Achieving Superior Tropical Cyclone Intensity Forecasts by Improving the Assimilation of High-Resolution Satellite Data into Mesoscale Prediction Models

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LONG-TERM GOALS

Forecasts of TC intensity change are often lacking in skill due in part to the paucity of conventional observations over the oceans that are assimilated into the operational models. The inability to accurately map the three-dimensional atmosphere and the underlying upper ocean has also constrained our understanding of how intensity fluctuations are governed by internal and environmental processes. Remotely-sensed observations from multiple satellite sources have become more routinely available as part

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of the atmospheric/oceanic observing system. As an important input to global numerical data assimilation and forecast systems, these data are providing crucial large-scale environmental information for better predicting such parameters as TC steering flow fields. However, in regards to TC intensity change, it is clear that a dedicated research effort is needed to optimize the satellite data processing strategies, assimilation, and applications within a higher resolution modeling framework. Contemporary strategies developed for assimilating satellite data into global NWP systems appear to be inadequate for retaining information on the scales of processes pertinent to TC analysis and intensity change. Our study attempts to focus on and evaluate the impact of integrated, full resolution, multi-variate satellite data on TC intensity forecasts using advanced data assimilation methods and coupled ocean-atmosphere mesoscale forecast models. The development of successful strategies to optimally assimilate satellite-derived data should ultimately lead to improved numerical forecasts of TC intensity.

OBJECTIVES

The ultimate goal of this project is the development and refinement of a capability to supplement the contemporary atmospheric observation network with optimal configurations and assimilation of advanced satellite-derived observations, to improve high-resolution operational analyses and intensity forecasts of TCs.

The primary objectives are to prepare a comprehensive database of full-resolution observations from multiple satellite platforms for selected TC case studies, for provision to the Navy, NOAA and NCAR collaborators in this study and other NOPP-funded studies. Then quantify how best to utilize the multiple satellite datasets in applications to TC structure/intensity prediction, using advanced data assimilation and high-resolution forecast models. Finally, provide a pathway towards advanced satellite data assimilation in the emerging operational TC forecast models (i.e. HWRF, COAMPS-TC).

APPROACH

Our approach is to first investigate and optimize the assimilation of the satellite data in the WRF ensemble-based assimilation system. The COAMPS-TC system is now also being employed in our later efforts. In the evaluation phase, the investigators are analyzing the parallel model analyses and forecasts that assimilate and do not assimilate the satellite data. In this manner, the utility of the various satellite data in improving TC intensity analyses/predictions is being assessed. The main science focus is on investigating and understanding how the assimilation of the satellite data modifies the model analyses and forecasts of TC structure. Moreover, the improvement in model representation of important synoptic features such as adjacent trough interactions, outflow channels, and available environmental moisture is expected to benefit the numerical forecasts of TC intensities. The effects of assimilating data from multiple satellite platforms will be investigated for each individual platform, and for combinations of platforms. Typhoon Sinlaku and Hurricane Ike, both from 2008, are being targeted as primary case studies, but time permitting, other TCs during our study period that undergo rapid intensity change will become candidates for further investigations.

WORK COMPLETED AND RESULTS

In Year 2, we set out the following tasks (responsible team members in parentheses):
1) Begin satellite data assimilation trials using EnKF/WRF. (NCAR)
2) Analysis and evaluation of initial WRF trials. (UMiami, CIMSS, RAMMB, NRL-H)
3) Prepare COAMPS-TC for trials, run initial experiments. (NRL-D)
4) Begin investigating an optimal bogus TC insertion that uses the satellite information. (CIMSS, UMiami)
5) Initial studies to examine perturbation techniques to identify observation impacts. (CIMSS, UMiami)
6) Present preliminary results. (All)

CIMSS-Velden

As part of the TCS-08 field program, CIMSS processed enhanced fields of atmospheric motion vectors (AMVs) from the JMA MTSAT geostationary satellites during Typhoon Sinlaku. These datasets were derived at hourly intervals, over the entire western North Pacific west of the dateline. In addition, JMA made MTSAT rapid scans available for a several day segment of Sinlaku. These more frequent images result in higher quality vectors over a limited domain around the typhoon. CIMSS also processed AMVs from these images. As part of this proposal, CIMSS added new quality indicators to the AMV datasets, which can be employed as observation confidence estimates or forward operator error estimates in data assimilation. Similar AMV datasets with the new quality indicators were derived for our other case study, Hurricane Ike. These datasets are being used in assimilation experiments with our NCAR collaborators. CIMSS scientists are helping to evaluate these experiments.

In order to assess the impact of the enhanced AMV observations at high model resolution (i.e. <4km spacing), a novel bogus ensemble data assimilation approach was developed. It involves sampling an ensemble of bogus vortices from selected parameters given in the tcvitals file, and then assimilating the AMV observations using an ensemble Kalman filter. The resulting ensemble mean analysis is then used to initialize a deterministic forecast using the UW-NMS model. While sacrificing the flow-dependent error covariances implicit in analysis cycling, this method has the advantage of allowing much higher model resolution for a fraction of the computational expense. Initial tests for Ike were encouraging, demonstrating an improvement in the intensity forecast relative to a control case in which no special AMV observations were assimilated (fig 1). However, additional testing over the full life cycle of Ike (46 separate analyses) revealed that the bogus vortex insertion resulted in an inadequate representation of the environmental flow in the neighborhood of the TC, resulting in an unacceptably large numbers of AMV observations being rejected by the quality control algorithm. To address this shortcoming, a more sophisticated bogus algorithm will be employed in conjunction with a short-window (6-hour) assimilation strategy. Such an approach retains the advantage of high model resolution but also allows for a better representation of the environment in the vicinity of the TC as well as the development of some degree of flow-dependence in the error covariances. This should allow a greater impact of the AMV observations on the resulting high-resolution analysis.

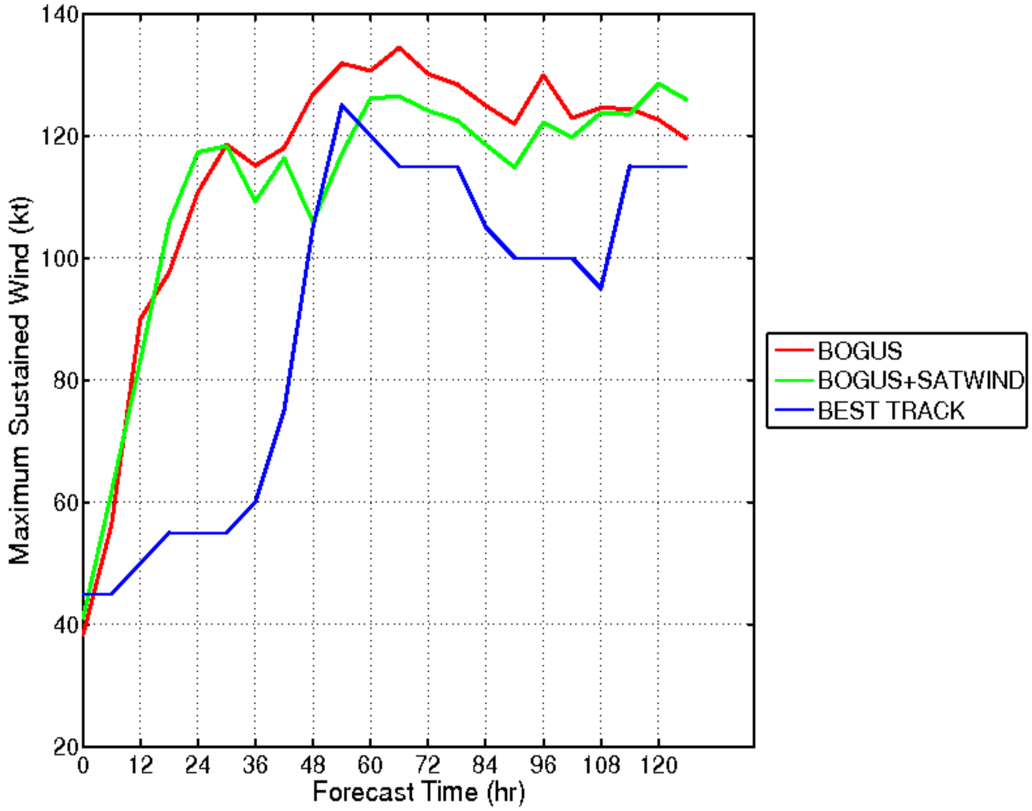

Figure 1. Forecast intensity (UW-NMS model) of the control (BOGUS) and AMV impact experiment (BOGUS+SATWIND) relative to the NHC best track for hurricane Ike initialized at 00UTC 02 SEP 2008.

We have also begun an evaluation of the sensitivity of TC steering to small (e.g. scale of likely analysis-increments) perturbations of the cyclone's environment, which can be calculated in several ways. Perturbation techniques such as the method developed at the University of Miami (Komaromi et al. 2011) are capable of evaluating the impact of specific (balanced) perturbations introduced into the model initial conditions from a nonlinear, full-physics perspective. Sensitivity gradients produced by an adjoint model can evaluate the impact of any small but otherwise arbitrary perturbation on a response function meant to measure the impact on TC steering, given a necessary assumption of linearity and simplified moisture physics in order to produce the adjoint of the numerical weather prediction model. These techniques can be combined to form a more robust understanding of the impact of perturbations/observations on TC track: an adjoint-based sensitivity analysis of TC steering may provide perturbation targets that are not immediately obvious based on the user's intuition about the TC's relationship to its environment. Given this sensitivity information a priori, a perturbation analysis could then be devised to determine the dynamical reason for the significance of these regions and test the veracity of the sensitivity gradients in a nonlinear, full-physics framework.

CIMSS-Li

1. New version of clear sky full spatial resolution soundings provided for assimilation studies.

The new version of Atmospheric Infrared Sounder (AIRS) single field-of-view (SFOV) soundings have been provided to NCAR collaborator Dr. Hui Liu for assimilation experiments. The new version of algorithm uses dynamic a priori error information according to atmospheric moistness and the use of quality controls in temperature and water vapor profile retrievals. Based on the dependency of the first-guess errors on the degree of atmospheric moistness, the a priori first-guess errors classified by total precipitable water (TPW) are applied in the AIRS physical retrieval procedure. Compared to the retrieval results from a fixed a priori error, boundary layer moisture retrievals appear to be improved via TPW classification of a priori first-guess errors. Six quality control (QC) tests, which check non-converged or bad retrievals, large residuals, high terrain and desert areas, and large temperature and moisture deviations from the first-guess, are also applied in the AIRS physical retrievals. Significantly large errors are found for the retrievals rejected by these six QCs and the retrieval errors are substantially reduced via QC over land, which suggest the usefulness and high impact of the QCs, especially over land. The AIRS SFOV soundings from the new version have been provided to Dr. Hui Liu of NCAR, and the assimilation with WRF/DART for Typhoon Sinlaku (2008) shows that AIRS SFOV soundings in clear skies improve both track and intensity analysis, especially for the rapid intensification.

2. CIMSS-processed TPW provided to NCAR collaborators for assimilation experiments.

The TPW algorithm for Moderate Resolution Imaging Spectroradiometer (MODIS) was developed by the CIMSS sounding team. The spatial resolution is 5 km, and we have provided both Terra MODIS and Aqua MODIS TPW to NCAR collaborator Dr. Hui Liu for our TC assimilation experiments. In addition, the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) TPW was processed; the spatial resolution for AMSR-E is approximately 17 km. MODIS has the advantage of high spatial resolution but is limited to clear skies. AMSR-E provides TPW in both clear and cloudy skies but with coaser spatial resolution and over ocean only. Figure 2 shows the Terra MODIS (upper left), Aqua MODIS (lower left) and Aqua AMSR-E (upper right) TPW images over ocean for 10 September 2008. Assimilation experiments from NCAR show that the combined IR (MODIS) and microwave (AMSER-E) TPW data provide positive impact on TC track and intensity analysis.

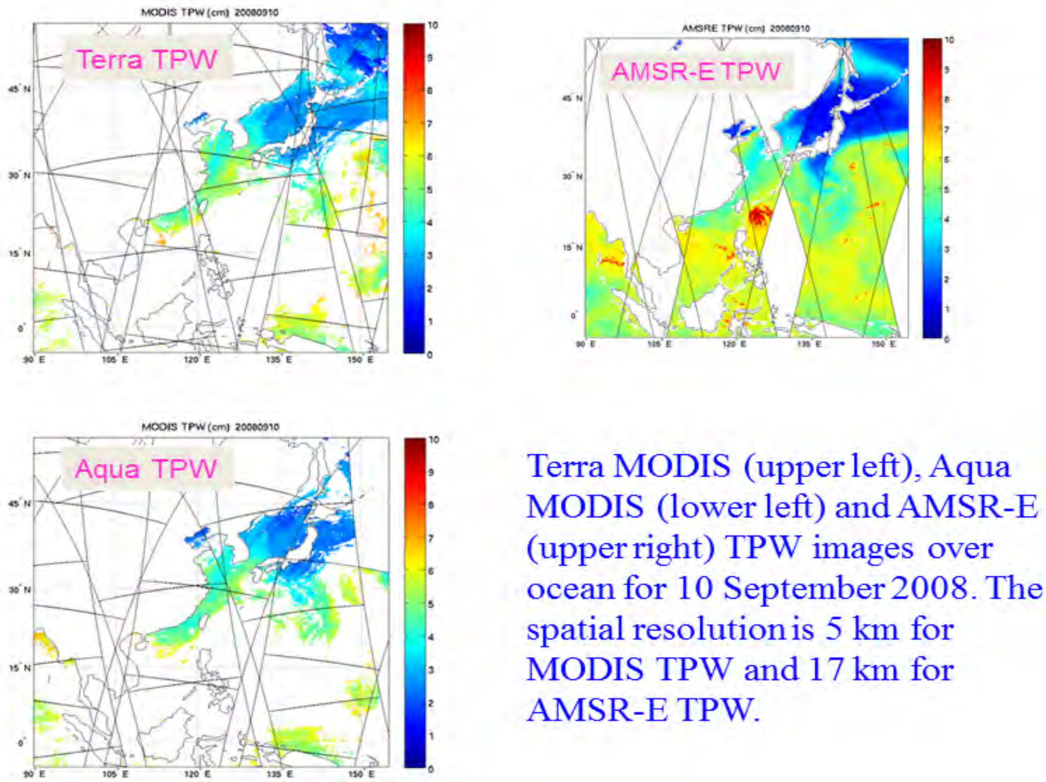

Figure 2. The Terra MODIS (upper left), Aqua MODIS (lower left) and Aqua AMSR-E (upper right) TPW images over ocean for 10 September 2008.

3. Algorithm for AIRS SFOV cloudy sounding developed.

SFOV hyperspectral cloudy sounding profile retrievals (with profiles being retrieved down to cloud level and below thin and/or scattered to broken clouds) are obtained using two sets of eigenvector regression relations; one trained on clear sky and the other on cloud height stratified cloudy atmospheric profile conditions. Stratification by cloud heights accounts for the non-linearity between the radiances and cloud parameters and atmospheric moisture. The tops of clouds are specified from the clear-trained and cloudy-trained temperature and humidity profiles at the level where the profiles start to deviate from each other. The profiles are then combined to make up the final sounding product. The retrieval products compare well with co-located radiosondes, operational retrieval products and model fields. This implies that the cloud height stratified dual regression retrieval technique is able to separate the molecular signal from the cloudy signal inherent in the observed radiances. This eliminates the need for a cloud mask, for cloud-clearing applications and in many cases the need for a more time-consuming optimal estimation physical inversion. The dual regression method is fast and can be used on any hyperspectral instrument (AIRS, IASI, CrIS). The resulting profiles and parameters at single field-of-view resolution will benefit various applications. Figure 3 shows the bias and standard deviation of the new AIRS SFOV sounding retrievals against RAOBs. The cloudy soundings for Hurricane Ike and Typhoon Sinlaku cases are being processed for assimilation experiements.

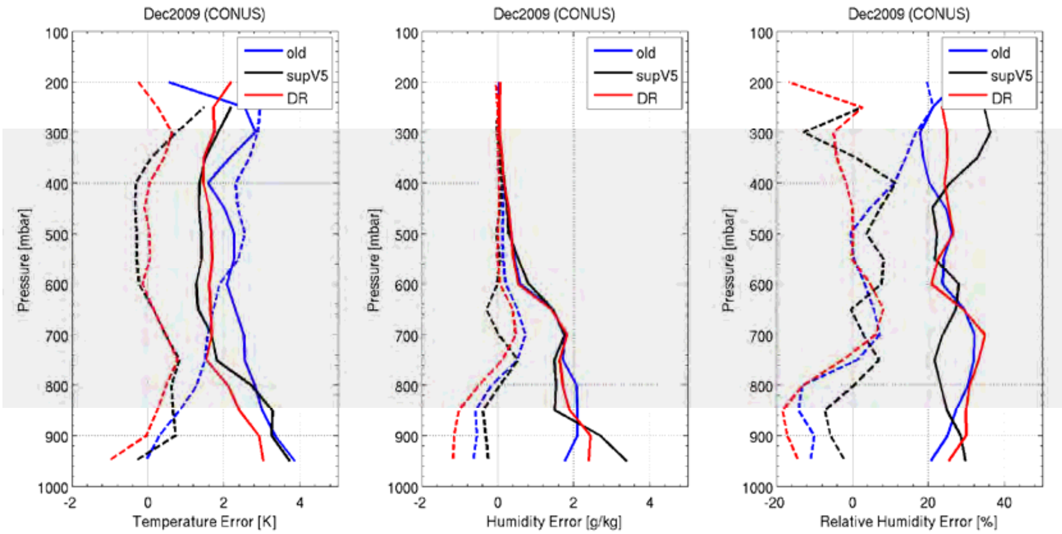

Figure 3. Comparisons of Bias (dashed) and Standard Deviation (solid) for differences between AIRS temperature and water vapor retrievals with radiosonde observations, for the entire month of December 2009 for the CONtinental United States (CONUS). Three retrieval types are shown: original (old) in blue, NASA operational version 5 (sup5) in black, and the new CIMSS Dual-Regression (DR) in red.

4. Assimilation of AIRS SFOV clear-sky soundings for hurricane track and intensity forecast with WRF/3DVAR.

The CIMSS sounding team has conducted assimilation experiments using WRF/3DVAR, with SFOV soundings from three AIRS granules in clear skies around 06 UTC on 06 September 2008. The control run uses NCEP 6-hour final operational global analysis including GTS radiosondes, operational satellite winds, pilot report, GPS, ship, profiler, surface observations etc., starting at 06 UTC on 06 September 2008. The AIRS (Control + AIRS) run adds the clear-sky AIRS granules and assimilates SFOV temperature and moisture profiles between 200 and 700 hPa. The upper panel of Figure 4 shows the 48 hour Hurricane Ike track forecasts with GTS (conventional data and other satellite measurements, dashed black), GTS + AIRS temperature profile (blue), GTS + AIRS moisture profile (green), GTS + AIRS temperature and moisture profiles (pink) assimilated, respectively. The combined AIRS temperature, moisture and GTS provide the best overall track forecast. However, it appears the temperature information leads to the greatest positive impact in this case. The lower panel of Figure 4 shows the respective track forecast errors.

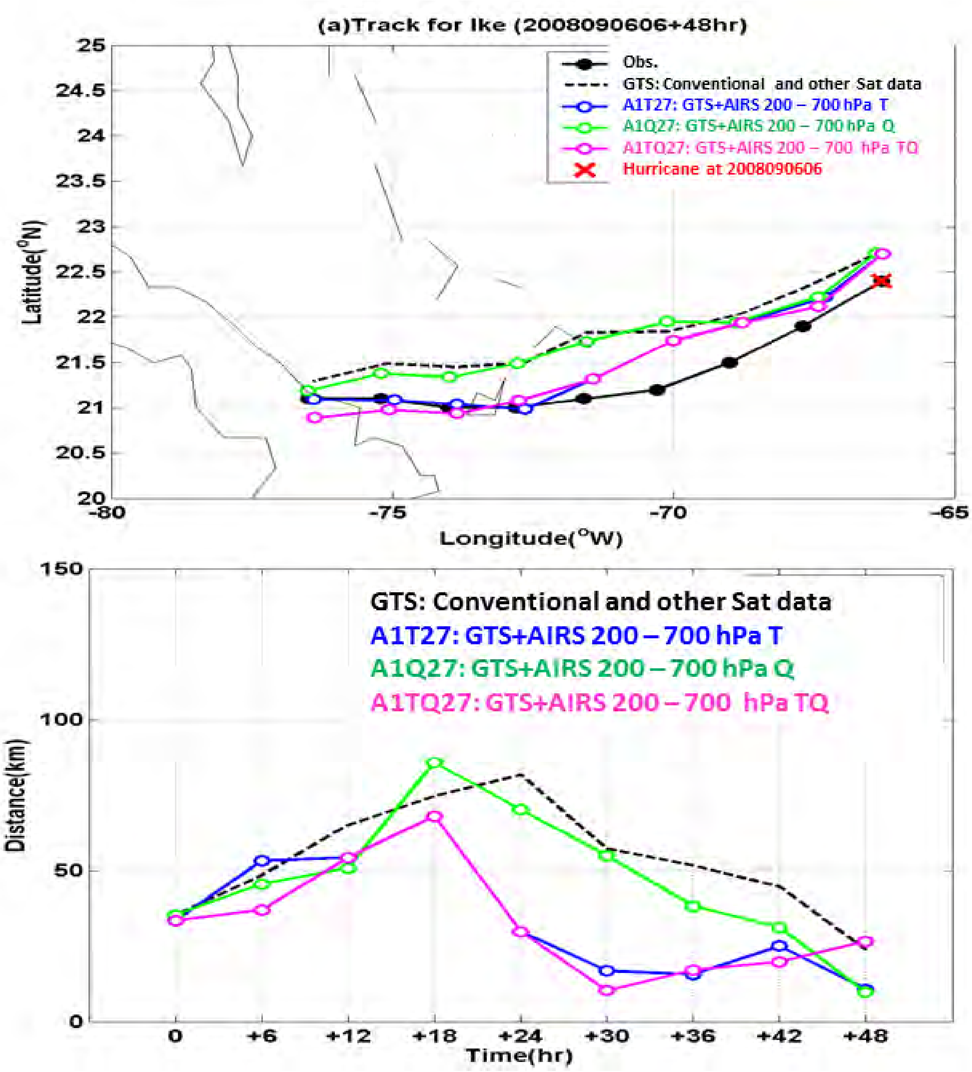

***Figure 4.** (Upper) The 48-hour forecasts with GTS (conventional data and other satellite measurements) (dashed black), GTS + AIRS temperature profile (blue), GTS + AIRS moisture profile (green), GTS + AIRS temperature and moisture profiles (pink) assimilated, respectively, for hurricane Ike track forecasts. (Lower) The respective track forecast errors.*

<u>NESDIS-RAMMB</u>

Addressing Task 1: Two satellite-based datasets were prepared as intended input to our modeling experiments for both Hurricane Ike and Typhoon Sinlaku, along with FORTRAN 90 software designed to read the ASCII files. These datasets include six-hourly Multi-platform Tropical Cyclone Surface Wind Analysis fields, and AMSU-based tropical cyclone data and products consisting of antenna temperatures, corrected (for ice and cloud liquid water) statistical temperature retrievals and non-linear balance approximation winds at standard pressure levels. These datasets will be used in our study analyses in the next reporting year.

NRL/MRY-Hawkins

The NRL team reprocessed the satellite-derived surface wind and associated SST, TPW, and precipitation products. We are ready to help the users to apply these datasets for their assimilation work and to get the feedback from them on how to produce a better future satellite-derived surface wind and related datasets. The dataset status report was updated. In addition, we conducted an initial data quality check on the high resolution BYU QuickScat wind datasets. Our analysis indicates that the BYU dataset has more errors than the QuickScat level-2 wind products.

NRL/MRY-Doyle

As part of the COAMPS-TC ensemble data assimilation effort, work has continued toward the development of the COAMPS-TC implementation of the Data Assimilation Research Testbed (DART). A moving nest option was added to the COAMPS-DART ensemble system which will allow for high-resolution ensemble simulations of tropical cyclones in a computationally feasible manner. This new feature will more readily allow for the assimilation of high resolution data sets such as those targeted by this project. At the same time, work has continued toward the development forward operators for satellite data sets. This includes the development of a forward operator for total precipitable water, a forward operator for the assimilation of global positioning satellite radio occultation (GPS-RO) bending angle observation, and a forward operator for the assimilation of satellite based microwave radiance observations. To assimilate GPS-RO bending angle observations the community supported Radio Occultation Preprocessing Package (ROPP) was implemented while the Community Radiative Transfer Model (CRTM) was implemented for microwave radiance observations. An example of the implementation of the CRTM is shown in Figure 5. Here the brightness temperature of the ensemble mean forecast of Hurricane Karl 2010, valid 2010091612, is simulated for the 53.6 GHz channel of the ASMU-A instrument aboard the NOAA-18 satellite is depicted. Experiments are currently underway to explore the impact of TPW, GPS-RO, and radiance observations on the track and intensity of tropical cyclones Ike and Sinlaku.

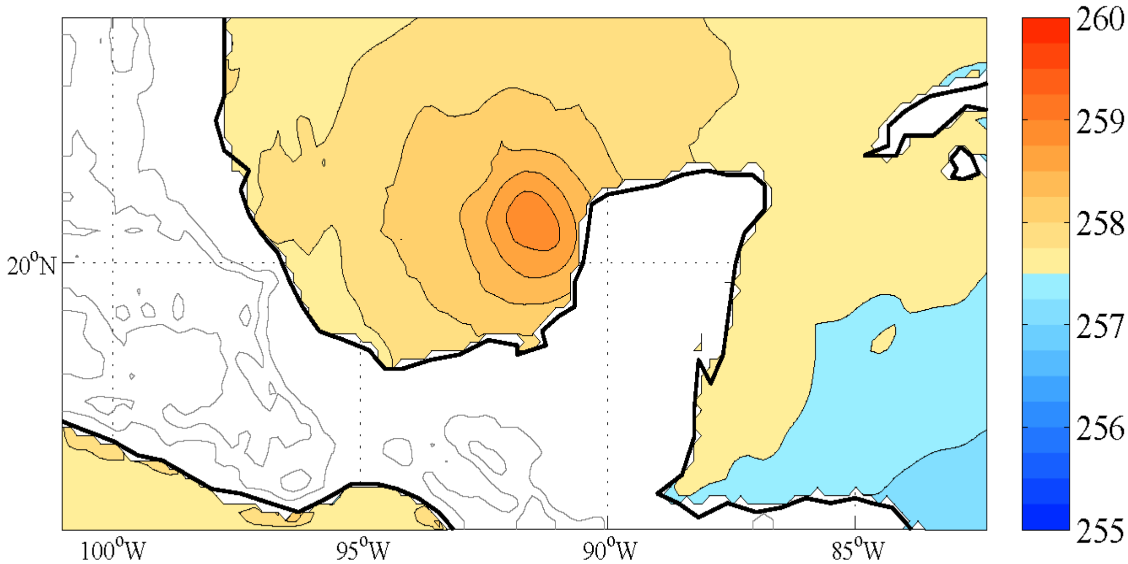

Figure 5. The simulated brightness temperature (K) of the 53.6 GHz channel of the ASMU-A instrument aboard the NOAA-18 satellite for an 96-member ensemble mean forecast of Hurricane Karl valid 2010091612.

In a complementary effort, the COAMPS-DART ensemble data assimilation and forecasting system has been used for real-time prediction during the 2011 hurricane season. This effort has been, in part, supported by the Hurricane Forecast Improvement Project. The system consists of an 80-member data assimilation system with a 6-h analysis interval and a 10-member ensemble forecast executed to 120 hours twice daily (00 and 12 UTC). Three independent 45-km horizontal resolution domains are used to cover the Atlantic, Eastern Pacific, and Western Pacific ocean basins. Within each of the 45-km resolution domains a 15-km and 5-km resolution domain is located to follow each storm. The innovation for the data assimilation system is defined by using the highest resolution nest that is available for a given observations. Observations incorporated into the model via the data assimilation system include surface stations, buoys, radiosondes, aircraft observations (such as ACARS and MDCARS), and the conventionally available cloud drift winds. Total precipitable water, GPS-RO bending angle, and microwave radiance observations are withheld from the real-time system. This set of control forecasts will be used to test the impact of observations from various satellite platforms, such as TPW, GPS-RO, and radiance observations. The large number of cases available will complement the investigation of Ike and Sinlaku.

From the real-time ensemble analyses, 10-member ensemble forecasts are performed for each tropical cyclone twice daily. Graphical output is made available at http://www.nrlmry.navy.mil/coamps-web/web/ens?&spg=1. Figure 6 compares the 10 member ensemble mean track forecast of hurricane Irene, initialized 2011082300, to the working best track. A two-dimensional Gaussian model is fitted to the ensemble members and plotted every 24-hours of forecast time. The inner-most curve of the Gaussian distributions in Fig. 6 contains 2/3 of the probability while the outer curve contains 1/3 of the probability.

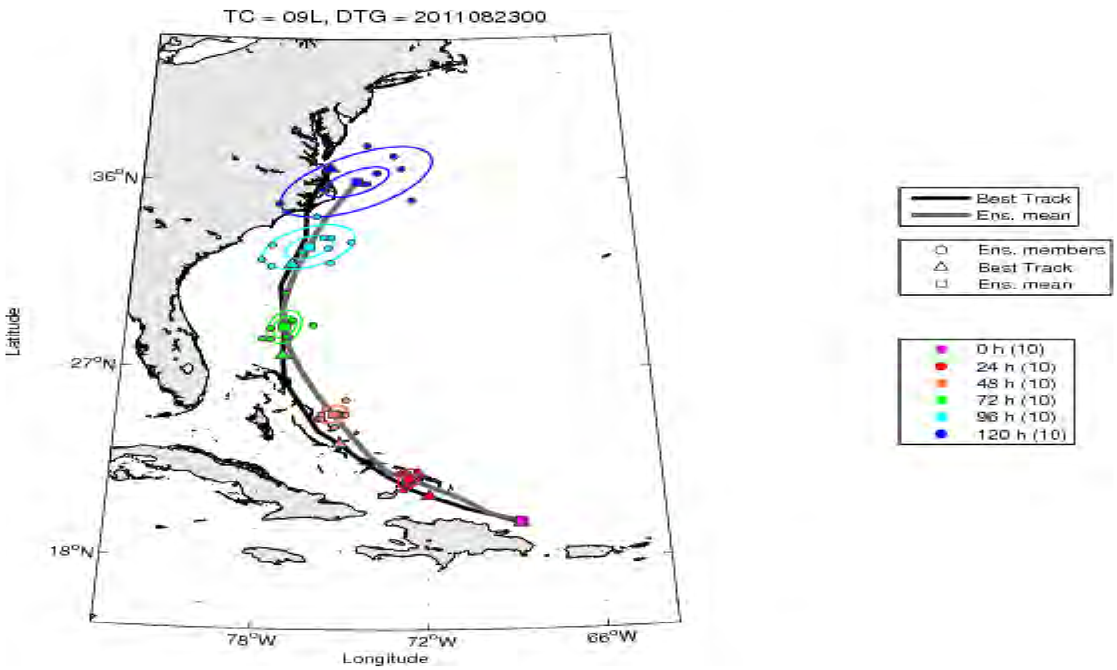

Figure 6. The ensemble mean track forecast of Hurricane Irene 2011 (grey) and the work-best track (black). The 10-member ensemble was initialized 2011082300 Individual ensemble members are plotted every 24-h with filled circles while the ensemble mean and best track are represented every 24-h with filled squares and triangles, respectively. The 1/3 and 2/3 contours of probability from a fitted Gaussian normal distribution are also plotted every 24 hours.

UCAR

1. WRF/DART system developments

In our initial assimilation trials, it was realized that the TC position estimation error (30km) was too small, which lead to too strong of a constraint to the analyses, and may have hindered the impact of the satellite observations. The NCAR team revised the TC track position estimation errors to larger and more reasonable values. The track errors of JTWC advisory positions is now defined as following:

90km for storm max winds <34 knots;
40 km for > 85 knots;
60km for intermediate winds.

The control analyses for Sinlaku were rerun, and it is found that the track errors in the analyses are a bit larger and the initial intensification of the TC is a bit slower at their initial times. This leaves more room for the various data types proposed to improve the analyses and forecasts.

An observation operator used to convert the model variable to get TPW data was developed. Also, a TPW data converter was written to convert the CIMSS processed MODIS and AMSR data into WRF/DART observation sequence format.

2. **Various data assimilation experiments**

Analyses using CIMSS hourly atmospheric motion vectors (AMVs) were done for TC Sinlaku. A Control (CTL): Radiosondes, cloud winds (AMVs from JMA) extracted from NCEP/GFS dataset, aircraft data, station and ship surface pressure data, JTWC advisory TC positions, 6-hourly analysis cycle. CIMSS-RS3h: CIMSS winds replace the JMA cloud winds, at 3-hourly intervals (00, 03, 06 UTC …). Assimilations started Sep. 1, 2008. A moving 9km nest grid with feedback to 27km grid is used in the 6-hour ensemble forecasts when the TC is present. The hourly AMVs within 1-h of the analysis times (-1h, 0h, +1h) are used. It is found that the assimilation of the extra AMVs reduce initial track errors and improve the intensification of Sinlaku in the analyses (Fig. 7).

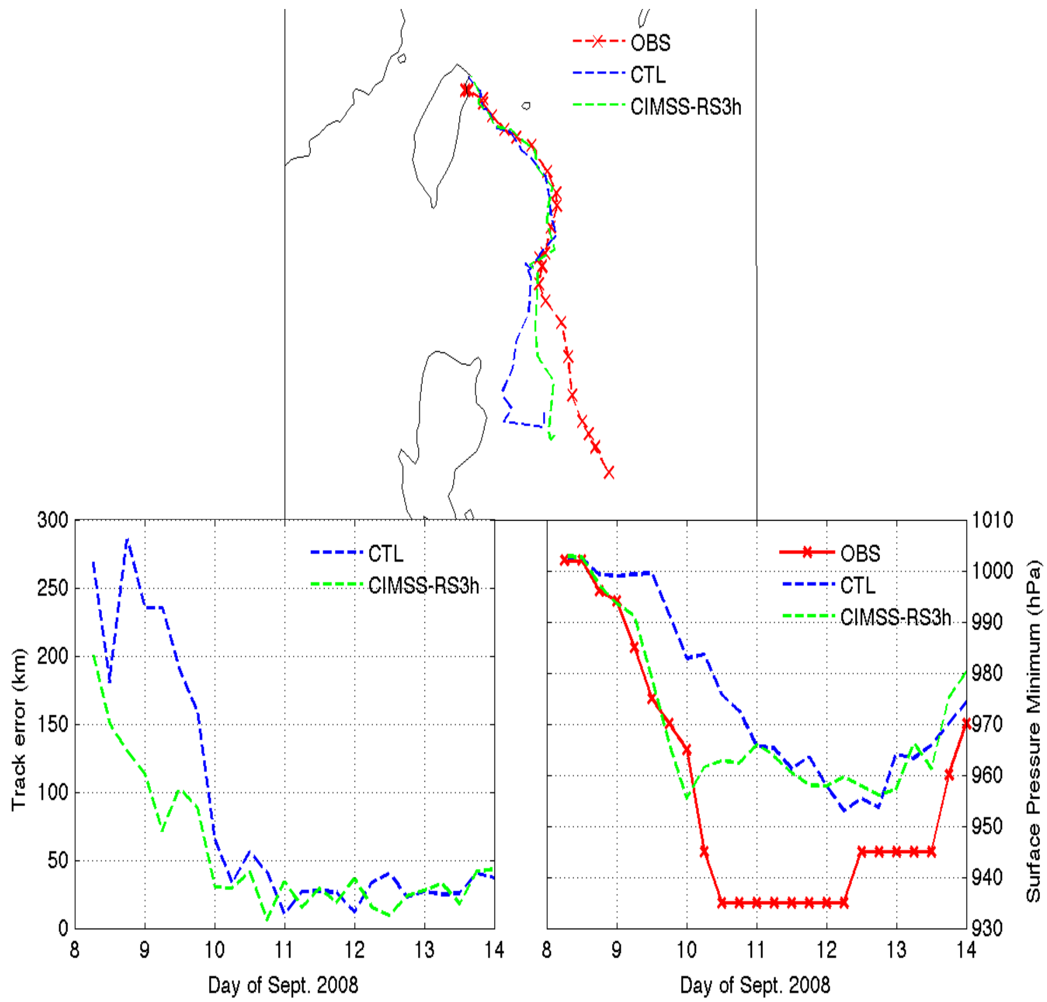

Figure 7. The tracks (upper), initial position errors (lower left), and intensity analyse errors (lower right) with and without CIMSS-produced hourly winds from MTSAT for Typhoon Sinlaku of 2008. Control analyses are dashed blue, and CIMSS winds analyses are dashed green.The observed values (red) are from JTWC advisories.

Another set of experiments were done to show the impact of assimilating AIRS SFOV T/Q soundings in clear skies to the development of TC Sinlaku. The experiments: CIMSS-T: Add only CIMSS SFOV (15km) T profiles to the Control analyses. CIMSS-Q: Add only CIMSS SFOV (15km) Q profiles to the Control analyses. CIMSS-TQ: Add both CIMSS T and Q profiles to the Control analyses. Assimilations were started on Sep. 1, 2008. A moving 9km nest grid is added to the 6-hour ensemble forecasts with feedback to a 27km grid when a TC is present. The results show that CIMSS T data reduces the initial track error of the storm and the Q data improves the initial intensification of the storm (Fig. 8).

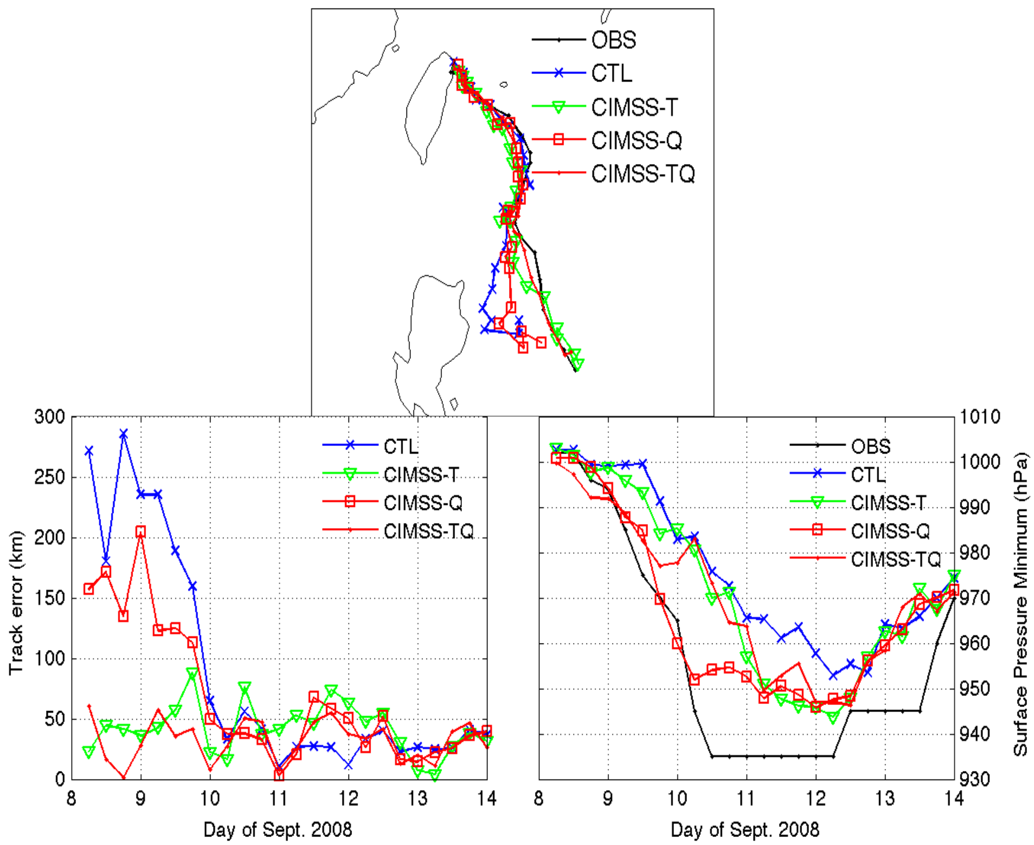

Figure 8. The track (upper), initial position errors (lower left), and intensity analyses (lower right) using SFOV AIRS T/Q soundings from CIMSS for Typhoon Sinlaku of 2008.

Another set of experiments using MODIS IR and AMSR-E MW TPW data were conducted in addition to the previously-described control analyses for TC Sinlaku: TPW-IR: Add only CIMSS processed MODIS IR TPW data to the Control analyses. TPW-MW: Add only CIMSS processed AMSR-E TPW data to the Control analyses. TPW-IR-MW: Add both the MODIS and AMSR-E TPW data to the Control analyses. The results show that the AMSR-E MW TPW data reduces the initial track error of the storm and improves the TC's intensification (Fig. 9).

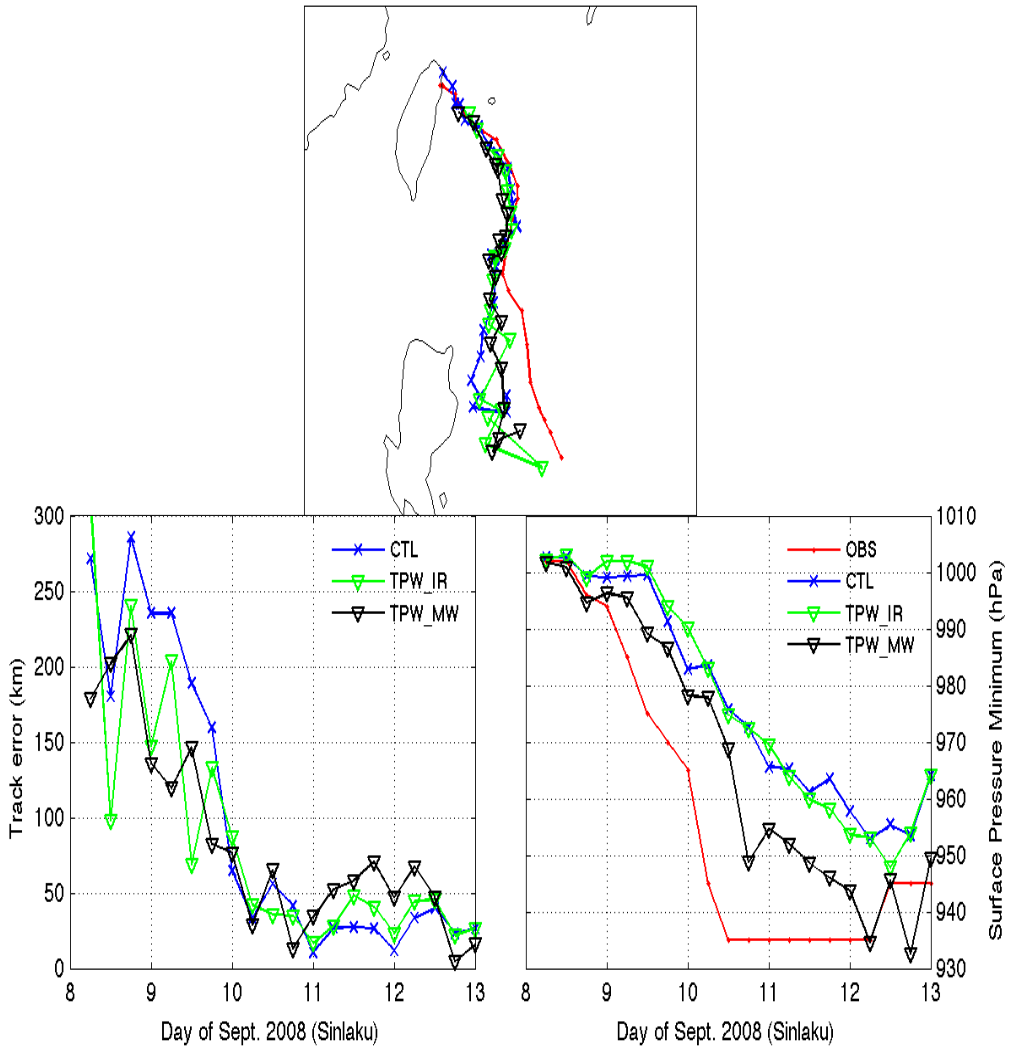

Figure 9. The track (upper), initial position errors (lower left) and intensity analyses (lower right) using MODIS and AMSR TPW data for Typhoon Sinlaku of 2008.

Finally, in an initial attempt too explore the potential impact of combining all of the above data types on intensification of the tropical storm Sinlaku, another set of experiment is done in addition to the previous control and CIMSS hourly winds analyses (RS3h) for TC Sinlaku: ALL: Add CIMSS-processed AIRS T/Q soundings and TPW data to the RS3h analyses.

The preliminary results (Fig. 10) suggest that the assimilation of the high-resolution multi-variate satellite data combined, further improves the initial track analyses and intensification of Sinlaku compared with the Control and analyses using just individual data types.

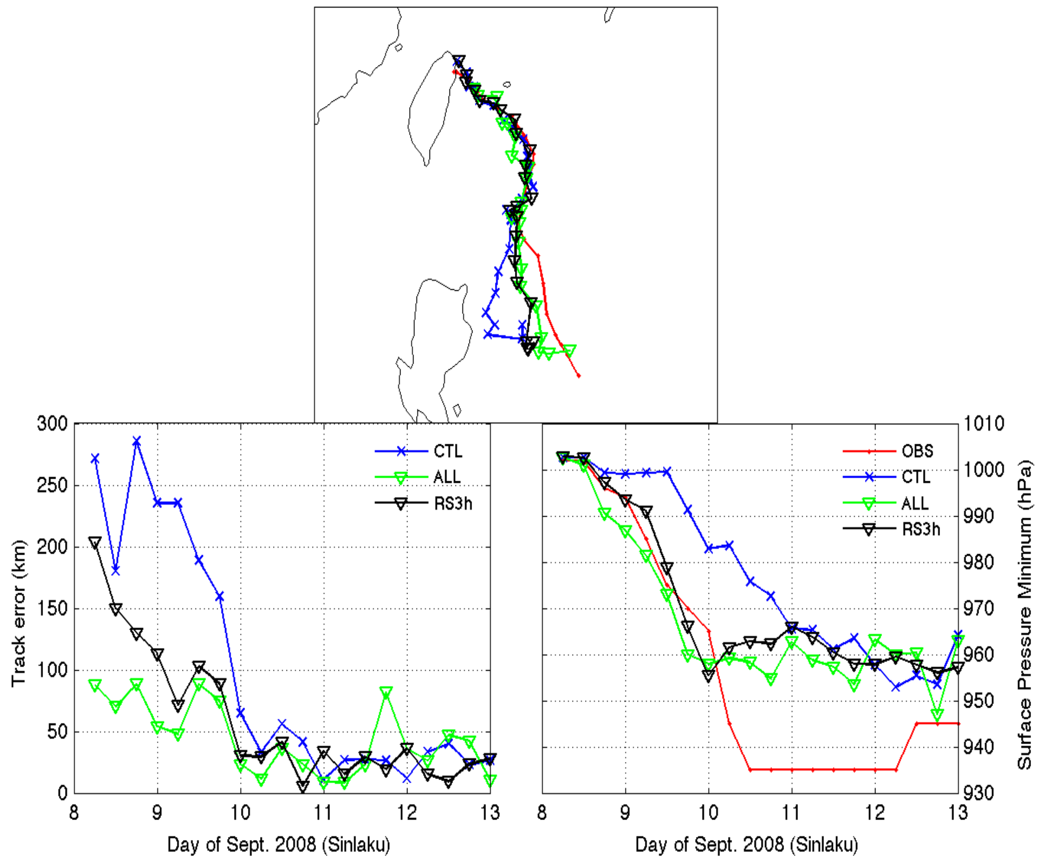

Figure 10. The track (upper), initial position errors (lower left), and intensity analyses (lower right) using combined high-resolution satellite data including hourly AMVs, AIRS T/Q soundings, and MODIS/AMSR TPW data for Typhoon Sinlaku of 2008.

<u>University of Miami</u>

Addressing Task 2: The WRF/EnKF ensembles of analysis fields have been investigated and evaluated in detail by the Ph.D. student paid on this grant, Ting-Chi Wu. Specifically, the influence of assimilating extra hourly and rapid-scan AMVs on analyses of the track and structure of Typhoon Sinlaku (2008) has been investigated. Data used for comparison include the TCS-08 dropwindsondes, BYU QuikSCAT post-processed surface winds, and a "best track" produced by CIMSS with values of mean sea level pressure, maximum surface winds, radius of maximum winds and wind radii based on a blend of satellite and aircraft data. Additionally, the NRL P-3 Eldora Doppler Radar wind observations from TCS-08 (produced by New Mexico Tech) were compared against the WRF/EnKF analysis fields. Detailed quantitative analyses of the influence of the assimilation of hourly and rapid-scan AMVs on the structure of Sinlaku and the large-scale steering motions have also been performed. The results are being written up in a manuscript, to be submitted for peer review by the end of 2011.

In order to assess the influence of the AMV data on WRF/EnKF analyses, three data assimilation cycles were performed. The first – CTL – included all conventional data (except radiances) and AMVs from NCEP. The second – CIMSS(h) – included additional hourly AMVs processed at CIMSS. The third – CIMSS(h+RS) – included hourly and rapid-scan AMVs which were available after 1200 UTC 10 September 2008. The CIMSS(h) cycle has nearly 10 times the volume of AMVs as CTL (Fig. 11a). The volume of AMVs is tripled further when rapid-scan AMVs are included, with a large number of AMVs now evident below 400 hPa (Fig. 11b). In the early stage of Sinlaku's life cycle (8-10 September), the assimilation of hourly AMVs kept the analyses of the central track and pressure considerably closer to the best track than the CTL cycle. The assimilation of rapid-scan AMVs improved the intensity further at later times (beyond 12 September). The horizontal wind structure in most ensemble members was more consistent with independent observations from QuikSCAT and the NRL P-3 Eldora Radar after the additional AMVs were assimilated (Fig. 12a), and higher values of the inner-core temperature, low-level vorticity and convergence suggested a faster spin-up time than CTL (Fig. 12b,c). Finally, the improvement to the mean steering vector due to the assimilation of hourly and rapid-scan AMVs was diagnosed, with a more north-westward flow in CIMSS(h) as opposed to the incorrect westward flow in CTL. Additional diagnostic studies investigating the ensemble covariance in the EnKF are underway. The main goal in the coming year will be to examine the respective roles of assimilating satellite-derived temperature and moisture for the same case, in order to determine the optimal assimilation strategy for integrated satellite data.

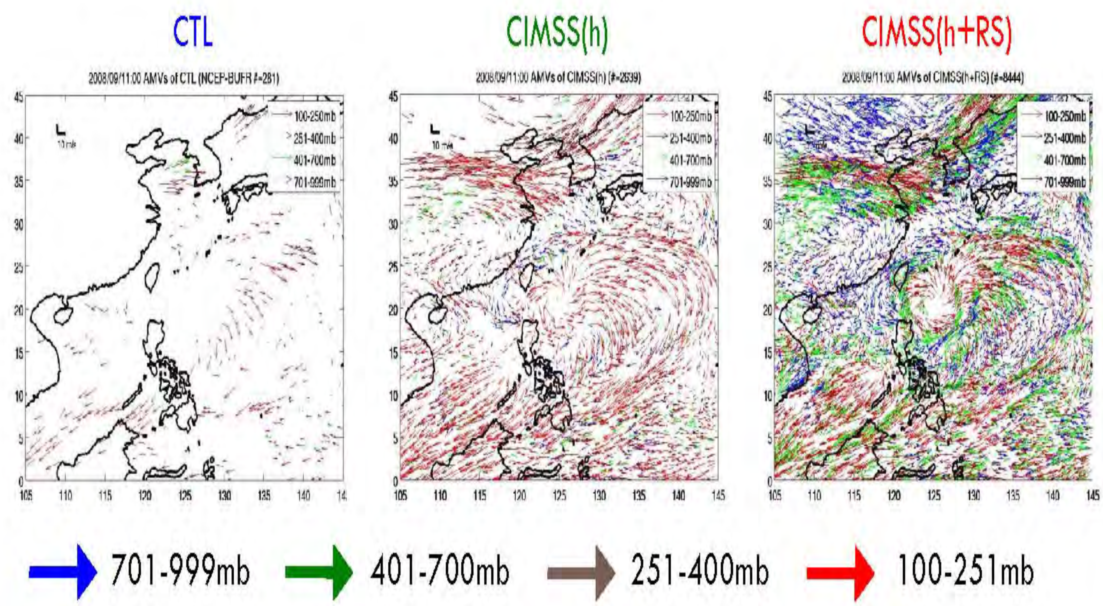

Figure 11. Distribution of AMVs assimilated in the CTL, CIMSS(h) and CIMSS(h+RS) analyses on 0000 UTC 11 September 2008.

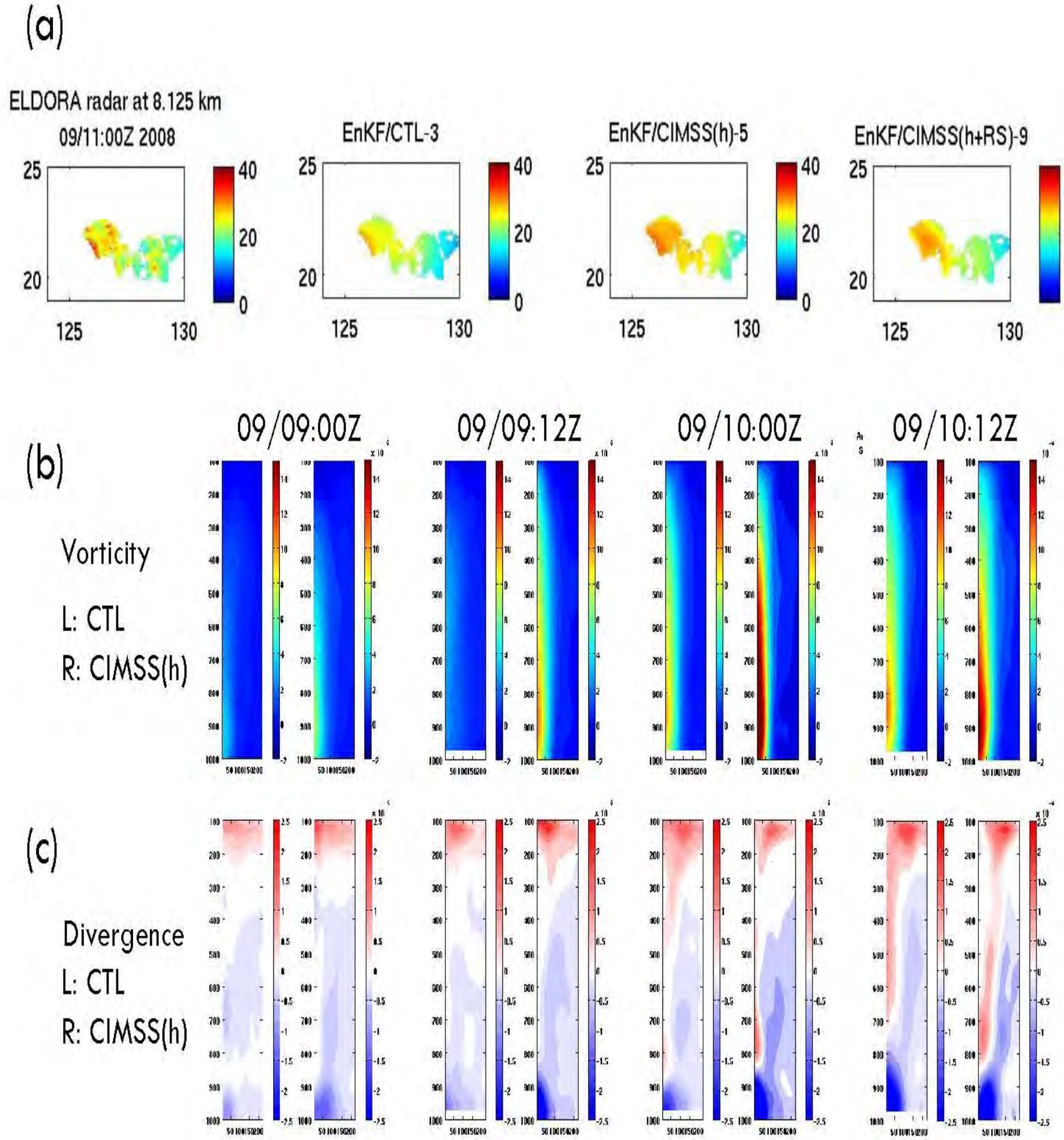

Figure 12. (a) Left: Horizontal cross-section of ELDORA radar wind observations at 0000 UTC 11 September 2008. Right: a typical ensemble member for the CTL, CIMSS(h) and CIMSS(h+RS) analyses respectively. (b) Evolution of vertical cross-sections of the axisymmetric component of relative vorticity centered on Typhoon Sinlaku, in 12-hourly intervals for the CTL and CIMSS(h) runs. (c) As for (b) for horizontal divergence.

IMPACT/APPLICATIONS

Quality of Life

The longer-term impact of this study will be derived from the improved assimilation of high-resolution satellite observations in Navy (and other) mesoscale models. These improvements should translate into superior numerical forecasts of TC track, structure and intensity. This, in turn, will benefit public safety and resource preparedness.

RELATED PROJECTS

This project is related to that funded to CIMSS by ONR grant N00014-08-1-0251: “Advanced Satellite-Derived Wind Observations, Assimilation, and Targeting Strategies During TCS-08 for Developing Improved Operational Analysis and Prediction of Western North Pacific Tropical Cyclones” (PIs Velden and Majumdar).

Another project at CIMSS that is related is "High impact weather studies with advanced IR soundings", funded by the NOAA GOES-R program office (PI Li).

Work at UCAR is related to a NASA GNSS proposal: “Improving Tropical Prediction and Analysis using COSMIC Radio Occultation Observations and an Ensemble Data Assimilation System with Regional and Global Models (PI Anderson). Also, a NCAR-CWB (Taiwan Central Weather Bearou) cooperative project “The Enhancement of the CWB Data Assimilation System (PI: Bill Kuo). Finally, a related NASA proposal submitted and in review "Evaluation of Hyper-spectral IR Data in Storm Forecast with Regional WRF/DART Ensemble Data Assimilation System" (PIs Liu and Li).

This project is also related to that funded to the University of Miami by ONR Grant N00014-08-1-0250: “Using NOGAPS Singular Vectors to diagnose large scale influences on tropical cyclogenesis”. Dynamic initialization methods for tropical cyclones developed on that grant will be examined for use on this project.

Work at NRL Monterey is related to three projects: (i) ONR PMW-120: “Prediction of Tropical Cyclone Track and Intensity Using COAMPS-TC”; (ii) the COAMPS-TC component of the NOAA Hurricane Forecast Improvement Project, and (iii) a NOPP (NOAA/ONR) award on Air-Sea Interaction.

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HONORS/AWARDS/PRIZES

Co-PI Doyle has been elected a Fellow of the American Meteorological Society, effective from 2011.

Co-PI Majumdar has been elected to the WMO THORPEX Data Assimilation and Observing Strategies Working Group.