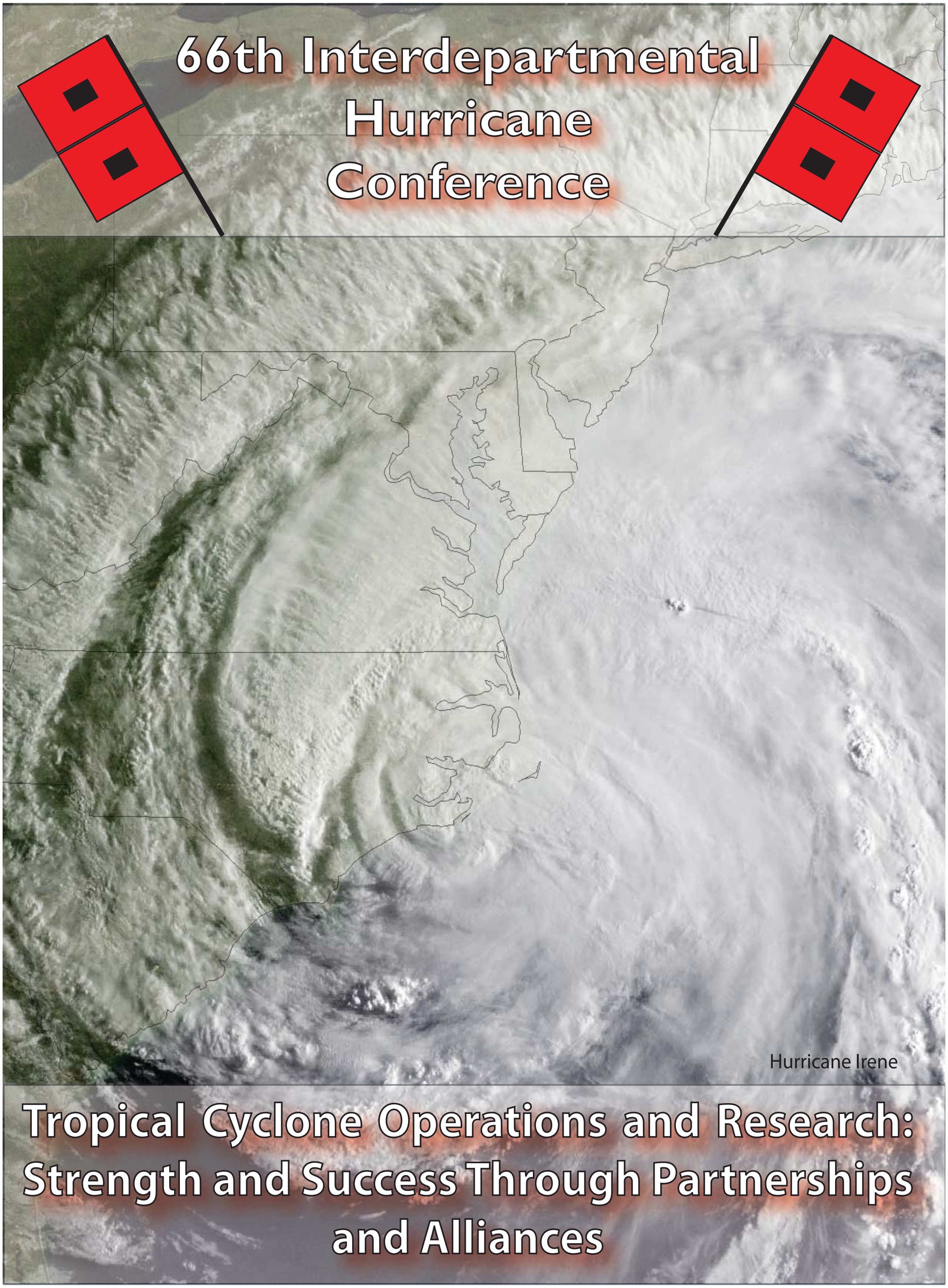
66th Interdepartmental Hurricane Conference



Tropical Cyclone Operations and Research: Strength and Success Through Partnerships and Alliances

City of Charleston

Joseph P. Riley, Jr.
Mayor

December 28, 2011

Dear Conference Attendees:

On behalf of the residents of the city of Charleston, I extend warmest greetings to each of you attending the 66th Interdepartmental Hurricane Conference. Charleston is keenly aware of the dangers of hurricanes and the important contributions the hurricane community is making to mitigate the impacts of these devastating storms and to protect the lives of those in harm's way. We are extremely pleased to host the return of this significant workshop, as it was also held in our beautiful city in 2004 and 2008.

While you are here, I hope you have an opportunity to enjoy our wonderful amenities and exquisitely preserved architecture in this extraordinary setting with its southern charm and grace. Our genteel town is as much about its people as it is about its history and sights. Complete strangers will smile and say "hello" as you visit our many attractions, port and great restaurants. You will know you are in a unique place from the minute you arrive.

The citizens of Charleston recognize the important work that you do for our city and the country. Thank you for the unique contributions you make to our safety, security, and preparedness. Again, we are very pleased to have all of you here and extend my very best wishes for a successful and enjoyable conference. Please come back again soon!

Most sincerely yours,

Joseph P. Riley, Jr.
Mayor, City of Charleston

JPR,jr./dm

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OFCM
OFFICE OF THE FEDERAL COORDINATOR
FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH
SUITE 1500, 8455 COLESVILLE ROAD
SILVER SPRING, MARYLAND 20910

March 5, 2012

Dear Colleagues,

Welcome to the 66th Interdepartmental Hurricane Conference! We are looking forward to a very productive and informative four days in the beautiful city of Charleston.

Last year we focused on the challenges and progress made on understanding the ocean and atmospheric influences on tropical cyclone predictions. This year we want to recognize the important role that partnerships and alliances contribute to the tropical cyclone operations and research communities. As part of the program, senior leaders will provide their invaluable perspectives on addressing critical challenges in these areas. This year's agenda also includes emphasis on storm surge and a special 2-part panel session on Thursday morning to address communications and social science issues and efforts.

Other topics at the conference include:

- The 2011 Hurricane/Typhoon Season in Review
- Joint Hurricane Testbed Project Updates
- Observations and Observing Strategies for Tropical Cyclones and its Environment
- Tropical Cyclone Model Development and Technology Transfer
- Other Research to Improve the Prediction of Tropical Cyclone Intensity and Structure, Track, Precipitation, and Coastal and Inland Inundation

Thank you for joining us this week in Charleston as we seek to enhance our ability to build a "Weather-Ready Nation" with focused efforts on improving our Nation's hurricane observing, forecasting, and warning system as we prepare for the upcoming tropical cyclone season and beyond. I hope you enjoy the conference and our great host city!

Sincerely,

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

Session 1a
2011 View of Working Group for Tropical Cyclone Research (WG/TCR)

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HFIP Real-Time Experimental Forecast System for 2012
Hurricane Forecast Improvement Program

Robert Gall[1], Fred Toepfer[1], Frank Marks[2], Ed Rappaport[3]
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The goals of HFIP include improving the numerical hurricane guidance to National Hurricane Center forecasters for both intensity and track by 20% in 5 years and 50% in ten years for all lead times. It also includes significantly improving the POD for rapid intensification events and extending current 5 day model-forecast skill to 7 days. To meet these goals, HFIP is organizing the US hurricane numerical prediction community to develop and implement the next-generation of numerical prediction techniques. This includes improved global and regional models, more capable data assimilation systems, better use of existing and planned aircraft and satellite data and advanced statistical post processing of model output to further increase in skill.

In 2011, HFIP ran a real-time experimental forecast system providing real-time experimental guidance to NHC, using HFIP funded computing resources in Boulder, CO. HFIP's current dedicated computing resource is a 16,000+ processor machine that is considerably larger than the current operational machine and will grow to 22,000+ processors by July this year. For the 2012 hurricane season, HFIP is planning an experimental forecast system using global models and global model ensembles running at twice today's operational resolution, and regional HWRF ensembles at 3 km along with a regional multi-model ensembles. Several statistical models will further process the model output for skill beyond that from the individual models. Results to date from the program show the 5 year goals immediately achievable and the 10 year goals within 5 years.

This talk will outline the program, show recent results, and outline the real-time forecast system to be run in the 2012 hurricane season.

Session 1b
The 2011 Tropical Cyclone Season in Review

The 2011 Atlantic Hurricane Season:
Only One U.S. Hurricane Landfall Despite Another Active Season

Stacy R. Stewart and Lixion A. Avila
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NOAA/NWS/National Hurricane Center

The 2011 Atlantic hurricane season another active year with 20 named storms, 8 of which became hurricanes and 3 of which reached major hurricane intensity. These totals are well above the long-term averages of 11 named storms, 6 hurricanes, and 2 major hurricanes. Although the 2011 season was somewhat busier than normal in terms of total number of named storms and hurricanes, only one hurricane struck the United States. Similar to the 2010 season, a persistent mid-latitude trough near the east coast of the United States steered most of the hurricanes out to sea, while ridging over the central United States kept any hurricanes over the western part of the Caribbean Sea and Gulf of Mexico farther south over Central America and Mexico.

The most significant U.S. impacts occurred with Hurricane Irene and Tropical Storm Lee. Irene brought hurricane-force winds to the mid-Atlantic region and produced torrential rains and floods to much of New York and the New England area. Lee merged with a frontal system that produced copious amounts of rainfall and flooding to regions of the U.S. east coast that had previously been ravaged by floodwaters caused by Irene's heavy rains. Irene was responsible for 49 fatalities, of which at least 41 deaths occurred in the U.S., plus about $7 billion in damage. Heavy rains and floods associated with Lee and its remnants produced another nearly $1 billion in damage.

Overview of the 2011 Eastern North Pacific Hurricane Season

Todd B. Kimberlain and Eric. S. Blake
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NOAA/National Hurricane Center

The 2011 eastern North Pacific hurricane season was slightly above normal relative to the long-term mean. A total of eleven tropical storms developed, of which ten became hurricanes and six became major hurricanes. Although the number of named storms is about four below average, this is the greatest number of hurricanes to form since 2006 and the greatest number of major hurricanes since 1998. Two tropical depressions formed this season that did not strengthen into tropical storms, although both made landfall in southwestern Mexico. The Accumulated Cyclone Energy (ACE) index for 2011 was 120% of the long-term median. Two hurricanes affected land this season. Beatriz brought hurricane conditions to near Manzanillo in late June. Hurricane Jova struck nearly the same area in mid-October as a category 2 hurricane, producing significant damage and two deaths in the region. Other seasonal facts will be presented along with some of the operational challenges encountered during 2011.

2011 Atlantic and Eastern North Pacific
Forecast Verification

James L. Franklin
(james.franklin@noaa.gov)

NOAA/NWS/National Hurricane Center

A verification of official track, intensity, and genesis forecasts from the National Hurricane Center during the 2011 season will be presented, along with a discussion of the performance of the guidance models.

A Review of Recent Changes at the Joint Typhoon Warning Center
and a Summary of the 2011 Tropical Cyclone Season

Captain Michael D. Angove, Mr. Robert J. Falvey
(michael.angove@navy.mil)

Joint Typhoon Warning Center

A review of recent changes and ongoing improvement efforts at JTWC and a summary of the 2011 tropical cyclone activity across the Pacific and Indian Ocean areas will be presented.

Review of the 2011 Central Pacific Tropical Cyclone Season and Preliminary Verification

Raymond Tanabe
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Director, Central Pacific Hurricane Center (CPHC)

In 2011, there was one tropical cyclone which moved into the central Pacific. Tropical Storm Fernanda formed in the east Pacific on August 15 and crossed into the central Pacific on August 18. CPHC will present an overview of Tropical Storm Omeka, the preliminary verification, changes for the 2012 season, and recent staff changes.

53d Weather Reconnaissance Squadron
2011 Hurricane Season Reconnaissance Summary

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

In terms of aircraft requirements, the 2011 Hurricane Season was slightly below the 2010 season with 191 total taskings. Of these 132 were required and 130 were accomplished for a 99% reliability rate. A total of 971.4 hours were flown in support of the hurricane warning program. The first mission was flown against TS Beatriz on 20 June in the Eastern Pacific. TS Arlene was the first storm flown in the Atlantic Basin on 28 Jun. Hurricane Irene became the first system flown as a Hurricane on 22 Aug. Hurricane Irene also became the most flown storm of the season with 73 fixes over 179.9hrs as it tracked from the

Caribbean and up the east coast to NY Harbor. TS Sean was the season's last storm flown, near Bermuda on 10 Nov. A total of 246 storm fixes were accomplished during the 2011 season.

2011 was the 4th season with the entire WC130J fleet outfitted with the Stepped Frequency Microwave Radiometer. This instrument continues to work very well in the hurricane environment remotely measuring surface wind speeds. However, there still is a bit of uncertainty in some tropical storm force and below conditions. A more robust algorithm is needed to reliably report surface wind speeds, within heavy rain conditions, in wind speeds lower than 45kts on the surface.

NOAA Aircraft Operations Center (AOC)
2011 Seasonal Summary and Future Plans

Jim McFadden, Nancy Ash, Jack Parrish, Paul Flaherty, A. Barry Damiano, Ian Sears,
Jessica Williams, Richard Henning
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NOAA Aircraft Operations Center

After a fairly busy season in 2010, during which NOAA aircraft flew a total of 71 flights and 453 hrs, the 2011 season was less active for the three hurricane aircraft. During the season the two WP-3Ds and the G-IV flew a total of 49 flights for 343 hours. These flights, in addition to storm flights, included public awareness trips, such as the East Coast Hurricane Awareness Tour and the Governor's Hurricane Conference, test and calibration missions as well as several transit flights.

Of significance during the 2011 season were the IFEX missions into Hurricanes Irene and Rina, the Eastern Pacific Decay Experiment on Hurricane Dora, the Global Hawk – G-IV dropsonde intercomparison and the Ocean Winds Summer flights into Hurricane Hilary in the Eastern Pacific. By far the most extensive flight effort was associated with Hurricane Irene with seven P-3 IFEX missions and 8 G-IV research and surveillance flights.

AOC continues to upgrade its aircraft and instrumentation and in 2012 expects to accomplish the following:

- Complete the acceptance tests of the tail Doppler radar on the NOAA G-IV
- Continue developing strategies for use of the new G-IV TDR in storm environment
- Complete the RVP-8 upgrade of the P-3 tail Doppler radar
- Complete AAMPS upgrade on P-3.
- Complete the integration of the Doppler Wind LIDAR (DWL) and WSRA on N42RF
- Center wing box replacement and SSI of Zone 5 inspection on N42RF
- Complete plans for the overhaul of the G-IV engines to take place in FY13.
- Possible induction of N43RF into PDM and SSI this summer.

Session 2a
Joint Hurricane Testbed Project Updates, Part 1

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2011 Update on The Joint Hurricane Testbed (JHT)

Jiann-Gwo Jiing, Christopher Landsea, Shirley Murillo
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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). Eleven 5th round (FY09-11) projects were tested and evaluated during the 2011 hurricane season, following any necessary technique modifications or other preparations. These projects include upgrades to dynamical models and model components, enhancements to observed data and assimilation techniques, track forecasting algorithms, intensity estimation and forecasting algorithms. Decisions on the 5th round projects will be presented. Additionally, fourteen 6th round new projects (FY11-13) were selected and began testing during the 2011 season.

Improvements in Statistical Tropical Cyclone Forecast Models:
A Year 1 Joint Hurricane Testbed Project Update

Mark DeMaria[1], Andrea Schumacher[2], John A. Knaff[1], Renate Brummer[2]
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[1]NOAA/NESDIS, Fort Collins, CO; [2]CIRA, Colorado State University, Fort Collins, CO

Three improvements to the SHIPS and LGEM statistical-dynamical tropical cyclone forecast models are proposed. These include (1) Improving the method to estimate the intensity growth rate in LGEM; (2) Developing special versions of SHIPS and LGEM for the Gulf of Mexico region; and (3)) Improving the databases used to develop SHIPS and LGEM through use of the NCEP's new coupled reanalysis system. The project also includes the development of extended range climatology and persistence (CLIPER) track and intensity models. These models are based on a trajectory approach so they can be run to any forecast length and can be used as a baseline for the evaluation of model skill beyond 5 days.

The emphasis in the first half of the first year was on the extended range baseline models and the new SHIPS/LGEM database. The new NCEP coupled reanalysis data was obtained back to 1979 and is being compared to the older reanalysis field. The baseline track model uses monthly mean vertically averaged wind field modified by the initial motion vector to provide a track forecast. The baseline intensity model uses a simplified version of LGEM with climatological input. The evaluation of the new reanalysis fields and the preliminary results with the baseline models will be described along with plans for the other project tasks listed above.

Improvements to the SHIPS Rapid Intensification Index

John Kaplan[1], Christopher M. Rozoff[2], Charles R. Sampson[3], James P. Kossin[4], Christopher S. Velden[2], Mark DeMaria[5]
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[1]NOAA/AOML, [2]CIMSS, [3]NRL, [4]NOAA/NCDC, [5]NOAA/NESDIS

The current operational rapid intensification index (RII) uses predictors from the SHIPS model to estimate the 24-h probability of rapid intensification (RI) in both the Atlantic and eastern North Pacific basins using linear discriminant analysis. Although recent results indicate that the RII is skillful and has tended to outperform the other operational intensity model guidance, its usefulness is somewhat limited since it was developed exclusively for a 24-h lead time, has somewhat limited skill (particularly in the Atlantic basin), and is entirely probabilistic in nature. Thus, the goal of this new two-year NOAA Joint Hurricane Testbed (JHT) project is to improve the utility of the current operational RII by performing the following model enhancements.

First, new versions of the RII are being developed for the added lead-times of 12-h, 36-h and 48-h to provide additional guidance to forecasters at the National Hurricane Center during the critical watch and warning period that has recently been extended to 48-h. Ensemble-based versions of the RII that incorporate both the current operational linear discriminant analysis RII as well as two new versions of the RII that are derived utilizing Bayesian and logistic probabilistic models are also being developed at each of the aforementioned lead times. In addition, versions of the newly developed rapid intensity aid that employ both the probabilistic RII output as well as other existing operational intensity forecast models to generate deterministic intensity forecasts are also being developed for those same lead times. Finally, new 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 are also being developed.

Although each of the above RII enhancements are to be completed by the conclusion of our current two-year project, the presentation at the upcoming meeting will primarily be focused on preliminary results of the year 1 task of developing new versions of the RII for the added lead times of 12-h, 36-h and 48-h. However, a verification of forecasts that were made utilizing the recently developed 24-h version of the rapid intensity aid as well as an update of the progress that has been made toward deriving new microwave-based versions of the RII will also be provided.

Improvements in the probabilistic prediction of tropical cyclone rapid intensification resulting from inclusion of satellite passive microwave observations

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Rapid intensification (RI) remains a challenging aspect of tropical cyclone (TC) forecasting. Probabilistic RI schemes incorporating environmental data and parameters derived from geostationary satellite infrared (IR) imagery have substantially improved objective RI prediction since such data describe structural aspects of TCs. Still, IR data often cannot detect the specific distribution of precipitation underneath overlying cirrus clouds. Unlike IR data, passive microwave (MW) sensors aboard low-earth orbiting satellites can observe the precipitation structure underneath the TC's cirrus canopy. While the temporal coverage of MW data is lower than regular IR observations, MW data provide unique information on TC structure changes that should further improve the statistical prediction of RI. In this presentation, we will describe the impacts of including MW-based predictors in a variety of statistical forecast models.

In this study, storm-centered structural predictors were developed from 19, 37, and 85 GHz brightness temperatures from WindSat, the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E), the Tropical Rainfall Measuring Mission Microwave Imager (TMI), the DMSP Special Sensor Microwave/Imagers (SSM/I and SSMI/S), and the Advanced Microwave Sounding Unit B (AMSU-B) data for 1995-2009. Each of these instruments measure similar aspects of precipitation structures throughout the depth of the troposphere, although at varying spatial resolutions. The three different frequencies can each depict and provide unique information on those structures. Therefore, a wide-variety of structure-based predictors is developed from this large dataset of MW data. These predictors generally describe things like the degree of symmetry, vigor, and distribution of precipitation. One set of predictors is developed using an objective ring-search algorithm that attempts to find an annular structure coinciding with the likely location of an incipient or fully developed eyewall. Another set of predictors is obtained from fixed-pattern type structures. These predictors are added to and evaluated in three probabilistic forecast models, which include logistic regression and Bayesian models (Rozoff and Kossin 2011), and the Statistical Hurricane Intensity Prediction Scheme (SHIPS) RI Index (RII) (Kaplan et al. 2010) currently used at the National Hurricane Center.

Analyses of MW observations indicate that TCs about to undergo RI tend to have more symmetric, vigorous, and tightly clustered convection. In a favorable environment, RI is more likely when an eyewall begins to appear in MW imagery. Independent testing of the logistic regression, Bayesian, and SHIPS-RI models in both the Atlantic and East Pacific Ocean basins shows that certain MW-based predictors improve the forecast skill of RI models significantly. Due to data latency, there is a degradation of skill in forecasts made at synoptic forecast times compared to forecasts made at the instance of a satellite overpass, the MW predictors still improve skill at synoptic forecast times. Also, predictors from higher resolution sensors are more beneficial to forecasts than predictors from lower resolution sensors.

Enhancement of SHIPS Rapid Intensification Index Using the 37 GHz Ring Pattern

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Recently, a distinctive cyan-color ring pattern around the tropical cyclone (TC) center has been found in the 37 GHz color product developed by the Naval Research Laboratory (NRL) to have a strong relationship with subsequent rapid intensification (RI). The NRL product is constructed by combining 37 GHz vertically polarized (V37) and horizontally polarized (H37) brightness temperatures, and polarization correction brightness temperature (PCT37), therefore quantitative information is sacrificed. We have determined quantitative values of H37, V37 and PCT37 for the cyan color region in the NRL 37 GHz color product by using the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI) observations. Based on these values, an objective 37 GHz ring pattern RI index is developed.

Evaluation of the ring index has been done by using the TMI observations of TCs in the ATL and EPA basins from 1998 to 2009. It is found that the 37 GHz ring pattern RI index is an independent predictor relative to the SHIPS RI index. By adding this ring pattern index, the performance of SHIPS RI index can be improved substantially. A real-time algorithm has been developed for the quasi-operational test of the combined RI index at NHC this year. A further refinement of the automatic ring detection algorithm is also underway.

Extending SHIPS Hurricane Intensity Forecasts with some Dynamical Variables

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Florida State University

The SHIPS algorithm developed by Mark DeMaria is well known as one of the best current statistical methods for the prediction of hurricane intensity. This is a multiple regression method that regresses the hurricane intensity change (at 6 hourly intervals) as a function of a number of variables such as observed maximum intensity, persistence, the observed 12 hour intensity change, 850mb-200mb vertical wind shear etc. The regression was carried out by DeMaria using 2008, 2009 seasons of 6 hourly data sets. The regression coefficients were next used for real time hurricane intensity forecasts. Our group at FSU makes use of the SHIPS method with an extension, the extension includes four dynamical parameters such as the vertical distribution of heating (in the context of the potential vorticity equation), the transformation of shear vorticity into curvature vorticity, the transformation of Divergent kinetic energy into rotational kinetic energy and the advection of angular momentum into the inner core of a hurricane. We use several hurricane cases from 2008 to 2009 for the training phase to extract the regression weights. The weights so obtained are applied for forecast to hurricanes of the 2009 season. This entire problem was subdivided

into hurricane intensity forecast skills from DeMaria's SHIPS alone, from the FSU diagnostic parameters alone and from the combined use of SHIPS plus FSU parameters. Our study includes a training phase that covers the hurricane forecasts for two years. This carries more than 250 forecasts of past hurricanes. The FSU diagnostic parameters are also calculated from the HWRF. The data usage for the training and the forecast phase of this SHIPS extension are as follows. We use HWRF run for many hurricane cases in the year 2008, 2009 for two nested domains at 27km and 9km. The data from innermost domain (9km) is used for the computation of the four FSU Diagnostic parameters.

We will be showing results for the hurricane intensity forecasts and showing a comparison of these results with a more recent development on hurricane intensity forecast called SPICE algorithm that was also developed by Mark DeMaria. Finally we shall cover the issues on real time forecasts of hurricane intensity from the modified SHIPS algorithm

A New Secondary Eyewall Formation Index; Transition to Operations and Quantification of Associated Hurricane Intensity and Structure Changes

A Joint Hurricane Testbed Project

Jim Kossin[1,2], Matt Sitkowski[2,3], Will Lewis[2], Chris Rozoff[2]
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Typically, the formation of a secondary (outer) concentric eyewall in a hurricane signals an impending fluctuation in the storm’s ongoing intensity evolution. These fluctuations are anomalous in that they constitute a transient behavior that is generally not captured well by the present suite of operational intensity forecast guidance. Consequently, when the formation of a secondary eyewall is observed or predicted in an operational setting, forecasters must rely on expert judgment based on experience to subjectively modify the intensity forecasts provided by the available objective guidance.

In Year-1 of this project, we transitioned a new probabilistic model into NHC operations to help predict the formation of secondary eyewalls (Kossin and Sitkowski 2009). In Year-2, we constructed an expanded record of low-level aircraft reconnaissance data and used this to construct an expanded climatology of intensity and structure changes associated with eyewall replacement cycles (ERC) in Atlantic hurricanes (Sitkowski et al. 2011). We found that a typical
ERC can be naturally divided into three distinct phases. Each phase has associated characteristic changes in intensity and wind structure, and a characteristic duration over which the changes take place.

In our subsequent work in Year-2 and spanning into Year-3, we’ve exploited the characteristics of these changes with the goal of constructing empirical/statistical models that provide objective real-time intensity guidance that specifically targets fluctuations associated with ERCs (Kossin and Sitkowski 2012). The model input comprises environmental features, and satellite-derived features that contain information on storm cloud structure. The models predict the expected intensity changes and the duration over which these changes occur during the most operationally relevant phases of an ERC. The models also provide predictions of expected radial changes in tangential wind structure, which may be useful for wave-height and storm-surge forecasting. These latest models will be introduced in this talk, as well as other Year-2 and 3 progress including ongoing work toward optimizing the transitioned operational model and model validation for the 2011 hurricane season.

Kossin, J. P., and M. Sitkowski, 2009: An objective model for identifying secondary eyewall formation in hurricanes. *Mon. Wea. Rev.*, **137**, 876–892.

Sitkowski, M., J. P. Kossin, and C. M. Rozoff, 2011: Intensity and structure changes during hurricane eyewall replacement cycles. *Mon. Wea. Rev.*, **139**, 3829–3847.

Kossin, J. P., and M. Sitkowski, 2012: Predicting hurricane intensity and structure changes associated with eyewall replacement cycles. *Wea. Forecasting*, to appear.

Development of a Probabilistic Tropical Cyclone Genesis Prediction Scheme

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[3]Colorado State University/CIRA; [4]Florida State University

Tropical cyclone (TC) genesis is perhaps one of the more difficult stages of the tropical cyclone lifecycle to diagnose and predict. Tropical disturbances are vastly under sampled phenomenon in the North Atlantic and account for <10% of all NOAA aircraft missions that have been conducted since the middle 1970s. Unfortunately, there are also limited resources available to forecasters to objectively identify and predict TC genesis in the North Atlantic basin. A new scheme for forecasting TC genesis is currently being developed under NOAA's Joint Hurricane Testbed (JHT) program to help address these deficiencies. The main goal of this project is to develop a storm-centric TC Genesis Index (TCGI) to provide forecasters with an objective tool for identifying the probability of TC genesis (0-48 hr and 0-120 hr) in the North Atlantic basin.

The TCGI scheme will test and incorporate several model and satellite derived predictors that are currently being used in the NESDIS TC Formation Probability (TCFP) product and Statistical Hurricane Intensity Prediction Scheme (SHIPS) model. Additionally, total precipitable water derived from microwave satellites and Dvorak T-numbers produced by the Tropical Analysis and Forecast Branch (TAFB) at NOAA NHC will also be tested for possible inclusion in the TCGI scheme.

Several objectives of this year-1 JHT project have begun or have been completed and will be discussed. These efforts include: 1) development of a 10-yr dataset that includes Dvorak T-numbers for North Atlantic tropical disturbances (non-TC cases) that will be tested in the TCGI scheme; 2) missing forecast positions in the tropical disturbance database were filled in using a combination of Best Track and Dvorak positions, GFS vortex tracks and BAMM forecast positions; 3) Disturbance-centric values of various potential TC genesis predictors were then computed for each case in the sample set; 4) Testing of these various predictors for possible inclusion in the TCGI scheme has begun.

Session 2b
Joint Hurricane Testbed Project Updates, Part 2

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2012 Upgrades to the Operational GFDL/GFDN Hurricane Model

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[1]GFDL/NOAA; [2]University of Rhode Island; [3]CCPO/Old Dominion University

The operational versions of the GFDL model used by the National Weather Service and the US Navy (GFDN) were upgraded in 2011 with the new version of the Simplified Arakawa-Schubert (SAS) deep convection scheme operational in NCEP's global model (GFS). Tests from the 2010 Atlantic hurricane season demonstrated reduction in track error at 4-5 days of nearly 20% with the new deep convection. Despite degradation in intensity performance, particularly for weak storms, the upgraded model was made operational in 2011. Results from the 2011 season indicated an excessive west track bias with the upgraded model, particularly for Hurricane Irene, and a large positive intensity bias for weaker storms. Much of the track bias was traced to three factors:

1.) The lack of detrained micro-physics in the new SAS scheme; (2) a major bug in the new SAS implementation in 2011 and (3) a long-standing bug in the 2003 implementation of the GFS PBL scheme. With modifications made to correct these 3 issues, the track errors were significantly improved in both the East Pacific and Atlantic. A similar result was found in the GFDN model for parallel runs made in the Western Pacific. Overall, the positive intensity bias in the Atlantic 2012 season was also significantly reduced with the average error reduced about 15 to 20%. Further investigation indicated the positive intensity bias could be further reduced by increasing the cumulus momentum transport term. These changes have been extensively tested for implementation in the 2012 versions of the GFDL/GFDN models. One of the largest improvements in track was found for Hurricane Irene, with the average 3 and 5 day track error reduced from 158 and 370 nm, to 85 and 131 nm, respectively (over a factor of 2 at 5 days).

Additional upgrades that are also being tested for the 2012 upgrade include implementation of the GFS shallow convection and new planetary boundary scheme reformulation of a more realistic value of the enthalpy exchange coefficient (ch); and modification of the advection of the microphysics species.

In this talk, the proposed changes will be discussed in detail, the final model configuration will be presented, as well as evaluation of the new model's performance for track and intensity, for reruns of the 2010 and 2011 Atlantic and East Pacific hurricane seasons. Finally, improvements to the model initialization planned in future upgrades will be briefly discussed.

Validation of HWRF forecasts with satellite observations

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Project summary and current results of the JHT project on "Validation of HWRF forecasts with satellite observations and potential use in vortex initialization" will be presented. The presentation would include outline of project goals and deliverables, description of the new software that was developed for implementation within the post-processing component of the forecast system for simulating wide range of satellite observations using the operational version of CRTM (Community Radiative Transfer Model), and demonstration of planned products for the forecast verification. The verification products would include comparison of simulated and actual satellite observations in terms of infra red and microwave brightness temperature images and the associated derived diagnostics, such as contour frequency diagrams and correlation between the observed and forecast fields.

The assimilation of non-NOAA and non-AF GPS dropwindsonde data into NOAA numerical models

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Since 1997, dropwindsonde data from NOAA, U. S. Air Force, and Taiwanese aircraft have been routinely assimilated into operational numerical models at NOAA. These data have been shown to dramatically improve forecasts of tropical cyclones globally. In addition to regular reconnaissance and surveillance by these aircraft, other aircraft have participated in field programs to study tropical cyclones and have released numerous dropwindsondes inside and in the environments of tropical cyclones globally. For example, the NASA DC-8 participated in the Convection And Moisture Experiment (CAMEX) in the Atlantic in 2001, the Tropical Cloud Systems and Processes (TCSP) experiment in the Eastern Pacific and Atlantic in 2005, the NASA African Monsoon Multidisciplinary Analyses (NAMMA) campaign in the Eastern Atlantic in 2006, and in the Genesis and Rapid Intensification Program (GRIP) in the Atlantic in 2010). The National Science Foundation G-V aircraft participated in the PRE-Depression Investigation of Cloud- systems in the Tropics (PREDICT) experiment in the Atlantic in 2010. The German Falcon released numerous dropwindsondes in the West Pacific during the THORPEX Pacific Area Regional Campaign (T-PARC) in 2008. With increased interest in tropical cyclones globally, further campaigns and experiments with participation by these aircraft are anticipated. This proposal is to test the assimilation of dropwindsonde data from NASA and NSF aircraft so that they can be assimilated into the NCEP guidance in the future.

To test the assimilation, a set of global model runs from 15 August through 30 September 2010 with the NASA and NSF dropwindsonde data assimilated is to be produced. Success will be determined depending upon the impact of the additional dropwindsonde data on global model forecasts. This impact will help NCEP/EMC decide whether to allow the assimilation of these data during future field programs. Preliminary results from the parallel runs will be shown.

Development of a Real-Time Automated Tropical Cyclone Surface Wind Analysis: A Year 1 Joint Hurricane Testbed Project Update

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This project seeks to create a real-time and fully automated surface wind analysis system at the National Hurricane Center (NHC) by combining the existing satellite-based six-hourly multi-platform tropical cyclone surface wind analysis (MTCSWA) and aircraft reconnaissance data. This project will leverage the automated quality control procedures and variational analysis techniques developed for use in the MTCSWA and previous studies that make use of flight-level wind observations to produce analyses. The most recent MTCSWA will be used as a very weakly weighted first guess field for aircraft reconnaissance wind data (flight-level and SFMR) that will be composited for the six hours prior and up to three hours following the synoptic time (i.e. the compositing window). Analyses valid at the synoptic time would be created 1) for TC vitals (CARQ data) creation in the minutes following synoptic times and 2) later in the analysis cycle for possible refinement of advisory products.

In Year-1, the following analysis assumptions are applied. The center locations during the data compositing window will be determined using a combination of operational best track and aircraft-based center positions and short-term forecasts. The individual data weightings used in the analysis scheme are based on the magnitude of the flight-level wind whereby when the flight-level wind is greater than or equal to (less than) hurricane strength more (less) weighting will be given to the SFMR data. Radial and azimuthal smoothness constraints used in the analysis are fixed and similar to those that have been used successfully in the past to create flight-level wind analyses from aircraft data. Flight-level to surface wind reduction (FLTS), will make use of convective reduction factors and asymmetries discussed in Franklin et al (2003). Specifically the eyewall region FLTS reduction factors are used when data is within twice the radius of maximum wind (RMW), the outer vortex FLTS reduction factors are used when data is located outside three times the RMW, FLTS reduction factors vary linearly from the eyewall region to the outer vortex region. Finally, a 20 degree surface wind inflow angle is applied for marine conditions. These details will be described and Year-1 progress related to this project will be reported.

Improved SFMR Surface Wind Measurements in Intense Rain Conditions: A JHT Project

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The stepped-frequency microwave radiometer (SFMR) has reliably provided hurricane-force surface wind speed data from aircraft for over a decade, but struggled with accurately observing wind speeds below hurricane strength in the presence of moderate to heavy precipitation. Typically, the SFMR shows a tendency to overestimate the wind speed when heavy rain exists. The goal of this JHT-funded project is focused on improving quality of SFMR wind observations in such conditions. In Year 1 of this work, the pre-existing database of GPS dropwindsonde vs. SFMR wind speed comparisons is expanded to include data through the 2011 hurricane season, which included NOAA flights targeting areas of heavy precipitation at lower wind speeds. Wind speed differences (sonde minus SFMR) are computed according to various rain rate and wind speed bins. In bins where sonde counts are particularly low, synthetic sondes utilizing flight-level wind observations are added to the database as well. As expected, the lower wind speed, heavier rain rate bins produced the largest difference between the two wind speed values while low rain rate and high wind speed bins produced the lowest differences. A functional fit is developed following these data, providing an estimation of the corrections to the wind speed bias. It is expected that this correction will be available for real-time testing during the 2012 hurricane season.

Improved Automation and Performance of VORTRAC Intensity Guidance

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This paper will present a progress report on the improvement of the Vortex Objective Radar Tracking and Circulation (VORTRAC) intensity guidance for landfalling hurricanes as part of the Joint Hurricane Testbed. VORTRAC uses a series of algorithms to deduce the central pressure and radius of maximum wind (RMW) of a landfalling TC in near real time from WSR-88D Level II radar data and environmental reference pressure data from nearby coastal weather stations. In its current operational form, VORTRAC requires external scripts to fetch required input data, as well as manual user input of an initial TC position, RMW estimate, and radar selection. As part of the JHT project, existing operational data streams will be utilized to make VORTRAC nearly automatic, reducing the amount of required user interaction while maintaining the capability to intervene and make adjustments. In addition, methods to improve performance will be investigated.

The progress of the first 6 months of the project will be reported at the IHC, along with a road map for the proposed enhancements to automation and performance of the VORTRAC package. A set of historical Atlantic TCs that made US landfall between 2005 and 2011 have been selected and run through the VORTRAC package to identify potential issues and areas for improvement. The lessons learned will be reported at the IHC, and form the basis for improving VORTRAC.

Session 3
Advances in Storm Surge Predictions

SESSION 3

The National Weather Service's Storm Surge Program: Past, Present, and Future

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Since its birth, this country has lost over 25,000 people to tropical cyclones. Every decade from the 1890s through the 1960s had at least one storm during which surge took hundreds or thousands of lives. More recently, Hurricane Katrina resulted in approximately 1200 deaths. Despite the fact that water, mainly surge is responsible for most of these hurricane related losses, nearly everyone, including meteorologists, think wind first when they hear hurricane. As a result, historically there has been relatively less emphasis on improving storm surge forecasts and products. Recent high impact storms have resulted in a new emphasis on storm surge hazards and improving the Nation's storm surge forecasting, evacuation, and coastal zone management/planning capabilities. With its prominent storm surge responsibilities, the National Weather Service (NWS) is helping lead efforts to meet rapidly expanding needs for accurate and timely storm surge products and services. This talk will focus on developmental efforts and operational changes underway within the NWS aimed at increasing public awareness and more clearly articulating the threat from storm surge.

Significant changes underway include:

* Upgraded storm surge graphics which display the risk more clearly.

* Expansion and greater use of probabilistic storm surge information.

* Referencing storm surge as feet of water above ground versus above a standard marine datum.

* Exploration and testing of a new warning type, explicitly for storm surge.

* Improvements to the operational storm surge modeling system.

* Improved storm surge outreach information in the way of brochures, videos, interactive web-tools, etc.

Moving Forward with Surge Communication Products

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Storm surge information has been removed from the Saffir-Simpson scale and improved methods for communicating storm surge information to the public and to NOAA's various partners are being investigated. The Hurricane Forecast Improvement Project's Socioeconomic Task Force is leading an initiative to develop and test various text and visual storm surge forecast products. This presentation will highlight the goals of the project and report on exploratory testing of several prototype products with citizens, warning coordination meteorologists and emergency managers. Participants will be provided information on how they can participate in the project by competing an Internet survey.

Documenting Hurricane Inland Storm Tides

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Historically, hurricane-induced storm-tides were documented through analysis of structural or vegetative damage and high-water marks. However, these sources rarely provided quantitative information about the timing of the flooding, the sequencing of multiple paths by which the storm-surge waters arrived, or the magnitude of waves and wave run-up comprising floodwaters. Nor could highwater marks be used to evaluate storm-surge model performance along the dynamic track of a hurricane with its accompanying changes in wind strength and direction.

In response to these deficiencies, the U.S. Geological Survey (USGS) developed a mobile storm-tide network to provide detailed time-series data for selected hurricane landfalls (URL: http://water.usgs.gov/osw/programs/storm_surge.html). As part of this program, water-level and barometric pressure monitors are deployed to areas of hurricane landfall resulting in a concentrated network of as many as 260 temporary, tide gages placed along water channels and nearby overland features such as beaches, wetlands, and constructed environments. USGS storm-surge networks have been successful deployed for Hurricanes Rita (2005, 32 water-level monitoring sites); Wilma (2005, 30), Gustav (2008, 80); and Ike (2008, 65); and Tropical Storm Ernesto (2006, 40), Hurricanes Earl (2010, 45) [data were not published for Ernesto or Earl], and Irene (2011, 260). Data were collected as frequently as every 2 seconds for 1-2 days prior to landfall and for as much as 2 weeks afterwards. Data at some sites in southwest Louisiana and Texas and along the Atlantic coast were collected for multiple storms. The data are available online at http://waterwatch.usgs.gov/hsss/).

For Hurricane Irene a web-based map viewer was developed to enable public tracking of the deployment in near-real time and to provide an easy to use portal to the resulting time series data (URL: http://wim.usgs.gov/stormtidemapper/stormtidemapper.html). The portal includes access to site photos, data plots, and some field notes and other documents. Where possible, information from other agencies such as the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) and Sea Grant, the U.S. Army Corps of Engineers, (USACE), and several universities have been added to the reports and data compilations.

Measuring Hurricane Storm Surge in South Carolina

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Preventing flood hazards, such as the hurricane induced storm surge, from becoming human disasters requires an understanding of the relative risks floods pose to specific communities and knowledge of the processes by which flood waters rise, converge, and abate. It is critical that the timing, magnitude, and duration of hurricane storm surge are accurately measured. The U.S. Geological Survey – South Carolina Water Science Center (USGS-SCWSC), in cooperation with various municipal, State, and Federal Cooperators, uses three monitoring approaches for measuring hurricane storm-surge dynamics. The

USGS maintains a network of 42 real-time water-level and water-quality gages along the South Carolina coast. The gages record water level, specific conductance, temperature, and (or) dissolved oxygen at 15-minute intervals and are available on the web with a maximum of a 1-hour time delay. The real-time network is maintained to monitor a large range of hydrologic conditions from droughts to floods and provide the data on the web for a broad base of stakeholders.

In addition to the real-time network, the USGS-SCWSC, in cooperation with the U.S. Army Corps of Engineers – Charleston District and the South Carolina Department of Transportation, established a hurricane storm-surge monitoring network for South Carolina. The network is designed for a cost effective and time-efficient monitoring of hurricane storm surge. Currently (2012), the hurricane storm-surge network consists of 36 sites distributed along the South Carolina coast. At each site, a bracket for a water-level sensor has been attached to a permanent structure, such as a bridge pier. The elevation of the bracket has been determined by differential surveying to a benchmark of known elevation. In the event of a storm, the sensors are attached to the bracket and the timing, duration, and magnitude of the storm surge is recorded. Upon retrieval of the sensors, there is minimal delay in disseminating the storm-surge elevation data to interested agencies and coastal resource managers because the water-level data are easily adjusted to mean sea level.

These two fixed networks can be augmented with real-time rapid deployment gages and the temporary deployment of pressure transducers attached to bridge piers or other substantial structures to provide more spatially dense monitoring of hurricane storm surge. For example, temporary deployment of sensors in the projected hurricane path can be placed to monitor the attenuation of the hurricane surge along coastal rivers and across barrier islands, low-lying areas, and wetlands. After the passing of a storm, the locations of the temporarily deployed sensors must be surveyed to a known elevation. The USGS has successfully deployed temporary storm surge-networks for Hurricanes Rita, Wilma, Gustav, Ike, and Tropical Storm Ernesto.

The 78 monitoring sites for the two fixed networks with the addition of temporarily deployed sites provide a cost-effective hurricane storm-surge monitoring network for South Carolina. The combined networks effectively leverage resources of over 10 cooperative funding agencies in South Carolina for monitoring hurricane storm surge.

A Testbed for the Evaluation of Wave, Storm Surge and Inundation Models for Tropical Storms

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We have created a modeling community testbed to help with the development of improved predictive capabilities for coastal waves, storm surge and inundation associated with tropical cyclones. The testbed enables the sharing of model grids, forcing data, observational data, model results, and model evaluation tools. Outcomes include documentation of model skill, computational efficiency, and sensitivity to implementation issues such as the physics included in the model and the grid resolution.

The testbed domain includes the Gulf of Mexico with higher resolution provided along the Louisiana – Texas shelf to model the regional responses to hurricanes Rita (2005) and Ike (2008). Models being evaluated in the testbed are ADCIRC, FVCOM, SELFE, SLOSH, SWAN, and WWM. Testbed activities include both the evaluation of model skill vs observed data and the inter-comparison of model results. The ultimate goal is to provide guidance on model selection and implementation to aid operational modeling needs in this field.

The testbed was initiated and has been substantially supported by the Southeastern Universities Research Association (SURA) with funding provided by the NOAA IOOS program.

ERDC's Coastal Storm Modeling System (CSTORM-MS)

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The USACE ERDC Coastal Storm Modeling System (CSTORM-MS) provides for a robust, standardized approach to characterizing the hurricane hazard that puts coastal communities at risk. It allows for multi-scale scenarios for reducing the uncertainty of storm impacts to existing and new structures and for design of new structures. Realistic coastal storm modeling requires the integration of several complex and sophisticated numerical modeling systems. In particular, the following systems are currently being used within CSTORM-MS: a tropical planetary boundary layer model, MORPHOS-PBL, to generate the cyclone wind and pressure fields, an ocean hydrodynamic model, ADCIRC, to generate the surge field, and both regional and nearshore ocean wave models, WAM and STWAVE, to generate the wave fields. In addition to these models that simulate the oceans response to a storm in the form of waves and surge, a bed morphology model, C2SHORE, is currently being included to simulate landscape changes due to the surge and wave effects. In order to gain a more complete representation of the response to the storm, many of these systems are tightly coupled to allow for timely feedback responses into each model. We will present a work flow that is easy to configure and execute with the aid of graphical user interfaces (GUI) in the Surface Modeling System (SMS). Include will also be some preliminary results from the inclusion of the bed morphology model into the system. This work flow system with GUI's and tightly coupled models represents an enabling technology for more comprehensive studies on flood and shore protection and sediment management. These same technologies can be applied for both hindcasting and forecasting scenarios. CSTORM-MS simulations are then able to be stored, queried, and visualized inside of the CSTORM database (CSTORM-DB).

Development of a Storm Surge Ensemble Modeling Methodology Using a Suite of Hurricane Track Predictions

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It is critical to accurately forecast hurricane storm surges, but this task is complicated by uncertainties inherent in hurricane track and intensity predictions. Storm surge model guidance can be based on the official hurricane forecast. Unfortunately, hurricane forecast uncertainties can lessen the value of a surge prediction made from one single track. NOAA's probabilistic hurricane storm surge predictions (P-Surge) address this uncertainty by running hundreds of SLOSH storm surge model simulations with perturbations of the official forecast track location, size and intensity.

However, while the official hurricane forecast track has historically been the most accurate prediction, it doesn't reflect all of the scenarios represented by the various atmospheric models of hurricanes. Therefore, NOAA is researching storm surge ensemble methodologies that account for such variability. The ensemble methodology uses track predictions from multiple weather prediction models to force storm surge simulations with the operational storm surge model SLOSH. Statistical analyses from these simulations are used to evaluate the accuracy of the ensemble, and can be used to develop ensembles with multiple wind fields and surge models. To accomplish this, P-Surge has been modified to use track and intensity predictions from operational hurricane models. These include statistical models such as CLIPER, and dynamical models such as GFDL, GFS, HWRF, and ECMWF. Preliminary test cases for Hurricanes Katrina (2005) and Irene (2011) are shown, along with statistical analysis of the ensemble results.

Fast Forecasting of Hurricane Waves and Inundation in Hawaii

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U.S. Pacific Island coasts are extremely vulnerable to tropical cyclones. Islands have steep bathymetry slopes, very large incident storm waves, and fringing coral reefs that differ significantly from US mainland coasts. Powerful hurricanes can raise water levels and generate large waves, resulting in coastal inundation, damage, and loss of life. This presentation describes the Surge and Wave Island Modeling Studies (SWIMS) fast forecasting system for Hawaii. The SWIMS fast forecasting tool provides a framework for dynamic and fast evaluation of waves, surge, and inundation for approaching hurricanes, and it provides valuable information for emergency management during hurricane events, for hurricane exercises, and for engineering evaluation. The fast forecasting tool employs high-resolution, high-fidelity wave and surge models (SWAN and ADCIRC) to simulate hundreds of hurricanes for Hawaii. The database of hurricane response is then used to forecast potential waves, surge and inundation quickly when a storm is approaching Hawaii using a surrogate model. The fast forecasting system produces the

storm response for deterministic assessment or probabilistic assessment based of the error cone of possible tracks and error characteristics of the forecasts. The high-fidelity simulations require a few thousand computational hours for a single deterministic hurricane, but the surrogate model provides deterministic predictions in seconds and probabilistic predictions in minutes on a PC.

Session 4a
Observations and Observing Strategies for Tropical Cyclones and their Environment, Part 1

SESSION 4a

Tropical Cyclone Intensity Estimation And Formation Detection Using The Deviation Angle Variance Technique

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Results using the Deviation-angle variance technique (DAV-T) to objectively determine: 1) the current intensity of existing tropical cyclones; and 2) determine which pre-genesis cloud clusters will go on to develop into tropical cyclones, are presented for the North Atlantic, western North Pacific, and eastern North Pacific basins.

The DAV-T is a method that objectively characterizes the level of axisymmetry of a cloud cluster using infrared brightness temperatures. To estimate intensity, the axisymmetry parameter is calculated for a set of training data in each basin and fitted to best-track wind speed intensity to produce a curve used to estimate intensity for an independent set of tropical cyclones. The DAV-T is slightly modified for genesis prediction to take into account the lack of a center location. Instead, a map of variances is calculated for the entire satellite infrared scene in each basin and minimum values of the DAV-T parameter are archived when they meet statistically based threshold values for development. In the presentation we will briefly describe the technique and show performance statistics for all three basins.

On the Application of the Dvorak Technique at SAB

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The International Workshop on the Satellite Analysis of Tropical Cyclones (IWSATC) held in Honolulu in April 2011 sought, in part, to identify the differences in the procedures between the participating warning centers and their relevance to final TC intensity estimates and resulting Best Track data. Even though it has no official warning capacity, the Satellite Analysis Branch (SAB) of NOAA/NESDIS provided input to the workshop at the request of the organizers.
This presentation will describe material presented at the IWSATC on how the Dvorak technique is applied in SAB with some emphasis on local adaptations. Of particular note, discussion will be made of:

- Dvorak constraints, including, but not limited to, changes in final T-number (FT) over time;
- Use of the model expected (MET) and pattern T-numbers (PT) as a basis for the FT number; and the relationship between the two;
- Application of the Dvorak technique for large and elongated eyes; and
- Managing extreme intensification rates

It will be noted that prior to 2006 several important aspects of the Dvorak technique were either incorrectly applied or ignored for simple lack of knowledge. SAB began an earnest effort in 2006 to apply the Dvorak technique as described and reconciled by A. Burton, Australian Bureau of Meteorology, in his **Notes on the Dvorak Technique** while making reasonable accommodations for new objective aids such as the Advanced Dvorak Technique (ADT). Potential consequences of this on validation will be discussed.

The 2011 GOES-R 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. Nine products were chosen for demonstration at NHC during most of the 2011 Hurricane Season (1 Aug to 30 Nov). Eight of the nine were ABI products, comprising the Hurricane Intensity Estimate (HIE) two 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 intensify 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. Results from 2011 will be summarized along with plans for a follow-on experiment during the 2012 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.

NRL Tropical Cyclone Satellite Web Page: 15 Years of Quasi-Operational and R&D Applications

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The Naval Research Laboratory's (NRL) tropical cyclone (TC) web page has enabled the global TC community to benefit from access to near real-time microwave imager/sounder imagery and derived products that assist in monitoring TC storm structure since 1997. Microwave sensors have the inherent advantage of seeing through non-raining clouds, thus mitigating a common problem associated with visible/Infrared (vis/IR) imagery that forms the bulk of the temporal sampling due to 30 minute or more rapid refresh afforded by geostationary sensors. However, access to the first few operational microwave imagers (Special Sensor Microwave/Imager, SSM/I on F-8 launched in 1987) was difficult outside a few US government organizations. NRL's Marine Meteorology Division in Monterey, CA (NRL-MRY) recognized the potential to use the SSM/I to map TC location, structure, and infer intensity, and thus began in 1997 a public web page that contained near real-time SSM/I products focused on existing TCs as monitored by the National Hurricane Center (NHC, Miami, FL), the Joint Typhoon Warning Center (JTWC, Pearl Harbor, HI) and the Central Pacific Hurricane Center (CPHC, Honolulu, HI). This effort was only possible due to our close collaboration with the Fleet Numerical Meteorology and Oceanography Center (FNMOC) collocated in Monterey, CA with NRL-MRY and coordination with the Automated Tropical Cyclone Forecasting system (ATCF).

Low earth orbiting (LEO) sensors like the SSM/I (1400-km swath) only view a given TC at most twice/day, typically less, thus temporal sampling is a prime limitation. However, as multiple SSM/Is became operational, “hits” per day increased and the utility grew. The SSM/Is were then augmented greatly by the addition of the Tropical Rainfall Measuring Mission (TRMM, launched in 1997 and came online with NRL in 1998). The 35 deg orbital inclination and tropical focus with a precipitation radar and microwave imager (750-km swath originally) added 1-3 “hits” per day per storm and since it was non sun synchronous, sampled storms at times outside of the SSM/I early morning orbits. TRMM began a precedent for NASA research and development (R&D) satellite data sets as NASA readily saw the significant benefits to the large TC community of providing TRMM data in near real-time to both the NRL TC page and others. Thus, NASA modified their data flow and processing systems to permit 1-3 hour data latency and thus directly aid the real-time TC forecasters around the world. TRMM then set the pace for later R&D sensors (MODIS, QuikSCAT, and CloudSat) that NASA launched and made data available in a timely manner for TC web page inclusion. Due to the NRL TC web page success, we transitioned the TC web capability to operations at FNMOC in 2001 and thus have had true 24/7 availability for over a decade.

The Special Sensor Microwave Imager Sounder (SSMIS) began the replace the SSM/I as the DOD operational microwave imager with the launch of F-16 in 2003 and F-17 and F-18 have successfully be added. In addition, the Advanced Microwave Scanning Radiometer (AMSR-E) on NASA’s Aqua (Japan sensor, 2002-2011) proved to be the best all-around TC imager due to its large swath (1800-km), full spectral channel set, and high spatial resolution due to the large antenna. NRL-MRY began including microwave sounder data from the Advanced Microwave Sounding Unit (AMSU-B) in 2003 to take advantage of the 89 GHz channel capability and the fact multiple sensors and the large swath (~2300 km) provided enhanced sampling, even if at lower spatial resolution and we look forward to adding NPP ATMS data in the near future. Additional microwave sensors capable of retrieving ocean surface wind vectors have been hosted using both scatterometers (ERS-2, QuikSCAT, and ASCAT) as well as the WindSat polarimetric radiometer that serves as an excellent microwave imager also. Wind vector data sets have assisted in defining the radius of gale winds and in limited cases storm intensity.

Passive microwave imagery has recently received a much needed boost with the launch of the French/Indian Megha Tropiques MADRAS microwave imager in September 2011, basically greatly supplementing the very successful NASA TRMM pathfinder with a larger swath and more frequent temporal sampling (3-5 “hits/day). Future NASA Global Precipitation Mission (GPM) sensors starting in 2014 will provide enhanced capabilities.

NRL TC web page products are available using Google Earth compatible kml files and enable the user to accurately extract earth location information while overlaying multiple data sets for any given storm. Data fusion enhancement applications using examples from several new microwave sensors will be presented.

Microwave sounders: The "swiss army knives" of hurricane research

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In recent years it has become clear that microwave sounders are very valuable tools in hurricane research and prediction. Although microwave radiometers typically have relatively coarse spatial resolution compared with visible and infrared imagers and sounders, they compensate by having an unusually broad range of functionalities. Currently, such sensors are operating from aircraft in focused field campaigns, such as the Jet Propulsion Laboratory's (JPL) High Altitude MMIC Sounding Radiometer (HAMSR), which most recently flew in the Genesis and Rapid Intensification Processes (GRIP) campaign in 2010 and will next fly in the "Hurricane and Severe Storm Sentinel" (HS3) campaign in 2012-2014. They are also operating from a number of low-earth-orbiting (LEO) satellites, such as the Advanced Microwave Sounding Unit (AMSU) and most recently the Advanced Technology Microwave Sounder (ATMS). And soon they will be operating from geostationary-earth-orbiting (GEO) satellites – the first of which is expected to be based on the Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) design developed at JPL. We survey and summarize the capabilities of these sensors and their value to the hurricane community, with illustrations of results from HAMSR in the GRIP campaign and comparison with AMSU observations during GRIP. The geostationary microwave sounders represent the culmination of this progression, with their ability to provide a continuous rapid-update three-dimensional picture of the thermodynamics, microphysics and dynamics – all at the same time – of a hurricane throughout its life cycle. No other single sensor system can match such capabilities.

Understanding The Rapid Intensification Of Hurricane Karl From Observations and Models: Using NASA's Airborne and Satellite Observations To Evaluate the Operational Hurricane Forecast Model HWRF

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Understanding and accurately forecasting hurricane rapid intensity changes is one of the main goals of the NOAA-led, multi-agency 10-year Hurricane Forecast Improvement Project (HFIP). Indeed, a major goal of NASA's Hurricane Science Research is improving the knowledge about the critical physical processes and evaluation of their representation in numerical models. Addressing this national imperative, NASA's Genesis and Rapid Intensification Processes (GRIP) field campaign was designed to provide new observational insights. It was conducted in the summer of 2010 in close coordination with NOAA's Intensity Forecast Experiment (IFEX) and NSF's PREDICT experiment which had similar goals. A total of 7 aircrafts with new and mature observing technologies were flown in highly coordinated mission.

The GRIP field campaign provided an unprecedented high-resolution view into the vortex evolution throughout a 13-hour period of continuous Global Hawk observations during the rapid intensification of hurricane Karl. These observations were complemented by flights of NASA's DC-8, NOAA's P-3s and

NSF's G-V. In addition, a large number of satellite observations were gathered to facilitate the mission planning and to provide the large-scale context for the detailed airborne observations (grip.jpl.nasa.gov).

The goal of our longer-term research is to use the detailed airborne observations to describe the storm evolution and to evaluate the operational hurricane model, asking the question "How does a model undergo a rapid intensification process and how representative is this process versus the reality?"

In a series of studies we will analyze observations and model to address the following questions: i) How does the warm core structure evolve and what is its origin? ii) What is the role of vortical hot towers versus that of the ordinary weaker updrafts (convective regions) that represent the bulk of the vertical velocity distribution? iii) What is the role of convective organization in relation to the warm core?

To address these questions, we will analyze HAMSR's temperature and humidity profiles in the hurricane eye to describe and understand the structure and the evolution of the warm core and its relation to the evolution of the convective structure in the eyewall. To describe this convective structure from observations we will first look at HAMSR brightness temperatures from the high-frequency channels that depict the ice-scattering signatures in the convective cores. In a later step we will use HIWRAP/APR2 reflectivity profiles to analyze in more details the vertical structure of the convective region. Furthermore, we will use dropsondes and satellite observations (AIRS/AMSU) of the thermodynamics outside the storm to understand the relative roles of internal structure changes versus environmental moisture.

A special focus of our study will be the evaluation of the operational Hurricane Weather Research and Forecasting (HWRF) modeling system. We will analyze the model fields in a similar fashion to understand why was the model right this time? Was it for the right reason? In addition, we will evaluate the forecasts from a number of different cycles in order to understand how the initial conditions and the large-scale environment impact the forecasted evolution. To facilitate the evaluation of the forecasted convective structure, we will use the model fields and will run them through a radiative transfer model to produce brightness temperatures and radar reflectivity observed by airborne and satellite instruments. In a follow-up study, we will analyze forecasts produced by the Hurricane EnKF Data Assimilation System (HEDAS) that is currently developed at NOAA's Hurricane Research Division in order to further highlight the importance of vortex initialization.

In this presentation we will: i) describe all available observations; ii) present preliminary results on the observed evolution of the warm core; iii) describe the storm structure as observed by the high-frequency brightness temperatures; iv) present similar analysis from the HWRF forecast, focusing on the forecasted warm core evolution and on the simulated brightness temperatures from one of the HWRF forecast cycles.

Observations of C-band brightness temperatures and ocean surface wind speed and rain rate from the Hurricane Imaging Radiometer (HIRAD)

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HIRAD flew on the WB-57 over Earl and Karl during NASA's GRIP (Genesis and Rapid Intensification Processes) campaign in August – September of 2010. HIRAD is a new C-band radiometer using a synthetic thinned array radiometer (STAR) technology to obtain cross-track resolution of approximately 3 degrees, out to approximately 60 degrees to each side of nadir. (The resulting swath width for a platform at 60,000 feet is roughly 60 km, and resolution for most of the swath is around 2 km.) By obtaining measurements of emissions at 4, 5, 6, and 6.6 GHz, observations of ocean surface wind speed and rain rate can be retrieved. This technique has been used for many years by precursor instruments, including the Stepped Frequency Microwave Radiometer (SFMR), which has been flying on the NOAA and USAF hurricane reconnaissance aircraft for several years to obtain observations within a single footprint at nadir angle.

Results from the flights during the GRIP campaign will be shown, including images of brightness temperatures, wind speed, and rain rate. Comparisons will be made with observations from other instruments on the GRIP campaign, for which HIRAD observations are either directly comparable or are complementary. Features such as storm eye and eyewall, location of storm wind and rain maxima, and indications of dynamical features such as the merging of a weaker outer wind/rain maximum with the main vortex may be seen in the data. Potential impacts on operational ocean surface wind analyses and on numerical weather forecasts will also be discussed.

Session 4b
Observations and Observing Strategies for Tropical Cyclones and their Environment, Part 2

Hurricane and Severe Storm Sentinel (HS3): A Multi-year Investigation of Atlantic Hurricanes

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The HS3 objectives are:

- To obtain critical measurements in the hurricane environment in order to identify the role of key factors such as large-scale wind systems (troughs, jet streams), Saharan air masses, African Easterly Waves and their embedded critical layers (that help to isolate tropical disturbances from hostile environments).
- To observe and understand the three-dimensional mesoscale and convective-scale internal structures of tropical disturbances and cyclones and their role in intensity change.

The mission objectives will be achieved using two Global Hawk (GH) Unmanned Airborne Systems (UASs) with separate comprehensive environmental and over-storm payloads. The GH flight altitudes (>16.8 km) allow overflights of most convection and sampling of upper-tropospheric winds. Deployments from Goddard's Wallops Flight Facility and ~26-hour flight durations will provide coverage of the entire Atlantic Ocean basin, and on-station times up to 5-22 h depending on storm location. Deployments will be in September of 2012 and from late-August to late-September 2013-2014, with up to eleven 26-h flights per deployment.

Measurements from the Environmental GH Payload

- Continuous sampling of temperature and relative humidity in the clear-air environment from the scanning High-resolution Interferometer Sounder (S-HIS).
- Continuous wind profiles in clear air from the TWiLiTE instrument beginning in 2013.
- Full tropospheric wind, temperature, and humidity profiles from the Advanced Vertical Atmospheric Profiling System (AVAPS) dropsonde system, which is capable of releasing up to 89 dropsondes in a single flight.
- Aerosol and cloud layer vertical structure from the Cloud Physics Lidar (CPL).

Measurements from the Over-Storm GH Payload

- Three-dimensional wind and precipitation fields from the High-altitude Wind and Rain Airborne Profiler (HIWRAP) conically scanning Doppler radar.
- Surface winds and rainfall from the Hurricane Imaging Radiometer (HIRAD) multi-frequency interferometric radiometer.
- Temperature, water vapor, and liquid water profiles, rain rates, and vertical precipitation profiles from the High-Altitude MMIC Sounding Radiometer (HAMSR).

Results from 2011 test flights, including comparisons of coordinated dropsonde releases with the NOAA G-IV aircraft, will be discussed.

An Advanced Dropsonde System For Hurricane Reconnaissance And Surveillance

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A new automated High Definition Sounding System (HDSS), which includes an Automated Dropsonde Dispenser (ADD) and new eXpendable Digital Dropsonde (XDD) instrument, has been developed for closely-spaced, in-situ profiling of hurricane inner-core features as well as their environment from either manned or unmanned aircraft. In addition to providing measurements of Pressure-Temperature-hUmidity (PTU) as well as vertical and horizontal wind at a sampling frequency of 4 Hz, the XDD measures sea surface temperature with a small infrared sensor and splash in-situ temperature. The ADD automatically Quality Controls (QCs) and deploys an XDD device as rapidly as one every five seconds, and can simultaneously monitor up to 40 sondes in flight. The system automatically screens and QC inspects sounding data post deployment. A new burst transmission communication strategy provides for low noise and reduced data dropouts in the sonde observations. The auto-checking and auto-deployment of the XDD within the ADD provides for improved safety of flight and operator situational awareness. It is anticipated that the HDSS will result in improved sonde post-deployment data QC by DropSonde Operators (DSOs) as well as TEMP DROP message QC sent via SATCOM by Air Force AWROs on WC-130J aircraft and NOAA flight directors on WP-3D and GIV aircraft. For planned operations on the NASA Global Hawk in 2013-14, and on other UAV aircraft, it is expected that HDSS will result in a low percentage of bad sondes.

To validate the data quality of the XDD, two test flights were conducted by the Navy Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) in June, 2011 aboard the P-256 Twin Otter aircraft. Fourteen YES XDD and Vaisala RD-94 sonde intercomparisons were made from simultaneous deployments against calibrated aircraft instruments and surface buoys located off the coast of California. Flights demonstrated XDD overall system reliability on par with RD-94 technology. Excellent PTU/Winds agreement, and excellent agreement between the XDD and buoy SST, is established via statistical analysis.

New eyewall dropsonde observations during rapid intensification events in Super-Typhoons Megi (2010) and Jangmi (2008)

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Unique dropsonde observations were obtained from WC-130J aircraft flights within and near the eyewalls of two Super-Typhoons (STYs): Megi and Jangmi, during the Impact of Typhoons on the Ocean in the Pacific (ITOP) and Tropical Cyclone Structure (TCS08) field programs conducted in the Western North Pacific in 2010 and 2008, respectively. These flights on 12-13 Oct, 2010 and 27 Sept, 2008 occurred during and following rapid intensification events resulting in peak SFMR surface wind speeds of 87- and 73 m/s, respectively, and minimum surface pressures of 890 and 905 mb. Of special interest were the dropsondes deployed in STY Megi (2010) using a new GPS module and thermodynamic observations at 4 Hz, twice the rate of older sondes. These improvements resulted in detailed wind and thermal observations all the way to the surface in 90% of the 16 Megi eyewall sondes deployed. Similar data in

eyewall extreme winds have been difficult to obtain in the past due to premature failure of wind observations well above the surface. One notable exception was the high-quality, extreme wind dropsonde observations in STY Jangmi's eyewall boundary layer, which are compared with those from Megi. These observations, together with Airborne eXpendable BathyThermograph (AXBT) profiles of sub-surface ocean temperature structure, were obtained from the WC-130J aircraft operated during these two projects by the dedicated crews of the U. S. Air Force Reserve Command's 53rd Weather Reconnaissance Squadron (Hurricane Hunters).

A unique aspect of the Megi observations was that most eyewall sondes were deployed in pairs closely spaced in time (typically one minute). The dropsonde pairs showed dramatically different boundary layer structures, and dramatically different surface wind speeds, which were remarkably consistent in different storm quadrants with one sonde showing relatively weak boundary layer wind shear and its partner showing extreme wind shear, a result due in part, to very different sonde trajectories within the eyewall. The highest winds near the top of the apparently well mixed layer were in excess of 100 m/s, and were associated with some of the lowest eyewall surface winds (strong shear), while strongest surface winds in excess of 85 m/s were associated with the weakest boundary layer wind shear. A well-defined surface layer extending to 50-100 m exhibited constant potential temperature (theta) and constant radial and tangential winds with height resulting in higher near-surface winds than would be suggested by the boundary-layer log law, applied in the past to estimate surface winds when only higher-level winds below 150 m (WL150) were available. Unusual high-theta layers were observed above the surface layer and within the supposedly well-mixed layer. Suggestions as to possible physical mechanisms responsible for the unusual variations in the inner core boundary layer structure will be presented.

Analysis of the Impact of Supplemental Dropwindsonde and Rawinsonde Observations on Model Track Forecasts of Hurricane Irene (2011)

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As Hurricane Irene approached the east coast of the United States in August 2011 a large number of supplemental observations were taken in an effort to improve operational analyses and model forecasts of the cyclone. The NOAA Gulfstream-IV jet flew 10 synoptic surveillance missions from 23-27 August and deployed between 22 and 36 dropwindsondes during each mission to collect data near and upstream of Irene, while one surveillance mission was flown by an Air Force Reserve C-130 aircraft on 23 August. In addition, supplemental 0600 and 1800 UTC rawinsondes were launched beginning at 1800 UTC 22 August from upper-air stations in the southeastern United States. Then, in an unprecedented move the coverage of the supplemental rawinsondes was then expanded to include all of the continental United States from the Rocky Mountains eastward beginning at 0600 UTC 25 August in an effort to better sample synoptic-scale flow features upstream of Irene.

In an attempt to quantify the impact of these supplemental data, data denial studies were performed for the dropwindsonde and supplemental rawinsonde observations. Analyses were created excluding the dropwindsonde and supplemental rawinsonde observations individually and then together using the National Centers for Environmental Prediction (NCEP) Gridpoint Statistical Interpolation (GSI) data assimilation scheme. The NCEP Global Forecast System (GFS) and Hurricane Weather Research and Forecasting (HWRF) models were run using the GSI analyses that excluded the supplemental

observations. Differences between the operational GFS and HWRF forecasts and the "data-denial" forecasts will be used to quantify the impact of the supplemental observations on the track forecast of Irene in both models.

Results suggest a small but overall positive improvement due to both the dropwindsonde and supplementary radiosonde observations on the track of Irene in the GFS. The dropwindsonde data showed the largest improvement in 2 to 3 day forecasts, while the supplemental rawinsondes showed the largest improvement at days 4 and 5. The supplemental data resulted in little change to the track of Irene in the HWRF model through day 3 and some degradation to the track at days 4 and 5.

Improving The Ocean Data Acquisition System (ODAS) For Research Aircraft

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In support of the Hurricane Forecast Improvement Project, this project is focusing on the design, implementation and testing of an improved oceanic data acquisition system for NOAA WP-3D aircraft. In collaboration with NOAA Aircraft Operations Center (AOC), Mark 10A receivers, Mark 21 processing units (and updated processing software and firmware), and Marantz 560 recorders were installed at station 5, together with three mini-computers. A keyboard/video/mouse unit is installed at station 2 to visualize incoming data and to remotely control the recording and processing of real-time signals. These new receiver units have sufficient bandwidth to receive, record and process data from Airborne eXpendable Current Profilers (AXCP) that require bandwidth of 200 kHz centered on the carrier frequencies of 170, 171.5 and 173 MHz for channels 12, 14 and 16, respectively. In addition, the new ocean data system is capable of receiving, recording and processing Airborne eXpendable Conductivity, Temperature and Depth Profilers (AXCTD) and the narrow-band Airborne eXpendable Bathythermographs (AXBT) signals.

We conducted two fairly extensive test flights in September and October 2011 from NOAA WP-3D (RF42) that included the deployment of all three, multiple channel profilers. In general, the new system performed well as the profiler success rate was between 80 to 85%. Some minor changes are being recommended to AOC streamline the process, which will be important during hurricane flights. However, considerable work remains on improving software for quality controlling the profilers on the aircraft and getting profiles (of temperature and salinity) off the aircraft in near-real time for the operational centers to assimilate into their ocean models.

Preliminary results from the AXBT demonstration project in support of hurricane coupled modeling products and improvement in guidance to NHC hurricane specialists

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The first year of the hurricane AXBT demonstration project mandated at the 65th Interdepartmental Hurricane Conference Working Group for Hurricanes and Winter Storms has been completed. This project was carried out as a collaborative effort between the 53rd WRS Hurricane Hunters and Naval Academy Midshipmen as part of the Training and Research in Oceanic and Atmospheric Processes In Tropical Cyclones (TROPIC) project. AXBTs were deployed on a no-cost, not-to-interfere basis, with tasked reconnaissance missions. A total of 107 AXBTs were deployed and transmitted in near-real time from the aircraft and ground station to Naval Oceanographic Office (NAVO) and NOAA Environmental Modeling Center from WC-130J aircraft on 12 flights comprised of 3 training flights and 9 storm flights in 4 storms, including Hurricane Irene where 40 AXBTs were deployed on 3 flights along the U. S. East Coast. A total of 85 AXBTs passed the NAVO quality control tests and were ingested into the Stennis ocean model and the coupled COAMPS-TC model. A preliminary description of the strategies employed and use of the data in two coupled modeling centers will be described.

In addition, operational and hindcast TC model runs were completed for cases in Tropical Storm Emily and Hurricane Irene with the fully Coupled Ocean/Atmosphere Mesoscale Modeling System (COAMPS®[1]), i.e. COAMPS-TC, which preliminarily suggested that the AXBT data had a positive impact on the ocean analysis used for the coupled forecast. Furthermore, the fully coupled COAMPS-TC model, utilizing data assimilation in the atmosphere and ocean, was used to examine the role of the upper-ocean thermal structure on the TC track and intensity. The sensitivity of COAMPS TC track and intensity predictions to operational AXBT observations was tested, and results from data denial experiments will be presented.

2012 Plans for NOAA's Intensity Forecast Experiment (IFEX)

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IFEX aims to collect observations throughout the tropical cyclone life cycle, develop and refine measurement technologies for real-time monitoring of TC intensity change. This season we will continue to address these goals. We plan to strengthen our partnerships within NOAA. NASA will be running their Hurricane and Severe Storm Sentinel field campaign and we will be coordinating flights with their Global Hawk Unmanned Arial System. Plans for the 2012 program will be presented.

[1] COAMPS is a registered trademark of Naval Research Laboratory

The Pre-Depression Investigation of Cloud Systems in the Tropics (PREDICT) Experiment: Scientific Basis, New Analysis Tools and Some First Results

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The principal hypotheses of a new model of tropical cyclogenesis, known as the marsupial paradigm, were tested in the context of Atlantic tropical disturbances during the National Science Foundation-sponsored Pre-Depression Investigation of Cloud systems in the Tropics (PREDICT) experiment in 2010. PREDICT was part of a tri-agency collaboration, with the National Aeronautics and Space Administration's Genesis and Rapid Intensification Processes (NASA GRIP) experiment and the National Oceanic and Atmospheric Administration's Intensity Forecasting Experiment (NOAA IFEX), intended to examine both developing and non-developing tropical disturbances.

During PREDICT, a total of 26 missions were flown with the NSF/NCAR GV aircraft sampling eight tropical disturbances. Among these were four cases (Fiona, ex-Gaston, Karl and Matthew) for which three or more missions were conducted, many on consecutive days. Because of the scientific focus on the Lagrangian nature of the tropical cyclogenesis process, a wave-relative frame of reference was adopted throughout the experiment in which various model- and satellite-based products were examined to guide aircraft planning and real-time operations. Here, the scientific products and examples of data collected by the PREDICT science team are highlighted for several of the disturbances. The suite of cases observed represent arguably the most comprehensive, self-consistent dataset ever collected on the environment and mesoscale structure of developing and nondeveloping pre-depression disturbances.

Planning for Success – An Operational Test Program for Unmanned Observing Strategies

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The technology readiness of unmanned aircraft systems (UAS) and autonomous surface vehicles (ASV) for robust operations has been rapidly increasing during the last decade. This progress can be attributed in large part to U.S. military investment in unmanned observing strategies. Additionally, Federal agencies such as National Aeronautic and Space Administration, National Ocean and Atmospheric Administration, National Science Foundation, US Geological Survey, and the US Forestry Service have been demonstrating the viability of unmanned platforms as civilian scientific observing systems. The hurdles of unmanned access to national and international air space will also be diminishing as governing policies and regulations are implemented during the next few years.

As unmanned observing systems are becoming routine components of scientific field experiments, the time has come to "plan for the success" of these robotic systems within an optimized operational observing strategy providing critical information for warnings and forecasts of high impact weather and disasters. Unmanned observing systems can provide increased range, endurance or data resolution when targeted adaptive strategies are needed to complement current operational observing systems. Unmanned observing systems could be especially effective filling critical data gaps associated with high impact weather systems, such as hurricanes, developing and intensifying in data void regions of the ocean. This presentation will discuss a concept for an interagency operational test program with a goal of improving 5-7 day forecasts of high impact oceanic storms starting in 2015. The ultimate mission of the test program will be to facilitate timely operational transition of unmanned observing strategies which have been maximized for measurable societal benefit, scientific return, cost-effectiveness, and operational efficiencies.

Session 5a
Tropical Cyclone Model Development and Technology Transfer, Part 1

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FY2012 Implementation of Advanced High-Resolution Triple-Nested HWRF at NCEP/EMC

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NOAA/NWS/NCEP/EMC

For the 2012 hurricane season, the NCEP/EMC operational Hurricane Weather Research and Forecast (HWRF) modeling system is being upgraded with triple-nest capability that includes a cloud-resolving inner most grid operating at 3 km horizontal resolution. This high resolution ocean coupled HWRF system is jointly developed by the HWRF team at NCEP/EMC and the hurricane modeling team at AOML/HRD, and was tested in real-time for the 2011 hurricane season through participation in and support from NOAA's Hurricane Forecast Improvement Project (HFIP). Results from retrospective and real-time runs from high-resolution HWRF for four hurricane seasons (2008-2011) indicated about 10-15% improvement in the intensity forecast skill compared to operational HWRF.

This presentation will provide an overview of advancements to the HWRF modeling system, with special emphasis on changes to model configuration and physics suitable for higher resolution. These include implementation of a new centroid based vortex tracking algorithm, re-design of the operational HWRF initialization procedure with improved interpolation algorithms, modifications to GFS PBL, Shallow Convection and Ferrier Microphysics parameterization schemes and further advancements to air-sea physics and ocean coupling.

The HWRF team at EMC has been very creative in optimizing codes and getting the most out of the computing as possible, and have made tremendous effort to fit the model to run in the operational window for the 2012 hurricane season with very little additional resources –a significant achievement associated with science and engineering. Details of computational efficiency experiments will be discussed along with a detailed pre-implementation strategy adopted for 2012 hurricane season. Preliminary results indicate significant improvements in track and intensity forecast skill compared to current operational HWRF. Better representation of hurricane structure is expected as a result of the higher resolution, advanced physics and improved vortex initialization procedures. High-resolution model diagnostics will be presented with a focus on comparisons to available aircraft and remotely sensed observations.

FNMOC Collaborations in Tropical Cyclone Forecasting and Aids

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The Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California provides operational tropical cyclone (TC) forecast models and aids in all ocean basins. All of our products are dependent on critical collaborations with the research and development community. Our primary partner is the Naval Research Laboratory (NRL) in Monterey, California, which developed the Navy Operational Global Atmospheric Prediction System (NOGAPS) [Rosmond *et al.,* 2002] from which we provide the NGPS tropical cyclone track aid. In addition, NOGAPS provides the members of our Ensemble Forecast

System from which we create a 20-member ensemble TC tracker aid, distributed as NG01, NG02,…NG20. Finally, we provide track and intensity guidance using the Navy's implementation of the Geophysical Fluid Dynamics Laboratory hurricane model (GFDN) [Rennick, 1999], which is embedded within the NOGAPS. Here, we have benefitted from a long-standing collaboration with GFDL and the University of Rhode Island. We discuss recent upgrades to each of our operational systems.

Furthermore, we discuss a variety of efforts to improve the FNMOC suite of TC aids in 2012. First, the dynamic core of the global atmospheric forecast system will be replaced by a semi-Lagrangian/semi-implicit formulation developed by NRL. The new system is called the Navy Global Environmental Model (NAVGEM). NAVGEM will enable higher-resolution implementations and will replace NOGAPS for all applications. Second, FNMOC plans to provide a new set of TC track and intensity aids for the 2012 season based on a new NRL formulation of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) which is optimized for tropical cyclone analysis and prediction (COAMPS-TC) [Doyle, 2011]. Third, FNMOC expects to provide a novel ocean wave product which provides estimates of the wave fields associated with the atmospheric forcing implied by official TC forecasts from the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center. Finally, in collaboration with the Naval Postgraduate School, FNMOC will add the JTWC historical best track data archive to the Advanced Climatology Analysis and Forecast system, which will be upgraded to include TC analysis tools.

Advancing NOAA's HWRF prediction system through enhanced physics of the air-sea coupling and ocean model initialization

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This is a collaborative effort between the URI, NOAA's EMC/NCEP and ESRL, focusing on the development of new and enhanced HWRF model physics of air-sea processes that are suitable for high resolution. This effort will lead to a new, fully coupled Atmosphere-Ocean-Wave system for operational hurricane forecasting, with a triple-nested (27/9/3km) HWRF atmospheric model, POM or HYCOM ocean model, and a multi-grid WAVEWATCH III wave model.

The coupled system requires a comprehensive, physics-based treatment of the wind-wave-current-sea spray interaction to simulate the impact of these processes on the tropical cyclone track, intensity, and structure. It is developed based on a flexible coupling infrastructure, capable of incorporating the knowledge of various time scales of the physical processes directly into the coupler, which facilitates additional physical computations as required by the component models. A generic coupling infrastructure with a modular coding is required to address the needs of the next generation high-resolution triple-nested HWRF.

The URI research group is evaluating the impact of initializing the ocean component of HWRF/POM with the global HYCOM daily data analysis, as opposed to the currently operational feature-based initialization. The global HYCOM has been used in the operational NCEP RTOFS ocean initialization since October 25, 2011. One of the key potential advantages of global HYCOM initialization is that the ocean currents and transports are sufficiently accurate. By contrast, the feature-based initialization requires a subsequent spin-up of ocean currents prior to the coupled HWRF model forecast. Evaluation of the global HYCOM-based initialization in the HWRF/POM coupled system will be discussed.

Comparison and Evaluation of Two ABL Mixing Schemes in HWRF

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This presentation highlights major results from a series of numerical experiments with NOAA's Hurricane WRF (HWRF) model that were carried out for the purpose of comparing and evaluating two atmospheric boundary layer (ABL) mixing schemes: the GFS K-profile closure scheme and the Mellor-Yamada-Janjić 1.5-order TKE closure scheme. The two schemes are driven by the same surface layer scheme in the sensitivity experiments so that only the sensitivity of the HWRF model to different formulations of the ABL mixing above the surface layer is examined. We will first compare the sensitivity of the asymptotic behavior of the HWRF-simulated intensification of an idealized tropical cyclone to the two ABL mixing schemes. We will then compare the vertical eddy diffusivities from the two ABL mixing schemes with those estimated from observations. Finally, we will compare the assumptions embedded in the formulations of the two schemes. Using the results from the sensitivity experiments and the comparisons of the ABL mixing scheme formulations, we will point out and, more importantly, provide an explanation for an unintended consequence of using the GFS scheme in the simulation of tropical cyclones: overestimation of vertical eddy diffusivity in the eyewall region. Based on our findings, we will propose a possible route that the HWRF research community could take for improving the boundary layer physics in the operational HWRF model.

Creation of a Statistical Ensemble for Tropical Cyclone Intensity Prediction

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A statistical-dynamical intensity guidance ensemble from available regional and global dynamical models is being developed as part of the Hurricane Forecast Improvement Project (HFIP). Statistical Prediction of Intensity from a Consensus Ensemble (SPICE) was created in 2011 based off combining two current statistical-dynamical models, the Logistic Growth Equation Model (LGEM) and the Statistical Hurricane Intensity Prediction Scheme (SHIPS). The operational versions of both LGEM and SHIPS rely on large-scale environmental predictors from the Global Forecast System (GFS) model fields along the interpolated official forecast track as input to forecast the change in tropical cyclone intensity.

SPICE combines the operational SHIPS and LGEM intensity guidance with SHIPS and LGEM runs based off the large-scale environments in the Geophysical Fluid Dynamics Laboratory (GFDL) and Hurricane-Weather Research and Forecasting (HWRF) regional models. The six total forecasts are combined into two unweighted consensuses: one from the three SHIPS forecasts and one from the three LGEM forecasts. The two unweighted consensuses are then combined into one weighted consensus, with the weights determined empirically from the 2008-2010 official SHIPS and LGEM sample. These

weights favored the SHIPS consensus in the early time periods, shifting to the LGEM consensus being weighted more heavily after about 36 hours.

Retrospective tests of SPICE over the 2008-2010 Atlantic hurricane seasons indicated that SPICE outperformed both SHIPS and LGEM at all lead times, and the improvements were statistically significant at almost all times. SPICE was run real-time during the 2011 season as part of HFIP, and results from the season will be presented here. Possible improvements for the 2012 season will also be discussed, including the addition of the Coupled Ocean/Atmosphere Prediction System (COAMPS-TC) and additional regional and global models.

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.

Real-time ACCESS-TC: Vortex Specification, 4DVAR Initialization, Verification and Structure Diagnostics

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A partnership between the Bureau of Meteorology and CSIRO

The Australian Community Climate and Earth System Simulator, ACCESS has been configured for operational and research applications on Tropical Cyclones. The base system runs at a resolution of 0.11^0 and 50 levels. The domain is re-locatable and nested in coarser-resolution forecasts. Initialization consists of 5 cycles of 4DVAR over 24 hours and forecasts to 72 hours are made. Without vortex specification, initial conditions usually contain a weak and misplaced circulation. Based on estimates of central pressure and storm size, vortex specification is used to filter the analysed circulation from the original analysis, construct the inner-core of the storm, merge it with the large scale analysis at outer radii, and locate it to the observed position. Using all available conventional observations and only synthetic surface pressure observations, the 4DVAR builds a balanced, intense 3-D vortex with a secondary circulation. Synthetic cloud imagery from the model is used to validate initial conditions and forecasts against actual satellite imagery. Mean track and intensity errors for Australian region storms during 2010-2011 are rather encouraging, as are results from real-time running at the Australian NMOC over the NW Pacific during 2011. From preliminary diagnostics, we illustrate interesting structure change features during intensification, dissipation, extratropical transition and landfall. Current limitations, future enhancements and research applications will also be briefly discussed.

The Potential Benefit of HIWRAP Doppler Radar Radial Velocity Data During HS3: An example From Hurricane Karl (2010)

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This study utilizes ensemble Kalman filter (EnKF) observation system simulation experiments (OSSEs) to analyze the impact of assimilating radial velocity observations with the high-altitude imaging wind and rain airborne profiler (HIWRAP) for Hurricane Karl. HIWRAP is a new Doppler radar mounted upon the

NASA Global Hawk unmanned airborne system, which has a cruising altitude of about 19 km and flight duration of 30 h. The radar uses conical scans with incidence angles of 30 and 40 degrees and produces data over a 30-40-km wide swath. The Global Hawk has the benefit of much longer range and on-station capabilities than conventional aircraft, which gives it the ability to observe tropical cyclones from a unique perspective. Thus, the Global Hawk is a desirable addition to other observation platforms, and quantification of the impact of these new observations is needed.

To set up the experiment, a high-resolution mesoscale ensemble is first created using the Weather Research and Forecasting (WRF) model at a convective permitting resolution. From this ensemble, the 'truth' is selected as the member that best represents Hurricane Karl for it's nearly 36-h track across the Bay of Campeche. Simulated data is then obtained from this simulation and assimilated with an EnKF into the remaining 30 members of the ensemble. Results are examined to determine the impact of assimilating such data. To do this, the accuracy of EnKF analyses is assessed, and ensemble and deterministic forecasts initialized from the EnKF analyses and perturbations are performed and compared to the pure ensemble forecast with no assimilation. In addition, multiple sensitivity experiments are examined, including changes to the truth, the assimilation start time, flight track through the simulated system, and random observation error.

Session 5b
Tropical Cyclone Model Development and Technology Transfer, Part 2

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Past, Present and Future of Coupled HYCOM-HWRF System (HyHWRF)

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At the stage where the next generation coupled hurricane forecast model development at NCEP has reached maturity and global applicability, we present the progress, including results from pre-operational parallel model tests. EMC/NCEP/NWS/NOAA has developed a coupled HYCOM- HWRF (HyHWRF) model as an alternative for the operational coupled HWRF-POM model, by a collaboration effort between Marine Modeling and Analysis Branch and HWRF team. Real-time parallel prediction exercises for the past three seasons have repetitively assured comparable forecast capability, even without having HWRF properly turned to HYCOM. Since October 25, 2011, a global ocean forecast model (RTOFS-Global, a HYCOM implementation) is in production at NCEP. This establishment has provided a new framework where not only the ocean component of HyHWRF can integrate IC/BC effectively anywhere in the world, but also HWRF is able to perform as a coupled mode for the Eastern Pacific with a capability to extend to other basins. The future plan of new HyHWRF includes full ocean data assimilation. The goal is to ensure a best possible ocean initial condition for coupled mesoscale systems, and also to assimilate AXBT data along with other observations, in order to fill data scarcity in the storm field where other measurements are impossible. Preliminary results of the data assimilation effort will be presented.

NCEP Ocean Modeling in support of TC forecasting

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The Marine modeling and Analysis Branch (MMAB) of the Environmental Modeling Center (EMC) of the National Center for Environmental Prediction (NCEP) provides ocean guidance for the National Weather Service (NWS), and the general US public in general. Recent implementation and upgrades of the model suite, as well as planned upgrades have provides new and improved guidance products directly and indirectly for Tropical Cyclone (TC) forecasting. The corresponding discussion will focus on

- The recently implemented Global Real Time Ocean Forecast System (RTOFS-Global), providing a daily 6 day global ocean forecast at 1/12° spatial resolution. This model was implemented in close collaboration with the US Navy, are consists of the corresponding Navy global HYCOM model, using Navy initializations and NCEP forcing.

- The recent upgrades to the hurricane wave models, dramatically including coastal resolutions, adding shallow water physics, and adding new wind sea and swell products.
- Development on global coupled hurricane modeling by further development of a coupled HYCOM-HWRF-wave model with full ocean data assimilation capability. This model is critically dependent on RTOFS-Global and includes new capabilities in the wave model geared to full three-way modelcoupling.

An Overview of Recent COAMPS-TC Development and Real-Time Tests

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A new version of the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC) has been developed specifically for forecasting tropical cyclone track, structure and intensity. In the presentation, we will provide an overview on the recent development and performance of COAMPS-TC. The COAMPS-TC has been tested in real time in both coupled and uncoupled modes over the past several 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 2008 ONR THORPEX Pacific Asian Regional Campaign (T-PARC) and the ONR Tropical Cyclone Structure-08 (TCS08) and 2010 Interaction of Typhoon and Ocean Project (ITOP), which took place in the W. Pacific, and iii) pre-operational testing of COAMPS-TC in W. Pacific basin. An evaluation of a large sample of real time forecasts for 2010-2011 in the Atlantic basin reveals that the COAMPS-TC intensity predictions have lower intensity errors than any other real time dynamical forecast models for forecast lead times of 36-120 h. As an example, real-time forecasts for Hurricane Irene (2011) illustrate the capability of COAMPS-TC to capture both the intensity and the fine-scale features in close agreement with observations. Evaluation of real-time COAMPS-TC forecasts will be presented using the ITOP and HFIP datasets with a focus on challenges and successes related to tropical cyclone intensity prediction. Additionally, highlights from a ten member 5 km horizontal resolution COAMPS-TC ensemble that was run over the W. Atlantic and W. Pacific basins during 2011 will be presented. The results of this research highlight the promise of high-resolution deterministic and ensemble-based approaches for tropical cyclone prediction using COAMPS-TC.

Diagnostic Verification Of COAMPS-TC Performance For The HFIP Retrospective Forecasts

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COAMPS-TC is a version of the Coupled Ocean/Atmosphere Mesoscale Prediction System designed specifically for prediction of tropical cyclones (TCs). Recently, a large sample of retrospective COAMPS-TC forecasts of storms in the Atlantic and Eastern Pacific basins was produced in support of the Hurricane Forecast Improvement Project (HFIP). This large sample of cases (over 700 forecasts) provides an excellent testbed for the application of advanced TC forecast verification methods. Here, we show an array of verification tools designed to comprehensively assess track and intensity forecast performance, with particular emphasis on overall and conditional forecast biases. Our verification approach incorporates graphical techniques to effectively display the forecast and the corresponding best-track observations, summary measures to encapsulate different attributes of forecast quality (accuracy, bias, etc.), and box-and-whiskers plots to represent the salient features of the forecast error distribution (quantiles, outliers). In addition, we will also show an example in which the verification data sample is stratified according to the best-track intensity at the forecast initial time, in order to assess how

COAMPS-TC forecast performance varies as a function of initial intensity. Overall, we will demonstrate that in-depth characterization of the quality of COAMPS-TC forecasts can lead to a much more complete understanding of model performance than can be derived from traditional summary accuracy measures alone.

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 (JNT) Program focuses on the verification of experimental forecasts of tropical cyclones (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 tropical cyclone forecast models. For the Hurricane Forecast Improvement Project (HFIP), the TCMT has designed and conducted verification studies involving various regional and global forecast 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. These methods include new diagnostic tools to aid, for example, in the evaluation of track and intensity errors and ensemble forecasts. Recently, the TCMT conducted a retrospective evaluation of eight experimental tropical cyclone forecast models that ranged from deterministic to ensemble forecast systems. These models were evaluated for storms that occurred in the 2008-2010 hurricane seasons in the North Atlantic and Eastern Pacific Oceans. The forecasts from these models were also evaluated for the 2011 HFIP demonstration experiment. This presentation will provide an overview of the evaluation methodology including new methods along with a summary of key results from the 2011 HFIP retrospective and demonstration studies.

Performance of Operational and HFIP-experimental Global Models during the HFIP 2011 Summer Demo and the Track-Intensity Error Relationship

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The performance of a suite of operational (NCEP-GFS, ECMWF-IFS, UKMO-UM, CMC-GEM, FNMOC-NOGAPS) and HFIP-experimental (ESRL-FIM and ESRL-GFS (EnKF) and ESRL-GFS (EnKF-ensemble) global models, during the northern Hemisphere 2011 tropical cyclone (TC) season, is evaluated. The main finding is that the deterministic run of the ECMWF model (since 2008) remains the superior track forecast aid in all basins, particularly in the medium range (48-120 h) and in the western North Pacific.

However, in the North Atlantic, the ESRL global model forecasts using the Ensemble Kalman Filter analysis (EnKF) were competitive with excellent NCEP-GFS forecasts in 2011. More significantly, the mean track from the ESRL-GFS (EnKF) and mixed GFS-FIM (EnKF) ensembles were the only ensemble

systems with greater skill than the higher-resolution deterministic model control run. Excepting the ESRL ensembles, the deterministic global model forecasts continue to provide the best track forecasts.

One of the main objectives of the NOAA Hurricane Forecast Improvement Project (HFIP) is to improve TC intensity prediction where little progress has been made over the last 20 years in the official forecasts. While any error is still an error, there is a notion that track and intensity errors may be uncorrelated, to the point that models with somewhat poorer track error can still provide improved intensity guidance.

The nature of the track-intensity error relationship is reviewed from two perspectives. The first perspective is by examining the statistical relationship, thorough scatter plots, of the bias-corrected errors for the individual models. The second method uses the SHIPS/LGEM statistical intensity-change forecast model to determine how the global model intensity from SHIPS/LGEM force (vice from the model fields) depends on the track used in SHIPS/LGEM model (e.g., model track v interpolated official forecasts). Studies by DeMaria et al. have shown that SHIPS/LGEM skill (intensity error) is strongly dependent on the input track. Implications of this analysis of track-intensity error for dynamical modeling will be addressed.

Community Support and Testing of the Hurricane WRF model at the Developmental Testbed Center

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The mission of the Developmental Testbed Center[*] (DTC – dtcenter.org) is to bridge the gap between research and operations across several key areas of the numerical weather prediction enterprise. Through partnership with NOAA's National Centers for Environmental Prediction (NCEP), the DTC transfers new technology to the Hurricane Weather Research and Forecasting (HWRF) model.
A paradigm for the transfer of new capabilities onto HWRF is that research geared towards near term operational implementation should be conducted with the operational model. To that effect, DTC has worked with NCEP to integrate the operational and community codes, creating a single code base to be used for all HWRF applications. This integrated HWRF model was used operationally during the 2011 hurricane season.

The DTC fosters the use of HWRF in research applications in several ways. First, the DTC provides public HWRF releases and community support. The latest release, HWRF v3.3a in August 2011, contains the eight components of HWRF, including the Princeton Ocean Model for Tropical Cyclones and a variational data assimilation system. The DTC also provides user support for HWRF, including a Users' Guide, scientific documentation, and a helpdesk. Additionally, resident and online tutorials are available at http://dtcenter.org/HurrWRF/users. There are currently 350 registered HWRF users from 34 countries.
Public releases of HWRF code correspond to the configuration used in the last operational season and occur approximately once a year. Additionally, the DTC now provides experienced developers with experimental code through a code repository hosted by the DTC. Accessing the code in this way allows researchers to work in state-of-the-art code and to deliver their contributions back to a centralized location. Currently, 33 expert users obtain code through this method, and the DTC supports 11 developers in adding their contributions.

In addition to providing support, the DTC has also established a functionally-equivalent testing infrastructure. This infrastructure helps to ascertain the quality of the integrated HWRF model and provides benchmarks of the community code so that researchers have a control to compare their innovations against. These aspects assist the DTC in establishing the HWRF Reference Configurations (dtcenter.org/config). In this presentation, we will describe the community HWRF system and show results of recent HWRF testing and evaluation activities.

Systematically Merged Atlantic Regional Temperature and Salinity (SMARTS) Climatology: Application to Hurricane Earl

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The new climatology, known as the Systematically Merged Atlantic Regional Temperature and Salinity (SMARTS) Climatology, carefully blends temperature and salinity fields from several climatologies (Meyers 2011). SMARTS was calculated from the monthly climatologies by applying a 15-day running average to eliminate discontinuities when transitioning between months at 1/4° spatial resolution. Using SMARTS with satellite-derived surface height anomaly and sea surface temperature (SST) fields from multiple platforms such as TOPEX and Jason and the TRMM Microwave Imager (TMI), estimations of isotherm depths and oceanic heat content (OHC) values have been estimated from 1998 to 2010 data set using a two and one-half layer model approach. These satellite estimates have been compared to more than 45,000 in-situ temperature profiles from airborne and ship-deployed expendable bathythermographs, long-term moorings in the Equatorial Atlantic Ocean, and Argo profiling floats over the basin. Thus, this revised approach creates a more accurate estimation of isotherm depths and OHC from satellite radar altimetry missions, which can then be used in hurricane intensity forecasts from the Statistical Hurricane Intensity Prediction Scheme.

During the joint NASA and NOAA field campaign in 2010, pre-storm SST distribution suggests little ocean structure relative to the track of hurricane Earl (2010). Subsequent to Earl's passage, the wake is obvious in the surface signatures after mixing of the surface water with the underlying ocean mixed layer northwest of the area of rapid intensification. The OHC field suggests a few areas of high OHC relative to Earl's track. In these "hot spot" areas, the OHC exceeded 75 kJ cm^{-2} which is substantially larger than the ~17 kJ cm^{-2} needed to sustain a hurricane. In the areas of highest OHC, Earl rapidly intensified to category 4 over a 12 to 18 hour interval. Based on a nearby Argo profiling float measurements, pre and post-storm OHC values were 65 and 53 kJ cm^{-2} respectively resulting in a difference of ~12 kJ cm^{-2} just northwest of the area of Earl's rapid deepening. In addition, the ocean mixed layer deepened by ~ 25 m from the prestorm state, which is within the envelope of oceanic observations acquired during severe hurricanes. Under relatively favorable atmospheric conditions, the ocean provided a sustained level of heat to Earl through the air-sea fluxes that exceeded 1 kW m^{-2} based on GPS sonde data. This type of behavior is observed in the Gulf of Mexico whenever hurricanes encounter the Loop Current and its warm eddy field.

Session 6
Other Research to Improve the Prediction of Tropical Cyclone Intensity and Structure, Track, Precipitation, Coastal and Inland Inundation

Thermodynamic Aspects of Tropical Cyclone Spin-up

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The dynamic and thermodynamic aspects of tropical cyclone (TC) formation near the center of the wave pouch, a region of approximately closed Lagrangian circulation within the wave critical layer, are examined through diagnoses of a high-resolution numerical simulation and dropsonde data from a field campaign. As a region of strong rotation and weak shear/strain deformation, the wave pouch center serves as a focal point for diabatic merger of vortical hot towers (VHTs) and their vortical remnants. The meso-β area near the pouch center is also characterized by high saturation fraction and small difference in equivalent potential temperature (θ_e) between the surface and the middle troposphere. Sustained deep convection tends to occur near the center of the wave pouch, and the strong vertical and radial gradients of latent heat release can effectively force the transverse circulation and spin up a proto-vortex near the surface. A tropical storm forms near the pouch center via system-scale convergence in the lower troposphere and vorticity aggregation.

The analysis of dropsonde data shows that the mid-level θ_e increases significantly near the pouch center one to two days prior to genesis but changes little away from the pouch center. This may indicate convective organization and the impending TC genesis, and also suggests that the critical information of TC genesis near the pouch center may be masked out if spatial average is taken over the pouch scale.

Diurnal Pulsing of Tropical Cyclones: An Overlooked Yet Fundamental TC Process?

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New GOES infrared satellite imagery has been developed to continuously monitor changes in the cloud top convective and cirrus canopy structure of tropical cyclones. This satellite imagery has also revealed a curious diurnal pulsing pattern that may represent an unrealized, yet fundamental process of mature tropical cyclones. “Cool rings” can be tracked in the infrared that begin forming in the storm's inner core at sunset each day. Similar to ripples that form after a pebble is thrown into a pond, the “cool ring”, or pulse, continues to move away from the storm overnight, reaching areas several hundred kilometers from the storm center by the following afternoon. There appear to be marked structural changes and disruptions to a storm as this pulse evolves and moves out from the inner core each day. The timing and propagation of these "cool rings" also appears to be linked to the diurnal cycle, making them remarkably predictable. Discussion will include: 1) Examples of recent and historical tropical cyclones exhibiting diurnal pulsing; 2) Diurnal pulse characteristics, hypothesized triggers, and potential predictability; 3) Tropical cyclone diurnal pulsing sampling strategies for the 2012 Atlantic Hurricane season.

Wind Speed Retrieval from Digital Communication and GPS Signals

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Accurate measurements of key ocean parameters such as wind speed, wind direction, and sea surface height are critical for accurate atmospheric and weather modeling. One promising method of measuring these parameters uses ocean-reflected signals of opportunity: navigation and communication signals transmitted by satellites. Until recently, Global Navigation Satellite System (GNSS) signals were primary signals used for measuring ocean parameters in bistatic parameters. However, GNSS-derived resolution and sensitivity are limited due to relatively low power of transmitted signals, a time-varying geometry of the navigation satellites due to their location in middle-Earth orbits, and the confinement of signal transmission to the L-band. In contrast, communication signals provide more accurate measurements due to nature of the system, including high-power broadcast signals, wide transmission bandwidth, and geostationary orbit of transmitters.

This study presents the results of wind speed retrieval from ocean-reflected XM Radio signal data recorded by an aircraft flying over Chesapeake Bay. In this experiment, raw data from both directly-received and ocean-reflected signals of XM satellites was in an aircraft flying at altitudes between 8,000-11,400 ft. Recorded direct and reflected signals were cross-correlated to generate waveforms that were compared to theoretical models. Non-linear least-squares fit was applied to data using scattering models to retrieve wind speed. The estimated wind speed was 7.2m/s for signals from “Blues.” Chesapeake Lighthouse recorded a wind speed of 7.5m/s during the test flight. This result indicates that theories developed for bistatic radar using GNSS signals can be extended to communication signals.

A Monte-Carlo simulation performed using synthetic waveforms to compare the retrieval error for XM radio, DirecTV, and GNSS-R up-to hurricane level wind-speed (150 m/s), results of which is shown in figure 1. A Monte-Carlo approach predicted errors of 0.3-1.2% from simulated reflected XM radio signals, less than 0.3% from simulated reflected DirecTV signals with high gain antenna, 3-14% from simulated reflected DirecTV signals with low gain antenna, and 2.5-6.5% from simulated reflected Global Navigation Satellite System (GNSS-R) signals. This low predicted error for XM radio signals was attributed to the higher (~30 dB compared to GNSS-R) power in the XM radio signal. The availability of communication satellite transmissions, in all frequency bands used for remote sensing, opens the possibility of using signals of opportunity as low-cost alternatives to radiometry or scatterometry.

A New Approach to Limited Area Forecasting of Tropical Cyclone Intensity

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The role of limited area models (LAMs) in tropical cyclone (TC) forecasting would appear to be rather precarious at present. Global models, such as those developed and maintained by NCEP and ECMWF, perennially outperform limited area models with respect to track forecasting, whereas statistical models (e.g. SHIPS, LGEM), driven by environmental predictors derived from the global models, routinely demonstrate superior performance when forecasting TC intensity. Both results point toward the fact that the global models, by virtue of their formulation, sophisticated physics, mature data assimilation methodologies, etc., are better able to simulate the large-scale environment which both steers TCs and, to large degree, modulates their intensity.

However, that being said, it is also true that the spatial resolution of global models currently (and likely for some time to come) prohibits their being able to resolve the core dynamics of TCs, thereby rendering processes such as rapid intensification and secondary eyewall formation unpredictable dynamically. It has long been hoped that LAMs, with their nesting capabilities, could provide access to this final frontier of TC forecasting, but thus far it has proven to be elusive. Numerous remedies have been prescribed to correct the deficiencies, among them increased model resolution, physics development and data assimilation techniques of increasing complexity and cost. While all offer promise, here we investigate the efficacy of a simpler and more cost effective technique using our LAM, the University of Wisconsin Nonhydrostatic Modeling System (UW-NMS).

Recognizing the strength of the global model in delivering the large-scale environment, we employ a two-domain configuration which relaxes toward the GFS solution on a greater portion of the outermost domain while allowing the moving nest to evolve freely. Results indicate that this technique appreciably improves both the track and intensity forecasts when compared to the traditional, completely freely-evolving solutions obtained as part of our participation in the Hurricane Forecast Improvement Project's (HFIP) 2011 Demonstration.

CLIQR: A climatological analog matcher to ongoing tropical cyclone

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In 2008, the Hydrometeorological Prediction Center attempted to find a better way of sorting through its tropical cyclone rainfall database, so it could be used more effectively by operational forecasters. The web page format was not considered ideal; as some forecasters could not remember the year certain storms occurred, while others didn't want to sort through long lists of storms which hit various regions of the lower 48 United States, Puerto Rico, and Mexico in either alphabetical or chronological order.

After some thought, and a summer student dedicated to the significant task of coding the utility within a few programming languages (Kyle Griffin), including C-shell, Perl, and Tcl/Tk within a couple months' time, a GUI was quickly developed for use within the HPC LINUX environment which automatically runs between one and three hours after synoptic time, matching possible analogs primarily by the storm's current position, its size as defined by its radius of outermost closed isobar (ROCI), and its forward motion. It became experimental in August 2008 and continues to run, utilizing tropical cyclone information from the CHGHUR/tropical cyclone objective guidance messages generated by the National Hurricane Center (NHC).

Since the tropical cyclone rainfall database stretches back into the 1950's, an archive of relevant track information for the northeast Pacific and northern Atlantic oceans for this time frame was collated into one data file, starting with the extended best track database (EBTD) which is derived by the Cooperative Institute of Research in the Atmosphere (CIRA) at Colorado State University from the National Hurricane Center's ATCF workstation. However, the database only begins in 2000 for the northeast Pacific basin and 1988 for the Atlantic Basin, and at the time, tropical depression information was just being digitized into an Atlantic non-developmental database for the northern Atlantic basin (1967-1987 time frames). A week-long trip down to the NOAA Miami Regional Library and NHC filled in most of the tropical depression track information during August 2008, while annual typhoon articles from the Joint Typhoon Warning Center were used to get tropical depression track information from the northeast Pacific for the 1960s, with Monthly Weather Review articles for the northeast Pacific depressions used for tropical depression information from the 1970s and 1980s.

For older years, the Atlantic and eastern Pacific hurricane databases (HURDATs) were expanded into the EBTD format. In order to gather the ROCI and value of the pressure of the outermost closed isobar (POCI) for older storms, a variety of North American (1954-1990), Northern Hemisphere (1966-1982), older Miami Forecast Office surface analyses (1956), and the Hurricane Map Series (1949-1961) were digitized at the NOAA Central Library in Silver Spring, Maryland, the University of Virginia in Charlottesville, and the NOAA Miami Regional Library. Copies of these maps were sent to the National Climatic Data Center (NCDC) after being scanned and placed on the HPC cloud (N: drive), where the developing surface analysis archive is being housed. The maps are being reanalyzed to determine the ROCI and POCI for the Atlantic systems within the database, with the ultimate goal of determining values for all North Atlantic and northeast Pacific tropical cyclones. This data will help along with the Atlantic Hurricane Re-analysis effort, which has been spearheaded by NHC since 2000.

Invited Speaker

Seven Years Later, Florida's Citrus Production Continues to Languish

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In August-September 2004, Florida's citrus belt was battered by Hurricanes Charley, Frances, and Jeanne. Little more than a year later, in October 2005, Hurricane Wilma tore across southern Florida, inflicting further damage. Prior to the disastrous hurricane activity, Florida's orange production had reached 242.0 million boxes in 2003-04—second only to the 244.0 million-box total in 1997-98. (Note: Florida's box weights vary by fruit but generally range from 85 to 90 pounds.) Following Charley, Frances, and Jeanne, orange production fell sharply to 149.8 million boxes in 2004-05. Wilma further harmed citrus potential, cutting the 2005-06 production to 147.7 million boxes in 2005-06. Florida's grapefruit crop was similarly damaged by the 2004 hurricane activity, with production falling from 40.9 million boxes in 2003-04 to 12.8 million boxes in 2004-05—the state's lowest output since 1935-36. In 2005, Wilma stayed south of Florida's primary grapefruit area, allowing 2005-06 production to recover slightly to 19.3 million boxes.

Although no hurricanes have struck Florida since Wilma, a variety of factors have prevented Florida's citrus industry from completely recovering from the 2004 and 2005 storms. Citrus-bearing acreage was already in decline when the hurricanes hit, from a modern high of 815,100 acres in 1996-97 to 679,000 acres in 2003-04. Acreage has continued to decline annually since the hurricane years, to just 517,100 acres in 2009-10—the latest year for which state-level information is available. One reason for the decline in acreage has been commercial and residential development in Florida's winter agricultural belt, although the rate of loss has slowed during the nation's economic downturn. Florida's citrus industry has also been contending with two serious pest issues—citrus canker and greening disease—the spread of which may have been exacerbated by the hurricane activity in 2004 and 2005. Finally, Florida's citrus belt has endured several recent episodes of cold weather, particularly in December 2010. As a result, Florida's highest post-hurricane orange production has been 170.2 million boxes in 2007-08. Prior to the 2004-05 hurricanes, Florida's orange production topped 200 million boxes in nine of ten years from 1994-95 to 2003-04. Florida's grapefruit industry has been even slower to recover, with post-hurricane production peaking at 27.2 million boxes in 2006-07. Prior to Hurricanes Frances and Jeanne, which struck the heart of the east coast grapefruit region, Florida's production had not been below 30 million boxes since 1963-64.

Interestingly, the total economic impact on the citrus industry of the 2004 and 2005 hurricanes has been hard to measure. For example, the price of oranges per box skyrocketed from $2.89 in 2003-04 to $10.28 in 2006-07. As a result, the value of Florida's orange production to producers rose from just under $700 million in 2003-04 to more than $1.3 billion in 2006-07. Prices per box have generally fallen since 2006-07 but remain above pre-hurricane levels.

Panels:
Effective Communications: An Important Key to Saving Lives

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Invited Speaker

When Science Meets Decision Making: How Visualization and Real-Time Collaboration Enables Impact-Based Decision Making

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Effective communication is critical in delivering any message that requires action. ‘Seeing is believing’ and the challenge of creating accurate visualizations is key to moving decision making to the next level. As an introduction to the final panel discussions of the day, Dave will kick off the morning discussing how real-time collaborative technology and powerful visualizations enabled the State of Maryland to exceed expectations when it came to preparing for Hurricane Irene last August while delivering critical geospatial information from the comforts of home to the center of the State Emergency Operations Center (SEOC). Dave will also introduce the concept of a ‘Shared Federal Briefing’ concept that cuts across the entire federal, state and local government space, leverages data holdings and enables geo-collaboration for rapid situational awareness and enhanced decision making. Effective communication is more than just words…“They **can** hear (and see) what we are saying and they **will** respond.”

Social Media in Disasters: What We Know Thus Far.

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Gaining information during an emergency is becoming easier for the public; there are a wide variety of channels from which to choose. However, it is important that emergency alerts come from a credible, reliable, timely source that encourages citizens to take protective action when necessary.

Based on what we know social media are becoming useful tools during emergencies because it has the ability to aid in warnings, communication, search and rescue, coordination of resources, collaboration among volunteer groups, and dissemination of information agencies. Currently, a wide ranging demographic of individuals and organizations use social media. By design, social media can alert the public, disseminate educational information to the public, link individuals to social ties for verification, and give information on what to do next.

While often thought of as most useful during the preparedness phase, social media can be useful during all phases of disaster. In the presentation, we will discuss how social media are currently used in disaster management, how the concept of social media is connected to convergence and emergent norm theories, as well as the benefits and drawbacks to using social media. Additionally we will discuss the newer technologies such as mobile applications and connecting platforms can link with social media to further educate the public on preparedness, locate local emergency shelters, coordinate resources and give information on protective actions.

TV, Radio, Mobile Alerting for Weather Emergencies: And the Winner is…

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The Emergency Alert System (EAS) in November 2011 transmitted its first national test to all TV and radio broadcast stations and the public; and in 2012 more people will begin receiving emergency information via their mobile devices through the Commercial Mobile Alert System (CMAS). These systems provide lifesaving information and can demonstrate how reliant (or *not*) the public is on them for source information. The reality is the public is becoming more proactive in their own safety as it relates to obtaining emergency communications. More than ever, the flow of information is dependent upon how people interact in person and on-line. The advent of consumer generated on-line content has impacted emergency communications, altering the flow of information from a controlled, top-down, linear model to a multi-linear, simultaneous flow of information from bottom up, top-down and laterally (peer-to-peer). People may trust TV and radio but they refer to social media and the mobile Internet to get rapid response information from emergency management agencies, friends, and other news and information outlets. The Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC) conducted focus groups with people with sensory disabilities (blind, low vision, hard of hearing and deaf) on the day of the national EAS test to explore the effectiveness and accessibility of the test message. This presentation will focus specifically on how people with sensory disabilities viewed the effectiveness of EAS to deliver its alert over TV, radio and compare it to how they view the effectiveness of receiving emergency information over mobile wireless devices. The discussion will also touch on how modes of communications such as social media can provide avenues for dissemination of emergency information. It will conclude with recommendations on how to leverage the unique features of television and radio broadcast of emergency alerts, and mobile emergency alerting over wireless networks using national policies to assure greater accessibility to citizens with disabilities.

Assessing Improvement in the Public Understands of the Risks Due to Storm Surge Through the Use of a Surge Visualization Model

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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 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. Only participants will be provided the confidential address of a home web page that 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.

If the visualization model proves successful, we envision two audiences for the model. The first will be educational, where people will use the model while no hurricane is present to improve their understanding of hurricane surge while also assessing which areas are particularly vulnerable to surge. This will assist in land use planning, home construction and other uses. The second audience will be those examining the latest NWS projections when a hurricane landfall is imminent. The visualization model could easily be modified to incorporate the latest SLOSH projections to provide realtime surge estimates. However, these are longterm uses of the visualization model that will only be implemented if the surveys demonstrate model effectiveness.

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Poster Session

P O S T E R S E S S I O N

Changes to the National Hurricane Center (NHC)
Tropical Disturbance Satellite Rainfall Estimates

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The current NHC Satellite Rainfall Estimate text product produces storm-relative rainfall amounts every 6 hours by applying the Griffith-Woodley technique to infrared satellite imagery. Significant improvements to satellite rainfall estimation techniques have occurred since Griffith-Woodley was developed in 1978. Today's most sophisticated satellite rainfall estimates blend polar microwave data with geostationary infrared imagery to provide rainfall rate estimates. The new blended techniques refresh the rainfall rate associated with a system based on the latest microwave passes and then propagate that rain rate forward based on movement seen in the infrared imagery. The resulting products combine the strengths of both instruments: accurate rainfall rates from microwave and high temporal resolution from geostationary.

During the 2011 hurricane season, NHC began producing experimental satellite rainfall estimate text and graphical products from two blended satellite rainfall estimation techniques available in near-real time:

- NRL-Blend – Blended technique from the U.S. Navy
- QMORPH – Blended technique from the NCEP Climate Prediction Center

Archived data from both of these techniques were evaluated, and both techniques were determined to be reasonable replacements for the Griffith-Woodley technique.

In addition to the two blended products, a rainfall forecast from the most recent GFS model run covering the same time period as the satellite rainfall estimates is also included for comparison in the experimental text and graphical products. The rainfall distribution from the satellite and model sources is provided in land-based coordinates every 6 hours when there is a tropical cyclone or invest system tracked by NHC. The text product provides rainfall estimates over a 6° latitude by 6° longitude region, with rainfall amounts to the nearest 10 millimeters provided in a range over each 1° degree latitude by 1° longitude grid box. The graphical products cover a 10° latitude by 10° longitude area. All of the products are centered at the latest NHC best track position for tropical cyclones and invests. In 2012, NHC should also have the ability to create these system-specific products for other heavy rainfall events in the NHC area of responsibility.

The NHC Experimental Tropical Rainfall webpage hosts these rainfall estimate products as well as 6- and 24-hour rainfall forecasts from the GFS, HWRF, and GFDL models.
http://www.nhc.noaa.gov/experimental/rainfall/

Towards Predicting Short-Term Intensity Using TC Structure Patterns from Recon and HURSAT Data

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While there have been numerous thrusts in TC numerical modeling, statistical and consensus models continue to have the highest predictive skill for intensity forecasts. These top performers respectively use environmental parameters and bias-correction. One potential caveat of these methods is that diagnosis of the TC core and structure is not well captured. Nevertheless, Piech (2007) has shown through aircraft reconnaissance measurements that there are specific regimes of hurricane core observations at different intensities, indicating a relationship between the structural organization and intensity of TCs. Murray (2009) has further demonstrated predictive skill that exceeds current operational methods using statistical analysis of such core observations.

However, a lack of regular in-situ observations remains the largest obstacle to operational inner-core based intensity forecasts. To overcome such a challenge, satellite measurements from the HURSAT database (Knapp 2008) are used to diagnose TC structure and intensity as a proxy to reconnaissance flights. An analogue to reconnaissance observations gathered from 1991-2010 is produced for all worldwide TCs from 1987-2009 using ARCHER software (Wimmers and Velden 2010) to more accurately determine the satellite-imaged TC center. Eye size and symmetry information provided by reconnaissance is replicated through HURSAT/ARCHER analysis. Satellite measurements of TCs are also used to determine proxy temperature and moisture assessments of the TC eye and core regions and are related to in-situ reconnaissance data. In addition, satellite-based metrics of inner-core structure are explored to characterize the TC beyond current reconnaissance capabilities (such as spatial, temporal, and measurement limitations). For example, two-dimentional patterns of raw brightness temperatures and derived physical parameters such as liquid water path are tested for utility in distinguishing regimes of current and future TC intensity.

Storm-centric view of Tropical Cyclone cold wakes

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Tropical cyclones (TCs) have a dramatic impact on the upper ocean. Storm-generated oceanic mixing, high amplitude near-inertial currents, upwelling, and heat fluxes often warm or cool the surface ocean temperatures over large regions near tropical cyclones. These SST anomalies occur to the right (Northern Hemisphere) or left (Southern Hemisphere) of the storm track, varying along and across the storm track. These wide swaths of temperature change have been previously documented by in situ field programs as well as IR and visible satellite data. The amplitude, temporal and spatial variability of these surface temperature anomalies depend primarily upon the storm size, storm intensity, translational velocity, and the underlying ocean conditions. Tropical cyclone ‘cold wakes’ are usually 2 - 5 °C cooler than pre-storm SSTs, and persist for days to weeks. Since storms that occur in rapid succession typically follow similar paths, the cold wake from one storm can affect development of subsequent storms.

Recent studies, on both warm and cold wakes, have mostly focused on small subsets of global storms because of the amount of work it takes to co-locate different data sources to a storm's location. While a number of hurricane/typhoon websites exist that co-locate various datasets to TC locations, none provide 3-dimensional temporal and spatial structure of the ocean-atmosphere necessary to study cold/warm wake development and impact.

We are developing a global 3-dimensional storm centric database for TC research. The database we propose will include in situ data, satellite data, and model analyses. Remote Sensing Systems (RSS) has a widely-used storm watch archive which provides the user an interface for visually analyzing collocated NASA Quick Scatterometer (QuikSCAT) winds with GHRSST microwave SSTs and SSM/I, TMI or AMSR-E rain rates for all global tropical cyclones 1999-2009. We will build on this concept of bringing together different data near storm locations when developing the storm-centric database. This database will be made available to researchers via the web display tools previously developed for RSS web pages. The database will provide scientists with a single data format collection of various atmospheric and oceanographic data, and will include all tropical storms since 1998, when the passive MW SSTs from the TMI instrument first became available.

A Web-Based Interactive Interface For Researching And Forecasting Tropical Cyclone Genesis And Intensity Using The Deviation Angle Variance Technique

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In this interactive presentation we will demonstrate the web-based interface that is under development for external researchers to use the University of Arizona Deviation Angle Variance Technique (DAV-T) to study and forecast tropical cyclone genesis and tropical cyclone intensity in the North Atlantic, western North Pacific, and eastern North Pacific basins. The DAV-T is a method that has been developed over the last several years that provides an objective assessment of the intensity of a tropical cloud cluster by quantifying symmetry in geostationary brightness temperature infrared imagery from the GOES-E, GOES-W, and MT-SAT platforms. The technique assesses the symmetry of a system by computing the deviation of the cloud cluster from perfect symmetry.

The DAV-T interface is being designed to allow external users to access the DAV output for both historical data in research mode or for real-time data in forecast mode. Currently, only the historical data are available in the Atlantic (2004 – 2010), Western North Pacific (2009 – 2011), and Eastern North Pacific (2004 – 2010) basins. We plan to have the system available in forecast mode for the second half of 2012 in the Atlantic and western North Pacific basins. The interface allows the researcher or forecaster to call up the available IR imagery and associated variance maps, automatically detect cloud clusters that satisfy a user-defined variance threshold, and overlay historical storm tracks for analysis purposes. We are planning an interactive database system that will allow users to track cloud clusters of interest for genesis forecasting, but this feature is not currently available. The DAV-T Interface Tool will be running at the presentation of this poster.

Development of a Hybrid Statistical-Dynamical Wind Speed Probability Model

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In an effort to incorporate global model track guidance into the Monte Carlo Wind Speed Probability (MCWSP) product, a hybrid statistical-dynamical wind speed probability model has been developed. Past efforts include a project where, under JHT support, MCWSP estimates were refined by making the underlying track error distributions a function of the Goerss Predicted Consensus Error (GPCE), which is itself a function of global model track spread. The GPCE modification improved the forecast skill of the MCWSP and was implemented in the operational version of the MCWSP in 2010. This project, which is a part of the Hurricane Forecast Improvement Project (HFIP), investigates another more direct method for incorporating global numerical model track information into the MCWSP. Forecast tracks from 93 global model ensembles are substituted in for the MCWSP-derived track realizations to create a hybrid statistical-dynamical wind model. Preliminary quantitative verification of the Atlantic prototype suggest the hybrid statistical-dynamical wind speed probabilities may have improved forecast skill over the MCWSP probabilities at longer forecast times. These results, along with plans for future product development and testing, will be presented.

A Case Study Of The Intensification Of Hurricane Maria (2011)
In A Real-Time COAMPS-TC Prediction

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The intensity forecast for Hurricane Maria (2011) proved to be quite challenging for the limited-area dynamical TC models, both operational (HWRF, GFDL, GFDN) and real-time experimental (e.g. COAMPS-TC). Like the aforementioned operational models, COAMPS-TC consistently over-intensified Maria, particularly for forecasts with initial times between 00 UTC September 11 and 00 UTC September 13, when Maria was in close proximity to an upper-tropospheric trough. Here, we examine a representative real-time COAMPS-TC forecast from this interval in order to diagnose why the model over-intensified Maria. The 200-mb wind forecast is compared with atmospheric motion vectors to assess the accuracy of the predicted interaction of Maria's outflow with the trough, and the forecast radar reflectivity is compared with microwave imagery to qualitatively validate the predicted spatial distribution of deep convection. Additional diagnostics concerning the tilt of the predicted vortex and the middle and upper tropospheric moisture in the vicinity of the predicted TC are also presented. These diagnostics show that COAMPS-TC was able to maintain active deep convection near the low-level center and a fairly upright vortex early in the forecast (unlike the observed TC), despite the seemingly hostile atmospheric environment provided by the trough. Subsequently, the forecast TC separated from the trough and the vertically-coherent vortex was able to take advantage of the improved environmental to intensity, whereas in reality the less-organized Maria was not able to do so. To conclude the case study, we speculate about the roles of the initial conditions and the model physics in

promoting this unrealistic 'resilience' of a COAMPS-TC predicted vortex to a hostile atmospheric environment.

Diagnostic Verification of Experimental Model Forecasts for Hurricane Irene and Maria

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As part of the Hurricane Forecast Improvement Project (HFIP), the Tropical Cyclone Modeling Team (TCMT) in NCAR's Joint Numerical Testbed (JNT) Program has designed evaluation methods and conducted verification analyses for the various regional and global forecast models that participate in the annual HFIP retrospective and near real time forecast demonstration studies. During the 2011 HFIP demonstration experiment, a variety of experimental models were run in near real time to support the HFIP's goal of improving forecasts of tropical cyclone track and intensity. The forecast model systems included deterministic, statistical, and ensemble configurations. For this study, the TCMT conducted in-depth evaluations of the forecast systems for two hurricanes: Irene and Maria. These two hurricanes were well-developed systems that occurred in the North Atlantic. Hurricane Irene made landfall along the Eastern US whereas Hurricane Maria remained over water throughout its lifecycle. These two storms provide a unique prospective to examine model performance with and without land interactions. This study focuses on traditional statistical evaluation of track and intensity errors, but also examines other aspects such as the sensitivity of the results to sample size and evaluation of sources of errors in the model forecasts. This presentation will highlight the key results from the two case studies.

Analysis of Aircraft Observations in Tropical Cyclones Using SAMURAI

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Research and operational aircraft have collected a wealth of tropical cyclone observations during recent successful field experiments and reconnaissance missions. A variety of available data types and flight patterns in tropical cyclones provide both unique challenges and opportunities for aircraft data analysis. A new finite-element based variational technique called SAMURAI (Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation) has been developed in order to integrate aircraft observations from multiple instruments into comprehensive mesoscale composites. A distinguishing characteristic of the SAMURAI technique compared to other 3DVAR packages is the use of a finite-element approach that is similar to a spectral transform method, but uses the cubic B-spline as a basis. The basis is computationally efficient and continuously differentiable to second order, allowing for accurate interpolation to observation locations, flexible incorporation of boundary conditions, and high numerical accuracy of kinematic derivatives. SAMURAI analysis can be performed with only a mass continuity constraint to ensure high fidelity to the data, or can be performed using a priori background information from global or other mesoscale analysis if desired. For tropical cyclone observations, analysis can be performed directly in a 2D axisymmetric cylindrical coordinate system or in a 3D Cartesian coordinate system. The 2D solver improves the computational efficiency and minimizes potential errors in mass conservation that arise when interpolating from a three-dimensional domain. A 3D cylindrical mode is currently in development. This poster will present an overview of the new technique, validation using synthetic data, and some multi-scale analyses of tropical cyclones that combine in situ, satellite, dropsonde, and Doppler radar data.

A comparison of modeled and observed ocean heat content using in-situ ocean observations collected during operational weather reconnaissance flights in Tropical Storms Don and Emily (2011)

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Results from recent field programs in the western North Pacific reveal that data from AXBT ocean observations improved the accuracy of coupled model tropical cyclone (TC) forecasts. The Hurricane AXBT Demonstration Project was mandated at the 65th Interdepartmental Hurricane Conference Working Group for Hurricanes and Winter Storms to assess the impact of AXBT ocean observations collected during operational hurricane missions (where significantly fewer sensors are deployed) on coupled model TC forecast accuracy.

The first year of this Hurricane AXBT Demonstration Project has been completed, and here we present differences in modeled and observed values of ocean heat content (OHC) during Tropical Storms Don (over the Gulf of Mexico) and Emily (over the Caribbean Sea). Observed values of ocean heat content were determined using thermal profile data from AXBTs released from USAF Hurricane Hunter WC-130J aircraft during operational missions. Model values of ocean heat content were determined using thermal profile data from the Intra-Americas Sea Nowcast/Forecast system (IASNFS), a 1/24 degree (~6-km equivalent) horizontal resolution with 41 sigma surfaces in the vertical that initializes ocean conditions using the 1/8 degree global Navy Coastal Ocean Model (NCOM).

Initial results of this research indicate a model tendency to consistently underestimate ocean heat content, which may reveal a systematic model bias toward lower hurricane intensities, as well as a possible cause for errant forecasts during rapid intensification periods. Further analysis is underway to (a) compare these results to those from the western North Pacific field program data using the East Asian Seas Nowcast Forecast System (EASNFS) and to (b) investigate the implications of these variations in OHC on TC intensity using statistics-based intensity forecast techniques.

An Advanced Dropsonde System For Hurricane Reconnaissance And Surveillance

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A new automated High Definition Sounding System (HDSS), which includes an Automated Dropsonde Dispenser (ADD) and new eXpendable Digital Dropsonde (XDD) instrument, has been developed for closely-spaced, in-situ profiling of hurricane inner-core features as well as their environment from either manned or unmanned aircraft. In addition to providing measurements of Pressure-Temperature-hUmidity (PTU) as well as vertical and horizontal wind at a sampling frequency of 4 Hz, the XDD measures sea surface temperature with a small infrared sensor and splash in-situ temperature. The ADD automatically Quality Controls (QCs) and deploys an XDD device as rapidly as one every five seconds, and can simultaneously monitor up to 40 sondes in flight. The system automatically screens and QC inspects sounding data post deployment. A new burst transmission communication strategy provides for low noise and reduced data dropouts in the sonde observations. The auto-checking and auto-deployment of the XDD within the ADD provides for improved safety of flight and operator situational awareness. It is anticipated that the HDSS will result in improved sonde post-deployment data QC by DropSonde Operators (DSOs) as well as TEMP DROP message QC sent via SATCOM by Air Force AWROs on WC-130J aircraft and NOAA flight directors on WP-3D and GIV aircraft. For planned operations on the NASA Global Hawk in 2013-14, and on other UAV aircraft, it is expected that HDSS will result in a low percentage of bad sondes.

To validate the data quality of the XDD, two test flights were conducted by the Navy Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) in June, 2011 aboard the P-256 Twin Otter aircraft. Fourteen YES XDD and Vaisala RD-94 sonde intercomparisons were made from simultaneous deployments against calibrated aircraft instruments and surface buoys located off the coast of California. Flights demonstrated XDD overall system reliability on par with RD-94 technology. Excellent PTU/Winds agreement, and excellent agreement between the XDD and buoy SST, is established via statistical analysis.