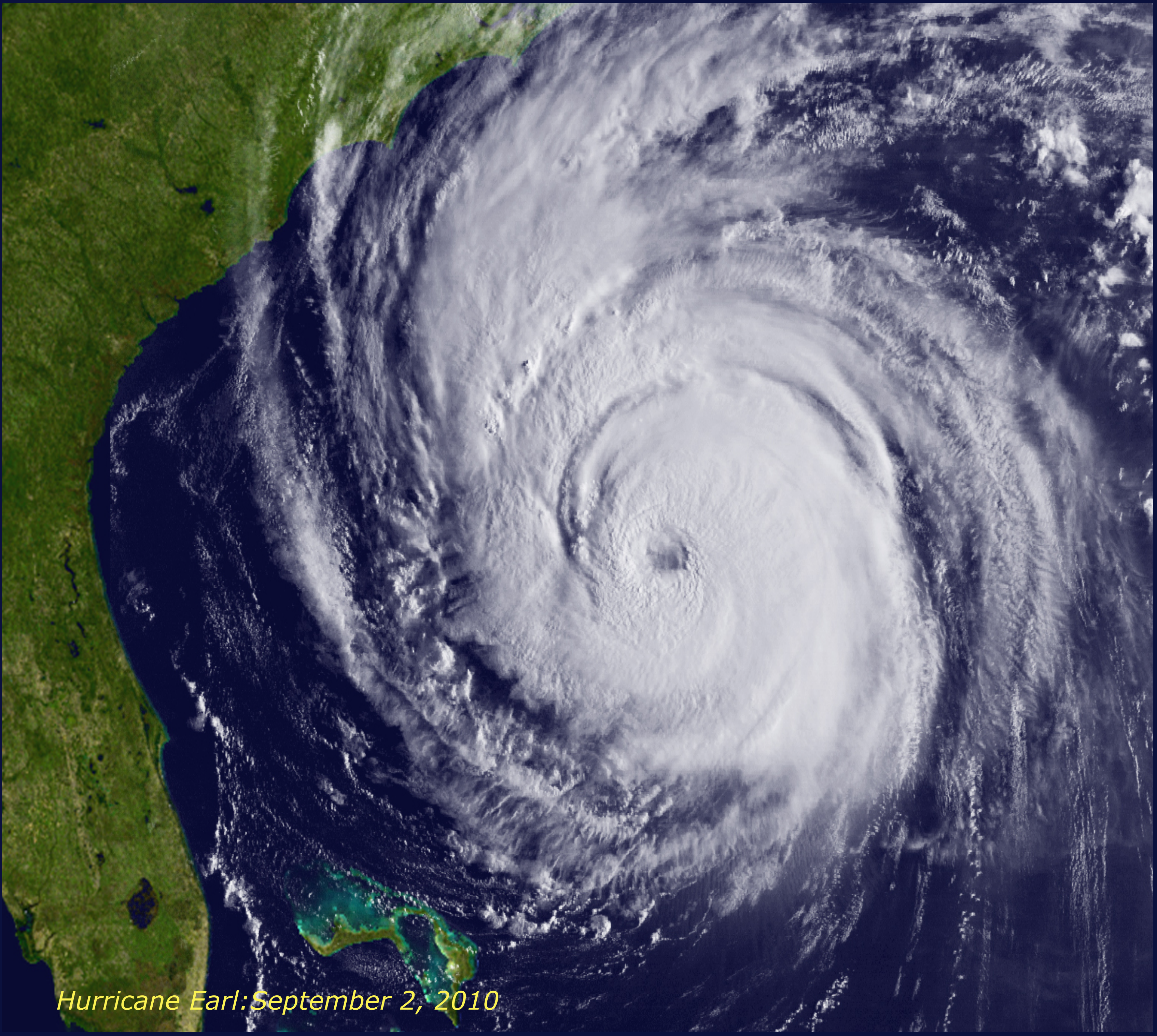
65th Interdepartmental Hurricane Conference

Miami, Florida

February 28 - March 3, 2011



Ocean and Atmospheric Influences on Tropical Cyclone Predictions: Challenges and Recent Progress

Session 2
The 2010 Tropical Cyclone Season in Review

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The 2010 Atlantic Hurricane Season:
Extremely Active but no U.S. Hurricane Landfalls

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The 2010 Atlantic hurricane season was quite active, with 19 named storms, 12 of which became hurricanes and 5 of which reached major hurricane intensity. These totals are well above the long-term normals of about 11 named storms, 6 hurricanes, and 2 major hurricanes. Although the 2010 season was considerably busier than normal, no hurricanes struck the United States. This was the most active season on record in the Atlantic that did not have a U.S. landfalling hurricane, and was also the second year in a row without a hurricane striking the U.S. coastline. A persistent trough along the east coast of the United States steered many 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 Tropical Storm Hermine, which brought hurricane-force wind gusts to south Texas along with extremely heavy rain, six fatalities, and about $240 million dollars of damage. Hurricane Earl was responsible for four deaths along the east coast of the United States due to very large swells, although the center of the hurricane stayed offshore.

Overview of the 2010 Eastern North Pacific Hurricane Season

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The 2010 eastern North Pacific hurricane season was historically the least active on record. Only seven tropical storms developed, three of which became hurricanes. This is the lowest number of tropical storms and hurricanes observed since routine satellite reconnaissance of the basin began in 1971. Five tropical depressions formed this season that did not strengthen into tropical storms. The Accumulated Cyclone Energy (ACE) index for 2010 was 46% of the long-term median. This is the third lowest ACE value, ahead of only the 2007 and 1997 seasons. Although the season was inactive, Tropical Storm Agatha was a high impact event causing 160 deaths and significant damage to portions of Central America and Mexico. This, along with other season highlights will be presented. In addition, some of the operational challenges encountered during the season will also be discussed.

2010 Atlantic and Eastern North Pacific
Forecast Verification

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A verification of official track, intensity, and genesis forecasts from the National Hurricane Center during the 2010 season will be presented, along with a discussion of the performance of the guidance models.

Review of the 2010 Central Pacific Tropical Cyclone Season and Preliminary Verification

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Deputy Director, Central Pacific Hurricane Center (CPHC)

In 2010, there was one tropical cyclone to have formed in or moved into the central Pacific. Tropical Storm Omeka originated as a subtropical storm west of the dateline and transitioned into a tropical cyclone just east of the dateline on 20 December 2010. CPHC will present an overview of Tropical Storm Omeka, the preliminary verification, changes for the 2011 season, and recent staff changes.

A Review of the Joint Typhoon Warning Center 2010 Tropical Cyclone Season

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Joint Typhoon Warning Center

A review of the 2010 tropical cyclone activity with discussion of significant events for the JTWC Pacific and Indian Ocean forecast areas of responsibility will be presented.

53d Weather Reconnaissance Review of the 2010 Hurricane Season

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53d Weather Reconnaissance Squadron

The 2010 hurricane season was a slightly below average year for the 53d Weather Reconnaissance Squadron with 981.4 total flying hours (compared to 1062 average flying hours per season over the previous 10 years). Although the storm season seemed relatively slow due to the lack of storms in the Gulf of Mexico, we stayed very busy flying the majority of our flights in the Caribbean Sea and Atlantic Ocean. We flew a total of 100 tasked missions meeting 97% of our requirements.

Overall, the Stepped Frequency Microwave Radiometer once again performed reasonably well on ten WC-130J aircraft, providing critical surface wind speed and rainfall rate data to the customer. Operator experience increased with the instrument and valuable inputs and improvements to instrument performance were accomplished.

NOAA Aircraft Operations Center (AOC)
2010 Seasonal Summary and Future Plans

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NOAA Aircraft Operations Center

After a relatively slow season in 2009, during which NOAA aircraft flew a total of 62 flights and 326 hrs, the 2010 season was a bit more active with its three hurricane aircraft, two WP-3Ds and the Gulfstream G-IV, flying 71 flights for 453 hours. These flights, in addition to storm flights, included trips for public awareness, such as the Gulf Coast Hurricane Awareness Tour and the Governor's Hurricane Conference, test and calibration flights as well as several transit flights.

Of significance during the 2010 season was the joint NASA, NOAA and NSF operation that utilized a number of aircraft from each of the Agencies in a study of tropical storm genesis and rapid intensification. In addition to NOAA's three aircraft, NASA provided its DC-8, aWB-57 and Global Hawk. The NSF provided the Gulfstream G-V. These aircraft often flew coordinated patterns associated with tropical systems in the Atlantic and Caribbean. The three NOAA aircraft also obtained the most comprehensive data set on the development and decay of a tropical system when they flew Hurricane Earl practically from the cradle to the grave – from genesis to extra-tropical transition.

AOC continues to upgrade its aircraft and instrumentation, and in 2011 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 avionics upgrade on N44RF, NOAA's 3rd P-3
- Complete integration of new aircraft data system (AAMPS) on the NOAA P-3s
- Complete installation of new AXBT receivers on both P-3s

Session 3
Observations and Observing Strategies for Tropical Cyclones and their Environment, Part 1

SESSION 3

Microwave sounder observations during GRIP: Preliminary results

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The High Altitude MMIC Sounding Radiometer (HAMSR), a microwave sounder similar to but more advanced than the AMSU sounders now operating on multiple satellites, was deployed on the Global Hawk unmanned aircraft during the Genesis and Rapid Intensification Processes (GRIP) hurricane field campaign during August and September 2010. HAMSR was developed at the Jet Propulsion Laboratory more than ten years ago and has been flown in several hurricane field campaigns. It was recently upgraded with the latest technology and is now the most sensitive and accurate sensor of its kind. Using observations from previous field campaigns, a new algorithm has been developed that makes it possible to emulate a radar and derive reflectivity profiles from the observed brightness temperatures. We present preliminary results from GRIP, including close-up views of the convective structure of Hurricane Karl as it intensified to category 3. The Global Hawk flew over Karl for 13 hours and passed over the eye 20 times during this period, and with HAMSR it is possible to analyze the three-dimensional convective structure of the inner core as it evolves. And since HAMSR is a sounder, it is also possible to analyze the thermodynamic structure in areas surrounding the core. GRIP was operated in coordination with NOAA and the NSF, and observations were collected from numerous sensors on multiple aircraft platforms. The analysis of this rich data set is just beginning.

NPP Microwave-sounder Based Tropical Cyclone Products

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NESDIS provides several Advanced Microwave Sounding Unit (AMSU)-based operational tropical cyclone (TC) intensity and structure guidance products. Using temperature retrievals corrected for scattering and attenuation a number of tropical cyclone products are generated. These products include storm-centered radius vs. pressure profiles of temperature and gradient winds, objective estimates of 1-min maximum sustained surface winds, minimum sea level pressure, the radii of 34-, 50-, and 64-kt winds in the northeast, southeast, southwest, and northwest quadrants, and balanced horizontal winds on standard pressure levels from 1000 hPa to 100 hPa within 600 km of tropical cyclones. Product algorithms use statistical methods to remove temperature biases due to scattering and attenuation, and by using NCEP boundary conditions and hydrostatic balance heights fields can be estimated. Statistical analysis is then used to estimate intensity and wind radii from storm-centered azimuthally averaged fields and gradient wind estimates. The 2-dimensional winds are estimated on standard pressure levels by solving the non-linear balance equations.

With the launch of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) satellite, data from a new microwave sensor, the Advanced Technology Microwave Sounder (ATMS) which has ~35% smaller footprint than AMSU, will be available. This presentation will discuss the procedure and timeline for updating the AMSU-based TC intensity and structure products to use ATMS data and the potential product quality improvements that may result from the updates.

The 2010 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. Six products were chosen for demonstration at NHC during most of the 2010 Hurricane Season (1 Aug to 30 Nov). Five of the six were ABI products, which included 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, and super-rapid scan operations imagery. The sixth was a combined GLM and ABI product to predict rapid intensification using global model fields, infrared imagery and lightning input. 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 2010 will be summarized along with plans for a follow-on experiment during the 2011 Hurricane Season.

Development and validation of a capability for wide-swath storm observations of ocean surface wind speed

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HIRAD (Hurricane Imaging Radiometer) flew on the WB-57 during NASA's GRIP (Genesis and Rapid Intensification Processes) campaign in 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. By obtaining measurements of emissions at 4, 5, 6, and 6.6 GHz, observations of ocean surface wind speed and rain rate can be inferred. 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. The advantage of HIRAD over SFMR is that HIRAD can observe a +/- 60-degree swath, rather than a single footprint at nadir angle.

Results from the flights during the GRIP campaign will be shown, including comparison with SFMR of preliminary images of brightness temperatures, and possibly wind speed and rain rate. If available, comparisons will be made with observations from other instruments on the GRIP campaign, for which HIRAD observations are either directly comparable or are complementary. Potential impacts on operational ocean surface wind analyses and on numerical weather forecasts will also be discussed.

Developments in 2010 in in-flight real-time reporting of the directional ocean wave spectra using Wide Swath Radar Altimeter (WSRA) from the NOAA WP-3D Hurricane Reconnaissance Aircraft

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This JHT project focuses on developing the processing algorithms and real-time software needed to perform in-flight data processing for the newly-developed Wide Swath Radar Altimeter (WSRA). The WSRA is a novel digital beamforming radar altimeter developed with funding from the NOAA SBIR program, with additional support from the University of Massachusetts and DARPA.

In March of 2010, we had a partially-successful test flight. It was only a partial success because the WSRA's power amplifier worked only intermittently during the flight. The WSRA hardware was fixed by June 2010. Throughout the summer of 2010, ProSensing engineers worked on the implementation of the real-time processing code for the unattended operation of the WSRA system. This effort included optimization of the WSRA digital beamforming and range centroid tracking algorithms, conversion of the processing algorithms into a multi-threaded C application, and deployment of a multi-core PC processor to execute in-flight processing. In the new code we also implemented several WSRA algorithm improvements: (1) antenna beam pointing angle adjustment factor calculated based on the estimation of the antenna array width distortion caused by the lateral movement of the aircraft during the data integration time (2) incremental (looped) estimation of the range-to-surface in each beam weighed by the range estimates in the neighbouring beams, (3) automatic adjustment of the WSRA radar parameters as the auxiliary-reported aircraft's altitude changes, (4) streamlining and automating the backend processing which estimates the ocean wave directional spectra from the surface elevations, and (5) developing the script that would format the data products and transmit in-flight the WSRA output data file from the aircraft to the archiving and displaying computers at AOC in Tampa and NHC in Miami. Upon completion of the software development, the WSRA was shipped to AOC for the installation on WP-3D.

The WSRA was installed on the WP-3D aircraft mid-September, thereby missing the opportunity to fly on several reconnaissance flights in hurricane Earl. For the rest of the season the WSRA operated during one flight into a tropical disturbance south of Haiti and one reconnaissance flight into CAT-1 hurricane Karl. The second half of the hurricane season did not provide any additional opportunities to operate WSRA. All parts of the WSRA software were successfully tested, including the transmitting of the data to AOC. Software and hardware performance during flights have shown the feasibility of a fully-automated unattended operational WSRA. The two flights we've conducted illuminated some problems in the WSRA code which have been since corrected and tested. Currently, the WSRA is at AOC ready for operation during the 2011 hurricane season.

NOAA Proof of Concept Demonstrations of Hurricane Observing Strategies using Unmanned Aircraft Systems

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The NOAA Unmanned Aircraft Systems (UAS) Program is evaluating the feasibility of UAS technologies to address the NOAA mission using a requirements-based systems approach. UAS have the potential to fill critical observation gaps in understanding and predicting high impact weather events impacting coastal communities. The NOAA UAS Program has been identifying and conducting conceptual studies of UAS platforms and payloads which could be beneficial for long endurance sampling of tropical cyclone boundary layers and remote sensing of storm structures. The NOAA UAS Program is also investing in Observing System Simulation Experiments (OSSE) to analyze whether positive impact to future tropical cyclone observing strategies could be achieved with UAS observations. This presentation will include an overview of the NOAA UAS Program High Impact Weather Roadmap for testing and evaluating UAS technologies. Recent accomplishments and key partnerships with NASA, NSF, and academic community will also be discussed.

Surface-Reflected GPS Wind Speed Sensing Results for 2010 Atlantic Season

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During the 2010 Atlantic storm season, NASA-Langley GPS receiver/reflectometers deployed on NOAA P-3 Hurricane Hunter aircraft were used to retrieve ocean surface wind speed for a number of storms including Hurricane Earl, Tropical Storm Alex, and for a rapid intensification flight into Hurricane Karl. The sensing technique uses surface-reflected GPS navigation signals in a manner analogous to bistatic radar, where Global Positioning System (GPS) satellites serve as surface illumination sources. A modified GPS receiver measures surface-reflected signal strength at increasing path delays, relative to the geometric mirror reflection point. Surface wind speed is inferred by monitoring ocean surface roughness (mean square slope) via the measured scattering of the reflected signal.

Results from earlier storm seasons verified the reflected signal sensitivity over a range of wind speeds: from nearly 0 (calm seas) to greater than 40 meters per second (m/s) [1]. Another study reported that, for 0 – 15 m/s wind conditions and well-developed seas, GPS wind speed retrievals were in agreement with TOPEX satellite altimeter-derived measurements to better than 1 m/s, with a precision ~2 m/s (1-sigma) [2]. Surface wind speeds obtained using an empirical calibration function also compared well to GPS dropsonde data, particularly for winds in the 0 – 20 m/s range [3]. In this paper, GPS reflection measurement results from the 2010 storm season will be presented and compared to co-located measurements from the operational Stepped-Frequency Microwave Radiometer, surface-adjusted flight level winds, and GPS dropsondes.

The GPS reflection measurements were achieved using light-weight (< 5 kg), low power, autonomously operated GPS receivers and nadir-viewing 3.5” hemispherical antennas – a system which requires only minimal aircraft accommodation. GPS wind speed instruments deployed on longer-duration aircraft missions could be useful for mapping the changing surface wind field and changes in momentum flux related to the ultimate intensity and classification of developing storm systems.

The sensitivity of the GPS instrument to low-speed surface wind conditions (< 10 - 15 m/s), where microwave radiometers can be less effective, implies that GPS surface-reflection instruments can provide independent wind speed retrievals to compliment those obtained with radiometers or other instruments currently utilized in tropical cyclone genesis and forecasting studies. Combining wind speeds based upon GPS surface reflections (due to larger surface slopes) with those derived from radiometric brightness temperature (involving finer surface features) can potentially provide a more complete understanding of tropical cyclone formation, and improve forecasts of storm intensity.

[1] Katzberg, S. J., O. Torres, and G. Ganoe (2006), ‘Calibration of reflected GPS for tropical storm wind speed retrievals,’ *Geophys. Res. Lett.*, 33, L18602, doi:10.1029/2006GL026825
[2] Garrison, J. L., *et. al.*, (2002) ‘Wind speed measurements using forward scattered GPS signals,’ *IEEE Trans. Geoscience and Remote Sensing*, vol. 40, no. 1.
[3] Katzberg, S. J., and J. Dunion (2009) ‘Comparison of refl. GPS wind speed retrievals with dropsondes in tropical cyclones,’ *Geophys. Res. Lett.*, 36, L17602, doi: 10.1029/2009GL039512.

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

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Real-Time Airborne Ocean Measurements and Predictions of Loop Current Eddy Shedding During the Deepwater Horizon Oil Spill: Implications for Hurricane Intensity Forecasting

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Several flights from NOAA WP-3D aircraft were conducted between 5 May and 9 July 2010 that focused on temperature, currents and salinity in a geographical location to the southeast of the Deepwater Horizon (DWH) rig, and over the Loop Current (LC) and associated eddies. These flights provided the evolving oceanic variability of the LC, the shedding of warm core eddy Franklin, and frontal eddies along its' periphery. Atmospheric dropsondes (for surface winds) and airborne expendable ocean profilers sampling to as deep as 1500 m (from expendable current profilers: AXCP) were deployed in a lawnmower pattern with essentially the drop points. Over 700 airborne ocean profilers were deployed that included AXBT, AXCP, and conductivity-temperature-depth profilers (AXCTD). These data, acquired over a weekly basis over the LC, were assimilated into operational ocean models (HYCOM) at NAVOCEANO to predict potential pathways of the oil from the northern Gulf of Mexico. In addition, these measurements provided data to vector ships to regions of mesoscale variability for detailed oil spill measurements, and are being used to evaluate satellite-based products such as oceanic heat content from altimetry and SMARTS climatology.

Surface currents derived from altimeter sea surface heights and direct current measurements from AXCPs indicate that, from May to June, the circulation patterns between the DWH rig and the northern boundary of the LC were dominated by nearly small-scale cyclones. Eddy Franklin detached from the LC between 28 May and 18 June, where the 20 ^{o}C isotherm depth (h20) reached maximum values of about 320 m at Franklin's core, compared with values ranging from 280 to 300 m before the shedding event. During early July, Franklin experienced significant erosion from several frontal eddies, where h20 values in Franklin's core ranged from 260 to 280 m. Subsequently, Franklin began to move westward as expected with large warm core eddies. Thus, the approach captured the complexities of the mesoscale LC-eddy shedding processes for the first time over weekly time scales. The thermal structure data from all profilers were assimilated into the operational HYCOM whereas the salinity and current data are being used to evaluate model performance. Analyses of twin numerical experiments with and without data assimilation clearly revealed the ***unprecedented*** importance of the real-time, 3-D measurements in improving the trajectories to guide cleanup efforts. This approach needs to be applied to oceanic and coupled model efforts and implemented for real-time ocean forecasting at the National Centers for eventual use in coupled model forecasts.

First Flights of HIWRAP During GRIP

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Wind measurements are crucial for understanding and forecasting tropical storms since they are closely tied to the overall dynamics of the storm. The High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) is a dual-frequency (Ka- and Ku-band), dual-beam (30^0 and 40^0 incidence angle), conical scan, solid-state transmitter-based system, designed for operation on the high-altitude (20 km) Global Hawk UAV. HIWRAP images the winds through volume backscattering from clouds and precipitation, enabling it to measure the tropospheric winds above heavy rain at high levels. It will also measure ocean surface winds through scatterometry, similar to QuikScat. These measurements from higher altitudes above storms, are useful for providing higher spatial and temporal resolution than obtained by current satellites and lower-altitude instrumented aircraft.

HIWRAP flew its first test flights during March 2010 on the NASA WB-57 manned aircraft (60-65kft ceiling) and then the first science flights on the unmanned Global Hawk (65kft ceiling) during the Genesis and Rapid Intensification Processes (GRIP) campaign conducted during August and September 2010. The Global Hawk flew for the first time over hurricanes during GRIP. The were 5 science flights over storms (Hurricanes Karl, Earl, and Matthew) during which there were as many as 20 passes over the storm center during a single flight. HIWRAP data analysis from these flights is in very early stages of processing and software development. We will present a summary of the instrument status, data analysis, lessons learned, and future plans.

WISDOM Intensity Program – Weather Hurricane In-situ Sea Surface Probe (WHISSP)

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Office of Oceanic and Atmospheric Research (OAR)/NOAA

The WISDOM Intensity program is a new research effort based in the Office of Oceanic and Atmospheric Research (OAR) with the aim of developing observing platforms capable of delivering continuous data within the eye of a tropical cyclone. At present data collection in the eye of a hurricane is limited. The WISDOM effort was inspired by the successful Aeroclipper design led by CNES in which two models were entrained into a tropical cyclone in the Indian Ocean and collected data for over a week. OAR/WISDOM aims to develop a low cost platform capable of collecting continuous observations for days in the eye of a hurricane including central pressure, wind speed, wind direction and air temperature. One of several possible approaches towards developing a simple and low-cost version of a platform for collecting data in the eye of a storm is the Weather/Hurricane In-situ Sea Surface Probe (WHISSP). This presentation will describe the simple wind model developed to assess a surface craft's ability to become entrained in a tropical cyclone as well as results from an initial proof of concept study conducted by OAR/WISDOM, where four experimental WHISSP models were tested in the field. Results of this study as well as future development plans will be discussed.

New Tools for Tropical Cyclone Radar Rainfall Estimation

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During the early years of the WSR-88D program, an empirical relationship, known as the default Z/R relationship, was used to convert radar reflectivity to a rainfall rate. However, it was known to underestimate rainfall in tropical-like systems. In June 1997, a tropical Z/R relationship was authorized by the Radar Operations Center (ROC) which yielded higher rainfall rates than the default relationship for tropical systems. However, the performance of the tropical Z/R relationship remained inconsistent. Part of the problem was that one Z/R relationship was applied to the entire 230 kilometer range within which rainfall estimates were computed even though different types of rain regimes are possible within a tropical cyclone (TC). Additionally, once the tropical Z/R relationship was selected, it was used until an operator changed it. These challenges highlighted the need for an improved method for estimating rainfall amounts. This presentation will provide an overview of the traditional (reflectivity-based) method, plus two new rainfall estimation tools worth considering for the upcoming tropical cyclone season - the vertical profile of reflectivity (VPR)-based method developed by the National Severe Storms Laboratory and the new Dual Polarization (DP) Quantitative Precipitation Estimation (QPE) method.

A Two-Dimensional Velocity Dealiasing Algorithm for the WSR-88D

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The current Weather Surveillance Radar-1988 Doppler (WSR-88D) utilizes two velocity dealiasing schemes, the Velocity Dealiasing Algorithm (VDA) and the Multiple Pulse Repetition Frequency (PRF) Velocity Dealiasing Algorithm (MPDA). The VDA remains virtually unchanged since the deployment of the legacy WSR-88Ds. The VDA primarily uses radial continuity, an average of nearby velocity neighbors, or an Environmental Wind Table (EWT) to help resolve winds exceeding the maximum unambiguous velocity (Nyquist Velocity, V_N) which for the WSR-88D is between 21 and 35 m s^{-1} for the following precipitation Volume Coverage Patterns (VCPs): VCPs 11, 12, 21, 211, 212, & 221 and the clear air VCP 32. The long-pulse clear air VCP 31 has a Nyquist velocity of about 8 m s^{-1}. While generally reliable, the VDA can fail: 1) under strong shear conditions; 2) in velocity data with moving clutter; 3) in areas with weak echoes; 4) when the Nyquist velocity is much lower than the prevailing winds; or 5) where the values in the EWT are not representative of the local storm winds. The MPDA, fielded in 2004 as VCP 121, takes multiple scans of velocity data at the same elevation using up to three different PRFs. It can dealias velocity with a high degree of reliability where there is more than one velocity estimate available. However, the utility of the MPDA in VCP 121 is limited during rapidly changing weather events because the additional scans required increases the volume scan time to nearly 6 minutes. VCP 121's utility is further diminished because it has only 9 unique elevation angles with which to interrogate storm structure.

The Radar Operations Center (ROC) tested a two-dimensional velocity dealiasing scheme (VDEAL) that is more robust than the current VDA. It works by simultaneously dealiasing all gates in an elevation scan using a least-squares approach to minimize the discontinuity caused by aliasing. Greater weight is given to velocity differences near zero or at multiples of $2V_N$ as well as velocity differences where the corresponding spectrum width values are low. VDEAL can be used by all VCPs except VCP 121 with no perceptible delay in product availability.

This paper presents the test results of VDEAL on historical WSR-88D data sets collected during hurricanes, tornadic storms, and storms with outflow boundaries. For this test, velocity products were scored qualitatively. Of 520 low-level velocity products evaluated, the VDA had 252 with dealiasing errors while VDEAL had only 71 with dealiasing errors. More striking was the reduction in velocity dealiasing errors and improved data quality of the VDEAL over the VDA in hurricanes. Of 201 velocity products evaluated, VDA had 185 total dealiasing errors while VDEAL had only 5 dealiasing errors. Based on these results and independent testing by scientists at the National Severe Storms Laboratory, the ROC plans to conduct a field test during the summer and fall of 2011.

A summary of new activities to expand the Caribbean sounding and surface networks
The IASCLIP and COCONet initiatives

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Two very different activities that are now spinning up should substantially improve surface measurements and tropospheric profiling across the Caribbean Sea region and neighboring regions. The Continuously Operating Caribbean GPS Observational Network (COCONet), funded by NSF, will install approximately 50 new GPS stations that, although intended primarily to measure tectonic motions for geophysical research, will also have co-located automatic weather stations reporting in real time. The COCONet observations will provide nearly continuous estimates of precipitable water much like the current Suominet sites. These estimates can be used both for real-time analysis and model initialization and for comparison with, and calibration of, routine radiosonde moisture information. More information on COCONet can be found at:

http://www.unavco.org/community/meetings-events/2011/coconet/agenda.html

Overlapping some of the objectives of COCONet is the Intra-Americas Study of Climate Processes (IASCLIP) program, being supported initially by NOAA, which although focused on climate variability, also seeks to improve the atmospheric and oceanic monitoring over the region on all time scales. Some of the desired improvements to the observing network over the Caribbean region overlap those being proposed by COCONet and there will likely be joint development of some aspects of the networks. More information on the IASCLIP can be found at:

http://www.eol.ucar.edu/projects/iasclip/

This talk will summarize both the COCONet network and the proposed initial IASCLIP enhancements over the region. Modification to the current CHUAS (Cooperative Hurricane Upper-Air Stations) network to include adaptive observations at additional sites, proposed as part of IASCLIP and also to the JHT, will also be described.

Establishing an Improved National Capability for Collection of Extreme Storm and Flood Data

This abstract was drafted by the members of the Office of Federal Coordinator's Workgroup on Disaster Impact Assessments: Weather and Water Data, including William Birkemeier (USACE), Dan Catlett (FEMA), William L. Coulbourne (Wind and Flood Hazard Mitigation Applied Technology Conference), Robert R. Holmes (USGS, Robert R. Mason, Jr. (USGS), Anthony R. Ramirez (NOAA), Wilson Shaffer (NOAA), and D. Phil Turnipseed (USGS) and presented by Robert Mason, Workgroup Chair, on behalf of the committee.

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) flood forecasting operations saves thousands of lives and reduce injuries and property damage by billions of dollars annually. But this process, which depends on data from thousands of U.S. Geological Survey streamgages and NOAA meteorological stations, usually does not provide data coverage sufficient to adequately document the extensive impacts of a major storm or flood or enable understanding of small-scale, localized processes. As a result, network observations often are supplemented by post-storm surveys and studies of rainfall, flood marks, and wind damage to fill in observational gaps and obtain a more complete spatial coverage. In turn, these data are studied by the Federal Emergency Management Agency, the National Institute of Science and Technology, and various State agencies resulting in advancements in building codes and construction practices.

Today, post-storm surveys and traditional networks can be greatly augmented by pre-event deployment of small, self-contained instruments in spatially dense, temporary networks to monitor the event directly and continuously. Clusters of self-logging pressure transducers and real-time rapid-deployment gages monitor waves and water-levels and anemometers and truck-mounted Doppler radars monitor wind speed and direction at rapid intervals. These data describe the evolution of storms and floods with unprecedented spatial and temporal detail, particularly floods of coastal waters and wetlands. The resulting data can be used to (1) develop more accurate and robust wind, storm-surge, and flood models; (2) derive better structure design criteria and building codes; and (3) improve warning systems.

Effective utilization of these mobile networks requires the timely and well-coordinated efforts to deploy equipment into targeted areas in anticipation of the storm. In response to this need, various Federal agencies and affiliated organizations have created the *National Plan for Disaster Impact Assessments: Weather and Water Data (NPDIA)*, which establishes a procedural template for coordinating various pre-storm readiness activities and post-storm responses. The plan is available from the publications web page of Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) at URL: http://www.ofcm.gov/homepage/text/pubs.htm.

This presentation will describe procedures for coordinating deployment activities, capabilities of the participating agencies and affiliated organizations; mechanisms for aggregating and sharing resources; plans for documenting the event; and links to acquired data. By working together and with other stakeholders we can better collect the timely and useful data needed to develop more robust and resilient communities and a safer, disaster resilient Nation.

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

Advancements to the Operational HWRF Modeling System at EMC

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NOAA/NWS/NCEP/EMC/HWRF

The National Centers for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC) operational Hurricane Weather Research and Forecast (HWRF) modeling system has been upgraded for implementation in 2011 hurricane season. Through a collaborative effort, EMC and the Developmental Testbed Center (DTC) have upgraded the non-hydrostatic mesoscale model (NMM) core of the HWRF system from V2.0 and synchronized it with the latest version of WRF NMM V3.2+, allowing the operational and research communities to share the same code base and help accelerate further advancements to the HWRF modeling system through an efficient Research to Operations (R2O) infrastructure. Developmental activities for the HWRF system for 2011 hurricane season also included improvements to the vortex initialization procedure, new GFS deep convection parameterization, improved surface physics formulation, expanded Princeton Ocean Model (POM) Eastern Atlantic domain and enhanced hurricane model diagnostics designed to identify areas for improvement.

The coupled HWRF system was uniquely designed to make significant advancements in improving operational forecast skill of intensity and structure forecasts in addition to advancing wave and storm surge forecasts to address the coastal inundation problem. Continued advancements in track prediction will remain an important focus of this prediction system.

Further improvements to the HWRF modeling system is being made possible through the support provided by the Hurricane Forecast Improvement Project (HFIP). Accelerating advancements in hurricane prediction will require an infusion of resources directed at concentrating vital modeling efforts at NCEP in the areas of model resolution, advanced triple nested grids, improved air-sea-wave-land coupling, advanced hurricane physics suitable for higher resolutions, improved data assimilation methods to ingest new and existing datasets in the hurricane core, and high resolution HWRF ensembles to account for uncertainties in the initial state and physics.

Issues in transitioning HWRF upgrades into operations at EMC
A Joint Hurricane Testbed (JHT) Program

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CCPO/ODU

The 2010-2011 JHT project funded through the Center for Coastal Physical Oceanography (CCPO) at Old Dominion University (ODU) has concentrated on HWRF development, its operational implementation, and recent upgrades. Over the last year emphasis on this project has been on trouble shooting problems involving model biases of intensity and issues involving land interaction. The long-standing HWRF problem with unrealistic, cold land surface temperatures was corrected with the 2010 forecast system. Some further analysis and possible refinements to these land-related issues will be discussed in addition to refinements in the new HWRF surface flux package.

A new surface flux package based on observations was implemented for the 2010 season that has in part contributed to some improvements of track and intensity in HWRF. This new 2010 surface flux package has been further examined and contrasted with packages used in other operational models. Furthermore, this new package was generalized and recast in terms of momentum and thermal roughness lengths. This new revised code has been installed in the new HWRF V3 model version to be installed for 2011 operations. Some comparisons will be shown in running the HWRF model using different flavors of the new formulation.

In order to quantify the impact of using a more sophisticated land model, i.e. the NOAH LSM, HWRF underwent extensive testing in 2010. These tests including running the operational system, H210, both for numerous historical cases of 2008-2009 and for nearly 300 cases in real-time for the 2010 Atlantic season. Besides using the NOAH LSM surface option, the tests also included changes to the operational system to allow more frequent output of surface and sub-surface runnoff - a requiremnt for a stream routing model. The standard verification parameters of mean track and intenity errors were applied to these suite of cases. As opposed to prelimiary results using a previous HWRF model version, the 20120 HWRF version with the NOAH LSM option led to some degradation in both track and intensity at some forecast times. These results will be shown. Further issues with the proposed 2011 HWRF version involving the transition from WRF 2 to WRF3 will also be shown.

2011 operational HWRF model upgrades

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EMC/NCEP/NWS/NOAA

The hurricane model team at EMC/NCEP is working on upgrade of the operational HWRF model for the year 2011 hurricane season. There are three main components of the upgrades, which are 1) modified vortex initialization method, 2) new deep convection parameterization with revised surface physics and 3) bug fixed of microphysics and radiation in addition to dynamic core upgrade to NMM v3.2.

The preliminary results indicate that the initialization and physics upgrades improve the accuracy of intensity and track forecast of HWRF model respectively while the bug fixes do not impact the skill of the model significantly. Especially, the new initialization scheme significantly improve the intensity forecast skill of 0-48 hour forecast ranges with maximum about 25% compare to the old method. The test cases, detailed explanations of upgrades will be presented during the conference.

Major Upgrades Planned in 2011 for the GFDL Hurricane Prediction System

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Major upgrades to the GFDL hurricane prediction system, run operationally by the National Weather Service, have been extensively tested and evaluated for operational implementation in 2011. These changes include upgrade of the deep convection scheme to the version implemented into NCEP's Global Forecast System (GFS) in 2010, implementation of the new GFS shallow convection, modification of the enthalpy exchange coefficient (Ch), inclusion of solar radiation into the ocean coupler, several bug fixes in the surface physics and ocean coupling code, extension of the eastern Atlantic ocean domain, and adoption of a more consistent dissipative heating scheme.

Preliminary results, using initial and boundary conditions taken from the new GFS planned for operational implementation in 2011, show about a 20% decrease in track error in the 4-5 day range, for 305 forecasts run for storms during the 2010 Atlantic hurricane season. This improvement was statistically significant at the 95% level. Reduction of track error was even more pronounced for major hurricanes Danielle, Earl and Igor, with over a 22% reduction in track error in the 2-5 day forecast time period.

Evaluation of the environment fields indicate that with the new physics package, the forecast evolution of the sub-tropical high was much better simulated over the central and western Atlantic. This resulted in a marked reduction in the model's bias for premature recurvature, particularly for intense hurricanes.

Examples of some of the storm tracks will be shown for select cases, as well as examples of differences in the environmental fields forecasted by the upgraded model compared to the current operational system. Since upgrades are also planned for the GFS before the start of the 2011 hurricane season, results will also be shown, on the impact of these changes for both the GFS and GFDL performance. Overall impact on intensity so far has been mostly neutral with the new model.

Funding for this work has been provided by the NOAA Joint Hurricane Testbed Program.

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

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The newly developed Coupled Ocean/Atmosphere Mesoscale Prediction System – Tropical Cyclone (COAMPS®-TC), designed to predict tropical cyclone track, structure, and intensity, has been applied in real-time in support of the recent Hurricane Forecast Improvement Project (HFIP). These real time forecasts were performed in the Atlantic basin; and in the Eastern, Central, and Western Pacific basins during the 2009 and 2010 seasons. Additionally, retrospective tests for HFIP were conducted on a large sample of storms (more than 400 cases) over the W. Atlantic and E. Pacific basins for hurricanes that occurred in the 2008 and 2009 seasons. For these real time and retrospective tests, the COAMPS-TC system was configured with three nested grids, with 45, 15, 5 km horizontal grid spacings. The inner two meshes automatically moved with the tropical cyclone center.

A number of improvements were made to the COAMPS-TC physics and data assimilation based on the results of the 2009 tropical cyclone forecast season. This version of COAMPS-TC was then evaluated using the HFIP retrospective cases performed for 2008 and 2009. The intensity forecasts for the retrospective tests show the model skill for intensity was superior to other dynamical models, particularly for the 30-72 h forecast range. Similarly, an analysis of the 2010 real-time forecasts in support of HFIP reveals that the COAMPS-TC intensity forecasts for the W. Atlantic were superior to other dynamical models for the 30-66 h forecast range. Statistical verification from these retrospective tests indicates that the COAMPS-TC system provided skillful track forecasts competitive with other limited area models such as the Navy's GFDN. Following the analysis of the 2010 real time forecast results, a number of improvements were made to COAMPS-TC including a new algorithm for synthetic observations, inclusion of additional observations such as satellite derived total precipitable water that are used by the Navy Atmospheric Variational Data Assimilation System (NAVDAS), and a new formulation of vertical mixing within clouds and deep convection. Sensitivity test results from this new improved version of COAMPS-TC will be presented. Additionally, real-time application of COAMPS-TC in the W. Pacific basin during the Interaction of Typhoons and Ocean Processes (ITOP) will be discussed.

Progress towards developing a coupled atmosphere-wave-ocean framework for research and operational hurricane models

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We will discuss our progress towards developing a coupled hurricane-wave-ocean framework for operational implementation at NOAA and the U.S. Navy. Our goals are to understand the physical processes that control air-sea interaction and to develop a physically based and computationally efficient coupling at the air-sea interface for use in research and operational hurricane models. The key element of the our approach is an air-sea interface module consisting of a wave boundary layer model and an air-sea heat and momentum flux budget model that explicitly resolve wind-wave-current interaction processes and sea spray effects. So far, the module has been imbedded into the experimental version of the GFDL hurricane-wave-ocean coupled model and calculates all of the flux boundary conditions for the atmospheric, wave, and ocean model components. This module will be implemented into the HWRF coupled system later this year. We will present the results of idealized and real-case simulations and evaluate the impact of explicit wind-wave-ocean coupling on hurricane track and intensity forecasts.

Evaluation and Improvement of Ocean Model Parameterizations for NCEP Operations

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The research focused on testing model initialization schemes primarily in the Gulf of Mexico (GOM) and processing data required for model evaluation. This dataset includes *in situ* Naval Research Laboratory Acoustic Doppler Current Profiler (ADCP) data from Ivan and during Katrina and Rita (courtesy of Minerals Management Service) as well as measurements acquired during NOAA Hurricane Research Division Intensity Fluctuation Experiments (IFEX) in pre and post Rita in 2005, and during Gustav and Ike (2008). All of these hurricanes have been shown to have been affected by warm and cold ocean features in the GOM. Numerical experiments for the Ivan case demonstrated the import of model sensitivity to vertical resolution, horizontal resolution, vertical mixing, air-sea flux parameterizations (drag coefficients), ocean dynamics, and the accuracy of the ocean initialization.

Analyses of the ocean response to hurricanes Katrina and Rita from in-situ (moorings, airborne profilers) and satellite-based measurements have shown significant modulation of the oceanic mixed layer cooling by the geostrophically balanced currents in both warm and cold eddies. Using an idealized, isopycnic ocean model and wind fields derived from data acquired during hurricane Katrina, aspects of the ocean response to tropical cyclones (TC) are investigated in the eddies. It is found that rather than a function of the wind stress curl, the upwelling response is a function of the curl of wind-driven acceleration of oceanic mixed layer (OML) geostrophic currents: upwelling (downwelling) regimes prevail under the TC's eye over cyclonic (anticyclonic) eddies. Predominant isotherm downwelling, wind erosion over deep, warm, and nearly homogeneous water columns, and dispersion of OML near-inertial energy only produce OML cooling of ~1^{o}C in anticyclones, consistent with observations. By contrast, widespread upwelling of the isotherms and wind-induced mixing over shallow OMLs with enhanced vertical current shears produce OML cooling of ~4^{o}C in cyclones. For oceanic models to correctly reproduce TC-induced OML cooling and feedback mechanisms to TC intensity, they must accurately resolve mesoscale oceanic features, including position and thermal, density, and velocity structures.

For this reason, ocean model improvement efforts at the National Centers must focus on improving the model initialization through assimilation methods. During the summer of 2010, an extensive data set was acquired in response to the Deep Water Horizon oil spill in the Gulf of Mexico. The 3-dimensional snapshots from NOAA research aircraft of the upper ocean structure captured the complex detachment/reattachment processes associated with Eddy Franklin from the Loop Current.

Session 6
Tropical Cyclone Model Development and Technology Transfer, Part 2

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Prediction of Consensus TC Track Forecast Error (2005-2010)

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Funded by a JHT project, a graphical predicted consensus error product (GPCE; Goerss 2007) was first developed and installed on the ATCF at both NHC and JTWC in 2004. Using GPCE's pool of predictors, revised regression models to be used for the upcoming season were derived and installed on the ATCF at both centers from 2005 to 2010. These regression models are used to determine the radii of circular areas drawn around the consensus model forecast positions within which the verifying TC position is expected to be contained approximately 70% of the time. These circular areas are then graphically displayed on the ATCF for use by the forecasters at NHC and JTWC. For each season from 2005 to 2010, GPCE is validated for the Atlantic and Eastern North Pacific basins. For each forecast length, the GPCE validation percentage is compared with the consensus forecast error for the season. As one would expect, since the GPCE regression models are derived using the results from previous seasons (e.g., for 2010 the dependent data for the Atlantic basin came from the 2003-2009 seasons), the GPCE validation percentages for a given season are larger/smaller than the 70% target when the consensus forecast errors for that season are smaller/larger than average. For the entire period from 2005 to 2010, the GPCE validation percentages for the Atlantic basin were 75%, 76%, 76%, 79%, and 79% for 24h, 48h, 72h, 96h, and 120h, respectively. The respective errors for the eastern North Pacific basin were 71%, 73%, 79%, 80%, and 82%. All of the GPCE validation percentages are larger than the target for the entire period. This result is consistent with the general reduction in consensus forecast error from 2005 to 2010 due to improvements in individual track forecast models and the addition of more "good" models (e.g., ECMWF and HWRF) to the consensus.

Ensemble Forecasting Products for Tropical Cyclones at the UK Met Office.

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The Met Office global ensemble forecasting model, MOGREPS-15 runs twice a day producing global forecasts at 60km resolution out to a 15 day lead time. There is 1 control member and 23 perturbed ensemble members. Since October 2006, tropical cyclone products have been produced twice daily. There are products for individual tracks and strike probability for named storms. There are also products generated for 6 worldwide basin areas which track both existing storms and potential developing storms. A subset of these products is currently disseminated to several international forecasting organisations including the National Hurricane Center. These products will be overviewed together with some specific examples of their use.

Additionally, as part of the TIGGE cyclone exchange project, Met Office ensemble storm forecast tracks are shared with those of other forecasting organisations. Some objective verification results for combining ECMWF and MOGREPS data will be presented. In addition, the combined performance of the 2 ensembles is shown for several examples.

Large ensemble tropical cyclone intensity forecasting

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The advent of ensemble prediction of tropical cyclone tracks has led to improvements in the quantification of uncertainty in track forecasts. But the severe computational demands for tropical cyclone intensity prediction have limited the utility of ensembles for quantification of tropical cyclone intensity forecast uncertainty. We here attempt to circumvent this difficulty by running large (100-1000 member) ensembles of tropical cyclone forecasts using the Coupled Intensity Hurricane Prediction System (CHIPS) bootstrapped from the ECMWF 51-member ensemble forecasts. The CHIPS model is phrased in angular momentum coordinates, allowing high resolution of the critical eyewall region at the expense of less resolution of the outer regions of the storm. Tracks are generated by calculating the ensemble mean and full covariance matrix of the ECMWF track velocities and using these to create a large number of tracks whose velocity mean and covariances match those of the ECMWF tracks. But with time, this track algorithm evolves into a beta-and-advection technique whose driving winds are derived from the ECMWF ensemble forecasts. This also allows us to extend the tracks from 5 to 10 days. Once the tracks are created, CHIPS is run along each track to forecast intensity. We will present some results from the 2010 hurricane season.

The Performance of a GFDL Hurricane Model Ensemble Forecast System during the 2010 Atlantic Hurricane Season

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NOAA / GFDL

Since 1995, the GFDL Hurricane Model (GHM) has been run operationally at NCEP. During the 2010 hurricane season, an ensemble forecast system was developed for the GHM and was run in near-real time as part of the HFIP Project on the NOAA Jet supercomputer. This talk will describe the design of the GHM ensemble forecast system and will summarize results from the 2010 Atlantic Season. In addition, plans for running this system for the 2011 season will be discussed.

The GHM ensemble forecast system developed in 2010 consisted of 11 members, with one control forecast and ten perturbed forecasts. All 11 member forecasts used the same triply-nested configuration as in operations at NCEP, with a horizontal resolution in the innermost grid of $1/12^{o}$.

Most of the modifications that were made to the GHM system to create the perturbed forecasts were designed with the intention of having an impact primarily on intensity forecasts. Six of the members were created by modifying storm size parameters that are included on the TC vitals storm warning message send from NHC. These members based on storm size were created by increasing or decreasing the observed storm size parameters by 25%. One member was created by using the environmental filtering scheme from a previous version of the GHM, and another member was created by not including the vortex asymmetries from previous forecasts as is done in operations. Another member was created by setting a minimum threshold on the radius of maximum winds that is different than is done in operations, and the final member was created by simply running the GFDL forecast system without including a bogussed vortex.

Evaluations of the GHM ensemble mean intensity forecasts indicated reductions in forecast errors from 24h to 96h ranging from 5.4% to 11.6%. These improvements were statistically significant from 36h through 96h. Reductions in track errors were found in the first 72h of the forecast period, statistical significance from 12h through 48h and a maximum improvement of 5.6% at 12h.

Despite these improvements, results indicated that the ensemble was under-dispersive for both track and intensity forecasts, and this will be an area of focus in modifying the system for the 2011 hurricane season. In addition to the current members which focus mainly on perturbations to the observed storm size, we will add some members that include modifications to some of the physics parameterizations within the model.

Evaluation and Development of Ensemble Prediction System for the Operational HWRF Model

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Ensemble prediction system (EPS) has been proven to be effective in reducing various uncertainties in model initial states and model physics, and therefore improving model forecast skills. This talk reviews the undergoing efforts at NCEP/EMC to develop EPS based on the operational Hurricane Weather Research and Forecasting (HWRF) model. The study attempts to understand the impact of various uncertainties on the model hurricane track and intensity forecasts, and to find out the best combination of ensemble perturbations for HWRF EPS.

The key to a successful hurricane ensemble forecast is to generate a set of ensembles that represent the uncertainties in hurricane model prediction system. The important uncertainties that need to be taken into account in hurricane EPS include the uncertainties in the hurricane initial structures, initial large scale environment flows, model lateral boundary conditions (LBC), and model physics. Following ensemble perturbations are evaluated within the operational HWRF model framework:

- Initial hurricane structures: in order to reduce the uncertainties in initial hurricane structure, the observed initial radius of maximum wind is perturbed by increasing/decreasing 25% of its value in tcvital file;
- Large scale environment flows and LBC at initial states: data sets from Global Ensemble Forecast System (GEFS), which have resolution of T190L28 and includes 21 ensemble members, are used to initialize HWRF domain and LBC;
- Physics-based perturbations: uncertainties due to model physics can be reduced by using various physics packages in HWRF. Several model physics packages have been used for this purpose. They include two convective schemes: Simplified Arakawa-Schubert (SAS), Kain-Fritsch, and two PBL schemes: GFS PBL scheme, MYJ PBL scheme.
- Combined ensemble perturbations: all above ensemble forecasts are then combined to construct one ensemble.

Forecast experiments of three hurricanes in 2010 season, Earl, Alex, and Celia, are carried out for different ensemble configurations. The track and intensity forecasts from each subset of ensemble are evaluated and compared. Different combinations of ensembles are examined to find out the best results for HWRF EPS. Various probabilistic forecast products resulted from EPS, such as track striking probability, ensemble track spread, are also discussed.

Forecasting Tropical Cyclone Genesis/Development Using an Ensemble of High Resolution Deterministic Global Models – Results from the HFIP 2010 Summer Demo

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Forecasters at the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center (NHC) have, over the past several years, used medium (72-120 h)-to-long-range (5-8 d) global model forecasts to qualitatively assess the potential for tropical cyclone (TC) formation. The general finding is that if the better-performing global models (ECMWF, GFS and UKMO) *all* generate a surface trough, in roughly the same location, with significant 850 mb relative vorticity and strong precipitation, then a TC is likely to occur.

For the 2010 HFIP summer demo, we applied the 'genesis' version of the GFDL TC tracker to quantitatively measure the genesis forecasts of six high-resolution global models available to JWTC/NHC, namely the NCEP GFS (dx ~30km), FNMOC NOGAPS (dx ~45km), ECMWF IFS (dx ~20km), CMC GEM (dx ~60 km), UKMO UM (dx ~30 km) and the ESRL FIM (dx=30km). An objective genesis forecast scheme depends critically on the definition of genesis, in both the atmosphere and in the models.

For the HFIP demo, genesis is defined from an operational perspective according to USPACOM INST 0539.1 and the NHOP that require JTWC/NHC issue warnings/advisories for all "tropical cyclones" (WMO definition) in their AOR. Thus, the first warning/advisory is issued when a system reaches tropical depression strength (typically Vmax = 25 kt) and from this genesis point, we define a 30-h 'genesis period' so as to give 00/12UTC models three chances to forecast genesis. A successful genesis forecast is when a model 'genesis' storm (cyclones that formed during the integration and not model tracks of existing TCs) matches an actual TC during the genesis period.

Results from the 2010 northern Hemisphere season are presented by basin (NIO, WPAC, EPAC and LANT); the main finding is that for systems that eventually reach hurricane strength, the better TC forecast models (ECMWF and GFS) successfully forecast genesis at day 5 about 65% of the time. We also use the genesis forecasts to diagnose spurious model storms or 'spuricanes' and how these false alarms depend on the model convective parametrization. Finally, the 2011 HFIP stream 1.5 web page will be previewed.

Ensemble-based prediction and diagnostics during the PREDICT field experiement

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During the NSF-sponsored PRE-Depression Investigation of Cloud-systems in the Tropics (PREDICT) field experiment, which took place during August-September 2010, a variety of synoptic-scale, mesoscale and convective-scale products based on ensemble forecasts were disseminated. In addition to operational global ensemble forecasts provided by ECMWF and NCEP, new higher-resolution, data-assimilative Weather Research and Forecasting ensembles initialized using the Ensemble Kalman Filter (WRF/EnKF) were also run in real-time. With the primary focus of PREDICT being to test the 'marsupial' theory on how clusters of thunderstorms organize into tropical depressions, ensemble mean and probabilistic measures of low-level circulation and thickness anomaly were provided to yield quantitative estimates of fields relevant to genesis. Other products included probability distributions of vertical wind shear, relative humidity, and upper-level divergence, and spaghetti contours of the curvature of the flow via the Okubo-Weiss parameter. The utility of all these ensemble products will be presented for the disturbance that eventually became Hurricane Karl, together with preliminary evaluations of the ensembles' abilities to quantitatively predict metrics relevant to genesis.

Session 7
Tropical Cyclone Model Development and Technology Transfer, Part 3

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Technology Transfer in Tropical Cyclone Numerical Modeling –
The role of the Developmental Testbed Center (DTC)

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The Hurricane Weather, Research and Forecasting (HWRF) model is one of two NOAA operational regional numerical weather prediction (NWP) models for tropical cyclones. HWRF is an important component of the numerical guidance used at the National Hurricane Center for tropical storm forecasting. For that reason, it is critical that HWRF be continuously improved and uses state of the art research and developments in tropical NWP.

The Developmental Testbed Center (DTC – dtcenter.org) has partnered with the NOAA National Centers for Environmental Prediction to work with the transfer of new technologies onto HWRF. The DTC is an organization with nodes at NOAA Earth System Research Laboratory and the National Center for Atmospheric Research that has as a mission bridging the gap between research and operations in several areas of numerical weather prediction.

The DTC's work in transferring new technology to HWRF follows two strategies. First, the DTC recognizes that the use of a single code base between research and operations facilitates the exchanges between the two groups. Over the last year, the DTC has worked with NOAA NCEP to merge the components of the HWRF model that are used operationally onto Community codes. This work has culminated with the transfer of a community model for operational implementation for the 2011 hurricane season. Since March 2010, the DTC has been providing code management and user support for HWRF (http://www.dtcenter.org/HurrWRF/users), having now reached 150 registered users. Our presentation will describe the process used to transfer the community model onto operations and the support that DTC provides to its users.
The second strategy is to have the DTC maintain a functionally equivalent HWRF testing and evaluation infrastructure in order to assess new developments that have a potential for operational implementation in the short or medium term. We will present results of multiple-season forecasts of the Community HWRF model and will discuss the upcoming evaluations to be conducted at the DTC to test new developments that have a potential for operational implementation.

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Objective evaluation of 2010 HFIP Stream 1.5 candidates

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The Hurricane Forecast Improvement Project (HFIP) provides the basis for NOAA and other agencies to coordinate hurricane research needed to significantly improve numerical guidance for hurricane forecasts. HFIP activities supporting the yearly upgrades made to operational numerical weather prediction (NWP) capabilities are referred to as "Stream 1"; whereas efforts taking multiple years to enhance operations are referred to as "Stream 2". In 2010, HFIP and the National Hurricane Center (NHC) established a new, intermediate pathway to operations known as "Stream 1.5". Stream 1.5 covers experimental models and/or techniques that NHC, based on prior assessments, wants to access in real-time during a particular hurricane season, but which cannot be made available to NHC by the operational modeling centers in conventional "production" mode. Stream 1.5 projects are run as part of HFIP's annual "Demonstration Project". To qualify, participation by a candidate project must be approved by HFIP management and the NHC. Part of the basis for this approval is demonstrated performance through extensive retrospective testing. The retrospective testing for the 2010 Stream 1.5 candidates focused on a representative sample of 27 storms from the 2008 and 2009 hurricane seasons. Four modeling groups participated in this retrospective test activity: Geophysical Fluid Dynamics Laboratory (GFDL) – GFDL hurricane model, Mesoscale and Microscale Meteorology (MMM) division of the NCAR Earth System Laboratory (NESL) – Advanced Hurricane WRF (AHW), Naval Research Laboratory (NRL) – Couple Ocean/Atmosphere Mesoscale Prediction System - Tropical Cyclone (COAMPS-TC), and Florida State University (FSU) – Advanced Research WRF (ARW). This presentation will discuss the objective evaluation of the submitted retrospective forecasts that was conducted by the Tropical Cyclone Modeling Team (TCMT) located in the Joint Numerical Testbed (JNT) of NCAR's Research Applications Laboratory (RAL). The presentation will briefly review the methodology used for this evaluation, summarize the high lights of the evaluation and discuss plans for the 2011 Stream 1.5 retrospective testing.

Hurricane Intensity and Structure Research Using NOAA's High Resolution Forecast Model and its Transition to Operations

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HWFRX is the high resolution, research version of the National Centers for Environmental Prediction's (NCEP) Hurricane Weather Research and Forecasting model specifically adopted and developed jointly at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) and Earth System Research Laboratory (ESRL) for studying the intensity change problem at 1-3 km model grid resolution. This modeling system is supported by NOAA's Hurricane Forecasting Improvement Project (HFIP). An overview of the model developments and the related research activities will be provided. As a part of the HFIP demo project a 3-km-resolution version of the HWRFX system was run using the operational HWRF initial conditions for the 2005, 2007, 2009 and 2010 seasons. Several sensitivity experiments on initial conditions, physics and resolution were also performed for at least a set of 89 cases of storms from those seasons. The seasonal performance of the model along with the results from the sensitivity experiments will be provided. A merger of the HWRFX and the operational version of the HWRF system, now dubbed as "HWRFV3.2" is under development. The 2012 operational upgrade will potentially include a triply nested system operating at a scale of about 3 km and is expected to provide improvements to structure and intensity predictions. We will provide a status report on this system.

Progress Towards a High-Resolution HWRF Model

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This presentation gives an overview of the joint NOAA EMC-HRD research towards developing a triple nested high-resolution hurricane forecasting system based on the EMC HWRF with upgrades from the experimental HRD HWRF-X and elsewhere. We show improvements in the representation of hurricane structure as a result of the higher resolution. We detail computational efficiency experiments that will eventually lead to operational implementation. We also overview upcoming work on improving the physics, initialization, ocean coupling and other model aspects to take advantage of the higher atmospheric model resolution and realize improved hurricane intensity and structure prediction.

Evaluation and Improvements of Cloud and Precipitation Physics in the Operational Hurricane WRF Model at NOAA/EMC

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The overall goal of this project is to evaluate and improve the cloud and precipitation physics used in the operational Hurricane Weather Research and Forecasting (HWRF) model developed in the Environmental Modeling Center (EMC) at the National Centers for Environmental Prediction (NCEP) of NOAA, achieving improved prediction of hurricane structure and intensity, including the size, by the HWRF model at NCEP/EMC. As the first step, we have implemented the current cloud microphysics scheme and convective parameterization scheme used in the HWRF model into TCM4 and compared the structure, intensity, and diabatic heating of the HWRF model cloud microphysics scheme with that used in TCM4. We have examined the possible effect of cumulus convective parameterization scheme in coarse model domains on the fine-resolution explicit simulations of hurricanes in TCM4. These comparisons have helped us identify the potential discrepancies of the current cloud and precipitation physics used in the HWRF model and provide the basis for our improvements of the HWRF cloud and precipitation physics.

We have also examined the possible discrepancies in the dynamical core of the HWRF model in comparison with the simulation using the WRF_ARW dynamical core with the same model physics options. It is our purpose to see whether biases in the prediction of hurricane size and intensity by HWRF are related to the dynamical core. Hurricane Katrina (2005) was selected in the comparison. Our results show that although the NMM dynamical core simulated weaker hurricane intensity, it simulated the track considerably better in terms of the timing and location of landfall than the ARW dynamical core for this case. This indicates that the NMM dynamical core might capture the evolution of the large-scale environmental flow, which is the key to the accurate prediction of storm motion. However, the storm intensity is largely controlled by the inner core dynamics, which was not well represented by the numerical scheme in the NMM dynamical core. The difference in the vertical structure of the simulated storm suggests that some discrepancies between the simulations with different dynamical cores might be related to the difference in the vertical descretization. We also found that the dynamical core may affect the cloud microphysics to some degree. We also found that the dynamical core may affect the cloud microphysics to some degree. We thus suggest that a systematic diagnostics of the dynamical core of the NMM is required in order to improve the prediction of storm intensity and structure by HWRF.

Controlling Factors of the Radius of Maximum Winds in HWRF

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NOAA/ESRL and NOAA/AMOL

This presentation highlights major results from a series of numerical experiments with NOAA's Hurricane WRF (HWRF) model. The purpose of the experiments is to investigate the sensitivity of the radius of maximum winds of an idealized tropical storm to the model's internal controlling factors (such as the size of the initial vortex, cloud physics and vertical diffusion) and external conditions (such as the latitude-dependent Coriolis parameter). The model is initialized with a weak axisymmetric vortex disturbance in an idealized tropical environment that is favorable for the vortex disturbance to develop into a hurricane. The initial mass and wind fields associated with the weak vortex disturbance are obtained by solving the nonlinear balance equation for the given wind distributions of the initial vortex, and the prescribed background thermal sounding and winds. Results from the idealized HWRF sensitivity runs are compared in terms of the radius of maximum winds along with the azimuthally averaged storm structure and the surface wind-pressure relationships, to gain an insight into how to improve the model.

Tropical Cyclone Inner-core Diagnostics

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Much work has gone toward evaluating the performance of numerical models using "traditional" metrics, e.g., position and intensity errors. As operational horizontal grid lengths approach 3 km (and eventually reach 1 km), the ability to represent many features within the inner core of tropical cyclones (TCs) increases. Robust evaluations of TC inner-core structure are therefore crucial to assess the realism of numerical simulations. A wealth of TC inner-core data collected and archived at the NOAA Hurricane Research Division (HRD) over many years provides an excellent opportunity for evaluating high-resolution numerical models.

In this talk composites from observations (airborne Doppler and dropsondes) and simulations of multiple storms will be compared. These composites are key to providing statistically robust measures and evaluations of numerical models. The focus here is on several scales within the TC inner core – symmetric and asymmetric vortex-scale properties, convective-scale statistics, and boundary-layer structure.

On the Characteristic Height Scales of the Hurricane Boundary Layer: Dropsonde Composite Analysis for the Purpose of Model Diagnostics

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In this talk, we present composite analysis results using hundreds of GPS dropsonde data from 13 hurricanes. We focus on the investigation of the characteristic height scales of the hurricane boundary layer. The height scales are defined in a variety of ways: the height of the maximum total wind speed, the inflow layer depth, and the mixed layer depth. The height of the maximum wind speed and the inflow layer depth are referred to as the dynamical boundary layer heights, while the mixed layer depth is referred to as the thermodynamical boundary layer height. The data analyses show that there is a clear separation of the thermodynamical and dynamical boundary layer heights. Consistent with previous studies on the boundary layer structure in individual storms, the dynamical boundary layer height is found to decrease with decreasing radius to the storm center. The thermodynamic boundary layer height, which is much shallower than the dynamical boundary layer height, is also found to decrease with decreasing radius to the storm center. The results also suggest that using the traditional critical Richardson number method to determine the boundary layer height may not accurately reproduce the height scale of the hurricane boundary layer. These different height scales reveal the complexity of the hurricane boundary layer structure that should be captured in hurricane model simulations. Methodology and preliminary results of using the dropsonde composites to evaluate the PBL scheme used in the Hurricane Weather Research and Forecast (HWRF) model are discussed.

Session 9
ITOP/TCS-10: Coupled Air-Sea Observations and TC Predictions

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Overview of the ITOP / TCS10 Program: Impact of Typhoons on the Pacific

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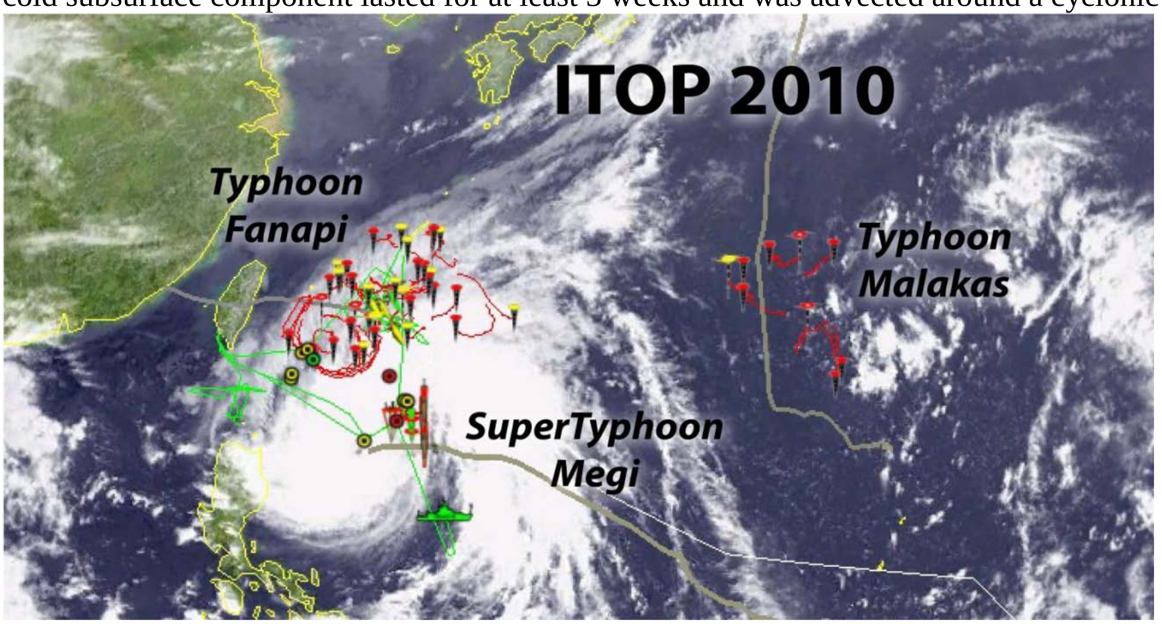
The **Impacts of Typhoons on the Ocean in the Pacific (ITOP)** program was a multi-national field campaign that aimed to study typhoons and the ocean response to typhoons in the western Pacific Ocean. ITOP focused on understanding how the cold wake of a typhoon forms and dissipates, the air-sea fluxes for winds greater than 30 m/s, the impact of ocean eddies on typhoons and the physical and biogeochemical ocean response to typhoons, the surface wave field under typhoons, and typhoon genesis and forecasting.

An array of 10 ocean moorings, including detailed air-sea flux instrumentation, was deployed from July to October, 2010. Two C-130J aircraft of the Air Force Reserve 53rd WRS operated from Guam from Aug. 20 to Oct. 20, 2010, working in cooperation with the Taiwanese DOTSTAR program. They conducted storm reconnaissance, deploying ~700 dropsondes and ~850 AXBTs in the vicinity of typhoons and deployed 89 oceanographic drifters and floats ahead of typhoons and into their wakes. US and Taiwanese research vessels made measurements in the wake of typhoons making ~3500 CTD profiles and deploying 10 long-term autonomous gliders. Operations were directed from a control center at the Naval Postgraduate School.

ITOP sampled the structure of and ocean response to 3 typhoons: Fanapi, Malakas and supertyphoon Megi, one of the strongest typhoons every measured (885 mbar). Detailed measurements of the air-sea fluxes were obtained in Fanapi and Megi. The ocean response to typhoons was complicated by strong internal tides in this region. All three typhoons made strong cold wakes. Megi's wake was very narrow, 20 km across, reflecting the small size of the storm, while Malakas' ranged from 100-250 km. The evolution of Fanapi's wake was followed for a month. The surface signature of the wake rapidly diminished due to surface warming, but a thick cold subsurface component lasted for at least 3 weeks and was advected around a cyclonic eddy.



ITOP was supported by the Office of Naval Research and the Taiwan National Science Council.

Multi-scale Observations of Cloud Clusters and Tropical Cyclones in ITOP/TCS10

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The goal of the Impact of Typhoon on Ocean over the Pacific (ITOP) and Tropical Cyclone Structure 2010 (TCS10) is to better understand and predict TC formation and intensity change through a comprehensive observation of TC structure and its oceanic and atmospheric environment over a broad spatial and time scales. An objective cloud-cluster tracking method is used to identify the TC precursor clusters using hourly satellite IR images over the entire West-Central Pacific basin. By tracking all cloud clusters, we are able to objectively determine both developing and non-developing TCs, which have been a one of the most difficult problem in understanding of formation (genesis) of TCs in the past, especially the lack of objective method for determining non-developing TCs. Comparing with results from previous years (2003-2009), 2010 consists of more long-lived cloud clusters that do not develop into TCs, even though some apparent large-scale conditions such as warm SST and synoptic wave-like disturbances are abundant. Composite of the environmental conditions for developing vs. non-developing cases using the global analysis fields and in situ airborne dropsonde and AXBT data are used to quantify the mesoscale and large-scale "forcing" for TCs. The ITOP/TCS10 field experiments were designed to follow the developing TC throughout their lifecycle with extensive observations of pre-, during- and post-TC oceanic and atmospheric conditions. More than 800 GPS dropsondes and 1000 AXBTs/AXCTs as well as drifters and floats were deployed in TCs from August-October 2010, including Typhoon Fanapei and Supertyphoon Megi. Some preliminary analysis and implication for coupled TC prediction model development and verification will be discussed. Furthermore, a comparison of TC activities between the western Pacific and Altantic basins using the cloud-cluster tracking analysis will be presented.

The Challenge of Measuring the Atmosphere-Ocean Interface in Tropical Cyclones: Observations from Air-Deployed Drifters

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Since 2003, air-deployed drifters have been used to make measurements of upper ocean temperature, surface currents, atmospheric pressure, wind velocity, and, more recently, of subsurface ocean currents and solar radiation, within tropical cyclones and in their cold wakes. The co-ordination of multiple projects sponsored by the Office of Naval Research and by NOAA has led to the accumulation of a dataset that includes drifter observations of six hurricanes and four typhoons, covering the Cat 1 through Cat 5 range. The air-deployment success rate of the drifters is 93%.

Drifters are typically air-deployed along a 400 km line, 18 to 24 hours ahead of the tropical storm. The spatial separation of the drifter array ranges from 30 to 50 km. Atmospheric pressure, sea surface temperature and surface winds are measured every 15 min. The data are transmitted in real-time through the Argos and Iridium satellite systems and are routinely placed on the Global Telecommunication System.

We focus on oceanic and atmospheric observations obtained during typhoon Fanapi in September 2010 during the ITOP/TCS10 field project in the Western Pacific. We discuss wind and atmospheric pressure measurements obtained with a new meteorological package, as well as upper ocean temperature changes. The preliminary results show that on 09-18-2010 between 0030Z and 0400Z Fanapi’s minimum recorded pressure was 940 mbar and it left a cold wake approximately 150 to 200 km wide with a maximum surface cooling of 2.5 °C

The first order challenge for forecasting and warning centers consists of accurately predicting intensity changes of tropical cyclones. Providing quality measurements of the upper ocean thermal structure is therefore crucial. The comprehensive drifter dataset represents an opportunity to improve data assimilation, to initialize forecast models and to validate research and operational models.

Pre-Genesis Monitoring of the 3-D Atmospheric and Oceanic Environment Via High Altitude Aircraft Observations

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The Tropical Cyclone Structure (TCS-08) and the Impact of Typhoons on the Ocean in the Pacific (ITOP) field programs enabled the first two tests of high altitude (300 MB) deployment of dropsondes and AXBTs into pre-genesis, incipient tropical cyclone (TC) systems within the western North Pacific basin (WPAC). This sampling strategy enabled a unique view of the three dimensional (3-D) atmospheric (winds, temperature and moisture) and oceanic thermal environments. Data sets from both developing and non-developing tropical systems were inter-compared through the use of the Air Force WC-130J data sets, which include dropsondes, Stepped Frequency Microwave Radiometer (SFMR), airborne radar, and flight level parameters, MTSAT-derived automated cloud motion winds, NRL P-3 Eldora 3-D winds (TCS-08), and satellite-derived ocean surface wind vectors (QuikSCAT – TCS-08 only, ASCAT, and WindSat). Aircraft flights were designed to overlap with satellite over-pass times as close as possible. In addition, satellite-derived total precipitable water (TPW), a measure of low/mid-level moisture content which maps mesoscale and synoptic scale features, was utilized to observe the potential of dry- and moist-air entrainment into the inner vortex. This combination of sensors allowed the aircraft-derived observations to validate satellite-derived observations of ocean surface and mid-level winds as well as sea surface temperature (SST) and subsurface ocean heat content (OHC).

During August 2008, TCS-08 candidate systems included many weak convective clusters as the western Pacific basin experienced an unusual ‘TC drought’ and an anomalous circulation pattern. Organized convective activity was suppressed and the monsoon trough was absent as low-level easterly flow predominated. Several wave-like systems entered the TCS-08 Guam domain from the east and were investigated by the WC-130J and NRL P-3 aircraft. ITOP conditions during 2010 included additional pre-genesis cases near Guam of several systems that later evolved into significant TCs.

Passive microwave imagers were able to augment the TCS-08 and ITOP aircraft data sets by mapping the rainfall and convective cloud cluster patterns during many daily overpasses. The combination of both operational and research microwave satellite sensors (SSM/I, SSMIS, TMI, AMSR-E, and WindSat) provided frequent temporal observations of convective system evolution. The temporal sampling from the microwave imagers provided the large-scale context in mapping convective organization of the three tropical systems using WC-130J recorded radar video and NRL P3 Eldora Doppler radar data (TCS-08), but does not provide the 3-D structure, nor spatial details needed to appropriately understand the full 3-D storm environment.

Preliminary analysis of the WC-130J dropsondes, AXBTs, and satellite digital data sets indicate complicated 3-D atmospheric and oceanic structures can be monitored by the high altitude WC-130J dropsonde square spiral flight patterns and effectively detail critical differences between low, mid and upper-level wind, temperature and moisture variables as the genesis system struggles within the sometimes very harsh environmental conditions. Important information pertaining to wind shear and possible decoupling between the low and mid level vortex and the extent of dry air intruding into or near the system's inner core can only be accurately obtained via these high altitude 3-D dropsonde measurements that systematically cover the entire storm grid and not just the periphery as currently accomplished within some NOAA G-IV flights. These 3-D atmospheric data sets have the potential to also initialize and help validate multiple ongoing TC mesoscale numerical weather prediction (NWP) forecast model diagnoses and forecast efforts as the community attempts to improve predictions of genesis, track, and intensity. In addition, the AXBT data has provided the means to effectively map the oceanic thermal front and eddy field and help us factor in OHC impacts on storm intensification and decay, not otherwise accounted for in previous WPAC studies.

Ocean observations in developing and mature TC's based on a new airborne observing strategy: 'Combo' deployments of AXBT's and GPS dropsondes from long-endurance, multi-altitude reconnaissance flights

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The first 'combo' deployment of AXBTs and dropsondes into pre-genesis, and mature tropical cyclones (TC's) within the Western North Pacific (WPAC) basin was conducted during the TPARC-Tropical Cyclone Structure (TPARC/TCS-08) field program. This strategy was repeated again during the Interaction of Typhoons over the Pacific experiment (ITOP/TCS10) in 2010. This sampling strategy enabled a unique view of the three- dimensional (3-D) oceanic thermal and atmospheric environments in evolving tropical systems to be obtained. Coupled with the low-level ocean buoy/float deployment capability of the AFRC WC-130J aircraft, its long-endurance in excess of 12-hours and high-altitude capabilities (300 mb) demonstrates a new era in TC operational ocean feature observation capabilities for initialization and validation of new coupled air-sea TC models such as the NRL coupled COAMPS-TC model, brought on line for the first time during ITOP/TCS10.

Preliminary analysis of the TPARC and ITOP WC-130J AXBT data indicated that three of four systems that developed into typhoons in 2008 and two of three systems in 2010 developed within the WPAC oceanic region referred to as the 'Southern Eddy Zone' between 16-24 N. In TPARC/TCS08, AXBT data for one case (Jangmi) showed rapid intensification (RI) over a warm eddy and subsequent rapid decay (RD) over a cold eddy while during ITOP/TCS10, another case (Fanapi) showed rapid development over a warm eddy. While underlying ocean conditions seemed not to be a factor in TC formation, or lack thereof, subsequent development did appear to depend on subsurface ocean eddy conditions, a result that makes monitoring these ocean conditions for coupled model use an important new consideration in TC observational requirements.

We suggest that this sampling strategy may prove effective in meeting emerging observational requirements for model initialization and validation in the Atlantic Basin as the use of coupled TC prediction models grows. This strategy of flying high in weak systems rather than flying low looking for closed circulations takes advantage of the high altitude and long range capability of the WC-130J aircraft and provides the ability to simultaneously map vertical atmospheric structure searching for signatures of mid-level as well as low-level spin-up at the earliest possible time while also mapping the surface wind field through use of the new Stepped Frequency Microwave Radiometer (SFMR), also flown on the WC-130J aircraft. Furthermore, simultaneous ocean vertical structure profiles reveal signatures of ocean eddies that may impact TC development and subsequent intensification. This type of strategy, especially in concert with G-IV surveillance flights in the storm environment would bring a powerful new set of observations into play that could be ideal not only for coupled model initialization and validation but for forecaster diagnostics for subsequent TC intensification or decay.

An overview of COAMPS-TC Forecasts and Targeting for ITOP

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An unprecedented typhoon field campaign that combined state-of-the-art observations in the atmosphere and ocean ("Tropical Cyclone Structure (TCS)-10" /"Impact of Typhoons on the Ocean in the Pacific (ITOP)") was conducted in the Western Pacific during the summer of 2010. Four different configurations of the Coupled Ocean/Atmosphere Mesoscale Prediction System-Tropical Cyclone (COAMPS-TC) were used to provide typhoon genesis, track, and intensity forecasts in real-time for TCS-10/ITOP. These COAMPS-TC configurations were (a) a fixed-domain (27 and 9 km nested grids) two-way air-sea coupled COAMPS-TC area (INVEST), (b) an atmosphere-only version of COAMPS-TC using a triply-nested grid down to 5 km that automatically moved with the tropical cyclone, (c) the atmosphere-ocean coupled COAMPS-TC system that used the same nested grids for the atmosphere as in (c), and (d) the COAMPS-TC atmospheric adjoint model coupled with a simple ocean mixed layer (ADJOINT),. The ADJOINT configuration was used to assist in determining where targeted observations could be employed in both the atmosphere and the ocean, while the INVEST configuration was used for daily assessments of typhoon genesis potential. The atmosphere-only and the coupled COAMPS-TC configurations were used to provide forecast track and intensity information, and were only activated when a typhoon warning message was issued by the Joint Typhoon Forecast Center. The major findings and results from these four COAMPS-TC forecast exercises include: (i) the INVEST configuration provided a three-day warning lead time for the genesis location of typhoon Fanapi; (ii) continuous assimilation of the ocean observations in the INVEST runs reduced the ocean model sea surface temperature bias which, in turn, improved the ocean forcing to the atmospheric model; (iii) upgraded microphysical and radiation processes improved the surface radiative forcing for the ocean model; and (iv) the seasonal-averaged (8 typhoons) intensity error was larger in the coupled COAMPS-TC forecasts than in the uncoupled COAMPS-TC forecasts, but the coupled COAMPS-TC exhibited a slightly smaller cross-track bias than the uncoupled COAMPS-TC in the 48-96 hour forecast period; and (v) the ADJOINT exhibits complex patterns of sensitivity to ocean-mixed layer depth for storms reaching typhoon strength along with large sensitivity to the low-level atmospheric moisture near typhoon Megi. More detailed discussions on the use, forecast performance, and lessons learned from our applications of the ADJOINT, INVEST, and the uncoupled and coupled COAMPS-TC configurations for eight typhoons during the 2010 season will be presented.

Multi-Model Coupled Air-Sea Forecasts of Typhoons during ITOP

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In support of the Impact of Typhoons on the Ocean in the Pacific (ITOP) experiment, high-resolution coupled models were run in a semi-operational setting in real time at the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS) during the ITOP dry run from Sep-Oct 2009 and field phase from August-October 2010. The high-resolution models include the University of Miami Coupled Model (UMCM) and the coupled WRF (CWRF) with triply nested grids of 12, 4, and 1.3-km grid spacing. The coupled models include the fully coupled atmospheric, ocean and wave model components. A multi-model, high-resolution prediction system used in ITOP consists of UMCM and CWRF that are run with various initial and boundary conditions from several operational global models including GFS, ECMWF, NOGAPS, JMA, and HYCOM. The coupled models provide not only the storm track, intensity and structure forecasts, but also the surface waves and ocean temperature and current fields in typhoons. The air-sea coupled forecasts were used in near real time to aid the deployment of the ITOP atmospheric and oceanic instrumentation from the C-130 aircraft and ships. Preliminary results from the coupled model forecasts and verification statistics from eight typhoons will be presented at IHC. Implications and potential applications for hurricane reconnaissance and prediction in the Atlantic will be discussed.

Session 10
Other Research to Improve the Prediction of Tropical Cyclone Intensity and Structure, Track, Precipitation, and Inland Inundation,
Part 1

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

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HS3 is a five-year mission specifically targeted to enhance our understanding of the processes that underlie hurricane intensity change in the Atlantic Ocean basin. The HS3 science questions can be distilled down to the extent to which either the environment or processes internal to the storm are key to intensity change. Is storm formation and intensification mainly a result of characteristics of the large-scale environment or internal processes? Are these internal processes driven by large-scale forcing or do they act independently of this forcing?

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 30-hour flight durations will provide coverage of the entire Atlantic Ocean basin, and on-station times up to 10-24 h depending on storm location. Deployments will be in September of 2012 and from mid-August to mid-September 2013-2014, with ten 30-h flights per deployment.

HS3's suite of advanced instruments will measure key characteristics of the storm environment and its internal structures. The measurements include:

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. TWiLiTE is a direct detection Doppler lidar capable of measuring the motion of air molecules in clear air environments.

• Full tropospheric wind, temperature, and humidity profiles from the Advanced Vertical Atmospheric Profiling System (AVAPS) dropsonde system, which is capable of releasing up to 100 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.
• Measurements of temperature, water vapor, and liquid water profiles, total precipitable water, sea-surface temperature, rain rates, and vertical precipitation profiles from the High-Altitude MMIC Sounding Radiometer (HAMSR).

2011 Plans for NOAA's Intensity Forecasting Experiment (IFEX)

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We continue to address the goals set forth by NOAA's Intensity Forecasting Experiment (IFEX). IFEX aims to collect observations throughout the tropical cyclone (TC) life cycle, develop and refine measurement technologies for real-time monitoring of TC structure and intensity, and improve understanding of the physical processes important in TC intensity change. This season our focus will be on strengthening the NOAA intra-agency partnership among HRD, AOC, EMC and NESDIS, as well as a new effort to enhance interactions between HRD and NHC. Plans for the 2011 field program, including how these interactions will impact it, will be presented.

Estimating Tropical Cyclone Intensity from Infrared Image Data

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A near real-time objective technique for obtaining features associated with the shape and the dynamics of cloud structures embedded in tropical cyclones from satellite infrared images is described. As the tropical cyclone develops from an unstructured cloud cluster and intensifies the cloud structures become more axisymmetric about an identified reference point. Using variables derived from remotely-sensed IR data, the technique calculates the gradient of the brightness temperatures to measure the level of symmetry of each structure and this level of symmetry characterizes the degree of cloud organization of the tropical cyclone. Previous results have shown that the technique provides a reasonable objective, independent measure of the intensity of the tropical cyclone.

In this presentation, seventy-eight tropical cyclones from the 2004-2009 seasons are used to both train and independently test the intensity estimation technique. Two independent tests are performed to test the ability of the technique to accurately estimate tropical cyclone intensity. Results from these tests will be presented.

Airborne Surface Water and Ocean Topography Mapping System

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A long history of spaceborne radar altimetry observations of the ocean surface has revolutionized oceanography enabling significant advances in our understanding of global ocean circulation [e.g., Fu and Cazenave, 2001]. More recently these measurements (in the last decade) have been extended to provide elevation measurements of land surface water bodies (ie lakes, rivers and floodplains) [e.g. Birkett 1998; Alsdorf et. al. 2007a]. Despite the significant contributions of these observations, the fundamental limitation presented is the lack of coverage that a nadir-looking sensor can provide with gaps between satellite tracks of 200-300km. The result is that smaller scale features (e.g., oceanic mesoscale processes) are not resolved and many rivers and lakes are not observed altogether [Alsdorf et.al. 2007b].

In response the NRC Decadal Survey acknowledged not only the compelling science needs, but also the measurement commonality between the ocean and surface water communities by recommending the Surface Water Ocean Topography satellite mission (SWOT). To satisfy the high-resolution sampling requirements needed for surface water hydrology, and the high accuracy requirements for the oceanography, the primary SWOT instrument is a Ka-band Radar Interferometer (KaRIN). This solution is capable of simultaneously meeting coverage, accuracy and resolution requirements and enhances greatly the science achievable from a traditional profiling altimeter. However the uniqueness of this solution, and application, means there remain some specific questions for which there currently exists little or no supporting data.

In this paper we present the Ka-band SWOT Phenomenology Airborne Radar (KaSPAR). This multi-baseline Ka-band InSAR will serve to provide the necessary measurements to address key SWOT mission risk items. With centimeter-scale precision, its ability for map ocean and surface water topography over a wide swath (near nadir to 25 degrees incidence), KaSPAR can provide unique high-resolution topography maps for directly observing storm surge caused by tropical storms. With its ability to map radial velocity as well, the surface water velocity and topography observations may also provide essential observations of coastal and inland inundation. These applications and KaSPAR measurement capabilities will be described.

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The Experimental HWRF-HEDAS system: Model Evaluation in Preparation for Satellite Microwave Data Assimilation Inside the Hurricane Precipitation Area

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Over the last two decades, data assimilation of satellite observations outside precipitation has lead to significant improvement in the ability of global models to represent the large-scale synoptic environment. This has resulted in measured improvement in the hurricane track forecast skills of the global models. However, improving the accuracy of hurricane intensity changes remains a very challenging problem. The main source of error for the large-scale models is their limited ability, due to the use of convective parameterizations, to resolve convective scale events and their interaction with the large-scale environment. Regional models have the resolution, and the physics to properly represent the convective processes. However, even today, there is large uncertainty regarding the assumptions used by the convective-scale parameterizations (e.g. parameterizations of the microphysical processes, the boundary layer processes and the ocean-atmosphere fluxes).

Assimilation of satellite observations inside the precipitation presents the next opportunity for hurricane intensity forecast improvements. It offers two benefits: the ability to improve the model forecasts through constantly pushing the model toward the observed precipitation structures; the ability to improve the model physics through parameter estimation as part of the data assimilation.

The data to be assimilated could be either the satellite-based retrievals of geophysical parameters, or, the observed radiances themselves. Assimilation of geophysical parameters is often easier since they are more closely related to the state variables. However, instantaneous satellite retrievals carry a lot of uncertainty. Assimilating the observed radiances is the more promising approach at the moment. However, to allow the model to efficiently assimilate the observed data, we need to first assure that the model-produced satellite observables compare well to the observations themselves.

To facilitate the model evaluation, we are developing the Tropical Cyclone Information System (TCIS- http://topicalcyclone.jpl.nasa.gov). As part of TCIS, a dedicated portal was developed to facilitate the NASA/NOAA/NSF hurricane field campaigns of 2010 (http://grip.jpl.nasa.gov). We used it to identify a number of cases to allow the evaluation of different hurricane forecasts. In particular, we focused on evaluating the performance of the Experimental version of HWRF (HWRFX) in forecasting the evolution of hurricane Earl. In a previous study we used the model forecast of the thermodynamic and hydrometeor fields to forward simulate satellite observables (microwave brightness temperatures). We compared the overall structure of the observed and the forecasted storms as depicted by the brightness temperatures at 37 and 89 GHz channels. We found that the model was highly capable in depicting the 2D structure of the precipitation field and its evolution. However, the previous study was mostly qualitative.

In this study we go further and perform a statistical comparison of the observed and simulated brightness temperatures. We evaluate their distributions as a function of the distance from the storm center. We look at the joint multi-frequency distributions of simulated and observed brightness temperatures to evaluate whether the vertical structure of the precipitation is properly reflected in the simulated storms. As part of this study, we also evaluate the impact of microphysical assumptions as manifested in the brightness temperatures of an ensemble WRF (ARW) simulations, each member using different assumptions about the hydrometeor's particle size distributions. Ongoing plans include developing composites from satellite observations to facilitate the model evaluation. The goal is to point toward a more realistic set of assumptions that would produce simulations with closer-to-the-observed radiometric signatures. Assuring a close comparison between observed and modeled radiances in precipitation is the first, and very important, step toward an effective assimilation of satellite observations in the HWRFX system. For this purpose the Hurricane EnKF Data Assimilation System (HEDAS) that is currently developed at NOAA's hurricane research division is proposed to be used.

Hurricane center-fixing with the Automated Rotational Center Hurricane Eye Retrieval (ARCHER) method

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Precise center-fixing of tropical cyclones (TCs) is critical for operational forecasting, intensity estimation and visualization. Current procedures are usually performed with manual input from a human analyst, using multispectral satellite imagery as the primary tools. While adequate in many cases, subjective interpretation can often lead to variance in the estimated center positions. In this paper we present an objective, robust algorithm for resolving the rotational center of TCs: the Automated Rotational Center Hurricane Eye Retrieval (ARCHER). The algorithm finds the center of rotation using spirally-oriented brightness temperature gradients in the TC banding patterns in combination with gradients along the ring-shaped edge of a possible eye. It is calibrated and validated using 85-92 GHz passive microwave imagery because of this frequency's relative ubiquity in TC applications. However, similar versions of ARCHER are also shown to work effectively with 37 GHz and infrared imagery of TCs. In TC cases with estimated low to moderate vertical wind shear, the mean accuracy of the ARCHER estimated center positions is 17 km (9 km for Category 1-5 hurricanes). In cases with estimated high vertical shear, the accuracy of ARCHER is 31 km (21 km for Category 2-5 hurricanes). Other structure parameters retrieved from this algorithm such as eye radius and eyewall brightness temperature are shown to have important value for intensity estimation.

Intraseasonal to Seasonal Prediction of Tropical Cyclogenesis: A Statistical-Dynamical Forecast System

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We have developed a statistical-dynamical prediction system for forecasting the probability of tropical cyclone (TC) formation at intraseasonal to seasonal scales and 2.5° horizontal resolution across the western North Pacific (WNP), with lead times out to 90 days. We use five large scale environmental factors (LSEFs) to represent the favorability of the climate system for tropical Cyclogenesis (low level relative vorticity, sea surface temperature, vertical wind shear, upper level divergence, and planetary vorticity). We use logistic regression to develop a statistical model representing the probability of TC formation based on the LSEFs. Data for the model development was obtained for the LSEFs from the NCEP R2 reanalysis, and for the corresponding TC activity from the JTWC best track data set. We use the NCEP Climate Forecast System (CFS) to obtain forecasts of the LSEFs at lead times of several days to several months, which we then use to force the regression model. The forecasts are ensemble means based on extensive ensembling of individual forecasts with multiple initial conditions and multiple lead times.

We have conducted independent hindcasts for 1982-2008 which show the forecast system has skill and potential value to risk adverse customers (e.g., positive Brier skill scores, skillful ROC values). For 2009 and 2010, we have generated and verified forecasts out to leads of 90 days. The skill of these forecasts is very positive, as indicated by several metrics. For example, for 2009, the 30 day lead forecasts had a probability of detection (POD) of 0.81 and a Heidke skill score (HSS) of 0.38. For 2010, the 90 day lead forecasts had a POD of 0.82 and a HSS of 0.26 (the 2010 skill results are preliminary until the release of the JTWC best track data in 2011). The 2009 and 2010 forecasts also correctly predicted several intraseasonal and interannual variations. For example, the 30-90 day lead forecasts for 2010 forecasted a northward and westward shift in the location of the main formation region from its long term mean position, and much lower formation probabilities than normal, consistent with the observed formations for 2010 and with the development of La Nina conditions in 2010. These formation anomalies were forecasted first by the 90 day lead forecasts issued in Mar-May 2010, three (five) months prior to the first La Nina watch (advisory) issued by NOAA/CPC.

We have also developed a corresponding system for forecasting North Atlantic TC formations, with positive early results. We are presently upgrading the forecast system to take advantage of NCEP's recently released and higher resolution Climate Forecast System Reanalysis (CFSR) and Climate Forecast System version 2 (CFSv2).

Session 11
Other Research to Improve the Prediction of Tropical Cyclone Intensity and Structure, Track, Precipitation, and Inland Inundation, Part 2

International Best Track Archive for Climate Stewardship (IBTrACS) activities at NOAA's NCDC

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The International Best Track Archive for Climate Stewardship (IBTrACS) is a project at NOAA's National Climatic Data Center under the auspices of the World Data Center for Meteorology – Asheville to collect and disseminate the historical tropical cyclone best track data from all available agencies, merging the disparate data sets into one comprehensive product for the user community. One of the goals of the project is to maintain open data processing methods, so that desired user feedback on data quality is more easily collected. In addition, data provenance is completely recorded so all observations and corrections, either through rigorous quality control or user feedback, may be attributed to their source. Data are available in various formats to accommodate the diverse needs of the tropical cyclone data user community. The presentation will summarize the purpose of the project, recent accomplishments and the future direction of IBTrACS. More information on IBTrACS is available at http://www.ncdc.noaa.gov/oa/ibtracs/

Dry Air in the Tropical Cyclone Environment

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Infrared and microwave satellite imagery has steadily improved our ability to detect dry air in the environments of tropical disturbances. However, forecasting when and how low to mid-level dry air will interact with these systems remains a difficult challenge. This presentation will discuss details of diagnosing interactions between low to mid-level dry air and tropical disturbances (i.e. arc cloud formation), trajectory analyses that may provide insight as to where and when a dry air intrusion will take place, and idealized simulations that further investigate trajectories of dry air intrusions into tropical cyclones (TCs).

When a dry air intrusion interacts with tropical convection, significant arc cloud events are often spawned. Although arc clouds are common features in mid-latitude thunderstorms and MCSs, they have only occasionally been noted in TC environments (Knaff and Weaver 2000). Arc clouds denote the presence of a density current that forms when dry middle level (~600-850 hPa) air has interacted with precipitation. The convectively-driven downdrafts that result can reach the surface/near-surface and spread out from a thunderstorm's convective core. It is hypothesize that the mid-level moisture found in the *moist tropical* North Atlantic sounding described by Dunion (2011) is insufficiently dry to generate extensive arc clouds around African easterly waves (AEWs) or TCs. However, substantial arc clouds (100s of km in length and lasting for several hours) consistently form in the tropics in the periphery of these tropical disturbances. Dunion (2011) described two additional types of air masses frequently found in the tropical North Atlantic and Caribbean (both with 50-60% less low to mid-level moisture than the *moist tropical* sounding) that could effectively initiate the formation of large arc clouds: the *Saharan Air Layer* and *mid-latitude dry air intrusions*. It is hypothesized that the processes leading to the formation of arc cloud events can significantly impact an AEW or TC (particularly smaller, less developed systems). Specifically, the cool, dry air associated with the convectively-driven downdrafts that form arc clouds can help stabilize the middle to lower troposphere and may even act to stabilize the boundary layer. The arc clouds themselves may also act to disrupt the storm. As they race away from the convective core region, they create low-level outflow in the quadrant/semicircle of the AEW or TC in which they form. This outflow pattern counters the typical low-level inflow that is vital for TC formation and maintenance.

Recent work looking at trajectory analyses and observations from aircraft and satellites suggest that there are preferred pathways for low to mid-level dry air to enter the periphery of tropical disturbances. These results may provide insight as to where and when a dry air intrusion may take place. To further study these preferred pathways, idealized simulations of a TC vortex embedded in easterly flow is examined on both an f-plane, a beta plane and relative to an easterly jet to examine the relative the impact of both beta drift and the Magnus effect on the entrainment of dry air into the TC. The conditions for the relative importance of these effects under differing horizontal and vertical shears of easterly flow expected with AEWs will be presented.

Improvements to Statistical Intensity Forecasts

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Tropical cyclone intensity forecasts have improved relatively slowly over the last decade and statistical models still remain state-of-the-art. Recently with NOAA's Hurricane Intensity Forecast Improvement Project (HFIP), great emphasis has been placed on numerical weather prediction models, which are fully expected to become the state-of-the-art methodology by the end of the the HFIP program. In the mean time, several new statistical techniques have been developed, existing techniques have been improved and the application of similar techinques are being developed for other tropical cyclone basins. Much of the recent improvements to existing methodologies have concentrated on improved use of satellite-based information from NOAA's Geostationary Operational Environmental Satellite (GOES) and Polar Operational Environmental Satellite (POES) programs and data from other low earth orbiting satellite platforms. Funding for these efforts has come from a variaty of different programs including the GOES I/M Product Assurance Plan (GIMPAP), the Joint Hurricane Testbed (JHT), and the GOES-R Risk Reduction (GOES-R3) program.

This presentation will detail the recent improvements to existing statistical intensity forecast techniques, recently developed techniques and planned future improvements. More specifically we will present recent improvements (and related verifications) to existing statistical techniques including the Statistical Hurricane Intensity Predictions Scheme (SHIPS), the Logistic Growth Equation Model (LGEM) and the Rapid Intensity Index (RII). This disucssion will include updates to the developmental datasets, new GOES-based, microwave-based and total precipitable water predictors and statistical methodologies as well as insight inferred from real-time experimental (JHT and GOES-R3 Proving Ground) versions of the RII that included lightning information. In addition, recently developed tools to anticipate rapid weakening (25-kt in 24 h) of non-landfalling tropical cyclones and extra-tropical transitions will be discussed. Here we will also review expected performance of a probabalistic estimate of rapid weakening and the factors found to be related to eminant (24-h) extratropical transition in a similar statistical framework. Finally, future plans to transfer these capabilities to other tropical cyclone basins will be briefly discussed.

Improvements in the Statistical Prediction of Tropical Cyclone Rapid Intensification

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The National Hurricane Center currently uses a skillful probabilistic rapid intensification (RI) index (RII) based on linear discriminant analysis of the environmental and satellite-derived features from the Statistical Hurricane Prediction Scheme (SHIPS) dataset. In this presentation, two new probabilistic models for RI prediction, along with the benefits of using an ensemble-mean of multiple models, will be reviewed. The remainder of the presentation will focus on the benefits of using structural predictors based on microwave imagery.

Two new probabilistic RI models, one based on logistic regression and the other on a naïve Bayes framework, are evaluated. Both models incorporate data from the SHIPS dataset and have been developed for a variety of RI thresholds for both the Atlantic and eastern Pacific. Cross-validation demonstrates that both models are skillful relative to climatology and that their skill is competitive with SHIPS-RII. Finally, a three-member ensemble-mean of the logistic, Bayesian, and SHIPS-RII models provides superior skill to any of the individual members. For a rapid intensification threshold of 25 kt per 24 h, the three-member ensemble-mean improves the Brier skill scores relative to the current operational SHIPS-RII by 33% in the Atlantic and 52% in the eastern Pacific.

This presentation will also highlight improvements in statistical models of RI resulting from the incorporation of predictors derived from 37-GHz microwave imagery. These predictors exploit the internal structure of tropical cyclones often obscured from view in geostationary satellite data. Cross-validation of the logistic RI model in both the Atlantic and East Pacific shows that adding certain microwave-based predictors improves both the Brier skill score and probability of detection significantly. Plans to include predictors from 19- and 85-GHz microwave frequencies will also be discussed.

Improving SHIPS Rapid Intensification (RI) Index Using 37 GHz Microwave Ring Pattern around the Center of Tropical Cyclones

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The physical processes associated with rapid intensification (RI) of tropical cyclones (TCs) remain unsolved. Predicting these events is one of the most challenging aspects for TC forecasters. Recently, a robust ring pattern in the inner core area of TCs has been found in the 37 GHz microwave images to be associated with RI. Margie Kieper initiated a subjective forecast method using the 37 GHz color product developed by the Naval Research Laboratory (NRL) to predict the onset of RI. She reviewed numerous microwave TC images, and found that a cyan color ring around the eye could be an early indicator of RI when environmental conditions are favorable. She tested this method in real time for the 2008 hurricane season in the Atlantic (ATL) and 2009-2010 hurricane seasons for both ATL and East Pacific (EPA) basins in conjunction with the SHIPS RI index. The result was very encouraging. So it will be optimal to translate this subjective forecast method into an objective one for wider forecast applications.

However, the NRL 37color product is constructed by using 37 GHz vertically polarized (V37) and horizontally polarized (H37) brightness temperatures, and polarization correction temperature (PCT37). V37 and H37 are sensitive to sea surface (cold) and low-level clouds/rain (warm), while PCT37 is sensitive to convection (cold). The product implements a red/green/blue color composite from PCT37, H37 and V37 so that the sea surface in the color product appears green, deep convection appears pink, and low-level water clouds and rain appear cyan. Although this product provides unique qualitative information, quantitative information is sacrificed. It has been a mystery for the TC community what the cyan color truly represents. This hinders us from translating Margie Kieper's eye-based subjective method into an objective and automatic prediction method.

In this study, we discovered the mystery by determining quantitative values for the cyan color region in the NRL 37 GHz color product using a 12-yr Tropical Rainfall Measurement Mission (TRMM) tropical cyclone precipitation feature database. Based on these findings, an objective 37 GHz ring pattern RI index is developed by strictly following Margie Kieper's ring pattern identification and forecasting methodology. Evaluation of the index has been done by using the TRMM Microwave Imager (TMI) observations of TCs in the ATL and EPA basins from 2002 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 to the SHIPS RI index, the skill score of the new combined indices can be as high as 55% for the ATL basin and 75% for the EPA basin for RI threshold at 25-kt intensity increase during 24 hours.

Forecasting Rapid Intensification of Tropical Cyclones in the Western North Pacific Using TRMM/TMI 37 GHz Microwave Signal

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The prediction of rapid intensification (RI) of tropical cyclones has always been a great challenge in tropical weather forecasting. Compared with the progress in RI forecast in the Atlantic and Eastern North Pacific, there are few works in RI forecast in the Western North Pacific. Following Margie Kieper's subjective forecast method using the 37 GHz color product developed by the Naval Research Laboratory (NRL) to predict the onset of RI, we have developed an automated detection method, 37 GHz ring pattern RI index, to identify the cyan-color ring pattern around the center of tropical cyclones from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI) 37 GHz observations (please see the abstract by Jiang et al. in the same conference). In this study, this ring pattern RI index is applied to the 12-yr TRMM Tropical Cyclone Precipitation Features (TCPFs) database to investigate the probability of improving RI forecast in the Western North Pacific. The result shows that the probability of detection (POD) of RI for storms reaching tropical storm intensity in the Western North Pacific is about 63%. Furthermore, it is found that the greater the intensity of tropical cyclones is, the larger the POD. The PODs are 40%, 75%, and 100% for tropical storms, typhoons, and super typhoons, respectively.

Our technique uses the 37-GHz ring feature in the storm's inner core, therefore it counts the effects of storm internal processes on intensity change. However, large-scale environmental conditions are the controlling factors of intensity change. We plan to use the environmental factors such as SST and wind shear to screen out those ring cases with unfavorable environmental conditions. The work is underway to generate environmental RI index similar to STIPS using the ECMWF INTERIM reanalysis data. The environmental RI index will be incorporated into the 37 GHz ring pattern RI index to further advance the RI forecast skill in the Western North Pacific.

Session 12
Joint Hurricane Testbed Project Updates and Improved Products

SESSION 12

2010 Update on The Joint Hurricane Testbed (JHT)

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Joint Hurricane Testbed

Forecasting tools and techniques, developed by the research community were tested and evaluated at the National Hurricane Center (NHC) facilitated by the Joint Hurricane Testbed (JHT). Eleven 5th round (FY09-11) projects were tested and evaluated during the 2010 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. An announcement of Federal Funding Opportunity for new FY11 funding was released in July. Letters of Intent followed by full Proposals were submitted by Principal Investigators and evaluated by the JHT Steering Committee for a 6th round of JHT projects to begin in August 2011.

Enhancements to the SHIPS Rapid Intensification Index

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Predicting the timing, magnitude, and duration of episodes of tropical cyclone rapid intensification (RI) remains one of the most challenging problems in tropical cyclone forecasting. In recent years, a statistically based rapid intensification index (RII) that uses predictors from the SHIPS model to estimate the probability of RI has been developed for operational use by forecasters at the National Hurricane Center (NHC) for systems in the Atlantic and eastern North Pacific basins. Although the operational RII forecasts exhibited some skill in each of the aforementioned basins when validated for the recent 2008 and 2009 Hurricane seasons, the skill of the RII was relatively low in the Atlantic basin and only in the low to moderate range in the eastern North Pacific basin. Thus with support from the NOAA Joint Hurricane Testbed (JHT), research is currently being conducted to improve the operational RII by including predictors derived from three new sources of inner-core information. The first of these three new sources is the time evolution of the structure of the inner-core as deduced using standard principle-component analysis of GOES infra-red (IR) imagery while the second is microwave-derived total precipitable water. The final source is lower tropospheric GFS model temperature and moisture data and sea-surface temperature estimates derived from an inner-core sea-surface temperature-cooling algorithm.

In year 1 of this JHT proposal, an experimental version of the SHIPS rapid intensification index (RII) was developed for the Atlantic basin utilizing predictors from these three new information sources. This new experimental version of the Atlantic RII was tested in real-time during the latter part of the 2010 Atlantic Hurricane Season for the first time. A verification of these real-time forecasts as well as those that were obtained by re-running cases that occurred prior to the commencement of these tests using real-time GFS data and operational NHC track forecasts will be shown. More recently, an experimental version of the RII was also developed for the eastern North Pacific basin using predictors that were quite similar to those that were used to derive the experimental Atlantic version. The results of these efforts will also be presented at the conference.

Status and plans for the development of a unified dropsonde quality assurance and visualization capability, ASPENV3

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In 2009 and 2010, the Joint Hurricane Testbed (JHT) funded a joint NOAA and NCAR project to develop a revised software package to perform real-time quality control (QC) of dropsonde observations from AFRC and NOAA aircraft. The primary goal of the project is to provide a more robust editing and visualization capability than is currently available to ensure that real-time observational and research data from dropsonde observations are of the highest quality and as error-free as possible. The software package combines the graphics capability and ease of use of NCAR's current ASPEN software with some of the additional editing capabilities and refined QC algorithms contained in NOAA's Editsonde software. The new software suite operates on multiple computer platforms, incorporates publicly available graphics frameworks, and will be configurable to run in either a real-time, basic mode or in an enhanced mode for post analyses of the dropsonde data.

An initial prototype software package, ASPENV3, has been completed, will run in Windows, Mac OSX, or Linux computer operating systems, and is available for testing by experienced users. Additional components are currently being added and an official release of the software is expected to occur prior to the start of the 2011 hurricane season. A progress report on the stage of development and plans for testing and refining the software will be given. A demonstration of ASPENV3 will be presented and some of the new capabilities will be briefly discussed.

Advanced Applications of Monte Carlo Wind Probability Model:
A Year 2 Joint Hurricane Testbed Project Update

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Under previous JHT support, a program for estimating the probability of occurrence of 34, 50, and 64 kt winds was developed by NESDIS and CIRA. A Monte Carlo (MC) method was utilized to combine the uncertainty in the track, intensity, and wind structure forecasts for tropical cyclones. The MC probability program was transitioned to NHC operations in 2006.

In the current project, four new applications of the MC model were proposed including (1) Landfall timing and intensity distributions; (2) Methods for using the MC model to enhance WFO local products; (3) Probabilities integrated over coastal segments; (4) Automated guidance for issuing coastal watches and warnings. A prototype graphical user interface has been developed for items (1), (3), and (4) above, and examples will be presented. A validation of the MC model for a large sample of cases for coastal and inland points was completed to help define probability thresholds needed for the WFO local application per item (2). Results from that study were presented last year, and will be very briefly summarized.

Four refinements to the MC model code were also proposed. These include (1) A procedure to adjust the model time step for fast moving and small storms; (2) Modification of the azimuthal interpolation routine that occasionally leads to inconsistent probability values for 34, 50, and 64 kt winds; (3) Evaluation of the spatial interpolation method that sometimes results in inconsistencies between the gridded and text probabilities; (4) Evaluation of the underlying wind radii model utilized by the MC model. Results from items (1) and (4) were presented last year, so the emphasis will be on results from (2) and (3).

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

A Joint Hurricane Testbed Project (Year 2)

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Eyewall replacement cycles in hurricanes are generally associated with rapid and dramatic changes in wind structure and intensity. While the intensity fluctuations are usually transient and of particular concern when storms are near land, the broadening of the wind-field tends to be a long-lived change that has substantial impacts on shipping and marine interests because of the associated increases in wave height, storm surge, and radius of 50 kt wind (R50). In fact, eyewall replacement cycles represent a highly efficient (and easily identifiable) pathway to storm growth.

Despite the implications and known impacts of eyewall replacement cycles, objective tools to forecast these events were not available prior to the 2010 hurricane season. Consequently, forecasters have relied on subjective methods for estimating the onset of these events and adjusting intensity forecasts accordingly.

In Year-1 of this Joint Hurricane Testbed project we transitioned a new objective model into operations at the National Hurricane Center, and the model was run in a real-time experimental mode during the 2010 season. The model provides probability of onset of an eyewall replacement cycle out to 48 hours based on observed and forecast environmental features and observed storm features (as measured with GOES infrared imagers). In the first part of this presentation, we will verify the model performance and skill for the 2010 season.

In the ongoing Year-2 of this project, we are constructing and documenting the first general climatology of intensity and structure changes associated with eyewall replacement cycles. This climatology is based on low-level aircraft reconnaissance data and is being utilized to construct additional objective forecast tools. These tools will provide prognostic information about the most likely intensity evolution based on measured environmental and storm features with the primary goal of reducing intensity forecast error. Recent results of this part of the project will be introduced in the second part of this presentation.

ATCF Requirements, Intensity Consensus and Sea Heights Consistent with NHC Forecasts (Year 2)

Charles R. Sampson[1], Ann Schrader[1], Efren Serra[1], Paul Wittmann[2], Hendrik Tolman[3], Chris Sisko[4], Chris Lauer[4], Jessica Schauer[4], John Knaff[5], Mark DeMaria[5], Andrea Schumacher[5]
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The Automated Tropical Cyclone Forecasting System (ATCF) is one of the core forecast systems at U.S. tropical cyclone forecast centers and has now been in operations at the NHC for twenty years. Modifications to the ATCF are relatively inexpensive, making it a preferred target platform for Joint Hurricane Testbed and Hurricane Forecast Improvement Project (HFIP) products and algorithms. This talk reviews progress in the second and final year of this ATCF-focused JHT project. The three parts of this project are to: 1) Address NHC User Requirements, 2) perform studies with intensity consensus aids, and 3) to run real-time, evaluate and possibly implement an algorithm to produce sea heights consistent with NHC forecasts. This JHT project is on schedule. Additional funding for improvements to the ATCF in 2011 and beyond comes courtesy of HFIP.

Atlantic Warm Pool SST Bias in HYCOM

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The rationale for this study is the recent scientific finding that the Atlantic warm pool (AWP) - a large body of warm water comprised of the Gulf of Mexico, the Caribbean Sea, and the western tropical North Atlantic - may add a value to improving the simulation of Atlantic tropical cyclone (TC) in operational hurricane forecast models. In particular, recent studies using both observations and models have shown that a large AWP reduces the vertical wind shear and increases the convective available potential energy over the main development region for Atlantic hurricanes, and thus facilitates the formation and development of Atlantic TCs. Therefore, our ultimate goal is to improve the forecast of the formation and intensification of Atlantic hurricanes in NCEP/EMC operational models, by improving the simulations of the AWP in that model during the Atlantic hurricane season of June to November.

In order to evaluate the simulation of the AWP in HYCOM, which is the ocean model component of the NCEP/EMC operational models, we have setup HYCOM for the Atlantic domain between 20^{o}S and 70^{o}N using RTOFS-Atlantic, the NCEP/EMC operational ocean model, as the basic platform. The HYCOM is thermally coupled to an Atmospheric Mixed layer Model (AML) to allow physically more realistic thermal interactions at the air-sea interface, thus to minimize thermodynamic inconsistency at the air-sea interface. Our major finding is that the HYCOM tends to create a large cold bias in the AWP region due to its inherent oceanic heat flux errors. Although the overall time evolution of the AWP bias is quite slow, a large cold SST bias with persistent spatial structure may emerge during a 5-day forecast, during which the RTOFS is not initialized. An important implication is that, since the RTOFS is used to initialize the NCEP/EMC operational hurricane forecast model, the cold AWP SST bias can be introduced to the hurricane forecast model and thus negatively affect the hurricane forecast.

Tools for Coordinating Aircraft During Hurricane Field Campaigns

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The NASA Real Time Mission Monitor (RTMM) is a situational awareness decision-support tool that integrates real time aircraft tracks, waypoints, satellite imagery, radar products, surface observations, model output parameters and airborne remote sensing variables in an easy to use and view web-based application. RTMM enables real time decision-making for mission scientists, pilots, mission managers, instrument scientists and program managers by providing up-to-date information about the weather, spacecraft, and the location, altitude and heading of the aircraft.

The Real Time Mission Monitor optimizes both airborne science experimental field campaigns and operational science aircraft missions. The second-generation version of RTMM is now fully integrated into a web browser portal and no longer relies on the standalone Google Earth application. The implementation in a web browser makes it easy for any authorized user anywhere with an Internet connection to follow and coordinate aircraft tracking during dynamic hurricane aircraft missions.

The Real Time Mission Monitor is a proven tool having been used in many field experiments from arctic forest fire missions to soil moisture mapping as well as tracking the BP Gulf Oil spill. In the summer of 2010, RTMM was integral to the success of the PREDICT, GRIP, and IFEX coordinated manned and unmanned hurricane flights. An overview of the use of RTMM during the 2010 hurricane flights, its planned usage in 2011 and potential future manned and unmanned aircraft flights will be described. RTMM animations of the 2010 hurricane flights and demonstrations of RTMM and the pre-flight waypoint planning tool will be provided.

Poster Session

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Real-time radar processing in the 2010 Hurricane Season and plans for 2011

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During the 2010 Hurricane Season there were milestones achieved concerning the NOAA WP-3D airborne tail Doppler radar (TDR) and its use to help initialize the Hurricane Weather Research and Forecasting Model (HWRF). One milestone was the use of the data in the experimental version of the HWRF model a number of times during the season. Another was the first assimilation of data in a parallel run of the operational HWRF during Hurricane Tomas. To accomplish the latter assimilation, several organizations worked to complete the construction and test the operation of the data pipeline from the P3 TDR, consisting of the processing, compression, and transmission of the quality-controlled Doppler-radial velocity data via the Aircraft Operations Center (AOC) to NCEP Central Operations (NCO). We will report briefly on the nature of this pipeline, and the success and problems encountered during the season in processing Doppler data in real time. We will also discuss the future plans for the radar as the P3 radar processing system is changed from an older Sigmet RVP-5 system to the RVP-8 system.

Real-time Transmission of NOAA Tail Doppler Radar Data

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The NOAA WP-3D aircraft provide X-band Doppler/reflectivity measurements of tropical storms and cyclones. Doppler measurements from volume backscatter precipitation profiles can provide critical observations of the horizontal winds as the precipitation advects with these winds. In 2010, NOAA NESDIS, NOAA AOC and Remote Sensing Solutions teamed to capture these profiles and send the radial Doppler profile observations to National Weather Service in near real-time over satellite communication data link. The design of this transmission system included features to enhance the reliability and robustness of the data flow from the P-3 aircraft to the end user. The end objective is to provide these Doppler profiles in a routine fashion to NWS and others in the forecasting community for operational utilization in support of hurricane forecasting and warning.

In this paper we present an overview of this work, accomplishments that were achieved in 2010 and discuss plans for 2011 hurricane season.

Improved Hurricane-force Surface Winds and Rain Rate Retrievals with the Step Frequency Microwave Radiometer

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With the operational deployment of the Stepped Frequency Microwave Radiometer (SFMR), hurricane reconnaissance and research aircraft provide near real-time observations of the 10-m ocean surface wind speed both within and around tropical storms and cyclones. These data are used by hurricane specialists to assist in determining wind radii and maximum sustained winds - critical parameters for determining and issuing watches and warnings. These observations are also used for post storm analysis, model validation, and even ground truth for future satellite-based wind sensors. It is therefore imperative that any errors in these observations be understood and reduced as much as possible.

In previous studies, SFMR rain retrievals have been shown to exhibit a bias of 5 mm/hr and to under report the rain rate, suggesting that the SFMR rain absorption model requires improvement. To address this, we present further studies documenting the problem, as well as a new rain absorption model. Using this new model in the SFMR retrieval process, significant improvements in both the wind speed and rain rate retrievals are achieved.

Collocated ASOS and WSR-88D Depict Collapsing Core and Maximum Wind Gust at Melbourne FL in the Eyewall of Hurricane Erin (1995)

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Landfalling tropical cyclones often contain collapsing cores of heavy precipitation within their eyewalls. Several studies indicate the likely linkage between downburst-like features and strong wind gusts in hurricane eyewalls; however, very few surface-based measurements of winds associated with these features actually exist. In these studies, National Weather Service WSR-88D Archive Level II data were analyzed in search of elevated reflectivity regions exceeding 50 dBZ and then temporally examined for signs of vertical collapse, in some cases near or over surface wind observation sites.

Holmes et al. (2006) presented an introductory glimpse into collapsing precipitation cores in hurricanes Ivan and Katrina; however no surface wind measurements were available in those areas to verify the actual strength of the wind within those features. Blackwell and Medlin (2008) produced a radar climatology of collapsing core frequency within all U.S. landfalling hurricane eyewalls between 1994 and 2007. This climatological study found that some storms were almost completely void of heavy eyewall convection and collapsing cores, whereby others contained extremely prolific activity. One of the most prolific collapsing core producers was Hurricane Danny (1997) in Mobile Bay, AL. Blackwell (2009) presented an example of a possible collapsing core within Danny's eyewall which produced a wind gust of 45 m s^{-1} (101 mph) at the C-MAN station on Dauphin Island, AL. Blackwell et al. (2010) detailed another collapsing core event in a spiral band of Hurricane Katrina which produced a reported wind gust to 122 mph on a docked ship and significant damage along the Mobile AL waterfront.

In each of the above studies, surface wind measurements were sparse or nonexistent and none were collocated with the radar location; thus, near-surface radar information was not available near the surface observation. The current study depicts a collapsing core eyewall event in which the radar and wind observation sites are <u>collocated</u>, providing low-level radar detail. Melbourne, FL (KMLB) experienced the northeastern eyewall of landfalling category 1 Hurricane Erin (1995) in the predawn hours of 2 August 1995. A large convective core of >50 dBZ reflectivity experienced a collapse from above 3000 m (~10,000 ft) to the surface as it approached and swept across the ASOS station. A hurricane-force wind gust of 34 m s^{-1} (76 mph) occurred with the passage of this feature, representing the highest wind measured at that location during the storm. The adjacent WSR-88D clearly shows the descending reflectivity core and acceleration of the near-surface winds as the feature approaches. The collocation of Doppler radar and surface wind measurements make this a unique and interesting event for study and clearly links a collapsing core with a strong hurricane wind gust. Details will be shown at the conference.

Wide Swath Radar Altimeter (WSRA) Wave Spectra from Hurricane Ike compared with WaveWatch III

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The WSRA was first deployed aboard the NOAA WP-3D hurricane reconnaissance aircraft during the 2008 hurricane season. Raw data gathered during several hurricane reconnaissance flights was processed into directional ocean wave spectra, demonstrating the basic functionality of the WSRA. During the flight into Hurricane Ike on September 11, sufficient data were collected to provide an overview of the wave field variation throughout the all regions of the storm.

These WSRA-obtained wave field spectra are compared with the WaveWatch III (WW3) numerical wave model. The WW3 results were provided by Isaac Ginis and Brandon Reichl of the University of Rhode Island. The WW3 wave field spectra were calculated for the time 1230 UTC on September 11, which is the midpoint of the 5-hour WSRA raw data acquisition period. There is generally a good agreement between the WSRA observations and the WW3 predictions of the spatial variation of wave height around the hurricane. The poster will show segments of WSRA wave topography throughout Hurricane Ike, as well as detailed comparisons of the resulting directional wave spectra with the WW3 model predictions.

Storm Surge Measurement Potential of the Wide Swath Radar Altimeter

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The Wide Swath Radar Altimeter (WSRA) has the potential to provide operational, targeted measurements of storm surge for land-falling hurricanes. The concept of airborne measurement of storm surge consists of subtracting the absolute altitude of the aircraft determined using the Global Positioning System (GPS) from the WSRA-measured distance to the sea surface. The result of that simple calculation is the absolute elevation of the water for the particular point in time and space. Wright, *et al*. (2009) demonstrated the technique in a research mode using the NASA Scanning Radar Altimeter (SRA) which has since been decommissioned.

The absolute range calibration of the WSRA can be determined and maintained during the flights using tide gauges within Tampa Bay when returning from each operation, as well as flying by tide gauges in the vicinity of the landfall. The poster examines the range accuracy of the WSRA and demonstrates the absolute calibration technique using a data segment over Tampa Bay when N42RF was returning from a flight into Hurricane Ike on September, 11 2008. Historical SRA data are used to demonstrate the potential benefits of targeted storm surge measurements.

Direct Interpretation of COSMIC Refractivity Data in the Tropical Cyclone Environment

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This study continues to explore the utility of the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) in measuring moisture in the vicinity of tropical cyclones. From a formula relating GPS signal refractivity to temperature, pressure, and vapor pressure (Smith and Weintraub 1953, Kursinski et al. 1995), especially high (low) values of refractivity at a known pressure level correspond to high (low) vapor pressure in a relatively high temperature environment. The implication is that a relative measure of moisture can be attained with only refractivity at a known pressure level, and without specific knowledge of temperature, in a tropical environment. The relation of refractivity to tropospheric thermodynamics further yields a critical value of refractivity below which water vapor saturation – and therefore clouds – cannot exist at a known pressure level.

The above findings are applied in the evaluation of a June-September climatology of COSMIC refractivity over the tropical and subtropical eastern Atlantic Ocean, as well as in the evaluation of individual COSMIC refractivity profiles with varying proximity to select Atlantic tropical cyclones. Nomograms relating refractivity to pressure and temperature have been constructed to assist in the determination of moisture content for given values of refractivity and pressure.

References:

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Ocean's Impact on the Intensity of Three Recent Typhoons (Fanapi, Malakas, and Megi) – Results from the ITOP Field Experiment

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During the 20 August to 20 October 2010 ITOP field experiment, three typhoon cases, Fanapi, Malakas, and Megi were studied. Using airborne C130 dropwindsonde data, C130 AXBT (Airborne Expendable Bathythermograph) data, *in situ* upper ocean thermal structure data from the Argo floats, satellite sea surface temperature and altimetry data together with an ocean mixed layer model, the impact of ocean's thermal structure to the intensity of these 3 typhoons are investigated. It is found that all three typhoons passed over regions of similarly warm sea surface temperature (SST) of ~ 29.5˚ C. However, much distinction is found in the subsurface. Category-2 Typhoon Malakas passed over region of the shallowest subsurface warm layer, as characterised by the depth of the 26˚ C isotherm (D26) of about 37 -40m and Upper Ocean Heat Content (UOHC) of ~ 38-44 kj/cm^2. Category-3 typhoon Fanapi passed over region of moderate subsurface warm layer, with D26 of ~ 60-70m and UOHC of ~ 65-78 kj/cm^2. Category-5 typhoon Megi passed over region of the deepest subsurface warm layer, with D26 reaching 124-132m and UOHC reaching 136-138 kj/cm^2. It is found that this distinction in the subsurface thermal structure played critical role in the intensification of the three typhoon cases. Due to the very deep D26 and high UOHC, very little typhoon-induced ocean cooling negative feedback (typically < 1˚ C) for Megi was found. This very minimal negative feedback enabled ample air-sea enthalpy flux supply to support Megi's intensification. Based on the preliminary report from the Joint Typhoon Warning Center (JTWC), Megi's peak intensity reached 160kts, a very high intensity not often observed even for category-5 typhoons. In contrast, though with very warm pre-typhoon SST of ~ 29.5˚ C, the subsurface ocean condition for Malakas and Fanapi was much less favourable. As a result, the subsurface cold water could be much easily entrained and upwelled to the surface to limit the intensification for Malakas and Fanapi. Finally, it was found that the very deep subsurface warm layer and high heat content over the region where Megi passed was about 10-30% higher than the climatological values. Preliminary results suggest the possible contribution of the La Nina event in causing such warm anomaly over the western North Pacific in October 2010.

Coupled Air-Sea Observations in Tropical Cyclones during ITOP/TCS10

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The effects of the atmosphere-ocean coupling on tropical cyclone (TC) intensity have been studied in numerical models with limited air-sea observations. One of the most challenging problems in TC intensity forecasting is the lack of quantitative measure of the impact of air-sea coupling process on TC structure and intensity change. Observations from ITOP/TCS10 provided a comprehensive data set in TCs with co-located atmospheric and oceanic measurements across the air-sea interface. One of the main objectives of ITOP10/TCS-10 is to measure air-sea fluxes as well as the boundary layer structure using co-located dropsondes and AXBTs. In this study we compare the coupled WRF (CWRF) model simulations of typhoons over the West Pacific with the ITOP/TCS10 observations to examine the presence of asymmetry in surface enthalpy fluxes over the storm-induced cold wake region, which causes a relatively shallow and stable boundary layer. A trajectory and tracer analysis in CWRF indicated that the stable boundary layer results in less depletion of energy from inflow to convection, and therefore such boundary layer asymmetry has energetic influence on TC intensity and convective structure. By analyzing the dropsondes and AXBTs data from ITOP10/TCS10, we aim to evaluate/validate coupled model forecasts and further test the effects of air-sea coupling processes on TC structure and intensity forecasts.

Coming soon: AMSU in GEO

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As a result of NASA's multi-million dollar investments in the development of the Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) at the Jet Propulsion Laboratory (JPL), the technology required to build a geostationary microwave sounder – "AMSU in GEO" – is now sufficiently mature that a space mission can be initiated. A JPL-led effort is under way to develop a low-cost GeoSTAR mission under the new NASA "Ventures" program in partnership with NOAA and European colalborators. If a Ventures proposal is successful, the development could start in 2012, and launch as a hosted payload would take place in the 2016-2018 time frame. The exact timing depends on the availability of hosting oppurtunities. This mission will be focused on storms in the North Atlantic: hurricanes during the summer and mid-latitude storms the rest of the year. With data products ranging from AMSU-equivalent brightness temperatures to derived temperature, water vapor and reflectivity profiles, it will be possible to monitor the intensity and structure of storms continuously. Hurricane applications range from real-time detection of rapid intensification to accurate estimates of vortex location and the structure of the inner core for enhanced forecast initialization, and this mission can contribute significantly to the Hurricane Forecast Improvement Project (HFIP). General numerical weather prediction is also expected to benefit from this mission, particularly from precipitation and height-registered wind-vector products. We discuss the status of the GeoSTAR development, plans for a Ventures mission, and opportunities to participate.

Assimilating COSMIC GPS RO data for Investigating TC Genesis in the Eastern Atlantic Region

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This study is aimed to investigate the impact of using Global Positioning System Radio Occultation (GPS RO) sounding data (i.e., Constellation Observing System for Meteorology, Ionosphere and Climate; COSMIC) for tropical cyclogenesis research. The Weather Research and Forecasting (WRF-ARW) model and the WRF data assimilation system (i.e., WRF 3DVAR) are employed to simulate tropical depression- 8 (i.e., TD-8) of 2006 when the African Easterly Wave (AEW) and vortex moved out over the Eastern Atlantic (12.5°N–18°W). A noteworthy feature was that Saharan dust outbreak was also observed during this period, which made this case more sophisticated. The time frame to be focused is from 1200 UTC 09 to 1200 UTC 12 UTC 12, August 2006. The level 2 wetPrf COSMIC data is adopted in this research. A 72-hr integration is performed in order to better simulate the evolution of TD-8. The initial and time dependent lateral boundary conditions are derived from the NCEP final analysis (FNL) data. A 3-domain nested simulation is configured with 30-km, 10-km and 3.3-km horizontal resolutions, respectively. The simulation results are evaluated using the African Monsoon Multidisciplinary Analysis (AMMA) field experiment as well as NASA TRMM MERG products. Statistical analyses (e.g., bias, absolute mean error, root mean square errors and correlation coefficients) are performed for quantitative comparisons. It is anticipated that the outcome from this research may further advance our understanding of the role Saharan Air layer (SAL) in association with tropical cyclogenesis.

Sensitivities of air-ocean-wave coupling on the prediction of Hurricanes Frances and Ivan

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A series of model runs were conducted to exam the sensitivities of air-ocean-wave coupling on the intensity and structure change of hurricanes Frances and Ivan as well as the associated ocean and wave response. The hurricane model used for this study is the newly developed six-way air-ocean-wave fully coupled COAMPS-TC. The coupling is achieved using the Earth System Modeling Framework to couple the COAMPS-TC with the Navy Coastal Ocean Model (NCOM) and Simulating WAves Nearshore (SWAN). Special in situ measurements of atmosphere, ocean, and wave during the Coupled Boundary Layer Air-Sea Transfer Experiment (CBLAS) field campaign sponsored by the Office of Naval Research were used to validate the model results. For the simulations of Hurricane Frances, it is found using a higher resolution ocean grid improved the magnitude of the trailing cold sea surface temperature anomaly forced by the hurricane. The forecast sea temperature bias below the ocean mixed layer was further reduced when the high-resolution ocean model initial condition was improved using the ocean data assimilation in the ocean spin-up period. In addition, the significant wave height bias was reduced if using the level-off wind stress value from CBLAS instead of the original generation 3 wind source term in SWAN. Including the wave feedback to the atmosphere also produced a much higher value of momentum drag near the eyewall region. The overall intensity and track forecast differences between the uncoupled and various coupled runs (one to six-way coupling) were found to be as large as 18 m/s and 10 nautical miles, respectively.

For the hurricane Ivan study, a special ADCP data array collected by NRL is also used to evaluate the shallow and deep water current response. Including the wave Stokes's drift, wave radiation stress, and wave bottom stress feedback improved the complex correlation coefficients and mean directional error for the ocean current. The wave spectrum comparison between SWAN and Scanning Radar Altimeter showed SWAN generated too much energy in long waves which in turns produced a larger significant wave height bias. These preliminary results indicate a more consistent treatment of momentum stress, sensible heat flux, and latent heat flux at the air-sea interface may be needed in order to improve the forecast of the hurricane environment. The development of a new unified air-sea interface module jointly with NOAA, University of Miami, and University of Rhode Island founded by National Oceanographic Partnership Program is discussed.

Developing an Atlantic Ocean initialization based on the Navy Coupled Ocean Data Assimilation (NCODA) product for the operational GFDL and GFDN hurricane models

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Currently, NOAA's operational GFDL hurricane model and the U.S. Navy's operational GFDN hurricane model use a feature-based modeling technique along with the U.S. Navy's Global Data Environmental Model (GDEM) monthly climatology for ocean initialization in the western North Atlantic basin. In other worldwide ocean basins, the GFDN hurricane model uses the Navy Coupled Ocean Data Assimilation (NCODA) daily product for ocean initialization. Here, we will discuss the development an NCODA-based ocean initialization for the western North Atlantic basin and evaluate its performance against the feature-based/GDEM initialization with the ultimate goal of determining whether or not it is advantageous to replace the feature-based/GDEM initialization with the NCODA-based initialization in the Atlantic basin in the GFDL and/or GFDN hurricane models.

Spatial Verification of Tropical Cyclone Model Track and Intensity Forecasts

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One component that is critical to the development of tropical cyclone modeling is the evaluation and verification of model forecasts. Models that perform well for track forecasting may or may not perform well for intensity forecasting, and vice versa. Likewise, a model that performs well in one ocean basin may have difficulty in another. In addition, even within a given ocean basin, there may be subregions within that basin where a model may exhibit better track or intensity forecasting skill. In this poster, we examine the spatial variability of track and intensity forecast performance within the Atlantic Basin for forecasts from various operational regional and global models for the 2006-2009 hurricane seasons.

We present results for several different types of analyses. Due to the varying density of forecast track points across the basin, we performed Barnes analyses for model errors and biases in order to spatially smooth the data. Spatial error plots derived from these analyses are shown which may be used for a qualitative overview, highlighting key areas of error among models. In addition, quantitative analyses are also included that detail track and intensity forecast performance over four subregions within the Atlantic Basin. Finally, we present results from an outlier analysis that determines, for each model, the geographic locations of two-, three- and four-sigma track and intensity forecast errors. Results from these analyses may help forecasters and model developers alike to better understand some of the biases that exist in the various models.

Improving Ocean Model Performance in Coupled Hurricane Forecasts through Improved Initialization

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The goal of the Shay-Halliwell JHT project is to improve the performance of ocean models for coupled hurricane forecasting. This goal will be achieved by improving the accuracy of ocean model initialization and improving ocean model physics and numerics. Based on our prior work, forecast SST depends so strongly on initialization accuracy that evaluation of ocean model upgrades cannot be reliably performed until significant initialization improvements are made. Candidate products that can be used to initialize ocean models include several real-time data-assimilative ocean analyses along with synthetic upper-ocean temperature-salinity analyses derived from satellite observations (altimetry and SST). Unfortunately, evaluation and identification of optimum initialization products has been hindered by the relative lack of three-dimensional synoptic observations of the ocean in comparison to the atmosphere.

An unprecedented set of ocean observations was collected in the eastern Gulf of Mexico during spring and summer 2010 in response to the Deepwater Horizon oil spill. Nine synoptic surveys from a NOAA P-3 hurricane research aircraft were conducted by NOAA and UM/RSMAS between 8 May and 9 July, deploying AXBTs, AXCTDs, and AXCPs. NOAA/AOML and other institutions conducted extensive in-situ surveys of upper-ocean temperature, salinity, and currents on cruises. NOAA/AOML produced satellite-derived products (e.g. SST, SSH, surface currents) and also deployed surface drifters to provide surface measurements and track Lagrangian trajectories. An extensive set of moored observations was collected by the Minerals Management Service. This unprecedented regional dataset will enable a high-quality evaluation of potential ocean initialization products to be performed in a dynamically active region.

In this presentation, six different products are evaluated, including three HYCOM analyses (Navy 0.08° global, Navy 0.04° GoM, NOAA/NCEP Atlantic RTOFS) and three other model types (NRL IASNFC NCOM, NCSU SABGOM ROMS, and NOAA/NOS NGOM POM). Evaluation of these products through comparison to P-3 profiles and AOML cruise observations demonstrates that the Navy HYCOM products consistently display the smallest bias and RMS errors relative to observations. In contrast, the NOAA/EMC RTOFS HYCOM displayed the largest bias and RMS errors as a result of known code problems. This problem has negatively impacted development of the HYCOM-HWRF coupled forecast model that uses RTOFS to provide initial fields. Fortunately, this problem should be cured when the planned transition of RTOFS HYCOM to the Navy global HYCOM system at EMC occurs during 2011. As of this writing, the Navy global HYCOM system produces the smallest bias and RMS errors compared to observations in the eastern Gulf of Mexico.

Validation of Coupled Hurricane Atmosphere – Ocean Model (HyHWRF)

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Under a goal toward the next generation of operational HWRF (Hurricane Weather Research Forecasting) Model, a collaboration effort has been made for the past years between the Marine Modeling and Analysis Branch and HWRF teams to build a framework of state-of-the-art hurricane prediction model. HyHWRF includes air-sea interactive processes explicitly by coupling the atmospheric hurricane model HWRF to the ocean model HYCOM. In addition to the necessity of adopting physics-driven ocean model to provide a better realization of meso-scale sea surface temperature, for example, a motivation of the effort is to utilize unique leverage that is offered by our organization NCEP (National Centers for Environmental Prediction). The hurricane HYCOM is nested to eddy-resolving, Atlantic basin model, RTOFS (Real-Time Ocean Forecast System). NCEP runs RTOFS daily in real-time, using data assimilation including remote-sensing, *in-situ* and moored measurements, and generates ocean products such as sea surface temperature and sub-ocean properties. This infrastructure provides tremendous efficiency to coupled system in running in real-time, owing to streamline supply of initial and boundary conditions.

Since the HyHWRF system has reached to a maturity in 2008, hundreds of the Atlantic tropical cyclone (TC) predictions have been performed. Also have been conducted in parallel to operational HWRF real-time forecast and operational implementation test each year. The results exhibit a comparable or better forecast skill to operational HWRF. This poster documents validation of ocean simulations. Sea surface temperature, upper ocean structure as well as ocean cooling are evaluated against available data including AXBT (Airborne eXpendable Bathy Thermograph), AVHRR and AMSR-E remote-sensing data.

HWRF Model Diagnostic Improvements

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The hurricane team at EMC works to continually improve the HWRF model for each hurricane season. A crucial way of determining model behavior and potential areas of improvement is through the HWRF diagnostics suite. The evolution of the HWRF model diagnostics will be detailed, specifically the previous season's inclusion of model-simulated GOES infrared and water vapor images. Potential upgrades for the 2011 hurricane season are described and involve a diagnostic module comparing three models side by side through vertical cross sections of relative humidity and wind speed, streamlines, and surface winds. The use of a new module that retrieves relevant pressure level data from model grib files and inserts them into an easy-to-read text file will also be explained. These upgrades coupled with the HWRF real-time statistics website will provide a new basis to assess model behavior and pinpoint areas of improvement with the goal of making HWRF updates more efficient and effective.

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

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In 2009, the National Center for Atmospheric Science (NCAR)/Research Applications Laboratory's (RALs) Joint Numerical Testbed (JNT) Program formed a new entity called the Tropical Cyclone Modeling Team (TCMT). The focus of this team is testing and evaluation of experimental models for tropical cyclone forecasting. TCMT evaluations may include models that are either in earlier stages of development or may not be intended for future operational application in the U.S. Much of this effort is sponsored by NOAA's Hurricane Forecast Improvement Project (HFIP). For the HFIP, the TCMT designs model evaluation experiments and provides general testing and evaluation of the various forecast models included in the HFIP annual forecasting demonstrations and retrospective experiments. Utilizing staff expertise in forecast verification, statistics, and atmospheric sciences, the TCMT is developing statistical approaches that are appropriate for evaluating a variety of tropical cyclone forecast attributes. These methods include new diagnostic tools to aid, for example, in the evaluation of track and intensity errors, precipitation and tropical cyclone structure forecasts. The TCMT also supports HFIP through other activities such as communicating results and providing a repository of model output and diagnostic information through a web-based data service site. The data service site will include model forecasts and some observational datasets as well as links and pointers to additional observational datasets. During 2010, the TCMT conducted an evaluation of a suite of experimental models that were candidates for future inclusion into the operational forecasting system at the National Hurricane Center (NHC). This retrospective analysis was conducted using a subset storms selected by NHC from the 2008 and 2009 tropical storms and hurricanes observed in the Atlantic and Eastern Pacific basins. In summary, the TCMT focuses on developing new methods for the evaluation of hurricanes, on the evaluation of experimental model forecasts for the annual HFIP retrospective and demonstration experiments, and on developing a hurricane database from these studies. An overview of TCMT activities along with a summary of results from the 2010 retrospective analysis will be given in the presentation.

A highly configurable vortex initialization method for tropical cyclones

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In order to provide realistic numerical predictions of tropical cyclone (TC) structure and intensity change, an accurate specification of the initial TC structure in a high-resolution model is necessary. The current capabilities of observational data (particularly when aircraft are not present) and data assimilation schemes preclude this from being achievable without considerable theoretical effort and computational expense. For many research and forecasting applications, a convenient but imperfect solution is the initialization of the model with a synthetic vortex.

In this study, a customizable approach towards vortex initialization is employed, beginning with a user-specified, relocatable vortex in gradient wind balance that is constructed to be consistent with operationally estimated parameters. The tangential circulation can be extended upwards through a variety of idealized configurations of vertical structure. Next, a three-dimensional wind structure in the hurricane boundary layer is derived using Monin-Obukhov similarity theory, based on the gradient wind profile, variations in boundary layer depth, surface momentum flux and eddy viscosity. Finally, the relative humidity in the tropical cyclone can be configured. In the future, the mid- and upper-tropospheric secondary circulation will be derived from analyses based on satellite-derived atmospheric motion vectors.

Simulations using the Weather Research and Forecasting (WRF) model will be presented. It is proposed that a well-constructed initial vortex will serve as a convenient benchmark against which new, sophisticated data assimilation schemes can be evaluated.

Diagnosis of Operational Model Track Forecast Error for Hurricane Ike (2008)

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The National Hurricane Center (NHC) issues track forecasts every six hours for all active tropical cyclones in its area of responsibility. These forecasts are made at projection times of 12, 24, 36, 48, 72, 96, and 120 hours. On 9 September 2008 track forecast errors from numerical model track guidance and the NHC's official forecast for Hurricane Ike increased substantially compared to errors from forecasts during the previous couple of days. This period of elevated track error occurred three to four days prior to Ike's Texas landfall early on 13 September. During this time, much of the track model guidance and the official NHC forecasts demonstrated a southward bias, taking the center of Ike to a landfall location along the central or southern Texas coast, instead of the upper Texas coast near Houston/Galveston where landfall ultimately occurred. The average error of the NHC 72-h track forecasts issued on 9 September was 92.8 nm, a 38% increase in the average error compared to the NHC 96-h track forecasts issued on the previous day (66.8 nm). Errors from many of the track models were even larger; the average 72-h forecast error for the interpolated GFS (GFSI) model on 9 September was 131.5 nm. This increase in track forecast error occurred during a critical time when federal, state, and local government agencies were making mitigation and disaster response decisions.

Examination of the 500-hPa height analyses from the members of the NCEP Global Ensemble Forecast System (GEFS) at 0000 UTC 9 September 2008 show significant spread in the strength of the mid-level subtropical ridge over the southern United States north of Ike. Ensemble members that showed a stronger (weaker) ridge north of Ike during the model integration moved Ike on a track farther to the left (right) of the track of the GEFS ensemble mean, which was close to the actual track of Ike. Given these observations, an experiment was performed where the initial conditions in the GFS run from 0000 UTC 9 September were altered to slightly weaken the ridge north of Ike. Results from this experiment showed Ike moving significantly to the right of the operational GFS forecast from that time and closer to the observed track of the hurricane. Additional experiments perturbing other synoptic scale features possibly impacting the track of Ike had limited impact on the hurricane's track. These results suggest that the evolution of the subtropical ridge was critical to determining Ike's ultimate track. This case also represents an instance where a single-model ensemble system provided value over the typically superior multi-model consensus aids for TC track forecasting.

An Update on the Status of FNMOC Projects to Improve Tropical Cyclone Forecasting

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This poster will describe the progress of four projects at Fleet Numerical Meteorology and Oceanography Center (FNMOC) aimed at improving tropical cyclone forecasting. Two of the studies relate to the Geophysical Fluid Dynamics Laboratory (GFDL) hurricane model (GFDN) that has provided operational guidance since 1996 for storms in all basins, including the Indian Ocean and Southern Hemisphere (Rennick, 1999). This makes GFDN the only moveable tropical cyclone model running in all tropical oceanic basins worldwide.

The first study investigates the relationship between forecast track error in nautical miles and intensity error in knots. Specifically, the study attempts to identify whether or not there is a relationship between track error and intensity error. The second study, specific to GFDN, analyzes the sensitivity of wind radii on track and intensity error. Particularly poor "outlier" forecasts during the 2010 season have been identified for analysis. The goal of the study is to isolate if the size of the 34-knot wind radii used to initialize GFDN have an important effect on the track and intensity forecasts.

The third component of this poster is an overview of the status of tropical cyclone (TC) wave modeling at FNMOC. The prediction of TC wind-generated waves have long been a major concern for US Navy vessels and installations. Currently, wave models such as the Wave Prediction Model (WAM) and Wave Watch III (WW3) models (Tolman, et al., 2007) are driven by individual Numerical Weather Prediction models such as the Navy Operational Global Atmospheric Prediction System (NOGAPS) model (Rosmond, et al., 2002) or the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) model (Naval Research Lab, 2003). The TC track and intensity forecasts by these models may differ significantly from the official track issued by JTWC and NHC. Hence, the waves forecast will be inconsistent with the official track. The goal of this project is to create a wave forecast consistent with the official track. The method used to do this is as follows. 1) Interpolate the wind radii from the official track to a high resolution grid. 2) Remove the TC vortex from the global NWP model (NOGAPS or GFS). 3) Blend the high resolution interpolated winds into the background wind field. 4) Force the WW3 wave model, on a regional grid, using the blended wind grids. Results will be detailed in the poster.

The fourth project that is described in this poster details the method of data assimilation and its potential effect on improving TC forecasting. The assimilation of Global Positioning System (GPS) bending angle has been a positive constraint on the moisture and temperature fields between 8 and 30 km (Healy, et al., 2007). After the GPS bending angle assimilation was added to the NAVDAS-AR (Xu, Rosmond, Daley et al., 2005) system it was possible to increase the spectral coverage from radiance data from all microwave and infrared sounders. The process is detailed in the poster.

Improving the Assimilation of High-Resolution Satellite Wind Data into Mesoscale Prediction Models

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Given that tropical cyclones (TC) spend most of their lifetimes over the ocean, the assimilation of high-resolution satellite data is necessary to provide accurate model analyses of the TC structure and its environment. An example is cloud-derived Atmospheric Motion Vectors (AMVs) prepared hourly by CIMSS, with additional AMVs from rapid-scan mode included when available. The Ensemble Kalman Filter (EnKF) in the Weather Research and Forecasting (WRF) model is used to assimilate these high-frequency and high-resolution satellite data.

The case chosen for this study is Typhoon Sinlaku (2008) during its period of intensification. In order to evaluate the influence of assimilating the experimental AMV data, a ‘control’ EnKF cycle is first produced with the assimilation of conventional observations (radiosonde, aircraft data, JTWC advisory TC position and operational JMA cloud winds). Next, a parallel EnKF cycle that also includes the experimental CIMSS AMVs is computed over the life cycle of Sinlaku. In order to offer a benchmark for the EnKF, a deterministic WRF run initialized from ECMWF is also produced.

Both the ‘Control’ and ‘experimantal CIMSS-AMV’ ensemble forecasts generally produce lower track errors than the deterministic run. Additionally, the ensemble forecasts exhibit a shorter spin-up time than the deterministic run in terms of intensity, with stronger wind structures. A comparison between the structures of Sinlaku in the respective EnKF analyses will be presented, and analyzed with respect to dropwindsonde observations during the TCS-08/T-PARC field campaign. The influence of assimilating the experimental CIMSS-AMV datasets on the ensemble forecasts of Sinlaku will also be presented.

Diagnosing initial condition sensitivity of Typhoon Sinlaku (2008) and Hurricane Ike (2008)

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An examination of the sensitivity of numerical simulations of tropical cyclone (TC) track to perturbations in the initial conditions has been conducted for Typhoon Sinlaku (2008) and Hurricane Ike (2008). Balanced perturbations of different amplitude, spatial scale and location were created via a modification of local relative vorticity at a chosen location and depth. For each TC, 5-day Weather Research and Forecasting (WRF) model track predictions are compared to an unperturbed ("control") simulation. The control simulations replicate forecast errors evident in the operational models specific to the chosen TCs, including a premature recurvature in the forecast for Sinlaku and a landfall too far south along the Texas coast for Ike.

In the case of Typhoon Sinlaku (2008), the premature recurvature in the control simulation is found to be corrected by a variety of initial perturbations, including the weakening of an upper-level low directly to its north and the weakening of a remote shortwave trough in the mid-latitude storm track. It is suggested that one or both of the shortwaves may have been initialized too strongly. In the second case, Hurricane Ike (2008) initialized four days prior to its landfall in Texas, the forecasts were not sensitive to most remote perturbations. The primary corrections to the track of Ike arose from a weakening of a mid-level ridge directly to its north, and the strengthening of a shortwave trough in the mid-latitudes. For both Sinlaku and Ike, targets selected objectively by the Ensemble Transform Kalman Filter (ETKF) were often but not always consistent with the most sensitive regions found in this study.

The methodology employed by this study may be used retrospectively by the research and operational communities to offer suggestions on the weather features in which the initial analysis required improvement, via a combination of improved modelling, observational coverage or data assimilation. The diagnostic technique may also be used to improve understanding of objective sensitivity methods, such as Singular Vectors and the ETKF, and their limitations.

Testing of a New Parametric Tropical Cyclone Wind Model for Implementation in the Gradient Wind Asymmetric Vortex Algorithm (GWAVA) to Drive Storm Surge Prediction Models

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A new tropical cyclone wind model, developed at the National Severe Storms Laboratory (NSSL), is presented that is primarily designed to depict realistic-looking tangential wind profiles that can better fit the wind structure around a tropical cyclone. The parametric wind profile employs five key parameters: maximum tangential wind, radius of maximum tangential wind (RMW), and three power-law exponents that shape different portions of the velocity profile. One of the exponents explicitly controls the broadness and sharpness of the peak locally in the annular zone that encompasses the tangential wind maximum.

To assess the performance of the new parametric wind model, gridded H*Wind horizontal wind analyses for Tropical Storm Dolly (2008), Hurricanes Katrina (2005), Ike (2008), Danielle (2010), Earl (2010), and Igor (2010) were used as input. These tropical cyclones were chosen because the wind fields are highly asymmetric. The gridded fields were interpolated using a bilinear interpolation technique to construct each radial profile of total wind speed from the storm center defined in a cylindrical coordinate system. At each of 360 radial profiles, optimization of the initial five model parameters was performed using the Levenberg-Marquardt method that solves the nonlinear least squares problem for curve-fitting applications. The calculated root-mean-square errors were computed to evaluate the accuracy of the fitted and analytical tangential wind profiles. Using the fitted model parameters, a two-dimensional wind field was reconstructed by interpolating the 360 radial profiles to the Cartesian coordinate system. The parametric wind model has shown considerable skill in accurately replicating tropical cyclone wind fields that compare favorably with those in the H*Wind analyses (Fig. 1). This versatile wind model will soon be implemented in GWAVA to improve the wind forcing that drives storm surge prediction models.

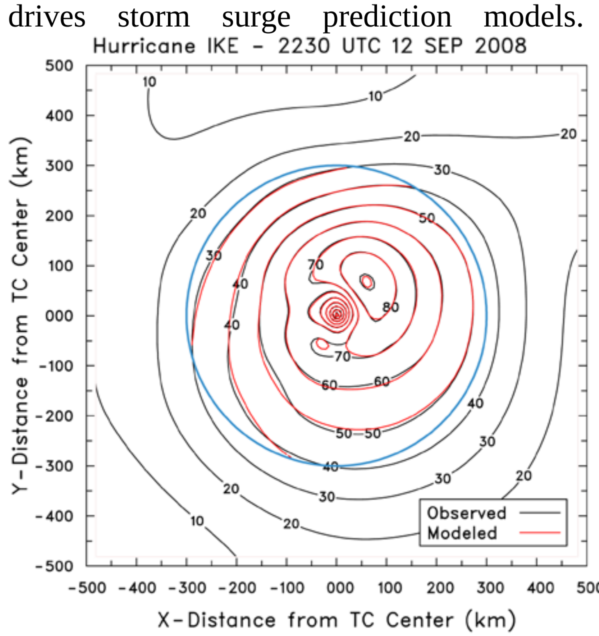

*Fig. 1. Fit of the NSSL tropical cyclone parametric wind model to a horizontal wind field (kt) from an H*Wind analysis for Hurricane Ike (2008). Blue circle indicates the limited region in which the winds are fitted. TC stands for tropical cyclone*

Objective Diagnosis of the Eyewall Replacement Cycle in Mature Tropical Cyclones

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Typhoon Sinlaku underwent an eyewall replacement cycle shortly before making landfall over Taiwan in September 2008 during the Tropical Cyclone Structure – 2008 (TCS-08) field program. Eyewall replacement cycles in tropical cyclones are often associated with intensity fluctuations and increased predictability challenges (Willoughby et al. 1982). Currently, microwave satellite imagery is an accepted and often effective means by which to detect various stages in the eyewall replacement cycle; however, the near 12-h temporal resolution and hit-or-miss spatial sampling of microwave sensors are insufficient to capture the detailed evolution of the eyewall replacement cycle process, which frequently lasts less than 24 h (Kossin and Sitkowski 2009).

Here, the eyewall replacement cycle during TY Sinlaku is examined using differences in water vapor and infrared satellite brightness temperatures from geostationary sensors to detect deep convection that penetrates the tropopause (Fritz and Laszlo 1993; Olander and Velden 2009). The geostationary data are transformed into a cylindrical grid about the storm center, and the water vapor – infrared differences are examined over varying radial bands. A new diagnostic technique is then used to map this deep convection over time. In the case of Typhoon Sinlaku, the deep convection is mapped during a 72-h period that includes the eyewall replacement cycle and provides clear evidence of inner eyewall decay as well as outer eyewall development and subsequent contraction. These results are compared with other satellite data and TCS-08 aircraft observations, and links between the evolution of deep convection and changes in intensity are assessed.

The eyewall mapping technique is then extended to other cases to examine the potential for improving intensity forecast accuracy during eyewall replacement cycles. While diagnostic in nature, this eyewall mapping technique may be applied on a real-time basis and provide the forecaster with unique, objective insight regarding the evolution of a tropical cyclone throughout its lifecycle and be of particular use in the diagnosis of eyewall replacement cycles. The technique may also provide new insights into the behavior of deep convection and possible correlation to periods of rapid intensification and rapid decay.

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Climatology of Hot Towers in Tropical Cyclone's Inner Cores and Rainbands Based on 12-year TRMM Data

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Recent studies have shown that hot towers may be an indicator of tropical cyclone (TC) genesis and intensification. Using a 12-year (December 1997 - December 2009) Tropical Rainfall Measuring Mission (TRMM) tropical cyclone precipitation feature (TCPF) database, hot towers in TCs are identified by using the TRMM PR observed maximum 20 dBZ echo height reaching four different reference heights, i.e., 14 km, NCEP reanalysis derived tropopause height, Level of Neutral Buoyancy calculated using NCEP sounding and surface equivalent potential temperature θ_e, Level of Neutral Buoyancy calculated using θ_e at 925 and 1000 mb, whichever is greater. The common properties of these extreme convective systems are examined in terms of geographical locations, different TC intensities, and different TC regions, i.e., the inner core (IC) region, the inner rainband region (IB), and the outer rainband region (OB). It is found that 13.2% of TC precipitation features reach 14 km, and 2.6% of them may even penetrate 16 km. Hot towers in TCs are more frequent in the Western North Pacific basin than any other TC-prone basins. The percentage of precipitation features with one or more hot towers is greater in the IC region than in the IB and OB regions by a factor of 10-20, depending on which reference height is used. It is also found that hot towers in the IC region have a higher mean maximum height of 20 and 40 dBZ echo, stronger ice scattering signature than in rainbands regions, no matter which reference height is used. The percentage of features with hot towers increases as TC intensity increases. The mean maximum height of 40 dBZ echo is higher in hurricanes than in tropical storms and tropical depressions.

Quantitative Comparison of Precipitation Algorithms in Tropical Cyclones

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The Tropical Rainfall Measurement Mission (TRMM) has been collecting Tropical Cyclone (TC) rainfall measurements since 1997. The Tropical Cyclone related Precipitation Feature (TCPF) database has been developed to process raw pixel-level satellite measurements into specific events that can be quickly sorted and compared. In addition, a semi-manual method has been used to divide 12 years of TC rainfall data into inner core (IC), inner rainband (IB) and outer rainband (OB) regions. The database consists of over 13,000 TC overpasses from December 1997 through December 2009. Using TCPF data, two TRMM rainfall retrieval algorithms are compared: The Version 6 TRMM Precipitation Radar (PR) 2A25 algorithm and the Version 6 TRMM Microwave Imager (TMI) 2A12 algorithm.

In this study, the differences in tropical cyclone (TC) rainfall algorithms are evaluated in terms of physical location, storm intensity, sub-regions inside the storm (eyewall or rain bands, stratiform or convective), and the diurnal cycle. Consistent with previous studies, considerable differences are found to exist between the algorithms. For all TCs over oceans, the TMI 2A12 algorithm produces the most volumetric rainfall, as it contains the highest mean rain rates in all TC intensity categories. The PR 2A25 algorithm contains a higher percentage of light (< 5 mms^{-1}) rain rates, but compensates with a greater total rain area. The difference in rainfall algorithms is most significant in TC inner cores. Total volumetric rain was found to be highest in the for the PR 2A25 algorithm in TC inner cores, while the TMI 2A12 algorithm produces the highest volumetric rain for TC inner bands and outer bands.

Numerical Studies of Lower Boundary Forcing on Tropical Storm Fay (2008) over Southern Florida

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This study is aimed to investigate the track and intensity changes of Tropical Storm Fay as it moved across south Florida. The maximum wind speed was achieved around 1800 UTC 19 August when the center was near the western side of Lake Okeechobee. The overages of precipitation in the days before landfall left the soil moisture saturated ahead of TS Fay. Yet, the warmer SST over the lake as well as the west coast of Florida may have played a role in maintaining the intensity of the storm. It is our working hypothesis that the storm moved near Lake Okeechobee, and intensified or closely held its intensity due to high soil moisture, and warmer SST over Lake Okeechobee and the west coast of Florida.

The simulations are performed using the Weather Research and Forecasting (WRF-ARW) model with 30, 10 and 3.3 km nested domains to examine our hypothesis. The FNL and the twelfth-degree RTG_SST analysis are adopted as the initial and lateral boundary conditions. The preliminary results demonstrate that the high-resolution simulation is able to recapture the track and deepening rate of the storm while passing through south Florida. The sensitivity experiments of land surface characters and SST in this case illustrate their impacts on the intensity and track of TS Fay during and after landfall. To further investigate the intensity changes experiment using the TC bogus approach were performed. The simulated results demonstrate that using the TC bogus approach the storm can effectively reach the intensity (e.g., low pressure center) as the NHC recorded. Nevertheless, the simulated track may still need to be improved.

Vertical Wind Shear Impacts on Hurricane Structure Deduced from Airborne-Doppler and HWRF Databases

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We will present the application of a newly-constructed database of radar-derived winds in hurricanes to the examination of structural characteristics of vertically sheared systems. At present, the database consists of over 150 passes of NOAA aircraft through hurricanes of varying strength. Metrics are developed to quantify the structure, including local shear, vortex tilt, and low-azimuthal-wavenumber wind components. A shear-relative composite analysis is performed, stratified according to large-scale shear magnitude, vortex strength and vortex size. As expected, stronger shear and weaker vortex strength tend to yield greater vortex tilt and a more pronounced quasi-steady vertical velocity asymmetry. Stronger vortices in particular exhibit a preference for tilt to the left of the large-scale, deep-layer shear vector.

A similar analysis has been applied to a database of over 100 HWRF ICs with 9 km horizontal grid spacing. The HWRF IC database reproduces many aspects of shear-induced structure revealed in the Doppler database. This analysis is being extended to forecast fields using HRD’s experimental HWRF model at 3-km resolution. These results will be presented at the conference with the aim of clarifying HWRF’s representation of the vortex-shear interaction relative to that depicted by the radar database.

Is hurricane rapid intensification possible from the energy released inside of a convective burst?

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When a hurricane intensifies, the NHC forecast discussion sometimes mentions particularly vigorous convection being observed in the eyewall. When Hurricane Earl (2010) was intensifying to category 4 on its approach toward the U.S., the NHC discussion stated: "THE EYE HAS CONTINUED TO CLEAR AND IS SURROUNDED BY CLOUD TOPS TO -70 DEGREES CENSIUS OR COLDER" [5 PM AST 30 Aug 2010]. Forecasters may mention such bursts of eyewall convection because they are common in infrared satellite animations of intensifying hurricanes. Or perhaps forecasters mention convective bursts because some of the intensity forecast schemes that forecasters rely on take into account the vigor of eyewall convection through various empirical parameterizations. It is still a subject of debate, however, what physical mechanisms connect convective bursts with energy flowing into the hurricane's tangential wind field.

Even before there is scientific consensus on these physical mechanisms, it would be helpful to estimate what energy conservation and other thermodynamic considerations permit in terms of a convective burst's effect on hurricane intensity. This study provides such a thermodynamic estimate, incorporating recently collected satellite datasets, modeling studies, and analyses of multi-instrument wind observations.

First, satellite observations provide estimates of the net amount of condensation occurring inside of a vigorous eyewall cell. Net condensation is proportional to net latent heat release. Making reasonable assumptions, a convective burst (a series of vigorous cells) could release 6e17 J of latent heat into the eyewall every 12 hours, in excess of the amount of latent heat that would have been released in the eyewall in the absence of a convective burst. Convective bursts have been observed to persist for 9 to 48 hours. Second, modeling studies provide estimates of the efficiency with which latent heat released in the eyewall may be transformed into increased kinetic energy of the hurricane's tangential wind. A 5% to 7% efficiency is consistent with recent modeling studies. Third, an examination of wind analyses provides a mapping between changes in kinetic energy and changes in surface wind intensity. An experimental extension of the H*wind analysis to three dimensions suggests a power-law relation between initial and final kinetic energy (KE) and initial and final surface wind intensity (I): $KE_f / KE_i = (I_f / I_i)^{1.34}$.

Putting these three pieces together, this study estimates that intensification at the rate of 11–19 m s^{-1} (21–37 kt) in 12 hours could result from the extra amount of latent heat that the convective burst releases inside of the eyewall. As a point of reference, rapid intensification is often considered ≥15 m s^{-1} (30 kt) in 24 hours, and some convective bursts persist for several days.

Hurricanes: Science and Society – an online resource collaboratively developed by scientists, education and outreach professionals, and educators

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There are many models for engaging scientists in education and outreach activities that can assist them in achieving broader impacts of their research. Successful models provide the participating scientists with an opportunity to contribute their expertise in such a way that there are long lasting effects and/or useful products from their engagement. These kinds of experiences encourage the scientific community to continue participating in education and outreach activities.

Hurricanes: Science and Society is an education and outreach program funded by the National Science Foundation that has successfully assisted scientists in broadening the impacts of their work. It has produced a new online educational resource (Hurricanes: Science and Society website) that was launched in October 2010. This multi-disciplinary tool has been developed with the guidance and input from a panel of leading U.S. hurricane researchers and the participation of U.S. formal and informal science educators.

This educational resource is expected to become a classroom tool for those both teaching and learning hurricane science. It contains information tailored for specific audiences including middle school through undergraduate educators and students, the general public, and the media. In addition to the website, a 12-page publication for policymakers and other stakeholders has been produced along with an accompanying CD-ROM/DVD to assist formal and informal science educators in maximizing the use of this new resource. Hurricanes: Science and Society can play a substantial role in the effort to educate both students and adults about the science and impacts of hurricanes and the importance of pre-hurricane planning and mitigation.

http://www.hurricanescience.org

The influence of cyclones on the BP oil spill

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The Deepwater Horizon oil spill impacted the Mississippi River Delta, Barataria Bay, the barrier islands east of Louisiana, and the Alabama and Florida coast for an extended period of time from May through July. However, the Rigolets and western Mississippi coast were impacted for a briefer period from late June to early July. An important component to understanding the oil transport is to distinguish the influences behind this apex moment. A simulation was conducted for the period 20 June to 10 July 2010 to understand this inland transport.

The simulation was based on a Lagrangian particle tracker with random walk diffusion. Input consisted of latitude and longitude positions of oil-contaminated parcels, wind, current, and a large array of random numbers. In addition, new parcels were released at the damaged Macondo rig location at each time step. Twenty-five parcels are released at each position, and when combined with the diffusion coefficient (set to $10m^2s^{-1}$), resulted in a realistic spread of the parcels with time. The initial parcel locations were subjectively determined based on a combination of NASA MODIS satellite imagery, SAR imagery, NOAA oil trajectory maps, and the NOAA/NESDIS Satellite Analysis Branch (SAB) experimental surface oil analysis. The parcels were advected at 80% of the ocean current speed and at 3% of the wind speed. Bilinear interpolation was applied every timestep to determine the currents and winds at each parcel. The pseudo-random numbers were uniformly distributed between 0 and 1 and generated by the Mersenne Twister algorithm. The initial seed was randomly obtained from machine noise.

The 10-m wind and near-surface ocean currents were provided from NAVOCEANO’s 3-km Navy Coastal Ocean Model (NCOM) in the Intra-Americas Sea (AMSEAS) domain, with atmospheric forcing from COAMPS. The wind forcing was validated against buoys using statistical and vector correlation techniques, concluding that the winds were reasonably accurate.

An examination of NCOM data, the oil spill simulation, buoy data, weather reanalysis maps, tide gauge data, scatterometer data, and HF radar currents show that two weather systems altered the currents and water levels such that oil was pushed into the western Mississippi Sound and the Rigolets. An easterly wind fetch from intensifying Hurricane Alex provided the first inland push, followed by a westward-drifting non-tropical low which had formed off the western edge of a Gulf cold front. In both cases, a weak pressure gradient was replaced by strong easterly winds which not only switched alongshore westerly coastal currents to an easterly direction, but also increased inland water levels by 0.6-0.8 m as mini-surge events. These results showed that cyclones can dramatically alter oil transport, even by fringe effects. The study also showed that this modeling formulation was capable of reproducing the oil spill transport and is being used in follow-up BP research.

SATellite Intensity CONsensus (SATCON) Evaluation and Recent Changes

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The SATellite CONsensus (SATCON) algorithm developed at CIMSS objectively combines Tropical Cyclone (TC) intensity estimates analyzed from satellite infrared and microwave-based methods to produce a weighted consensus estimate which is more skillful than the individual members. SATCON provides the TC forecaster with the ability to quickly reconcile differences in objective intensity methods, and as a comparative guidance tool for evaluating subjective Dvorak estimates. Real-time SATCON estimates have been provided to NHC, BOM and JTWC along with other TC forecast agencies as part of a demonstration phase since the 2008 TC season.

Current members of SATCON include the CIMSS ADT along with the CIMSS and CIRA AMSU algorithms. Each member of SATCON is weighted based on that member's performance in a given situation (eye size, intensity, infrared scene type, etc.). Separate weights are used for minimum pressure and maximum wind estimates. The SATCON algorithm logic and weighting structures were developed using coincident reconnaissance aircraft data from storms in the Atlantic, Eastern Pacific and Western Pacific. To date, we have accrued 562 cases when all three SATCON members were available and matched up with recon data. This dataset is divided into a dependent development sample, and an independent validation sample using a "leave every other case out" approach.

In addition to updating the consensus weight structure as new cases become available, a number of recent changes have been made to further improve the MSW estimates. These upgrades, as well as the resultant performance statistics, will be summarized in the poster. Further information on SATCON can be found at:

http://cimss.ssec.wisc.edu/tropic2/real-time/satcon/

A Methodology for Incorporating Hurricane Forecast Errors into Decision-Support Systems for Energy and Utility Companies

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A variety of decision-support systems, such as those employed by energy and utility companies, utilize the National Hurricane Center (NHC) forecasts of track and intensity to inform operational decision-making as a hurricane approaches. Changes in hurricane intensity and track, especially just prior to landfall, can negatively impact the accuracy of these decision-support systems. This study demonstrates how the Monte Carlo wind speed probability (MCWSP) can be applied to develop probabilistic estimates of the impact of the approaching storm. Our methodology utilizes the 1000 individual forecast realizations generated by the MCWSP algorithm, instead of the wind speed probabilities, coupled with a power outage model to generate a distribution of power outage predictions for three past storms. Based on power outage data from a Gulf Coast utility company we found that the ensemble average was a better predictor of damage to the power system than predictions made using the official National Hurricane Center forecast. We believe that this methodology can be used to incorporate information about tropical cyclone forecast errors into decision support systems that utilize NHC track and intensity data.

What might a global TC reanalysis project look like?

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Tropical cyclone intensity, distribution and frequency significantly impact life and property. Understanding these aspects of cyclones, however, requires a uniformly constructed dataset. The International Best Track Archive for Climate Stewardship project has provided a centralized collection of TC best track data. Despite efforts to minimize discontinuities in IBTrACS, inhomogeneities remain caused by changes in instrumentation, personnel, forecast agencies and operational procedures, which has led to a catalog of storms that is incongruous. To ameliorate this issue, efforts are underway in the North Atlantic to perform a reanalysis of storm intensity, however no global effort is currently in progress.

We plan to build upon work already in progress by NHC and HRD in conjunction with the National Climatic Data Center to facilitate the development of and to archive a record of re-analyzed global TC intensity. NCDC is uniquely positioned to facilitate this project given the datasets and expertise on hand. IBTrACS is a global inventory of known tropical cyclones, while the HURSAT dataset is a collection of all satellite brightness temperatures from polar and geostationary satellites for the storms in IBTrACS. Using these NCDC resources, the Dvorak technique can be applied to estimate TC intensity during the satellite era.

NCDC's extensive archive of *in-situ* data already in the process of being modernized by the Climate Data Modernization Program as well as data in the paper archives at yet to be discovered can be made available to the global tropical cyclone research community, but necessitates a coordinated multi-agency effort.

Getting the Surge Message Across

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Major initiatives are underway to improve storm surge forecasting – and to find better ways to communicate surge risk to vulnerable coastal residents. Evidence continues to reveal that the public under-recognizes the dangers of storm surge. The most recent example is that 15,000 people did not evacuate from Galveston Island for Hurricane Ike in spite of a forecast of up to 20 feet of storm surge. The message regarding the 200+ deaths on the Mississippi coast from Hurricane Katrina's surge was somehow lost.

Acknowledgement of the need to better understand how people view forecasts and warnings has resulted in several on-going initiatives within the climate and weather enterprise including the social sciences portion of NOAA's Storm Surge Roadmap project and several projects on Communicating Hurricane Information funded by the National Science Foundation. Research with coastal citizens, local emergency managers and others provides evidence that a major portion of the population does not understand the surge hazard adequately to take appropriate action. If improvements are not made in the public's understanding of storm surge threat, extensive loss of life is likely to occur. Considerable research within numerous fields and disciplines from the social sciences has contributed to a better understanding of how people perceive and react to risk. This presentation will provide an overview of the research followed by a discussion of several initiatives underway within NOAA to improve the public's understanding of the storm surge threat.