

## **Tropical Cyclone Ensemble Data Assimilation**

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### **LONG-TERM GOALS**

The ultimate goal of this project is to demonstrate that in the presence of tropical cyclones (TCs) a multi-scale approach for data assimilation can significantly enhance the analyses and the ensuing forecasts. Our multiscale approach is based on coupling a lower resolution global data assimilation system and a higher resolution limited area data assimilation system in the TC region. The coupled approach has the potential to lead to a better utilization of the computer resources in atmospheric modeling.

### **OBJECTIVES**

Ours is the first attempt to use an ensemble-based, coupled global-limited-area data assimilation system to improve the analysis and the forecast of TCs and their effects on the larger scale atmospheric processes. In fact, to the best of our knowledge, we have been the only research group working on a data assimilation system that generates both global and limited area analyses. Our key scientific objective is to explore the potentials and the limitations of the coupled global-limited-area data assimilation approach. This research objective is particularly relevant for the numerical weather forecasting applications of the Navy, as the Fleet Numerical Meteorology and Oceanography Center (FNMOC) prepares both a global forecast and a larger number of limited area forecasts (more than 60) than any other forecast center in the world.

### **APPROACH**

Our data assimilation system is based on the Local Ensemble Transform Kalman Filter (LETKF) algorithm (Ott et al. 2004; Hunt et al. 2007) and its specific implementation on the NCEP GFS model (Szunyogh et al. 2005 and 2008). The first effort led by the PI to build a coupled global-limited-area data assimilation system was described in Merkova et al. (2011). That paper compared the performance of four different coupling strategies: three strategies propagated information from the global to the limited area system, while the fourth strategy also propagated information back from the limited area system to the global system. The system described in Merkova et al. (2011) was implemented on an extended North-American region. Our plans for the current project called for implementing the system of Merkova et al. (2011) on the region of the West Pacific typhoon basin.

Because we have had extensive experience with the global component of the data assimilation system for summer 2004, we decided to carry out the initial testing of the system using observations from the 2004 Typhoon season. This decision was also motivated by the extensive experience of our collaborators from AER Inc with the Quick-Scat data for the same period (e.g., Hoffman and Leidner 2010).

The development and testing of the coupled data assimilation system is carried out at Texas A&M University under the supervision of the PI. The key members of the Texas A&M group are Christina Holt, a Graduate Research Assistant, whose full support for FY11 was provided by the current ONR grant, and Gyorgyi Gyarmati, an Assistant Research Scientist (whose full support for FY11 was provided by Texas A&M). Christina Holt successfully defended her Master of Science Thesis, based entirely on research carried out with the support of the present grant, in May 2011. She continues her studies and research toward a Ph.D. degree. The Quick-Scat data have been processed by AER scientists Ross Hoffman and Mark Leidner. They are also in charge of developing the observation operator for the Quick-Scat data.

## **WORK COMPLETED**

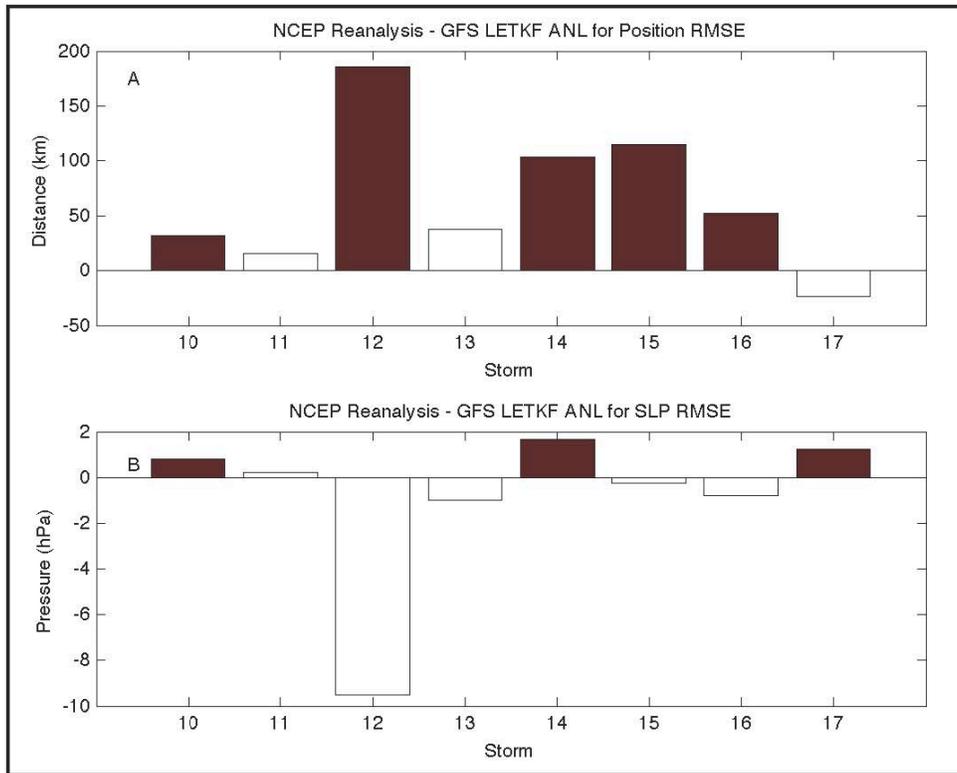
In the first year of the project, we completed implementing our system on the North-Pacific region. In the current reporting period (the second year of the project) we carried out a large number of analysis/forecast experiments using different resolutions of the limited area component of the system. The resolutions we tested were 200 km, 100 km, 48 km, 36 km and 24 km. To assess the quality of the analyses and the forecasts, we verified them against the best track position and intensity estimates of the Joint Typhoon Warning Center (JTWC). The results of these experiments have been summarized in a Master of Science Thesis (Holt 2011a) and a paper (Holt 2011b).

Our collaborators at AER Inc., who have been funded by a subcontract of the current grant, processed all Quick-Scat data available for the two-month period of our investigation. As of yet, we have assimilated only the small subset of Quick-Scat data, which were also assimilated operationally. The analysis and forecast effects of the Quick-Scat data from these experiments have been neutral, but we hope that once we assimilate the full set of data, the results will be more positive.

With our collaborators at the University of Maryland (they are not funded by the current grant), we have developed a more advanced algorithm to couple the global and the limited area data assimilation process (Yoon et al. 2011). The key new feature of the algorithm is the addition of a constraint term (to the cost function minimized by the data assimilation algorithm) to penalize large differences between the global and the limited area analyses within the limited area.

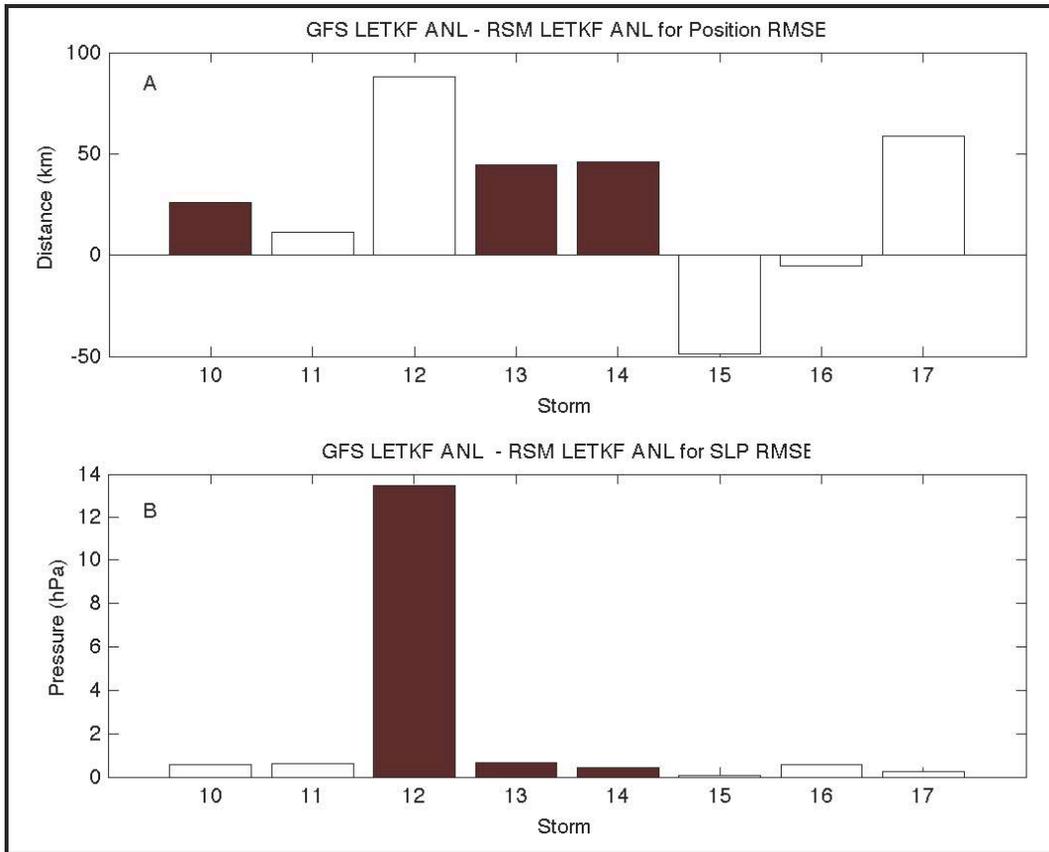
## **RESULTS**

The purpose of the first set of our experiments was to validate the global component of the data assimilation system. We carried out this task by comparing the accuracy of our analyses to the accuracy of analyses from the NCEP-NCAR Reanalysis project. The NCEP-NCAR Reanalysis data were chosen for comparison, because they were obtained using (i) the same model, (ii) the same horizontal and vertical resolution and (iii) about the same observation data set as in our global system. The results of this set of experiments are summarized in Fig. 1. This figure shows that when the difference between the two systems is significant, it is always in favor of our system.



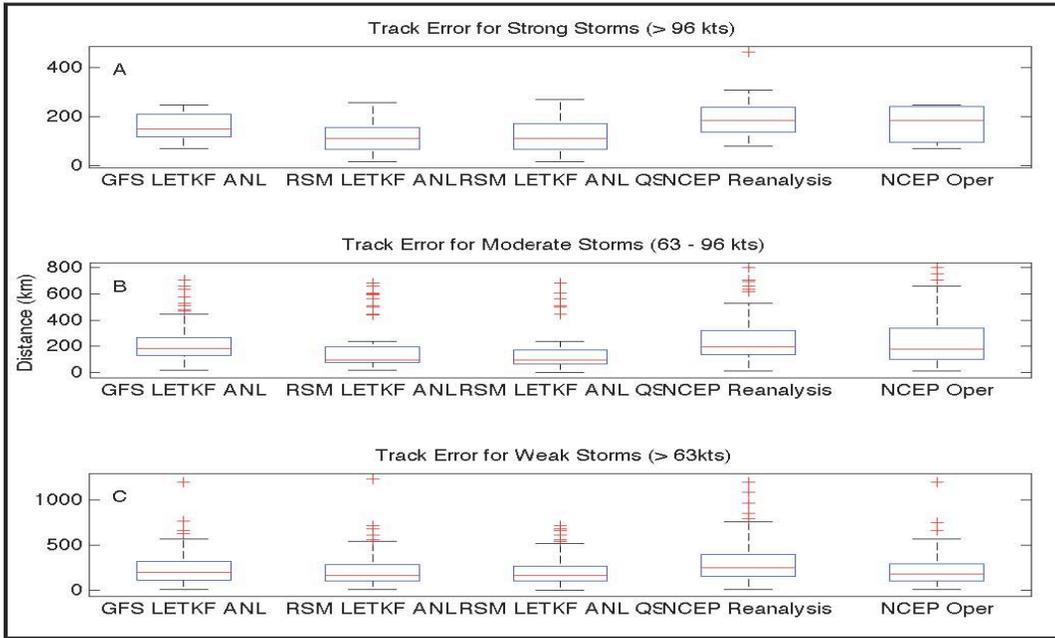
**Figure 1. Shown are the differences between the root-mean-square errors of the NCEP-NCAR reanalyses and our global analyses for each typhoon during the time period covered in our experiments. The mean in the root-mean-square is computed based on data for every 12-h over the life cycle of each storm. Maroon shading indicates a statistically significant difference. (A positive value indicates that our analyses are more accurate than the reanalyses for the given storm.)**

After verifying that our global analyses were of reasonably high quality, we added the limited area component of the system. We carried out analysis/forecast experiments gradually increasing the resolution of the limited area component. Since the resolution of the global system in the limited area domain was about 240 km, the lowest resolution of the limited area system we tested was 200 km. For that resolution, the limited area analyses were clearly inferior to the global analyses, indicating that the modest increase in the resolution was insufficient to compensate for the degradation caused by the introduction of the lateral boundaries. When the resolution of the limited area system was increased to 100 km, the accuracy of the limited area analyses surpassed that of the global analyses; and further increases in the resolution led to further increases of the accuracy of the typhoon position and intensity analyses. Here, we show results only for the case where the resolution of the limited area system is 48 km (Fig. 2). This figure shows that the statistically significant differences, both for the track and the intensity errors, are in favor of the limited area component of the data assimilation system.

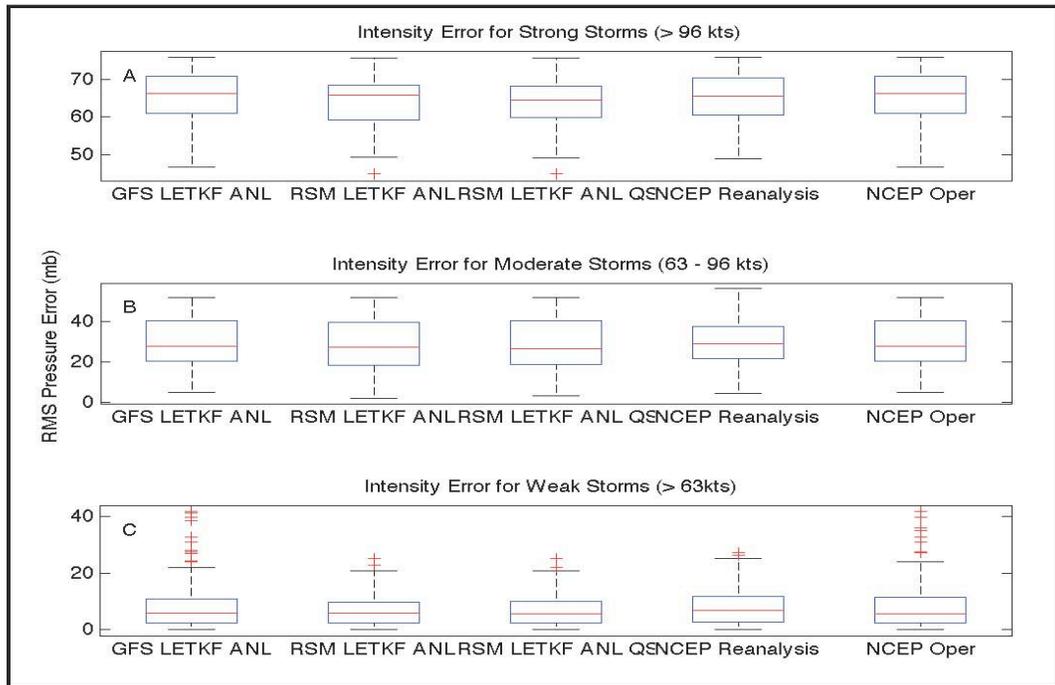


**Figure 2. Shown are the differences between the root-mean-square errors of the global analyses and the 48-km resolution limited area analyses for each typhoon in the investigated period. The mean in the root-mean-square is computed based on data for every 12-h over the life cycle of each storm. Maroon shading indicates statistically significant difference. (A positive value indicates that the limited area analysis is more accurate than the global analysis.)**

We also investigated the effect of the intensity of the storms on the results. To carry out this investigation, we classified each storm as strong, modest or weak and used box plots to analyze the distribution of the analysis errors in each category. Examples of the results of this investigation are shown in Figs. 3 and 4. (The limited area results shown in these plots are for the 48-km resolution experiments.) These figures show that all analysis systems we investigated can more accurately analyze (i) the position of the strong storms than the position of the weaker storms and (ii) the intensity of the weak storms than the intensity of the stronger storms. In terms of position errors, the overall better performance of the limited area component is due to its better performance for the stronger storms. In terms of intensity errors, the overall better performance of the limited area component is due to the reduction of the frequency and the magnitude of cases of anomalously large errors for weak storms.



**Figure 3. Box plots to illustrate the distribution of the track analysis errors for the different analyses. The results are stratified based on the strength of the typhoons.**



**Figure 4. . Box plots to illustrate the distribution of the track analysis errors for the different analyses. The results are stratified based on the strength of the typhoons.**

## IMPACT/APPLICATIONS

Our results add to the growing body of evidence that ensemble-based Kalman filters provide an efficient way of data assimilation in the presence of TCs. In particular, ensemble based Kalman filters do not require the use of “TC relocation” or “bogusing”, approaches which are still used in some variational data assimilation systems. Our results also indicate that a coupled global-limited-area data assimilation system can take advantage of the higher resolution of the limited area component in the region where TCs form and evolve.

The strategy for the coupling of the global and the limited area data assimilation components can, most likely, be further improved. One candidate for such an approach is described by Yoon et al. (2011). We are planning to carry out research in that direction in close collaboration with researchers of the Naval Research Laboratory, Monterey.

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- Yoon, Y.-N., B. R. Hunt, E. Ott, and I. Szunyogh: Ensemble regional data assimilation using joint states. Submitted to *Tellus*.
- ## PUBLICATIONS
- Holt, C. R., I. Szunyogh, and G. Gyarmati, 2011b: Testing a coupled global-limited area data assimilation system using observations from the 2004 Pacific typhoon season. To be submitted to *Mon. Wea. Rev.*
- Yoon, Y.-N., B. R. Hunt, E. Ott, and I. Szunyogh: Ensemble regional data assimilation using joint states. Submitted to *Tellus*.

Holt, C. R., 2011a: *Testing a coupled global-limited area data assimilation system using observations from the 2004 Pacific typhoon season*. Master of Science Thesis, Texas A&M University, 60 pp.

Merkova, D., I. Szunyogh, and E. Ott, 2011: Strategies for coupling global and limited-area ensemble Kalman filter assimilation. *Nonlin. Processes Geophys.*, **18**, 415-430.