrades included in this major effort are as follows"

- Modernization of the P-3 TDR to include TWT xmtr/rcvr, RVP-9 processor, dual flat-plate antenna and an increase in antenna rotation speed from 10 to 24 RPM for improved Doppler resolution
- Auto-pilot replacement, multi-functional cockpit displays, digital engine instruments
- Nose radar and multi-mode lower fuselage radar replacements, cloud physics pylons and new instrument racks

Session 2
Transitioning Research to Operations (JHT, DTC, and FNMOC)

An Update on The Joint Hurricane Testbed (JHT)

Christopher Landsea, Shirley Murillo
(Chris.Landsea@noaa.gov)

NOAA/National Hurricane Center

New forecasting tools, techniques and model advances, developed by the research community were tested and evaluated at the National Hurricane Center (NHC) and the Environmental Modeling Center (EMC) facilitated by the Joint Hurricane Testbed (JHT). The sixth round (FY11-13) projects were tested and evaluated during the 2013 hurricane season, following any necessary technique modifications or other preparations. These projects completed their funding cycle and are being evaluated for operational implementation.

Seven new projects were selected for the seventh round (FY13-15). These projects include upgrades to dynamical models and model components, enhancements to observed data and assimilation techniques, storm surge modeling, track forecasting algorithms, intensity estimation and forecasting algorithms. In this session, the PIs will present their progress.

Improvement to the Satellite-based 37 GHz Ring Rapid Intensification Index

Haiyan Jiang[1], Margie Kieper[1], Yongxian Pei[1], and John Kaplan[2]
(haiyan.jiang@fiu.edu)

[1]Department of Earth & Environment, Florida International University
[2]NOAA Hurricane Research Division

Many tropical cyclones (TCs) experience one or more rapid intensification (RI) events during their life time. The physical processes associated with these events remain unsolved. Predicting these events is one of the most challenging aspects for TC forecasters. Recently, a distinctive ring pattern around the TC center has been found in the 37 GHz microwave images to be associated with RI. Real-time testing and statistical evaluations show that the method is very promising. The primary goal of our previous FY-11 JHT project is to translate the subjective forecast method into an objective one. After two hurricane seasons (2012-2013) of real-time testing, the automatic 37 GHz ring pattern identification algorithm works well for the eastern Pacific basin. However, for the Atlantic basin, the storm center fix error was one of the two major factors (the other factor was low SHIPS RI probability values) that caused the misses of RI forecasts. For our FY-13 JHT project, it is planned to incorporate the CIMSS ARCHER center fix technique. Algorithm modification and offline testing will be done in year 1. Real-time testing will be performed in year-2, in coordination with CIMSS JHT FY-13 real-time testing schedule.

Another improvement of the ring RI index is also planned. The major product of our FY-11 JHT project is a "yes" and "no" type of RI forecast only for 30 kt/24 hr intensity increase. Upon discussions with our NHC points of contact, it is realized that the optimal approach for RI prediction is to produce a probability type of RI forecast, not only for 30 kt intensity increase for

24 hours, but also for 25 and 35 kt/24 hr increases. Using 11 years of TRMM TMI data, a set of inner core rainfall and convective parameters has been compared between RI and non-RI storms. It is found that statistically RI storms always have larger raining area and volumetric rain than non-RI storms. According to the results, the best predictors additional to the 37 GHz ring are the inner core area with 85 GHz PCT < 275, 250, and 225 K. The probability of RI is almost doubled from the climatological mean if using one of these predictors alone. By adding these additional predictors, improvement of the 37 GHz ring RI index is possible.

Predicting Tropical Cyclone Intensity Forecast Error

Kieran T. Bhatia[1], David S. Nolan[1], Andrea B. Schumacher[2]
(kbhatia@rsmas.miami.edu)

[1] Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida
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The lack of consistency between the current operational tropical cyclone intensity forecast models and large fluctuations in model performance decreases the value of tropical cyclone forecasts. One approach to creating more reliable tropical cyclone 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. This a priori expectation of forecast performance combats the adverse effects of the substantial day-to-day, model-to-model, and storm-to-storm fluctuations in forecast quality.

As a first step towards providing real-time error predictions to accompany each tropical cyclone intensity forecast, Bhatia and Nolan (2013) studied the relationship between synoptic parameters, TC attributes, and forecast error. Their results indicate that certain storm environments are inherently more challenging for individual models to forecast. In this study, we build on previous results by using storm-specific characteristics as well as parameters representing initial condition error and the stability of the atmospheric flow to predict forecast error. All of the predictors are available prior to the official forecast deadline and are obtained from SHIPS diagnostic files for the Atlantic basin in 2007-11. Error predictions were generated for 24-120 hour intensity forecasts for LGEM, DSHP, HWFI, and GHMI. Using independent data from the 2012 Atlantic hurricane season, predicted forecast error was verified against actual data. Different regression techniques were compared to evaluate which method will provide the most utility in an operational setting.

Upgrades to the Operational Monte Carlo Wind Speed Probability Program: A Year 1 Joint Hurricane Testbed Project Update

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Under previous JHT support, the Monte Carlo wind speed probability model (hereafter MC model) was developed to estimate the probability that any given location will experience 34, 50, or 64 kt winds over a given forecast period. The MC model has been run in NHC operations since 2006. Subsequent JHT support has led to several improvements of the MC model, including the development of a verification program, the addition of forecast-specific track uncertainty through the inclusion of the Goerss Predicted Consensus Error (GPCE) parameter, and the development of the stand-alone Hurricane Landfall Probability Application (HuLPA). As the developers and primary users continue to gain experience with the MC model new opportunities to improve the model have been identified. This proposal seeks to complete a number of upgrades to the current MC model, many of which are based on NHC feedback over the past few hurricane seasons.

In the current project, three improvements to the MC model were proposed. These include (1) replacing the linear forecast interpolation scheme with a more precise spline fit scheme, (2) applying a bias correction to the model track error statistics to provide consistency between NHC's uncertainty products, and (3) applying a bias correction to the radii-CLIPER used by the MC model to improve the accuracy of the wind speed probabilities for exceptionally small or large (e.g. 2012's Hurricane Sandy) tropical cyclones. The time interpolation scheme has been successfully replaced with a spline fit scheme and a comparison of the verification of both schemes will be presented. Initial bias correction results for (2) and (3) have been developed and will be presented as well.

The current project also includes three enhancements to the MC model. These include (1) estimates of the arrival and departure 34, 50, and 64-kt winds, (2) development of integrated GPCE guidance, and (3) extending the MC model to 7 days. Coordinating with NHC hurricane specialists, weighting functions necessary to create a single integrated GPCE parameter have been developed for (2). Preliminary verification of this GPCE guidance will be presented, along with plans for completing enhancements (1) and (3).

Disclaimer:
The views, opinions, and findings contained in this article are those of the authors and should not be construed as an official National Oceanic and Atmospheric Administration (NOAA) or U.S. Government position, policy, or decision.

Optimized multi-sensor application in the ARCHER automated TC center-fixing algorithm

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The Automated Rotational Center Hurricane Eye Retrieval (ARCHER) algorithm is used in research applications for TC center-fixing and the retrieval of eye statistics, and is also used experimentally in real-time. It is currently supported by the National Hurricane Center Joint Hurricane Testbed for further validation and development. The most recent version of this algorithm combines information from geostationary (infrared, visible) and polar-orbiting (microwave) satellites into a single optimized track. We will share the latest results of the algorithm validation against best-track and reconnaissance positions, and discuss the meaning of these results for upcoming real-time operations. The newest version described here uses passive microwave imagery, multiple geostationary channels, and scatterometer ambiguities to resolve the optimal storm track.

UPGRADES TO THE GFDL/GFDN OPERATIONAL HURRICANE MODEL FOR 2014

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Major upgrades are planned for the 2014 version of the GFDL/GFDN operational hurricane models. These changes include increasing the horizontal resolution of the inner nest from 1/12th to 1/18th degree grid spacing, which is the highest physically-justified resolution that can be achieved for a hydrostatic model. In collaboration with the HWRF group at EMC/NCEP, the Princeton Ocean Model for Tropical Cyclones (POM-TC) used for the ocean coupling in both GFDL/GFDN and HWRF, is being replaced with an upgraded version (MPIPOM-TC). The grid configuration of MPIPOM-TC in the North Atlantic consists of a single, transatlantic ocean domain, which has ~1/12° horizontal grid spacing. This transatlantic domain replaces the two overlapping POM-TC domains in the Atlantic Ocean, each of which have ~1/6° horizontal grid spacing. Not only does the transatlantic domain alleviate the need for multiple Atlantic domains, it also extends further eastward than the old POM-TC East Atlantic domain, thereby allowing for ocean coupling of tropical cyclones that are closer to the African coast. A similar MPIPOM-TC ocean domain has also been developed for the East Pacific.

A number of improvements are being planned for the model atmospheric physics, including improvements to the formulation of the wind stress at the surface, modification of surface

exchange coefficients (C_h, C_d), modification of the PBL scheme, improvements to the Ferrier microphysics, and more accurate specification of the initial storm intensity.

Preliminary results are showing significantly improved track and intensity forecasts in both the Atlantic and East Pacific, with reduced negative bias for most of the intense storms and reduced positive bias for intensifying storms, which the 2013 operational version of the GFDL model tended to intensify too quickly. Overall, the reduction of errors in intensity was statistically significant at all forecast time levels, and exceeded 10% in 3-5 days, with improvements of about 6% in the earlier forecast lead times. Examples will be shown. To evaluate the impact of the improved model on multiple seasons, retrospective forecasts have been run for the 2008 -2013 Atlantic and East Pacific seasons. A summary of these results will be presented and compared to the 2013 operational GFDL and HWRF models, as well as the new upgraded HWRF model that is also planned for operational implementation in 2014.

Tropical cyclone genesis:
Verifying historical forecasts and developing a statistical model from NWP output

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Recent research by Halperin et al. (2013) has shown that global models have become increasingly able to predict tropical cyclone (TC) genesis at lead times out to four days. That paper verified TC genesis events over the North Atlantic (NATL) basin from five global models (CMC, ECMWF, GFS, NOGAPS, UKMET) during 2004-2011. Here, we expand the analysis temporally to include genesis events out to five day lead time and to include 2012 genesis events. We also expand the analysis spatially to include genesis events over the eastern North Pacific (EPAC) basin. Results show that the models' ability to predict TC genesis varies in time and space. Conditional probabilities when a model predicts genesis and more traditional performance metrics (e.g., critical success index) are calculated. When the models are ranked among each other, results show that the best performing model varies from year to year. A spatial analysis of each model identifies preferred regions for genesis, and a temporal analysis indicates that model performance expectedly decreases as forecast hour (lead-time) increases. Verification of multi-model consensus forecasts shows that genesis is considerably more likely when the models predict the same event.

During the 2013 hurricane season, we modified our TC identification and tracking algorithm to run in real-time. Each detected TC was assigned a genesis probability based on the historical performance of model genesis forecasts in that region (e.g., main development region, Gulf of Mexico, etc.). These probabilities were displayed in a graphical format. We will test these experimental genesis probabilities in real-time during 2014 with several enhancements. We will provide text bulletins to give additional information to the Hurricane Specialists Unit. A summary bulletin will include general information about each model-indicated TC (e.g., lat, lon, time of genesis, probability of genesis, etc.). Another bulletin will include more detailed

information about each disturbance, including values of the variables that are analyzed to determine the existence of a TC, and whether those values exceed the thresholds required. Time series plots of these variables and their respective thresholds will also be available.

We propose that additional genesis predictability can be teased out of model forecast output by adding new physically-based predictors (e.g., vertical wind shear, mid-level relative humidity, etc.) to those already being used. Thus, multivariable logistic regression models will be developed for each global model and each basin. These regression models will provide the probability of genesis for a specific disturbance at any time within 48 h and within 120 h. Methodology and preliminary results from a logistic regression model based on GFS output over the NATL will be presented as a "proof of concept."

AdcircViz: A Visualization and Analysis Application for Distributed ADCIRC-based Coastal Storm Surge, Inundation, and Wave Modeling

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Simulations of storm surge, inundation, and wave predictions using the ADCIRC tide, storm surge, and wind wave model generally require substantial computational resources. This is particularly true in a forecast, real-time operational mode using very high-resolution numerical grids, since the forecast products must be available early in the six-hour forecast cycle. In the past, this has largely limited the use of ADCIRC to non-forecast applications such as forensic studies of past hurricanes, process studies, and coastal risk evaluation and risk reduction analyses. For forecast applications, the resource need is exacerbated by the need for an ensemble of storm surge realizations to address uncertainty in the hurricane forecasts. Since each model run generates many large files, it is impractical to download the output from the computational facility(s) to a forecaster's desktop computer.

However, a community of regional ADCIRC-based forecast systems operates in several risk-prone areas of the eastern US and Gulf coasts, using the Adcirc Surge Guidance System (ASGS). Multiple ASGS instances may be running at any time on widely distributed computing resources, and they publish model output using community-driven conventions for data format, description, and access. The distributed nature of ASGS instances and ADCIRC's triangular finite element grid require an efficient and effective way to discover, gather, organize and visualize the model results across multiple data servers.

To bridge this information gap and to broaden the distribution of ADCIRC-based results to a wider audience of end-users, we have developed a *data grid* to provide uniform access to the collection of ASGS outputs. The data grid has three essential cyberinfrastructure components: 1) THREDDS and OPeNDAP servers to host and serve ADCIRC output; 2) CF-UGRID, a NetCDF Climate and Forecast metadata convention extension for non-rectangular grids; and 3)

NCTOOLBOX, a MATLAB toolbox that accesses datasets using NetCDF-Java as the data access layer.

The NOAA Joint Hurricane Testbed 2013 program has funded the development of AdcircViz, an end-user MATLAB-based GUI for visualization and analysis of the collection of ASGS system outputs. AdcircViz uses the data grid to access the collection catalog, uses the UGRID metadata descriptions to populate the GUI fields and data structures, and uses NCTOOLBOX to retrieve data fields only when needed. It provides a consistent display of model results, inter-comparison of time series output at user-selected locations, animation of time-dependent output fields, and export to GIS shapefiles.

In this presentation, we will describe the data grid concept, describe the current and near-future state of regional ASGS systems, demonstrate the use of AdcircViz on recent tropical cyclone events, and the project development roadmap. While our project focus is on ADCIRC-based results, the data grid and AdcircViz application can be applied to any model whose output files are CF-UGRID compliant and posted on a THREDDS data server.

Developmental Testbed Center (DTC) Activities in Support of Transition of Research to the Operational Hurricane WRF model

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The NOAA/NCEP/EMC operational HWRF model is an important component of the numerical guidance used at the National Hurricane Center, making it critical that the HWRF model be continuously improved. Given the complexity of the HWRF model, which consists of the WRF atmospheric model coupled to the Princeton Ocean Model for Tropical Cyclones (POM-TC), a sophisticated initialization package including a data assimilation system, and a set of postprocessing and vortex tracking tools, NCEP has partnered with the Developmental Testbed Center (DTC) to help accelerate the infusion of the new technologies onto the model.

The DTC's approach follows two strategies. First, the DTC recognizes that the use of a single code base between research and operations facilitates seamless exchange between the two groups. In 2008 and 2009, the DTC worked with EMC to merge the components of the operational HWRF onto Community codes. Since March 2010, the DTC has been providing code management and user support for the community HWRF. There are currently over 600 registered HWRF users from around the globe, who benefit from a web portal for code downloads, access to documentation and datasets, online tutorial, and a helpdesk.

The second strategy is to conduct testing and evaluation to assess new research that has potential for transition to operations. Over the last three years, the DTC has conducted numerous diagnostic activities, as well as evaluated several cumulus parameterizations, an alternate configuration for quantifying atmosphere-ocean fluxes, and an experimental physics suite with

an alternate microphysics and radiation parameterization. In this conference we will provide an overview of the work the DTC has done in the hurricane area in the last five years, present the services it provides to the community, and collect input about how it can best serve.

Testing and Evaluation of the GSI-Hybrid Data Assimilation and its Applications for HWRF at Developmental Testbed Center

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Numerous studies have found using a hybrid ensemble-variational (VAR) technique in a data assimilation (DA) system may impose positive impacts on weather forecasts by incorporating flow dependent background error information into a traditional VAR system. The Gridpoint Statistical Interpolation (GSI) based hybrid data assimilation system (GSI-hybrid) was primarily developed by National Centers for Environmental Prediction (NCEP) Environmental Model Center (EMC) and National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) and implemented operationally at NCEP for global applications in May 2012 and hurricane applications in June 2013. The Developmental Testbed Center (DTC), beginning in late 2011, is supporting and complementing these implementations and associated research studies through the sponsorship of the NOAA Hurricane Forecast Improvement Project (HFIP). Testing and evaluating the GSI-hybrid system, particularly for Hurricane Weather Research and Forecasting model (HWRF) applications, were performed in collaboration with code developers and researchers, including the ongoing construction of the community code framework for the GSI-hybrid system.

This paper will give a brief summary of the DTC data assimilation activities in recent years, investigating alternative configurations of the GSI-hybrid system and the potential for improvement of the system performance in a tropical storm environment. Highlights will be given of the ongoing work testing the GSI-hybrid system using HWRF ensembles versus global ensembles for the HWRF 3km inner domain data assimilation in selected high impact tropical cyclone cases. This paper will conclude with a discussion of lessons learned and potential directions for further studies.

The Development of COAMPS-TC, Transition to Navy Operations, and Future Plans

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The Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC) has been developed specifically for forecasting tropical cyclone track, structure, and intensity over the past five years. In this presentation, we will provide an overview on the development and performance of COAMPS-TC during this five year period, as well as the transition of the system to Navy operations at the Fleet Numerical Meteorology and Oceanography Center in 2013. The COAMPS-TC has been tested in real time in both coupled and uncoupled modes over the past five tropical cyclone seasons in the Pacific and Atlantic basins at a horizontal resolution of 5 km. The real-time testing has been motivated by several recent multi-agency programs and efforts: i) the Hurricane Forecast Improvement Project (HFIP), which is focused on the W. Atlantic and E. Pacific basins, ii) the recent NASA HS3 program, and iii) pre-operational testing of COAMPS-TC in W. Atlantic and W. Pacific basin. An evaluation of a large sample of real time forecasts for 2010-2013 in the Atlantic basin reveals that the COAMPS-TC intensity predictions have intensity errors on par or better than many of the established real-time dynamical forecast models.

As an example, real-time forecasts for Hurricane Sandy (2012) illustrate the capability of COAMPS-TC to capture the track, intensity and the fine-scale features in close agreement with observations. Observation impact experiments highlight the importance of satellite-derived atmospheric motion vectors for accurate forecasts of Hurricane Sandy. Additionally, evaluation of real-time COAMPS-TC forecasts will be presented with a focus on challenges and successes related to tropical cyclone intensity prediction. Recent results for a high-resolution (3 km) COAMPS-TC ensemble that was run over the W. Atlantic basins will be discussed as well. The results of this research highlight the promise of high-resolution deterministic and ensemble-based approaches for tropical cyclone prediction using COAMPS-TC.

Oceanography Center in 2013. The COAMPS-TC has been tested in real time in both coupled and uncoupled modes over the past five tropical cyclone seasons in the Pacific and Atlantic basins at a horizontal resolution of 5 km. The real-time testing has been motivated by several recent multi-agency programs and efforts: i) the Hurricane Forecast Improvement Project (HFIP), which is focused on the W. Atlantic and E. Pacific basins, ii) the recent NASA HS3 program, and iii) pre-operational testing of COAMPS-TC in W. Atlantic and W. Pacific basin. An evaluation of a large sample of real time forecasts for 2010-2013 in the Atlantic basin reveals that the COAMPS-TC intensity predictions have intensity errors on par or better than many of the established real-time dynamical forecast models.

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Session 3a
Tropical Cyclone
Observations and
Observation Applications,
Part 1

Hurricane and Severe Storm Sentinel (HS3): Results from the 2013 deployment

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The NASA Earth Venture (EV-1) Hurricane and Severe Storm Sentinel (HS3) campaign for 2013 (the second of three campaigns) took place between Aug. 20-Sept. 23. HS3 had two of NASA's unmanned Global Hawk (GH) aircraft to study Atlantic hurricanes during the deployment at the Wallops Flight Facility in Virginia. The goal of the mission is to improve understanding of the processes that control hurricane formation and intensity change and to determine better the relative roles of the large-scale environment and smaller-scale processes in the inner-core region of storms (i.e., the eyewall and rainbands). One GH (Air Vehicle 6 or AV-6, designated the environmental GH) is designed to sample temperature, humidity, winds, and Saharan dust in the storm environment while the other (AV-1, designated the over-storm GH) is focused on measuring winds and precipitation within the storm.

During the 2013 deployment, HS3 conducted seven flights of the environmental GH and two of the over-storm GH. The first flight (Aug. 20-21, AV-6) was over the remnants of Tropical Storm (TS) Erin, which had dissipated two days prior to flight. The dropsonde system lost power shortly after getting on-station, but S-HIS and CPL obtained information on the movement of a major Saharan Air Layer (SAL) outbreak over the low-level remnants of Erin. On Aug. 24-25, AV-6 obtained detailed measurements of another intense SAL outbreak. The next four flights (3 with AV-6, 1 with AV-1) over the period of Aug. 29-Sept. 8 examined the pre-Garbrielle disturbance, its formation into a TS, and its later potential for redevelopment. An AV-1 flight on Sept. 15-16 obtained two overpasses of Hurricane Ingrid in the Gulf of Mexico before low fuel temperatures required a return to base. A Sept. 16-17 AV-6 flight examined the reformation of TS Humberto, revealing a hybrid tropical/extratropical storm structure. The final science flight, on Sept. 19-20, used AV-6 to examine the potential genesis of a disturbance in the Gulf of Mexico. Ultimately this storm failed to develop and the HS3 data should provide valuable information on the factors that prevented genesis.

The Global Hawk operations included the first deployment of both Global Hawks, the first use of the Wallops GH Operations Center (known as GHOC-East), and the first back-to-back flights. HS3 even proved that back-to-back-to-back flights are possible. All of the instruments performed extremely well and HS3 set a record for sondes dropped in one flight (88) and dropped a total of 439 sondes. HS3 flew approximately 273 flight hours.

The third and final HS3 campaign is currently scheduled for approximately August 25-September 29, 2014.

HIWRAP Global Hawk Status and Future Plans

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The High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is a dual-frequency (Ka- and Ku-band), dual-beam (30^0 and 40^0 incidence angle), conical scan, solid-state transmitter-based system, that flies on the high-altitude (20 km) Global Hawk UAV. HIWRAP images the winds through volume backscattering from clouds and precipitation, enabling it to measure the tropospheric winds above heavy rain at high levels. It measures ocean surface backscatter from which ocean surface winds can be derived through scatterometry techniques similar to QuikScat. These measurements from higher altitudes above storms provide higher spatial and temporal resolution than obtained by current satellites and lower-altitude instrumented aircraft. HIWRAP flew its first science flights on the Global Hawk AV-6 during the Genesis and Rapid Intensification Processes (GRIP) campaign conducted during the 2010 hurricane season, and then again on AV-1 during a test flight in November 2012 and during the 2013 Hurricane Severe Storm Sentinel (HS3) program based at NASA Wallops Flight Facility.

We will report on the status of processing and wind retrieval algorithms, current and future instrument upgrades, and overall performance of the system. We will present preliminary data from 3 flights during the 2013 season mostly from precipitation regions since we did not fly over any active storms. On the return flight to NASA Dryden on 25 September 2013, AV-1 flew coordinated flights off the coast of Florida with NOAA 43 with IWRAP installed. The purpose of this coordination was intercomparison of HIWRAP and IWRAP surface winds, and profiling capability in precipitation. This analysis is still in very early stages and will be discussed as much as possible.

HIWRAP observations from the Hurricane and Severe Sentinel (HS3) campaign: Comparing retrieval techniques

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The High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is a dual-beam, dual-frequency, Doppler radar system designed for operation on board the Global Hawk aircraft unmanned aircraft system. The HIWRAP radar system recently obtained observations of Hurricane Ingrid during the 2013 Hurricane and Severe Storm Sentinel (HS3) field campaign. The antennas of HIWRAP point downward and scan conically at two different tilt angles. This scanning geometry, which is unlike previous airborne radar systems, presents unique challenges to retrieving the full three-dimensional wind field. We present observations from the HS3 field

campaign using two dual-Doppler retrieval techniques that were specifically modified for the HIWRAP geometry.

The first technique is a coplanar retrieval method that solves for the wind field in a cylindrical coordinate system natural to the radar's scanning geometry. Utilizing scans pointing fore and aft along coplanar beams, two wind components are calculated while the third wind component is retrieved using mass continuity and boundary conditions in the nadir plane and at the surface. The second technique is a global optimization approach that minimizes the difference between radar-measured and retrieved velocity components while approximately adhering to mass continuity and boundary conditions at nadir and at the surface.

Each technique was first tested using a radar-scanning simulator on model output in a hurricane environment. A comparison of the retrieved and true velocities revealed low errors throughout most of the field. This application also highlighted relative strengths and weaknesses for each method. The coplanar method performed well with all wind components near the nadir plane, while the optimization method was more capable near the surface and near the domain edges. Results from the HS3 observations show that both techniques retrieved a realistic wind field that documents the outer regions of Hurricane Ingrid. The observed features contain kinematic structures that are consistent with previous modeling and observational studies. The coplanar method performs well at capturing convective-scale structures, while the optimization method appears to be less sensitive to noise and other measurement errors in the radar data.

Ensemble Kalman Filter Assimilation of HIWRAP Observations of Hurricane Karl (2010) from the Unmanned Global Hawk Aircraft

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This is a pilot study that utilizes an ensemble Kalman filter (EnKF) to assess the impact of assimilating observations of Hurricane Karl from the High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP). HIWRAP is a new Doppler radar onboard the NASA Global Hawk unmanned airborne system, which has the benefit of a 24-26-h flight duration, two to three times that of a conventional aircraft. The observations were taken during NASA's Genesis and Rapid Intensification Processes (GRIP) field campaign in 2010. Observations considered are Doppler velocity (Vr), and Doppler-derived VAD wind profiles (VWP). Karl is the only hurricane to date for which coherent HIWRAP data is available, but a number of data problems required some innovative tactics for velocity assimilation.

Assimilation of either Vr or VWP has a positive impact on the EnKF analyses of Hurricane Karl, but the performance of assimilating Vr observations is considerably less accurate than a recent proof-of-concept study with simulated data. Likely causes for the discrepancy for the current

real-data case include the quality and coverage of the HIWRAP data collected for Karl and the presence of model error in this real-data situation. The results from the VWP-assimilating experiments are more promising. Using a number of different configurations, EnKF analyses assimilating VWP data showed better agreement with the observed hurricane in terms of the track, maximum intensity, and size. Vertical structure in the VWP-based analyses was also more realistic. The advantage of the VWP data is likely due to its ability to simultaneously constraint both components of the horizontal wind and circumventing reliance upon fall speed corrections and vertical velocity error covariance.

In summary, the results from this pilot analysis show that radar data from an unmanned aircraft can be useful for hurricane analysis and forecasting. Future work needs to develop an SO procedure for assimilating VWP data, which will likely improve results further. When HIWRAP data becomes available from other storms, the general applicability of these results should be tested, though preliminary analysis of assimilating HIWRAP VWP data from Tropical Storm Matthew (2010) has also been encouraging. Many of the problems associated with the early HIWRAP datasets have now been resolved, suggesting the data will be even more useful for assimilation in the future. The radar is being used for the HS3 field campaign, which will allow for further tests in the near future.

High Definition Sounding System (HDSS) for atmospheric profiling

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The HDSS deploys the eXpendable Digital Dropsonde (XDD), which measures atmospheric profiles of Pressure, Temperature, hUmidity (PTU), horizontal and vertical winds as well as Sea Surface Temperature (SST) via a new mini-InfraRed (IR) sensor. The XDD was developed for measurements in the Tropical Cyclone (TC) inner core and environment as well as in other high-impact weather events. This paper discusses validation aboard a Navy Twin Otter from 4 km, the NASA DC-8 from 12 km, and a NASA WB-57 from 18 km. The HDSS allows for rapid deployment of multiple sondes, with system design for data reception from up to 48 sondes simultaneously. In addition to conventional dropsonde sampling strategy presently being undertaken as part of the Hurricane and Severe Storms Sentinel (HS3) program, the HDSS opens up the possibility for a new TC sampling strategy from high-altitude aircraft, such as the NASA Global Hawk or WB-57 flying above the storm. This sampling strategy would involve seeding the TC with multiple sondes periodically, say at 6-, 12- or 24-hr synoptic times, and tracking the

data inputs for model assimilation in a Lagrangian frame of reference as the sondes dispersed throughout the storm's inner core and/or environment.

HDSS/ XDD validation was first undertaken in 2011 on two successive days off the California coast over offshore buoys. Observations from Twin Otter aircraft spiral descents from 4 km to 30 m altitude were compared to PTU, winds and IR SST measurements from 10 XDDs deployed simultaneously. The XDD profiles showed excellent agreement with those from the spirals as well as with 14 coincident NCAR/Vaisala RD-94 dropsonde PTU and wind profiles. Differences between successive XDD and RD-94 profiles due to true meteorological variability were on the same order as profile differences between the spirals, XDDs and RD-94s. Buoy SST and surface winds were within 0.5C and 1.5 m/s of the XDD measurements.

A second validation experiment was conducted from a NASA DC-8 flight in which six XDDs were intercompared against each other over the Eastern Pacific to the east of ex-TC Cosme (2013), southwest of Cabo San Lucas, Mexico. Good agreement was found between successive PTU and wind profiles as well as SST over a range of 10C. SSTs and surface winds again agreed well with two SVP drifting buoys, satellite-derived IR SSTs and satellite scatterometer-derived surface winds.

The third validation experiment was conducted from NASA WB-57 flights over the western Gulf of Mexico, just offshore from the Texas coast between Corpus Christi and Brownsville. For these flights, 16 XDDs were intercompared with National Weather Service (NWS) radiosonde soundings from Brownsville (BRO) and Corpus Christi (CRP). A north-south racetrack pattern was flown just offshore between BRO and CRP followed by an overflight of a mini-squall line system just to the east of the racetrack in which 8 sondes were deployed at 3-5 sec intervals. Onboard for- and aft-looking cameras documented sonde release as well as squall line overshooting turret structure. Slow-fall (12-18 m/s) and fast-fall (36-18 m/s) configurations were tested with the fast-falls showing superior agreement with the NWS soundings, especially between wind profiles on scales of 100-m from XDD fast-fall sondes.

Extreme Wave Height Reports from NDBC Buoys during Hurricane Sandy

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The National Weather Service's Hurricane Sandy Assessment documented:
> *Additionally, many EMs expressed surprise at the large and damaging waves Sandy caused. Of coastal residents surveyed after Sandy, 77 percent described the impact of waves as more than they expected (Gladwin, Morrow & Lazo, 2013).*

> *Even small to moderate storm surges can cause life-threatening and damaging conditions because of severe coastal waves on top of surge.*

Similarly, the National Hurricane Center found:
> *Katrina had already generated large northward-propagating swells, leading to substantial wave setup along the northern Gulf coast, when it was at Category 4 and 5 strength during the 24 hours or so before landfall.*

In both cases, National Data Buoy Center (NDBC) buoy wave reports presaged the potential of wave setup to exacerbate the devastating effects of the oncoming storm surge. Radiation stress both raises and lowers the mean water level across the shore. Integrating the stress term, shows that the mean water level from setup and setdown is a function of wavelength, which is determined by the wave period or frequency and water depth) and the square of the wave height. Other factors to consider are the direction and spreading of the waves. All these parameters are available in the NDBC spectral wave reports, but the focus of this paper will be on the wave heights from the non-directional (or omnidirectional) spectrum.

Prior to Sandy's landfall, a number of buoys operated by the NDBC reported significant wave heights greater than 30 feet. Significant wave height represents the average of the highest one-third of the waves during the sampling period, and not the largest wave. NDBC's, and in fact most buoy measurements, estimate significant wave heights from the wave elevation spectrum derived from vertical accelerations of a moored buoy's hull. Nearly all NDBC acceleration measurements are made from strapped-down accelerometers. Strapped-down accelerometer measurements have drawbacks in a measuring the single highest wave. We examine those drawbacks and present estimations of maximum wave heights and confidences limits using the wave spectra and a Rayleigh distribution and an empirical distribution.

In extreme wave events, it has been found that small-hull, shallow-water measurements from a strapped-down accelerometer can lead to overestimation of wave heights (Bender *et al*., 2010). We present preliminary results of NDBC's approach to address this overestimation.

Progress on Upper Ocean Measurement Strategies During Hurricane Passage: AXCP and AXCTD Profiling

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Over the past five years, there have been few coupled ocean-atmosphere interaction measurement campaigns (Gustav and Ike in 2008; Isaac in 2012; Deep water Horizon (DwH) in 2010) conducted in the Atlantic Ocean basin from NOAA research aircraft. Such field experiments are crucial in assessing the ocean's role in modulating the enthalpy fluxes as well as the levels of the oceanic response for improving the coupled operational models. While there have been thermal measurements such as the AXBT demonstration project from the USAF WC-

130J during a few storms, current, temperature, and salinity profiles from expendable sensors such as current and temperature profilers (AXCPs) and conductivity, temperature and depth profilers (AXCTDs) have not been routinely made from the research aircraft. Over the past two decades, these measurements have been shown to be required in carefully assessing the various parameterization schemes in the oceanic component of the operational coupled models. One such parameterization is the vertical mixing process where several schemes have been reported in the literature. Proper parameterization of this wind-driven current shear process is crucial since it affects cooling and deepening of ocean surface mixed layer (and SST) and hence the ensuing enthalpy fluxes that impact intensity change. Additionally, gridded measurements provide the initial ocean state that may not be well resolved through satellite altimetry and sparse float measurements for proper ocean model initialization in the pre-storm state.

Based on a recent OSSE study by Halliwell and colleagues using airborne profiler measurements acquired during DwH in the Loop Current and Eddy Franklin in 2010, which traditionally have deeper and warm mixed layers even under quiescent conditions, shallow AXBTs to 350-m depth were shown not to be enough to resolve the pre-existing deep ocean structures to ~1000-m depths. That is, deeper measurements are critical to initialize ocean models and calibrate sea surface height anomalies from radar altimetry in deriving isotherm depths and oceanic heat content variability. Since the research aircraft are already acquiring atmospheric measurements from both *in-situ* and remote sensors, more resources are needed to acquire these deeper oceanographic profiles. The benefits of simultaneously deploying combinations of AXCP/AXCTD profilers and Global Position System sondes deployments in the SFMR derived surface wind footprint outweigh the sensor costs and have been shown to be invaluable for coupled modeling efforts. There is clearly a significant potential for improved ocean model initializations and parameterizations implemented in the forecast models with these tools. Thus, the 3-D measurements of the mutual responses must be captured by the coupled model strategy at National Centers aimed at improved operational forecasts of weakening and deepening cycles of hurricanes.

The AXBT Demonstration Project: Implementation, Impact, Collaboration, and Outlook

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In 2011 the Working Group for Hurricane and Winter Storms Operations and Research approved a multi-year AXBT Demonstration Project to assess whether the collection of upper-ocean temperature observations during operational tropical cyclone (TC) reconnaissance missions could improve coupled numerical model forecasts of TC track and intensity. Results from the first three seasons, in which over 450 AXBTs were deployed during more than 40 operational U.S. Air Force 53rd Weather Reconnaissance Squadron missions, included the following: successful near-real time assimilation of upper-ocean temperature observations, increased accuracy of the upper-ocean thermal structure in ocean model analyses, significant error

reduction in upper-ocean temperature forecasts, improved TC track and intensity forecasts in a coupled dynamical model, and identification of intensity forecast uncertainty in the leading statistical model. Effective collaborations have been established across a dozen operational and research organizations and agencies, thereby leveraging scarce resources to conduct operations and evaluate skill improvement through adjoint analysis and data-denial studies. Looking ahead, additional cases are needed to evaluate the consistency of the improvements noted to date and to assess the value of these observations to TC track and intensity forecasts, particularly during major hurricanes. Over the next three years, the AXBT Demonstration Project is focused on continued data collection and model evaluation, development of an optimal ocean sensing strategy, equipment modernization, and a potential transition to operations.

Upper-Ocean Thermal Structure Variability during Hurricanes Ernesto and Isaac (2012)

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More than 200 Airborne eXpendable BathyThermographs (AXBTs) were deployed from U.S. Air Force Reserve 53rd Weather Reconnaissance Squadron WC-130Js during 19 operational tropical cyclone (TC) reconnaissance missions in Hurricanes Ernesto and Isaac in August 2012. As part of the AXBT Demonstration Project to improve coupled model forecasts of TC track and intensity, these AXBT observations were processed onboard the aircraft and transmitted to numerical modeling centers worldwide in near-real time. Here, the upper-ocean thermal structure within these observations is analyzed and compared to a gridded 1° x 1° vertical temperature profile climatology created for the Gulf of Mexico, western Atlantic Ocean and Caribbean Sea from historical observations archived in the Master Oceanographic Observation Data Set (MOODS). Large sub-surface variances within the climatology clearly outline regions where AXBT observations may improve the initialization of the ocean within coupled models, and therefore also identify targeted observation locations for potential AXBT deployments during future operational weather reconnaissance missions. To highlight this potential targeting framework, AXBT observations from Hurricane Isaac are compared to ocean temperature forecast error reduction noted through an adjoint analysis of the COAMPS-TC coupled model.

Impact of AXBT ocean observations on the COAMPS prediction of Tropical Cyclones

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The impact of an operational demonstration program using ocean temperature profile observations from Airborne eXpendable Bathy Thermographs (AXBTs) deployed during TC reconnaissance flights on the prediction of Tropical Cyclone (TC) atmosphere and ocean environment is studied using the air-ocean and air-ocean-wave Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclone (COAMPS-TC). Preliminary results from the AXBT data denial hindcast experiments on three 2011 Atlantic hurricanes show that the assimilation of the AXBT had the following effects: (i) increased model accuracy in upper-ocean temperatures, (ii) improved COAMPS TC track forecasts, and (iii) minor improvements in the TC forecast intensity. The AXBT impact was tested using COAMPS and HYbrid Coordinate Ocean Model (HYCOM) with a newly developed adjoint version of the NAVY Coupled Ocean Data Assimilation System (NCODA) on hurricane Isaac (2012). We will discuss these modeling results and progress toward obtaining an optimal AXBT sampling strategy for the initialization and validation of the coupled ocean component.

Session 3b
Tropical Cyclone Observations and Observation Applications, Part 2

Observing Upper Ocean Structure Changes in Hurricane Conditions using Profiling Glider Technology

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The development of ocean profiling gliders has allowed the collection of high density temperature and salinity profiles in hurricane conditions, at a much lower cost and higher resolution compared to traditional ship observations. This technology has proven its ability to operate through Typhoons in the Pacific since 2010. For the past two hurricane seasons in the Gulf of Mexico, greater than 97% data have been made available in real-time. Mission plans are coordinated in real-time with the modeling group at the Environmental Modeling Center (EMC) in the National Centers for Environmental Prediction to target specific features, and provide validation of satellite derived Ocean Heat Content in the Gulf of Mexico ensuring relevant information is collected. Measurements are quality controlled and distributed freely in real-time through the Global Telecommunication System (GTS) using the World Meteorological Organization (WMO) FM-64 code format. Also, flight information and graphic products in addition to observations are posted in real-time on the National Data Buoy Center's website. Observations are assimilated into the coupled Ocean-Hurricane model, HYCOM-HWRF at EMC.

Results from the 2012 & 2013 hurricane season, including the ocean mixing and water temperature cooling due to Hurricane Isaac (09L), will be shown. Additionally, examples of adaptive sampling for hurricanes and challenges of piloting profiling gliders will be covered.

Impact of simple parameterizations of coastal upper ocean heat content on modeled Hurricane Irene (2011) intensity

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In 2011, Hurricane Irene's intensity was over-predicted by several hurricane models (maximum sustained 10m winds and minimum sea level pressure) and over-forecast by the National Hurricane Center (NHC). The NHC final report on Irene lists possible factors leading to the consistent high bias in the official intensity forecasts (an incomplete eyewall replacement cycle while in an environment of relatively light wind shear and over the warm waters of the South Atlantic Bight) and even a high bias in the operational analysis of its intensity (deep central pressure and strong flight-level winds but comparatively low surface winds).

This paper investigates one potentially major control on Irene's intensity in its latest stages: the upper coastal ocean's impact in the hours before NJ landfall. Using buoy, satellite, and

underwater glider observations, we determine the magnitude, timing, and spatial structure of the surface ocean cooling in the Mid-Atlantic Bight. These observations indicate 4-6°C to as much as 11°C surface cooling occurring primarily ahead of the eye's passage, presumably under the first outer wind bands of Irene. Further, we combine temperature and depth-averaged current data from the glider with HF radar surface current measurements to attain physical understanding of the turbulent mixing occurring at the thermocline due to shear between strong onshore surface currents and opposing offshore bottom currents. These physical conclusions are confirmed with the Regional Ocean Modeling System (ROMS).

With this knowledge, we conduct a series of 110 simulations with the Weather Research and Forecasting-Advanced Research WRF (WRF-ARW) model to compare the sensitivity of Irene's intensity to 1) model setup [e.g. horizontal, vertical resolution; boundary conditions], 2) atmospheric physics [e.g. microphysics, planetary boundary layer scheme, radiation scheme], 3) Advanced Hurricane WRF options [e.g. parameterizations of air-sea fluxes, 1D ocean mixed layer model], and 4) sea surface temperature (SST). We find one of the largest sensitivities using satellite-observed cold post-storm SST (a new coldest dark pixel composite developed at Rutgers University) vs. fixed warm pre-storm SST (Real-Time Global High Resolution, RTG HR SST). This sensitivity totaled over 35 m/s in maximum sustained 10m winds and about 20 hPa in minimum sea level pressure across 13 hours of simulation (nearly 2.7 m/s and over 1.5 hPa each hour, respectively) while the storm was over the MAB and New York Harbor.

Future work includes comparing modeled heat fluxes to observed/derived fluxes, analysis of storm size and structure, improving model vortex spin-up issues by using a cycled initial condition approach, and eventually analysis with a fully-coupled WRF to ROMS system.

This work provides some evidence that a nested high-resolution ocean model (e.g. ROMS) within a larger scale ocean model could add significant value to tropical cyclone prediction in the coastal ocean—the last several hours before landfall.

The 2013 Satellite Proving Ground at the National Hurricane Center

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GOES-R is scheduled for launch in late 2015 and will contain a number of new instruments, including the 16-channel Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM). The GOES-R Proving Ground was established to provide forecasters with advance looks at GOES-R data and products using proxy information, and to obtain user

feedback for the product developers. Eleven GOES-R products were chosen for demonstration at NHC during most of the 2013 Hurricane Season (1 Aug to 30 Nov). Ten of the 11 were ABI products, comprising the Hurricane Intensity Estimate (HIE) four Red-Green-Blue (RBG) products designed to provide forecasters experience with image combinations, split window (10.8 and 12.0 µm) infrared imagery for tracking low to mid-level dry air, a tropical overshooting tops detection algorithm, two natural color products, and super-rapid scan operations imagery. The ninth was a combined GLM and ABI product to predict rapid intensity changes using global model fields, infrared imagery and lightning input. Spinning Enhanced Visible Infrared Imager (SEVIRI) data from Meteosat and the imager from the current GOES were used as proxies for the ABI and the ground-based Global Lightning Dataset 360 (GLD-360) was used as a proxy for the GLM. The 2013 Proving Ground was expanded to include the Day-Night band from the recently launched Suomi-NPP mission. Results from 2013 will be summarized along with plans for a follow-on experiment during the 2014 Hurricane Season.

DISCLAIMER: The views, opinions, and findings in this report are those of the authors and should not be construed as an official NOAA and/or U.S. Government position, policy, or decision.

Exploiting SNPP VIIRS Day Night Band (DNB) for Tropical Cyclone Monitoring

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Nighttime monitoring of tropical cyclones (TC) has been inherently limited by the reliance on infrared (IR) sensors since they typically have spatial poorer resolution than coincident visible imagers. These sensors also have difficulties in handling sheared storms where the low level circulation center (LLCC) becomes displaced from the mid to upper-level convection.   This difficulty arises when upper clouds mask viewing the LLCC below or when weak thermal contrast precludes adequate detection of the LLCC. The new Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar orbiting Platform (SNPP) contains the Day Night Band (DNB) which provides multiple unique attributes that can help mitigate night time viewing issues and thus complement the current suite of passive microwave sensors that lack the temporal and spatial sampling needed to fulfill the reconnaissance mission.

Night time visible imagery has been available for 30+ years via the Operational Linescan System (OLS) flown aboard the Defense Meteorological Satellite Program (DMSP), but suffers from several severe drawbacks: 1) lack of onboard calibration, 2) 6-bit digitization, 3) 2.7 km spatial resolution, and 4) poor geolocation. Thus, while NRL-MRY has displayed near real-time OLS night time visible products on their TC web page (http://www.nrlmry.navy.mil/TC.html), the real world utility has been quite limited due to the need to have nearly a full moon to establish enough lunar illumination while dealing with noisy and relatively coarse data. The SNPP VIIRS

DNB removes these hurdles by providing 1) full onboard calibration, 2) 14-bit digitization, 3) 740 m resolution, and 4) pointing accuracy on the order of 100 meters.

Having calibrated and highly digitized data has permitted NRL-MRY to develop and implement a lunar model to more fully exploit DNB data. The lunar model converts DNB radiances into top-of-the-atmosphere reflectances by taking into account the moon's phase, Sun/Earth/Moon geometric distance fluctuations, and the lunar zenith angle. Thus, instead of dealing with a highly variable lunar illumination of clouds from one image and one night to the next, a consistent reflectance product is created that can be used with improved accuracy both subjectively by satellite analysts as well as quantitatively by automated algorithms for multiple applications. In essence, the reflectance product significantly extends the time frame or number of days in the lunar cycle night time visible data can be used, since we can "correct" low lunar illumination values to appear as if they are occurring during full moon conditions.

Often, due to the thin nature of upper-level thin cirrus, DNB imagery can view beneath the cirrus canopy and view the LLCC below. In many other cases, DNB lunar corrected data can view LLCCs not detectable by coincident IR since the thermal contrast between the low level cloud tops and the background sea surface temperatures (SST) are marginal and feature extraction is difficult on a routine basis. Our efforts include the use of multi-channel red-green-blue (RGB) products that combine DNB with IR channels, thus leveraging the benefits of each channel to highlight both low and high clouds with details not feasible via viewing each channel by itself.

Demonstrations using the NRL-MRY TC web page have been ongoing for approximately one year and are assisted by the near real-time warning positions supplied by the National Hurricane Center (Miami, FL), the Joint Typhoon Warning Center (JTWC, Pearl Harbor, HI) and the Central Pacific Hurricane Center, (Honolulu, HI). This effort was only possible due to our close collaboration with the Fleet Numerical Meteorology and Oceanography Center (FNMOC) that supplies near real-time global VIIRS digital data and coordination with the Automated Tropical Cyclone Forecasting system (ATCF). Examples showing DNB lunar corrected TC and multi-channel DNB and IR products will be highlighted to illustrate the potential VIIRS has in assisting the night time monitoring of global TC location and structure.

Satellite-Derived Oceanic Heat Content Estimates in the North Pacific Ocean Basin For Typhoon Intensity Forecasts: ST Haiyan

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The Systematically merged Pacific Ocean Regional Temperature and Salinity (SPORTS) climatology was developed to estimate Ocean Heat Content (OHC) for the Northern Pacific Basin. A technique similar to the creation of the Systematically Merged Atlantic Regional

Temperature and Salinity (SMARTS) climatology was used to blend temperature and salinity fields from the Generalized Digital Environment Model (GDEM) and World Ocean Atlas 2001 (WOA) at a 1/4º resolution. A 15-day running average was applied to the monthly GDEM and WOA climatologies to eliminate discontinuities when transitioning between months. The appropriate weighting for the blending of these two climatologies was estimated by minimizing the residual covariances across the basin and accounting for drift velocities associated with eddy variability using a series of 3-year sea surface height anomalies (SSHA) to insure continuity between the periods of differing altimeters. In addition to producing daily estimates of the 20º and 26°C isotherm depths (and their mean ratios), mixed layer depths, reduced gravities, and OHC, the SSHA surface height anomalies product includes mapping errors given the differing repeat tracks from the altimeters and sensor uncertainties. This is especially important across the eddy-rich regime in the western Pacific Ocean.

Using SPORTS in concert with satellite-derived SST and SSHA fields from radar altimetry, daily OHC has been estimated from 2000 to 2011 using a two-layer model approach. Argo-floats, expendable probes from ships and aircraft, long-term moorings from the TAO array, and drifters provide approximately 267,540 quality controlled *in-situ* thermal profiles to assess uncertainty in estimates from SPORTS and satellite-derived products. From 3 to 12 Nov 2013, typhoon Haiyan rapidly intensified to a super typhoon (ST) status along the northern perimeter of the western Pacific warm pool where OHC variations from SPORTS exceeded 100 kJ cm^{-2}. During its passage, several ARGO floats provided both pre and post temperature measurements to as deep as 1000 m close to the best track. In addition, Haiyan made a direct hit on a NOAA TAO buoy located at 8°N, 137°E where temperature, salinity and current measurements were also acquired as the typhoon was intensifying to ST status. These data along with a satellite fields derived from SPORTS climatology are used to document the levels of ocean response and presumed warming in the thermocline in the western Pacific warm pool prior to the Haiyan's passage.

*Presenter

Forecasting Flossie, a Look at Using the Most Progressive Satellite Technology

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On Sunday, July 26, 2013, Tropical Storm (TS) Flossie was bearing down on Hawaii's Big Island with landfall expected Monday morning. As TS Flossie moved closer to landfall Sunday night it entered into increasing atmospheric shear. Because the usefulness of the geostationary satellite imagery was limited even with the use of infrared channels, including the fog product, identifying the center position was going to be difficult unless the most progressive satellite technology was available. This meant using sensors mounted on the polar orbiters. Fortunately,

the Central Pacific Hurricane Center/Honolulu Weather Forecast Office (CPHC/HFO) was participating in the GOES-R proving ground and had access to the night-visible imagery from the Visible Infrared Imager Radiometer Suite (VIIRS) located on the Suomi National Polar-orbiting Partnership (NPP) spacecraft. Because of the availability of the night-visible imagery early Monday morning, the Hurricane Specialist forecasting TS Flossie was confident making a crucial change to the track forecast. The change in this track allowed emergency management to adjust their preparations, refocus the locations of their resources and stand-down in areas where resources were already deployed. The participation in determining research priorities and transitioning research to operations allowed CPHC/HFO to use the most progressive satellite technology in a forecasting environment while providing feedback to the research community. This talk will show how the latest technology has been incorporated into operations through an example of a critical forecast time for TS Flossie.

Sensing Hazards with Operational Unmanned Technology (SHOUT) to Mitigate the Risk of Satellite Observing Gaps

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Environmental data from satellites have become critically important to the delivery of accurate weather forecasts for the nation. This criticality has become so significant that potential gaps in satellite environmental observations are expected to diminish the quality of the nation's weather services and reduce the effectiveness of emergency preparations for high impact weather events. The National Weather Service (NWS) is now assimilating vertical atmospheric temperature and moisture profiles from the National Polar-orbiting Partnership (NPP) satellite into the NWS operational global forecast models. Thus, any future problems with NPP data delivery or delays in launching the NPP follow-on satellites (i.e. Joint Polar Satellite System (JPSS)) will create vulnerability for the nation's weather services. To offset this threat, the U.S. Congress included $111 million in the Disaster Relief Appropriations (DRA) Act of 2013 to test and evaluate options to mitigate the risk of potential polar-orbiting environmental satellite observing gaps.

One activity funded by the DRA Act is the development and testing of a targeted observations project using unmanned aircraft systems (UAS) to collect vertical atmospheric observations and other crucial environmental information to assist weather predictions of high impact weather. This NOAA project entitled "Sensing Hazards with Operational Unmanned Technology (SHOUT)" is a partnership with NASA to evaluate the science impact and feasibility of a Global Hawk UAS to mitigate the risk of satellite observing gaps for weather prediction of high impact events. NASA and NOAA have previously demonstrated that Global Hawk UAS can overfly storms in the Atlantic, Pacific, and Arctic Oceans and deliver real-time vertical atmospheric profiles and environmental data to scientists. NASA Global Hawk UAS payloads have included infrared and microwave sounders similar to the Cross-track Infrared Sounder (CrIS) and the

Advanced Technology Microwave Sounder (ATMS) flown on NPP to provide vertical atmospheric profiles of temperature and moisture for the NWS. CrIS and ATMS data are currently assimilated in the operational NCEP Global Forecast System. Environmental information collected by a UAS cannot completely replace the global coverage of a satellite data. However, the long endurance and long range of a Global Hawk UAS does provide new capabilities to reach and stay with high impact oceanic weather events that previously were best observed by satellite. Additionally, NASA is testing new radar and lidar systems designed to observe vertical wind profiles from a UAS. These new observing capabilities may improve high impact weather forecasts even further by providing a valuable augmentation to satellite environmental observations that currently do not include wind profile information.

Session 4
Tropical Cyclone
Numerical Modeling
Initiatives

Evaluation of Experimental Models for Tropical Cyclone Forecasting in Support of the NOAA Hurricane Forecast Improvement Project (HFIP)

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The Tropical Cyclone Modeling Team (TCMT) in NCAR's Joint Numerical Testbed Program (JNTP) focuses on the evaluation of experimental forecasts of tropical cyclones (TCs). The TCMT contributes directly to progress in the Hurricane Forecast Improvement Project (HFIP) through independent and consistent evaluations of research and operational model forecasts of TCs. Activities of the team include the development of new verification methods and tools for TC forecasts, and the design and implementation of diagnostic verification experiments to evaluate the performance of TC forecast models. For HFIP, the TCMT has designed and conducted verification studies involving various regional, global forecast models, and statistical models that participate in the annual HFIP retrospective and real-time forecast demonstration studies. The TCMT has also developed new statistical approaches that provide statistically meaningful diagnostic evaluations of TC forecasts, including methods that examine the forecast performance of the new forecasting systems in comparison to the highest-performing modeling systems that are currently available, and as contributors to consensus forecasts. The TCMT has evaluated experimental forecasts of TCs for the past three hurricane seasons for tropical storms observed in the North Atlantic and Eastern Pacific Ocean basins. In particular, the TCMT has evaluated TC forecasts of track and intensity against a variety of operational and HFIP baselines to quantify the performance of the experimental models for the past three years. This presentation will provide an overview of the evaluation methodology and summary experimental tropical cyclone forecast performance in support of HFIP for the 2010-2013 hurricane seasons.

Significant Improvements in Hurricane Intensity Forecasts from NCEP/EMC Operational High-Resolution HWRF Modeling System

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The 2013 version of atmosphere-ocean coupled operational Hurricane Weather Research and Forecast (HWRF) modeling system developed at the Environmental Modeling Center (EMC) of National Centers for Environmental Prediction (NCEP) demonstrated significant improvements in hurricane intensity forecast skill compared to other statistical or dynamical guidance available for forecasters at the NHC and the JTWC. This leap-step advancement is a result of implementation of regional hybrid data assimilation system that includes assimilation of real-time Tail Doppler Radar (TDR) data from NOAA-P3 aircraft reconnaissance, along with many other significant upgrades. Track forecast skills from HWRF were also found comparable with highly skillful NCEP Global Forecast System (GFS). This talk will focus on describing the progress accomplished at NCEP/EMC in advancing the high-resolution hurricane modeling capabilities through an unprecedented retrospective testing and evaluation of model upgrades using HFIP's dedicated computing facilities in Boulder.

This presentation will also provide highlights on the performance of the operational HWRF model for other oceanic basins including North Western Pacific and North Indian Ocean regions. 2013 typhoon season was dominated by strong storms with several rapid intensification (RI) events, and the HWRF model guidance for these storms is quite impressive with more than 23% POD and very little FAR. Starting in January 2014, HWRF team at EMC started providing real-time forecasts for the Southern Hemispheric oceanic basins (Southern Pacific and Southern Indian) as well, making the HWRF model unique global tropical cyclone model for operational needs.

Ongoing model development plans for 2014 HWRF implementation include increased vertical resolution, assimilation of more inner core observations (especially from dropsondes), addition of satellite data, and more advanced physics options for land surface (NOAA-LSM), radiation (RRTM-G) and microphysics (Ferrier-Aligo high-res MP) apart from coupling to more advanced high-resolution (1/12 degree) POM model with uniform trans-Atlantic domain configuration and 3-D ocean for the Eastern Pacific basin. Results from pre-implementation retrospective tests will be presented at this conference.

The physics suite upgrades of the operational HWRF model for 2014 implementation

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Based on HFIP stream 2 physics experiments and external community collaborations, the hurricane team at EMC has identified several areas for upgrading the physics suite of the operational HWRF model for 2014 implementation. In particular, the GFDL land surface model (LSM) will be upgraded to NOAH LSM, the GFDL LW/SW radiation scheme is replaced with the RRTM-G and the Ferrier microphysics scheme will be modified by adding multiple-species advection and high-resolution related changes. The diagnostics results have shown that GFDL slab LSM model and GFSL radiation schemes had problems with cold bias over the land and cloud-radiation interaction, respectively. Although those GFDL schemes are computationally efficient, the scientific deficiencies may cause degradation of model performance. The plans to upgrade the LSM, radiation and microphysics schemes in HWRF will be laid out along with detailed description of results from the HWRF pre-implementation retrospective tests will be presented in this talk.

Real-Time HWRF Forecasts for the Joint Typhoon Warning Center

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In the past few years, the HWRF model has become one of the most skillful hurricane forecasting models, greatly benefiting the National Hurricane Center (NHC) forecasting ability. Based on this success, and with the support from NOAA's Hurricane Forecast Improvement Project (HFIP), the HWRF team at EMC has expanded the scope of the NCEP Operational HWRF model for other tropical oceanic basins for which the Joint Typhoon Warning Center (JTWC) is responsible for providing official forecasts. Starting with the 2012 typhoon season, using dedicated resources on HFIP R&D supercomputing (Jet machines in Boulder), the HWRF team started running an experimental HWRF model in the West Pacific (WP), Indian Ocean (IO), and Central Pacific (CP) west of 140E, providing real-time forecasts to the JTWC. Despite being run on unreliable research machines, through the use of a mesh network and backup machines, we are able to deliver real-time HWRF forecasts for all tropical cyclones in the Northern Hemisphere in a very tight operational forecasting windows, and have attained a reasonable reliability (about 90%) and a high forecasting skill, comparable to or better than any other regional dynamical or statistical models operating in those oceanic basins. Starting in January 2014, further expansion of the HWRF capabilities allowed us to provide experimental real-time guidance for the tropical cyclones of the Southern Hemisphere, bridging the gap in providing useful guidance to JTWC for all areas of their responsibility. We believe the value of this model, and its reliability in the face of hardship, makes a case for transitioning the WP/CP/IO/SH HWRF to operations at NCEP or Navy, where a near-100% reliability can be achieved.

Experimental Real-Time Forecasts for the 2012-2013 North-Western Pacific Season with the NCEP Operational HWRF

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This study presents recent efforts of the Environmental Modeling Center (EMC) at National Centers for Environmental Prediction (NCEP) in implementing the operational Hurricane Weather Research and Forecast (HWRF) model for real-time typhoon forecasts in the North Western Pacific (WPAC) basin during the 2012-2013 seasons in support of operational forecasters at the Joint Typhoon Warning Center (JTWC). Evaluation of model performance for the 2012-2013 typhoon season shows that HWRF model outperformed other regional models in track forecast errors with the 3-day, 4-day and 5-day track errors of 120 nm, 180 nm, and 237 nm, respectively. Intensity forecasts also show better performance with the most significant performance achieved during the first 24-h owing to better vortex initialization. In particular, performance of the HWRF model during 2013 typhoon season demonstrates that HWRF has a promising capability not only

in track and intensify forecast skill as compared to the forecast guidance from a suite of other regional models used by JTWC but also several important aspects including the rapid intensification, and the consistent genesis.

Further stratification of the track and intensity forecast errors based on the storm initial intensity reveals that HWRF tends to under (over) estimate storm intensity for weak (strong) storms in the WPAC basin. Analyses of the horizontal distribution of track and intensity errors over the WPAC basin suggest that HWRF possesses a systematic negative intensity bias, slower movement, and right bias in the lower latitudes. At higher latitudes, HWRF showed positive intensity bias and faster storm movement. This appears to be related to underestimation of the dominant large-scale system associated with the Western Pacific Subtropical High, which renders weaker steering flows in this basin.

Application of Coupled HWRF-HYCOM System for the Northwestern Pacific Typhoon Prediction

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After being implemented in 2012, real-time experiments of tropical cyclone prediction for the Northwestern Pacific (WPAC) basin have been conducted using coupled Hurricane Weather Research Forecast model (HWRF) and HYbrid Coordinate Ocean Model (HYCOM) during the 2013 season. This HWRF-HYCOM system bases on the same operational version of the HWRF model that has provided real-time forecast guidance to the Joint Typhoon Warning Center since 2012. The ocean model component is configured to one-way nesting to the NCEP (National Centers for Environment Prediction) Global RTOFS (Real-Time Ocean Forecast Systems). It solves the 3D primitive equations on the 1/12-degree and 32 hybrid layer resolutions at meso scales, the same as for Global RTOFS, using daily nowcast as initial conditions and hourly forecast products as boundary conditions. This study presents the 2012-2013 Typhoon forecasts (total 701 cases) and comparisons with uncoupled runs, all using the same atmospheric model initial and boundary conditions, and the model physical parameters, including the air-sea flux parameters. The results show that the track forecasts are almost no different, except that the coupled run corrects the southeastward track bias. Ocean coupling improves the mean intensity errors for longer forecast lead times, but it tends to have relatively weaker intensity, which is accounted for the negative feedback of sea surface temperature. Verifications of stratified storms suggest that the intensity improvement, particularly for Pmin bias, is primarily observed for strong TCs (Vmax $\geq$ 50 kt).

HWRF based Ensemble Prediction System Using Perturbations from GEFS and Stochastic Convective Trigger Function

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In this study, an ensemble prediction system (EPS) for the operational Hurricane Weather Research and Forecasting (HWRF) model at the Environmental Modeling Center (EMC) of National Centers for Environmental Prediction (NCEP) is introduced and evaluated. The suggested EPS takes into account two main sources of uncertainties related to the initial/boundary conditions and the model physics by 1) using the large scale flows from the EMC's Global Ensemble Forecast System (GEFS) to include uncertainty in the initial conditions as well as boundary conditions; and 2) stochastically perturbing the convective trigger function in the model cumulus convection parameterization scheme to capture model physics uncertainties.

The verification results demonstrate that the proposed HWRF EPS outperforms its deterministic versions at all lead times in terms of both track and intensity forecast errors. The statistical characteristics of the system are investigated and analyzed to ensure the effectiveness and robustness of the system. The 'climatological' distributions of the ensemble spread are compared with the 'climatological' forecast error for both track and intensity forecasts. It is found that the intensity ensemble spread is likely more useful as a predictor of forecast skill than the track ensemble spread because its 'climatological' distribution remains much different from the corresponding forecast error distribution than the track ensemble spread. The rank histogram analysis shows that the proposed system is well dispersed in both track and intensity forecasts except for the systematic errors inherited from the deterministic versions.

Further comparisons with top-flight model results in 2012 shows that in general the HWRF EPS track and intensity forecast skills are either statistically indistinguishable from or improved over that of the top-flight models.

Coastal Storm Modeling System (CSTORM-MS)

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The US Army Corps of Engineers' Engineer Research and Development Center's Coastal Storm Modeling System (CSTORM-MS) is a physics-based modeling capability for simulating tropical and extra-tropical storm, wind, wave, water level and coastal response (erosion, breaching, and accretion). Realistic coastal storm modeling requires the integration of several complex numerical models. The following models are currently part of the CSTORM-MS: a tropical planetary boundary layer model, MORPHOS-PBL, as an option for generating tropical wind and pressure fields; an ocean hydrodynamic model, ADCIRC, to generate the water level and currents fields; and both regional and nearshore ocean wave models, WAM and STWAVE, to generate the

wave fields, a nearshore hydrodynamic model, AdH with a sediment library, SEDLIB that includes a bed morphology model, C2SHORE. Components of this system have been used in numerous USACE site evaluation and FEMA flood map studies, including the Great Lakes region. The system is configurable and expandable, for example the cyclone wind model can be replaced with other meteorological wind fields as is the case in the Great Lakes region studies.

Recently the system has added the capability to use output data from NOAA's GFDL meteorology model. A presentation of ongoing research of using GFDL's ensemble forecast products to force the CSTORM models for surge and waves will be presented.

Verification Of Tropical Cyclone Genesis Prediction In A Suite Of Operational Global Numerical Weather Prediction Models

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The first step in developing any forecast tool is to define 'the forecast' and, perhaps more importantly, how it will be verified as "you're only as good as what your measure."

While there are many displays of model track forecasts for existing and/or forming tropical cyclone (TC), less attention has been given to how model storms, in either the initial conditions or that form during the integration, compare to both existing 'numbered' TCs and 'invest' systems that are the precursor to all TCs -- what I call 'pTCs' or pre/potential TCs.

A suite of six operational global numerical weather prediction (NWP) is evaluated for the northern Hemisphere TC season during the years 2009-2013: 1) NCEP Global Forecast System (GFS); 2) ECMWF HiRESolution (HRES); 3) CMC Global Deterministic Prediction System; 4) FNMOC NAVal Global Environmental Model (NAVGEM); 5) UKMO Unified Model; and 6) ESRL Finite-volume, flow-following, Icosahedral Model (FIM). The GFDL TC genesis tracker is run to output TC tracks from TCs in the initial conditions and TC system that form during the integration. In addition to TC tracks, I also calculate basin-wide, over-ocean precipitation both large-scale and convective to relate to under-over TC formation in the model.

Genesis is defined as time of the first advisory/warning issued by the operational US TC forecast agencies JTWC and NHC as these centers are required to issue advisory/warnings for all systems that are analyzed to be tropical cyclones regardless of initial intensity. Comparison of both types of model tracks to both TCs and pTCs is rather complex task that is essential to defining success and making products that have operational forecast utility.

Generally we find the models in the later part of the 2009-2013 period the models do forecast genesis well, but have differing degrees of false alarms or the spurious systems ('spuricanes'). The false alarm rate is positively correlated to the total basin-wide precipitation and negatively correlated to the ratio of convective to total precipitation (more resolved rain, more spuricanes)

This improvement in TC genesis skill over the last 5 years is undoubtedly 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 processes.   Product development that more directly supports the current 2- and 5-d NHC formation forecasts is another area needing further work.

New Challenges and Expectations of Dynamical Seasonal Prediction of Tropical Cyclones

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Seasonal prediction of hurricane activities in the north Atlantic basin has been shown to be remarkably skillful during 2001-2010 (Chen and Lin 2011). However, it has met its challenges since 2011. For the 2013 season, Atlantic hurricane activity was much quieter than most forecasting groups predicted. For the 2011 and 2012 seasons, many weak TCs formed, verifying TC number predictions, but only a few of them intensified into major hurricanes, a bust hurricane number prediction. After Hurricane Sandy's landfall near New Jersey and New York metropolitan area in 2012, the more challenging problem of assessing the probability of landfall events in a seasonal prediction has started to draw attention.

To address the above issues, a new version of Geophysical Fluid Dynamics Laboratory (GFDL) High-Resolution Atmospheric Model (HiRAM) is being developed. In Chen and Lin (2011, 2013), the 25-km GFDL HiRAM showed high prediction skill of Atlantic tropical storm counts in the 21 years since 1990, with a correlation of 0.94 between the observed and model predicted hurricane counts during 2000-2010. In the new generation of HiRAM, a non-hydrostatic option has been added, with improved microphysics and convection schemes, making the model more suitable for cloud-resolving simulations. With the finer vertical resolution and higher model top, the improved modeling system can now better resolve the upper troposphere and the stratosphere, thus improving the simulation of the tropical quasi-biennial oscillation (QBO) and Madden-Julian Oscillation (MJO), which may play important roles in the seasonal TC activities. The forecast skill of the new HiRAM for the past decade and recent seasons, using the persistent sea surface temperature (SST) assumption, will be presented.

Session 5
Research Priorities of the Operational Centers

Multi lead-time Statistical Rapid Intensification Guidance

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Predicting episodes of tropical cyclone rapid intensification (RI) remains one of the highest operational forecasting priorities of the National Hurricane Center (NHC). In recent years, a statistically based rapid intensification index (RII) that employs predictors from the SHIPS model has been developed for both the Atlantic and eastern North Pacific basins. The SHIPS-RII provides estimates of the likelihood of RI over the succeeding 24h utilizing linear discriminant analysis (Kaplan et al. 2010) and is currently employed as an operational forecasting tool by the NHC. Although the SHIPS-RII has generally been shown to be skillful, its utility has been somewhat limited since it was developed exclusively for a 24-h lead-time and its skill has tended to be on the low side particularly for systems in the Atlantic basin.

Thus, in an effort to improve the overall forecasting utility of the current operational SHIPS-RII, a number of model enhancements have been developed as part of a recently completed Joint Hurricane Testbed (JHT) project. First, ensemble-based versions of the RII that employ both the current SHIPS-discrimant RII as well as newly developed Bayesian and Logistic RI models (Rozoff and Kossin 2011) were derived for the current operational 24-h forecast lead-time as well as the added lead times of 12-h, 36-h, and 48-h to provide additional guidance during the critical watch and warning period that has been recently extended to 48-h by the NHC. Secondly, enhanced versions of the deterministic rapid intensity aid guidance that was developed by Sampson et al. (2011) were derived utilizing these new multiple lead-time ensemble-based RII models. Lastly, microwave imagery-based versions of the RII that have been shown to be capable of providing a more accurate measure of the overall inner-core tropical cyclone structure were also developed.

At the upcoming meeting, the results of our aforementioned efforts to develop both new multi lead-time ensemble-based RI models as well as enhanced versions of the rapid intensity aid guidance will be summarized. Additionally, a description of the new microwave-based RI models will be provided in a companion presentation that will be made by Rozoff et al. at the meeting.

Real-Time Verification of a Passive Microwave Imagery-Based Statistical Model of Tropical Cyclone Rapid Intensification

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Recent studies show promise in including passive microwave data from low-earth orbiting satellites in probabilistic forecasts of tropical cyclone rapid intensification (RI). Along these lines, we have developed microwave imagery-enhanced probabilistic RI forecast schemes for the northern Atlantic and eastern Pacific Ocean basins based on the logistic regression model. These models predict the probability of RI occurring in a 24-h period and include various RI thresholds (i.e., 25, 30, and 35 kt per 24 h period). Model predictors were derived from climatological data describing the storm's intensity trend, its environment, and structure. The structure predictors are obtained from global reanalysis data, satellite infrared imagery, and passive microwave data. The microwave predictors were developed from 19, 37, and 85 GHz passive microwave brightness temperatures from Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E), the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), and the DMSP Special Sensor Microwave/Imagers (SSM/I and SSMI/S) data for the period of 1998-2012.

Independent testing of the microwave imagery-enhanced logistic regression model in both the Atlantic and East Pacific Ocean basins shows that adding selected microwave-based predictors improves both the Brier skill score and reliability of forecasts significantly. As part of the Joint Hurricane Testbed project, we developed a real-time suite of these RI models. In this presentation, we will show how a real-time version of this model performed in the 2013 Atlantic and Eastern Pacific hurricane seasons. This evaluation is augmented with retrospective tests using real-time data from the 2008-2012 hurricane seasons. The real-time results show the improvements found in independent testing are, on the whole, maintained in the quasi-operational environment.

Finally, we will discuss ways in which this promising approach to RI forecasting can be further augmented. A path toward further advancements in RI prediction includes the use of a consensus of microwave imagery-enhanced empirical models, improved statistical models, and more sophisticated predictors from satellite passive microwave imagery.

Tropical Cyclone Genesis Ensemble Forecasts

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Tropical Cyclone (TC) genesis prediction is a super challenge work for the forecasters in operational centers. In the 2013 NOAA Seasonal Hurricane Outlook, Climate Prediction Center (CPC) predicted 13-20 Named Storms in Atlantic basin, but there are only 13 named storms in 2013 hurricane season. Since 2009, National Hurricane Center (NHC) has provided the Graphical

Tropical Weather Outlook to track hurricane genesis in Atlantic and East Pacific basins. Their subjective hurricane genesis probability forecasts are not very reliable.

TC genesis is closely related to large-scale environmental flows and mesoscale convection bursts. NWP model has lots of uncertainty in predicting environmental flows and local convections. The uncertainty could be revealed through the NWP ensemble forecast systems. In Environmental Modeling Center of NCEP, we have four global ensemble forecast systems, which are being run in National Center of Environmental Prediction (NCEP), Fleet Numerical Meteorology and Oceanography Center (FNMOC), Canadian Meteorology Center (CMC), European Center for Medium range Weather Forecasting (ECMWF). Since 2012, the Ensemble Team in EMC/NCEP has developed new products for 48 hours TC genesis probability forecasts based on the characteristic features of the vortices and their environmental flows in each ensemble forecast systems. The verifications for 2012 and 2013 hurricane seasons indicate this product provides promising guidance for TC genesis forecasts in operational centers such as National Hurricane Center (NHC) and Joint Typhoon Warning Center (JTWC). As the model resolution and physics get upgraded, and more observation data are assimilated in the forecast system, our ensemble forecasts for TC genesis will be significantly improved in the next five years.

Analysis tools for online evaluation of the operational hurricane forecasts using satellite data

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To achieve the HFIP goals of improving the forecast accuracy of hurricane intensity, track and impact at landfall we first need to understand whether the models properly reflect the physical processes and their interactions.   Some of the important questions to be answered are: Is the representation of the precipitation structure correct? Is the storm scale and asymmetry reflected properly? Is the environment captured correctly? Is the interaction between the storm and its environment represented accurately?

Such studies require the use of large amounts of satellite data, coming from diverse instruments in order to create robust statistics. Due to the complexity of the remote sensing data and the volume of the respective model forecast this in-depth evaluation is usually limited to a number of case studies.

With the goal to facilitate model evaluation that goes beyond the comparison of "Best Track" metrics, we are working on providing fusion of models and observations by bringing them together into a common system and developing online analysis and visualization tools.

To help support the HFIP objectives, this NASA/ESTO/AIST-funded project is developed in close collaboration with our colleagues from NOAA/EMC and NOAA/AOML/HRD to bring the operational and research versions of HWRF forecasts into the satellite database.

We will start by presenting how the operational HWRF forecasts are integrated.   In particular, we focus on projecting the model fields into the observational space.   For that purpose, we integrate the operationally-produced synthetic brightness temperatures (based on the use of CRTM and provided courtesy of EMC) with the brightness temperatures observed by a number of satellites (TMI, AMSR2, SSMI and SSMIS).

In addition, we are working on bringing into the system the synthetic brightness temperatures that are produced by a different satellite simulator (NEOS3) while still using the same HWRF input. By providing this alternative way of modeling the synthetic brightness temperatures, we aim at shedding light on the uncertainty that comes from the forward modeling itself, an uncertainty that is not well understood or even explored, even though it is rather significant.

A major focus of our efforts is to develop and implement a set of online analysis tools.   In this presentation we will describe our current system that allows the user to select a region of interest and to perform statistical analysis of the brightness temperatures inside that region.   Such an approach allows us to go beyond the point-to-point comparison and to obtain robust statistics that reflect important features of the storm structure and go beyond using only "Best Track" data for model evaluation.

Finally, we will outline our goals for the coming year, namely the development of additional analysis tools, the investigations of the impact of the microphysical assumptions and the incorporation of the basin-scale HWRF into our database of satellite observations.

Outer Vortex Wind Structure Changes during and following Tropical Cyclone Secondary Eyewall Formation in the Atlantic

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Some recent studies have utilized flight-level (700 mb) winds to document the maximum wind speeds (V_{max}) and radius of V_{max} (R_{max}) of the original and secondary eyewalls during 24 Atlantic hurricane eyewall replacement cycles (ERC).   In this study, Hurricane Wind (H*Wind) analyses of Atlantic hurricanes during 2003-2005 are utilized to document changes in the outer vortex surface wind profile beyond the secondary eyewall, with a focus on the radii of gale-force winds (R_{34})   that are often defined operationally as size changes.   In Mode 1, complete and partial ERCs in which the pre-, during-, and post-ERC outer wind profiles have approximately the same shape, the outward displacements of R_{max} leads to size (R_{34}) increases as much as 100 km.   Mode 2 ERCs are characterized by sharpened wind profiles outside the secondary eyewall that offset the larger R_{max} radii to produce only small R_{34} increases.   While statistically significant results are not obtained, the differences in size changes for Mode 1 and Mode 2 SEF cases suggest practical significance for forecasts and warnings.

MDL Research for Hurricane Storm Surge

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As a result of Sandy Supplemental Funding, MDL is now able to tackle some much needed enhancements to the Sea Lake and Overland Surges from Hurricanes (SLOSH) model suite of products. The SLOSH model is used for climatological, deterministic, and probabilistic prediction of storm surge induced by landfalling hurricanes, and is the workhorse behind MDL's suite of storm surge guidance products which include Probabilistic Storm Surge (P-Surge), and Extra Tropical Storm Surge (ETSS).

MDL's priorities for storm surge development reflect these three main areas: improving the SLOSH model, enhancing the P-Surge guidance, and upgrading ETSS capabilities. The improvements to the SLOSH model include improving our tide calculation and underlying basins, and allowing wind forcing to come from gridded wind fields, thereby improving storm tide guidance. The enhancements to the P-Surge guidance will increase the lead time, increase temporal resolution from guidance provided every 6 hours to every hour, and provide guidance for tropical storms in addition to hurricanes. Upgrades for ETSS guidance will provide improved guidance for Alaska, enable better data dissemination, and make progress toward probabilistic extra-tropical storm surge products.   These improvements will allow us to provide better storm surge guidance, whether it is a tropical or extra-tropical event.

Rapid Evaluation of Hurricane-driven Storm Surge using Pre-computed ADCIRC Solutions

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Accurate and efficient predictions of storm surge and wave conditions are critical for creating effective forecasts of tropical cyclone impacts.   However, accuracy often requires the use of complex, high resolution modeling systems, such as ADCIRC, that can be difficult and computationally demanding to operate.   While the use of these models has become standard in hindcast, risk assessment and design studies, resource requirements and time constraints have limited their use for forecasting thus far.

As a result of recent risk assessment studies (e.g., for the FEMA National Flood Insurance Program), a significant database of high resolution, surge and wave predictions could be

constructed for much of the US East and Gulf of Mexico coasts.   This could enable the construction of approximate surge and wave predictions from the existing solutions, as a complement to computing new dynamic model predictions, for forecast applications.   While a simple approach would be to select the closest match in the database to the forecast storm, such a procedure is ad hoc and does not make full use of the available information.   Instead, we have developed a second-order, moving least squares response surface method (RSM) that effectively interpolates between the storms in the database and computes both a predicted response and error statistics for the predicted result.

This RSM has been implemented using a 675-storm database of ADCIRC+SWAN surge and wave results for the North Carolina coast.   Calculations are very fast, (e.g., maximum surge / wave conditions are computed on a single processor in seconds), and take advantage of the underlying high resolution model simulations.   This methodology is highly amenable to a variety of applications, from scenario testing to the computation of large ensembles of storms as required for probabilistic surge and wave products.

Our talk with briefly explain the RSM methodology and present results for coastal North Carolina.

Session 6
Applications of Social Science to Tropical Cyclone Forecasts and Warnings

**Enhancing the Timeliness of Tropical Cyclone Watches and Warnings:
Issuance of Watches/Warnings Prior to Genesis**

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During the past decade the National Hurricane Center (NHC) has improved its service to
preparedness decision makers by increasing tropical cyclone watch and warning lead times, and
providing probabilistic tropical cyclone formation forecasts at longer lead times. These
particular enhancements provide emergency managers and the public with increased lead time to
properly prepare a community for the effects from a potential land-falling tropical cyclone.
When a tropical cyclone threatens the United States, the NHC typically issues tropical storm
watches and warnings 48 and 36 h, respectively, before the anticipated arrival of tropical-storm-
force winds. Current NWS policy, however, ties the issuance of watches and warnings to NHC
tropical cyclone advisory products, and as a consequence, no watches or warnings can be issued
before the cyclone forms and advisories are initiated. This means that when tropical cyclones
form very close to land, watches or warnings cannot always be issued with the desired lead time.

In order to provide decision makers and the public with more timely warnings when tropical
cyclones form near land, NHC is exploring the viability of issuing tropical cyclone watches and
warnings during the disturbance (pre-TC) stage of development. These watches/warnings would
be issued for systems that are expected to develop into a tropical storm or hurricane and affect
land within the standard watch/warning time periods. The watches and warnings would likely be
communicated using the NHC Tropical Weather Outlook and would <u>not</u> be accompanied by a
track, intensity, or wind radii forecast. NHC has performed an in-house experiment during the
last two seasons to test the concept of providing pre-TC track and intensity forecasts, but the
results do not support the public issuance of these forecasts at this time. Therefore, the NHC is
exploring and requesting feedback from key partners regarding the utility of issuing pre-TC
watches/warnings without an accompanying track and intensity forecast. NHC believes that pre-
TC watches and warnings would increase public awareness and response in these critical
situations, even if not accompanied by the standard suite of NHC tropical cyclone products.

**Progress over the past five years on a hurricane surge visualization model and future plans
to use the model to assess public understanding of risks due to storm surge**

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Storm surge from hurricanes can travel well inland in low-lying coastal areas. However, the vast
majority of the public is not aware of their exposure to this risk. Attempting to make the threat
of surge more understandable, an interactive website was developed over the past five years that

combines SLOSH estimated surge with elevation and tide data and then simulates the level of surge on photographs of a thousand landmarks throughout the 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. Multiple problems that were encountered in constructing this simulation will be discussed.

When development of the surge visualization model is completed, the effectiveness of our approach will be examined by surveying randomly selected members of the public. A home page will provide them with background information on hurricanes, background information on the project, information on how to use the model and a link to the model itself. Before accessing the visualization model, users will be directed to a survey that will assess their current understanding of storm surge as well as collect standard demographic data. Once the survey is completed, users will be connected to the model and allowed to navigate the model to any extent that they desire. Users will then be directed to another survey where their understanding of hurricane surge will again be addressed. Additionally, users will be probed for problems they encountered while using the model, suggestions for improvements to the model, and their understanding of uncertainties in hurricane prediction and model development will be assessed. Thus, we hope to determine specifically how their understanding has improved, as well as examine how their appreciation of the uncertainties has improved.

Longterm, we envision the public using the model while no hurricane is present to improve their understanding of hurricane surge while also assessing which areas are particularly vulnerable to surge. This will assist in land use planning, home construction and other uses. Also, the visualization model could easily be modified to incorporate the latest SLOSH projections to provide realtime surge estimates.

Improving Local Hurricane Forecast Communication

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Appropriate protective actions require that people understand the hazard risk associated with each hurricane threat. Acknowledging the role of communication in the forecast process, several organizations within NOAA have undertaken projects to improve hurricane forecast messaging. We report on work underway that is examining how hurricane forecast information is communicated from local National Weather Service offices. Specifically, we report findings from interviews and focus groups with emergency managers, broadcast meteorologists and

community leaders directed at improving specific products such as the Hurricane Local Statement and developing new ways to graphically present the hazards and potential local impacts associated with tropical cyclones.

Invited Talk

Real-Time Geospatial Sharing Between Agencies-An Update

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Since the last IHC held at this time in 2013 StormCenter's technology development regarding the real-time sharing of geospatial data in a collaborative environment has advanced further within NASA and NOAA. As a result of the Small Business Innovation Research (SBIR) Phase I & Phase II contracts through NASA, the Federal Government has determined that the geospatial data sharing capabilities and opportunities that the technology and approach delivers is not only 'unique' but 'profoundly valuable to the Federal Government.'

In recognition of the Federal Government-wide sole source nature of the SBIR contract, NOAA recently (September 2013) awarded StormCenter Communications a sole source SBIR Phase III five-year IDIQ contract. This contract vehicle now enables any line office within NOAA to task StormCenter with analysis of workflows and performance of any work relating to geospatial data sharing and collaboration between offices and agencies. Any Federal agency can implement the same IDIQ contract vehicle on a sole source basis with StormCenter for analysis and implementation of this technology which can accelerate the sharing of federal datasets for improved situational awareness and decision making. StormCenter's collaborative software enables the company to build unique Common Operating Pictures (COPs), upgrade existing COPs and connect disparate COPs in a secure collaborative environment. This technology will accelerate the sharing of geospatial information between agencies, states, counties, and others.

In September 2013, StormCenter was issued a task order by NWS to connect the NWS WFO in Sterling, VA to the Maryland Emergency Management Agency (MEMA). This geospatial collaboration will enable WFO Sterling to fuse NWS products directly into MEMA's existing COP within their Emergency Operations Center (EOC). Interactive map movement and highlighting combined with multiple layers of information delivered by NWS allows WFO Sterling meteorologists to provide improved Impact-Based Decision Support Services (IDSS) to the Emergency Management community. This technology offers an opportunity to enable geospatial data sharing for improved research, research to operations (R2O) and operations to research (O2R) results which feed back into the product improvement process.

Geospatial data sharing related to hurricane observation, modeling and forecasting could be shared to enhance multi-agency research and operational activities to improve situational awareness and decision making.