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OSSE EVALUATION OF A HYPERSPECTRAL SOUNDER AND ITS POTENTIAL IMPACT ON HURRICANE PREDICTION

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1. INTRODUCTION

The lifetime of observing systems is finite and it is important to plan for replacement instruments that meet the current and next generation numerical weather prediction (NWP) system needs. The Atmospheric Infrared Sounder (AIRS) is one such instrument nearing the end of its design life. This instrument provided accurate daily coverage of temperature and water vapor soundings and had among the highest impact of any single instrument to the operational forecast (Cardinali, 2009). Observing system simulation experiments (OSSEs) have been developed to evaluate the potential impact that new observing systems could have on analyses and forecasts (Atlas, 1997). OSSEs were also used to study observing system design trade-offs and even improve data assimilation techniques.

The improved prediction of tropical cyclones (TCs) is one particularly important area of interest. High resolution regional OSSEs are now used to assess possible impact an observing will have on TC track and intensity predictions. In addition to the impact on forecasts, regional OSSEs can also provide guidance on observing system design configuration, sampling strategies, and advance data assimilation and vortex initialization methodology. The motivation for this study is to examine the impact of the next generation AIRS- an advanced hyperspectral sounders with high temporal and spatial resolutions on tropical cyclone track and intensity predictions.

2. DATA AND METHODOLOGY

OSSE are generally characterized by four major components and two important, but secondary components. Figure 1 shows a schematic of the all components needed to perform an OSSE:

(1) ***A long atmospheric model integration using a very high-resolution numerical model.*** The first element is comprised of an extended atmospheric model forecast that uses an advanced high-resolution numerical model to provide a “true” state referred to as the “nature run.” The nature run (NR) needs to demonstrate realistic atmospheric processes where its degree of realism is determined via the process of validation.

The nature run for this study was generated using the Weather Research and Forecast model - Advanced Research WRF (WRF-ARW). WRF-ARW was used to simulate 13 days (28 July 2005 to 10 August 2005) of an Atlantic hurricane (named HNR1), beginning at genesis and including rapid intensification and extratropical transition (Nolan et al., 2013). It is important to note that HNR1 was not an actual TC observed in nature but one that was generated in this modeling framework for analysis purposes.

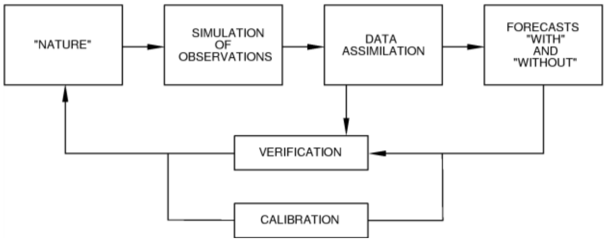

Figure 1. Schematic of OSSE

The model structure consisted of one parent domain with 27 km horizontal spatial resolution and three storm-following “nested” domains with horizontal grid spacing of 9, 3, and 1 km. What was unique about this nature run was that its boundary and initial conditions were provided by a global nature run. The global nature run originated from a 13-month integration of the European Center for Medium Range Weather Forecasting (ECMWF) forecast model with T511 spectral resolution and 91 vertical levels (Reale et al., 2007; Masutani et al., 2009). To ensure that the synoptic scale evolution was similar between the regional and global NRs, “analysis nudging” (FDDA; Stauffer and Seaman 1990,1991) was used to weakly force the parent domain of the regional NR towards the global NR. This resulted in similar track forecasts for HNR1in the global and regional NRs as shown in Figure 2. However, due to the substantially increased spatial resolution of the regional NR, the evolution of the minimum central pressure largely differs from the global solution showing a category 4 TC at its peak strength.

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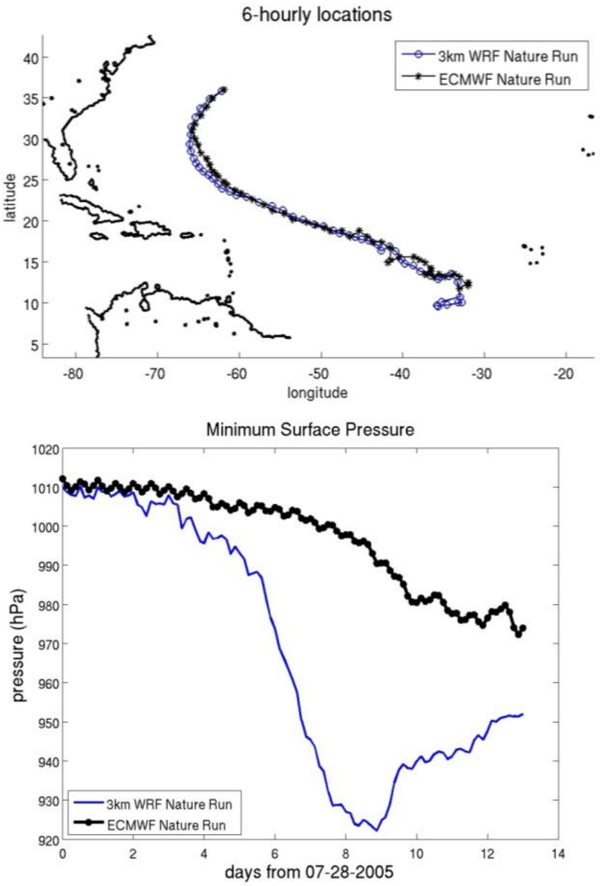

Figure 2. Upper panel shows the track forecast of HNR1 from 0000 UTC 28 July 2005 to 0000 UTC 11 Aug 2005 in the global (ECMWF) NR (black) and 3km grid of the regional NR (blue). Lower panel shows evolution of minimum central surface pressure in the global NR (black) and the regional NR (blue).

(2) ***Simulated conventional and satellite observations from nature run.*** The second component of the OSSE was the simulation of observations from the validated nature run. Simulated observations, both from existing and new observing systems, need to include the same characteristics (coverage pattern, resolution, accuracy, and error statistics) as observations attained using currently available instrumentation in the real world. This can be done in two ways: (a) interpolation of the nature run to observation locations and the addition of errors or (b) retrieve observations from the nature run in the same way as observations are retrieved in the real atmosphere.

The flexibility of an OSSE setting allows a user to create multiple sets of purposed observing system observations with different configurations. That is the approach a team at NASA's Jet Propulsion Laboratory lead by Thomas Pagano utilized when simulating the next-generation AIRS observations. Four sets of observations were simulated, all including temperature and moisture retrievals at different temporal and spatial resolutions. The first was a control set, simulating the current AIRS with twice daily coverage at 45 km spatial resolution. This set was simulated from the parent (27 km) domain of the NR. The second was a high spatial resolution version of AIRS called Advanced Remote-sensing Imaging Emission Spectrometer (ARIES) with the same twice daily coverage at 2 km. Only the innermost nest (1 km) of the nature run had the sufficient spatial resolution to allow simulation of ARIES data. Figure 3 shows the full coverage (over the 1 km NR domain) over the entire length of the nature run.

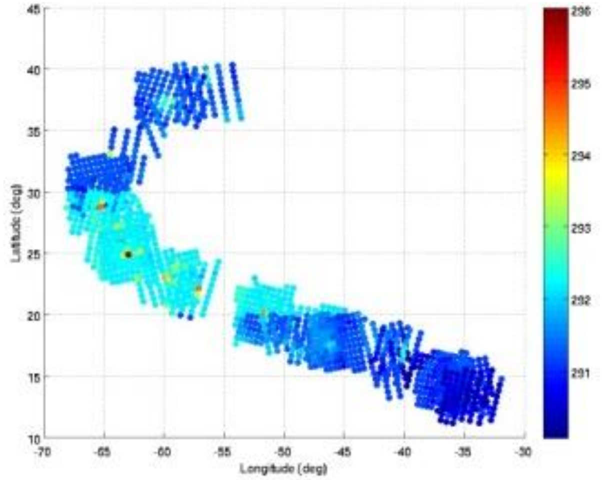

Figure 3. 850 hPa temperature (K) retrievals simulated from 1km storm-following nest WRF-ARW Nature Run over 13 day period

The third and fourth sets were simulated assuming AIRS was placed on a geostationary (GEO) satellite. This allowed for higher temporal resolution but lower spatial resolution when compared to ARIES. One set was created with 5 km horizontal resolution every 72 minutes from the innermost domain of the nature run. The other set was at 10 km horizontal resolution every 72 minutes from the parent domain of the nature run.

One aspect to note about the control dataset (comprised of current conventional and space-based observations) is that it was simulated from the ECMWF global nature run. Thanks to the use of nudging in the HNR1, the synoptic scales of both nature runs was sufficiently similar allowing for the reuse of the simulated data.

(3) ***Control and Experimental data assimilation cycles.*** Simulated observations then were fed into the third part of the OSSE, the data assimilation (DA) system. The DA system creates an analysis using the simulated observations. Control was created first, followed by control in addition to observations from the experimental observing system.

The data assimilation system used in this study was the 3.3 version of Gridpoint Statistical Interpolator (GSI). Analyses were performed on the 9km parent domain shown in Figure 4.

(4) ***Forecasts launched from Control and Experimental analyses.*** Analyses created by the DA system are then used in the fourth component, the forecast model. The forecast model should be a different model than the one used to generate the nature run (to avoid the identical twin problem described in Atlas 1997).

A regional forecast model was used in the OSSE system- Hurricane-WRF (HWRF) model (v3.5). It was configured with a 9km parent domain (d01) and 3km storm-following nest (d02) shown in Figure 4. No DA was performed on the storm-following nest, it was spawned on top of the 9km analyses.

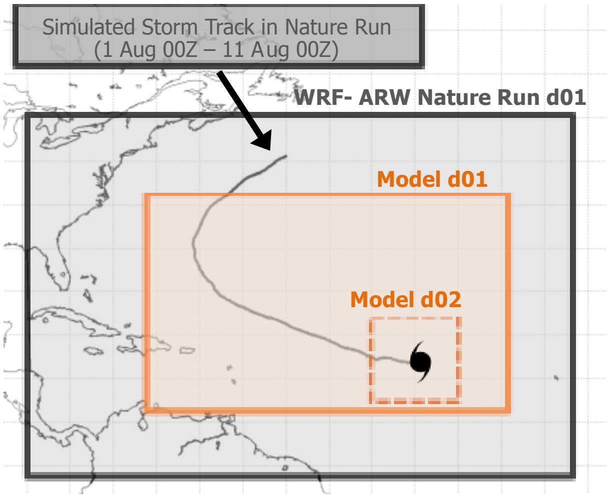

Figure 4. HWRF domains within the regional NR. D01 is the parent domain; D02 is the nested, storm-following domain.

3. EXPERIMENTS

The purpose of the experiments was to begin an assessment of the next generation AIRS instrument. Three experiments in addition to the control were conducted for this study. All of the initial experiments focused on the effect of high resolution observing over the immediate vortex. Therefore only observations simulated over innermost 1km domain of the NR were utilized. Additionally, only temperature observations were assimilated to make interpretation of results easier. Impacts of these data were not expected to have a long lasting effect due the limited spatial coverage and discontinuity between the vortex and the synoptic environments created by the small spatial coverage.

Unless otherwise specified, each experiment consisted of assimilation and model forecast cycling every 6 hours with 120-hour forecasts launched from each analysis. 16 cycles total were completed (0600 UTC 01 Aug through 0600 UTC 05 Aug).

The control experiment assimilated all conventional and current space-based observations (including AIRS radiances). The first experiment added temperature retrieval observations to the control from ARIES (denoted ARIES_2km_d04). The second experiment added temperature retrieval observation to the control form GEO (denoted GEO_5km_d04). The third and final experiment also assimilated the same data as the second experiment, but instead of cycling every 6 hours, 3 hourly cycling was employed (denoted GEO_5km_d04_3hrly) to increase the importance (or weight) of the data at the analysis time.

4. RESULTS

The three traditional metrics used to evaluate improvement of tropical cyclone prediction are track, maximum 10m wind speed, and minimum sea level pressure error. These errors were averaged over all cycles for each forecast hour. As seen in Figures 5-7, positive impact in all three metrics was shown in the first 6-12 hours with the addition of any temperature retrievals. The best performing of the three experiments in terms of intensity forecasts was GEO_5km_d04_3hrly, with an improvement seen out as far as 36 hours.

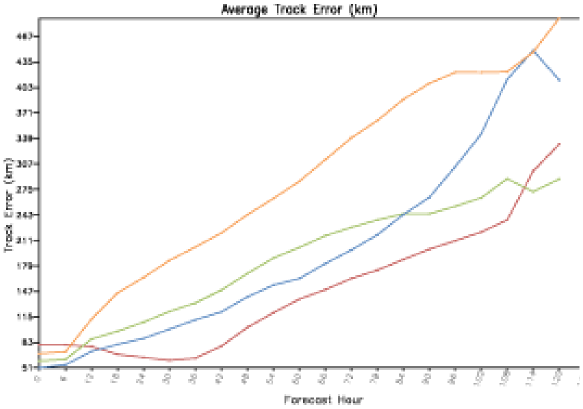

Figure 5. Average error over 16 cycles. Position (track) error in km

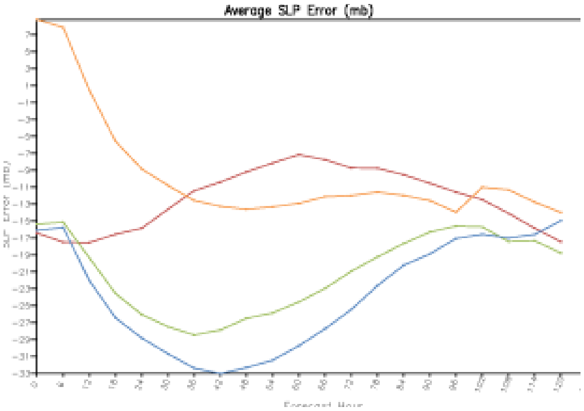

Figure 6. Average error over 16 cycles. Minimum central pressure error in hPa.

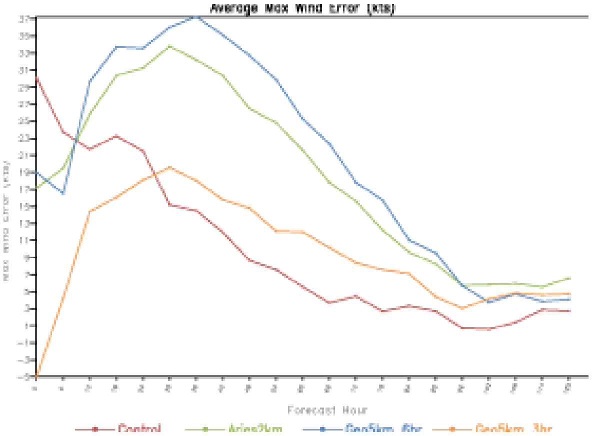

Figure 7. Average error over 16 cycles. Maximum 10m wind speed error in kts

Closer examination of the GEO_5km_d04_3hrly experiment reveals that while the experiment had a more accurate prediction of the TC intensity, the analysis of the vortex structure tended to be too strong and over too large of an area (Figure 8).

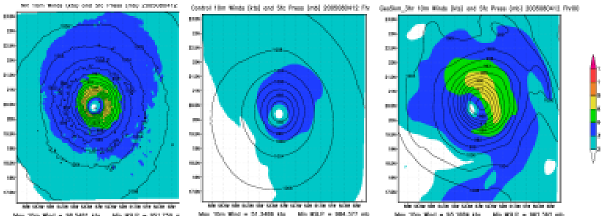

Figure 8. Analyses of 10m wind speed (shaded) and surface pressure (contoured) from the 0000 UTC 4 Aug 2005 forecasts. Left is NR, center is Control, right is GEO_5km_d04_3hrly.

While it was unexpected that the addition of temperature retrievals over the storm would have a significant effect, results also showed that the temperature field (at 850, 500, and 200 hPa) over the parent domain experienced a positive impact from the data (Figure 9). No single experiment was consistently the best performer and it was difficult to interpret the error trends in the forecast. More analysis of these results is needed.

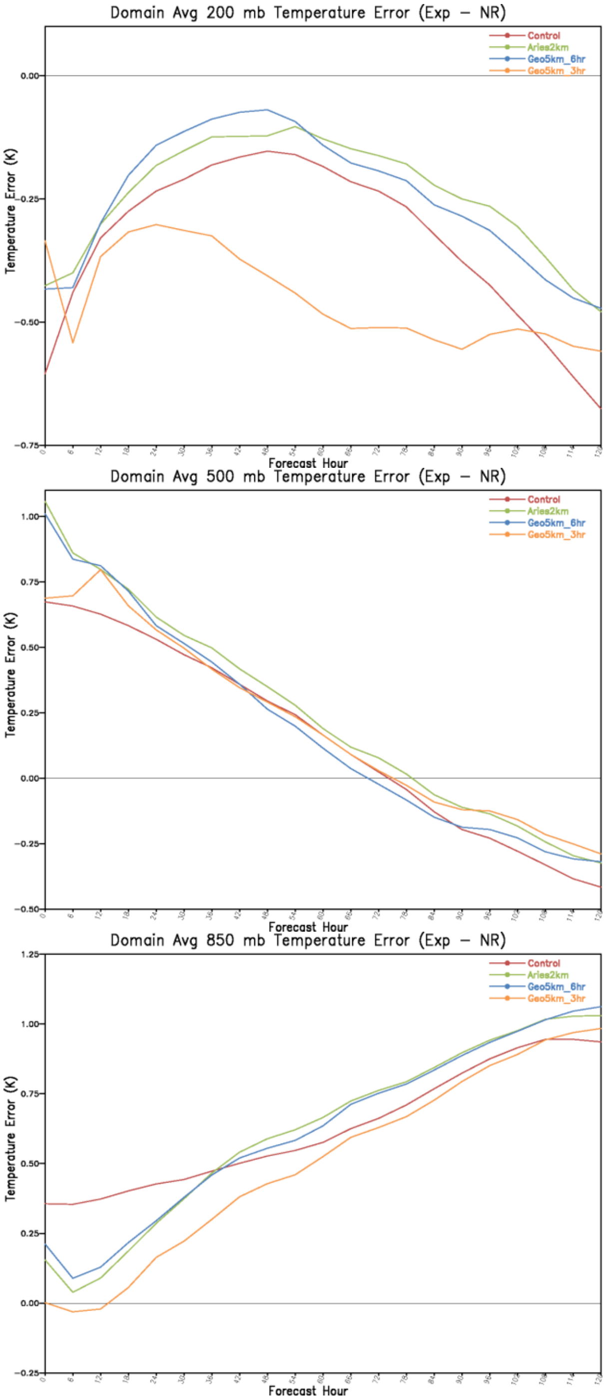

Figure 9. Absolute errors averaged over entire “d01” and over all 16 cycles of temperature at 200 hPa (top), 500 hPa (middle), and 850 hPa (bottom).

5. CONCLUSIONS AND FUTURE WORK

OSSEs provide an effective means to determine potential impact and offer insight into design and configuration of new observing systems such as the next-generation AIRS. Studies show that improvement is made in the short term forecast when adding high-resolution temperature retrievals over the hurricane.

Surprisingly, over the larger basin-scale domain the improvement is seen longer into the forecast than on the storm scale. Increasing the cycling from six to three hours improves the intensity forecast but degrades the track forecast and vortex structure.

Future work includes expanding the data coverage to the basin scale domain to examine a more realistic coverage pattern of the ARIES and GEO instruments. It will also be useful to examine the impact of assimilating water vapor only and the combination of temperature and water vapor. Finally, it is important to establish an “upper-bound” on each instrument and explore the idea of how perfect observations from that instrument would perform in the OSSE system. This would provide users with the benefit of understanding the potential room for growth that the observing system is capable of achieving.

Acknowledgements. The lead author wishes to thank NESDIS OSD, NOAA's Office of Weather and Air Quality and the Sandy Supplemental for providing funding for this research, as well as the Jet Propulsion Laboratory for synthetic observations, Professor David Nolan for the generation of the WRF nature run, and the NOAA HFIP program for computing support.