

Ensemble Data Assimilation and Predictability of Tropical Cyclones

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LONG-TERM GOALS

The ultimate goal is to improve tropical cyclone track and intensity prediction through further development of the regional-scale, cloud-resolving ensemble-based data assimilation and prediction system capable of efficiently assimilating in-situ and remotely sensed observations.

OBJECTIVES

The primary objectives will be (1) to examine the dynamics and predictability, as well as observation targeting and observability, of tropical cyclones primarily over the western Pacific regions in comparison to the Atlantic Basin, (2) to transfer, implement and develop new ensemble-based data assimilation and prediction techniques based on the COAMPS model, and (3) to enhance the performance of the COAMPS ensemble analysis and prediction system through inter-comparison and potential coupling with other limited-area operational models.

APPROACH

Since the beginning of the project a few months ago, two new graduate students (Jonathan Poterjoy and Baoguo Xie) and a postdoctoral research associate (Dr. Yonghui Weng) have been recruited to work on this project at the Pennsylvania State University. Dr. Weng is primarily responsible for the development and implementation of new ensemble data assimilation techniques to be transferrable to COAMPS. Mr. Poterjoy is exploring the structure and parameterization of tropical cyclone background error covariance through ensembles with a hierarchy of numerical models ranging from the simple Rankine Vortex, to the Emanuel axis-symmetric model, and to the fully cloud-resolving non-hydrostatic model WRF-ARW. Mr. Xie is to apply the ensemble data assimilation techniques to examine the observation targeting and observability of tropical cyclones in the western Pacific, and has just begun working on Typhoon Morakot which brought record-breaking flooding to Taiwan in August 2009.

We are also actively collaborating with Dr. Allen Zhang at NRL in transferring the ensemble based data assimilation system to the Navy mesoscale forecast model (COAMPS), with Drs. Michael Bell at NPS and Wen-Chau Lee at NCAR on processing ONR P3 airborne Doppler observations of TCS08 storms in the western Pacific, with Drs. Frank Marks, John Gamache, Sim Aberson and Altug Aksoy at NOAA/HRD in assimilating airborne Doppler observations in hurricane prediction models, with Jeff Whitaker at NOAA/ESRL on coupling global and regional ensemble data assimilation systems, and

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with Dr. Jason Sippel at NASA and Dr. Juan Fang visiting from Nanjing University on the dynamics and predictability of different tropical cyclones.

We have continued our real-time cloud-resolving implemented ensemble analysis and prediction of Atlantic tropical cyclones through assimilating airborne radar observations and through coupling with a global ensemble data assimilation system. Through ensemble simulations and sensitivity experiments, we aim to examine the flow- and regime- dependent predictability and observability of tropical cyclones.

WORK COMPLETED

As a continuation and expansion of the PI's YIP project that just ended, we make significant progress in understanding the predictability of tropical cyclones and in further development of assimilating airborne Doppler radar observations for tropical cyclones. The transition of the ensemble data assimilation to the COAMPS is well underway thanks for the leading effort by Dr. Allen Zhao at NRL.

RESULTS

Highlights of the work completed during the past year are listed below:

(1) *Mesoscale dynamics and predictability of tropical cyclones and hurricanes (Zhang and Sippel 2009; Sippel and Zhang 2009; Fang and Zhang 2009)*: The use of probabilistic methods and ensemble analysis and assimilation to investigate the genesis dynamics and predictability of Hurricane Humberto (2007), a null case in which the MM5 predicted a tropical cyclone that never formed in late July 2004. Ongoing work also explores the predictability of Typhoon Morakot (2009), a Western Pacific typhoon that produced record-breaking, catastrophic rainfall across Taiwan, and tropical storm Erika (2009), a weak Atlantic storm in a highly sheared environment with strong forecast uncertainty by many operational models. It is found that at least for some cases, the predictability of tropical cyclones may be limited by the randomness of moist convection and the uncertainties in representing larger-scale environment.

(2) *Improve tropical cyclone track and intensity prediction through further development of the regional-scale, cloud-resolving ensemble-based data assimilation and prediction system capable of efficiently assimilating ground-based and airborne Doppler observations and satellite-derived products (Zhang et al. 2009a, 2009b)*. We examined the performance of the ensemble-based data assimilation and prediction system for several high impact historical cases with Doppler radar observations that includes Hurricanes Katrina (2005), Emily (2005) and Rita (2005) and Humberto (2007); we also applied the system in realtime or near-realtime for several of the 2008 and 2009 storms (Dolly, Fay, Gustav and Ike of 2008, and Ana, Bill, Danny and Errika of 2009). In all these cases, it is found that the ensemble analysis and forecast system with Doppler observations assimilated can significantly improve the track/intensity prediction while reveal significant uncertainty in the forecast. We also examined the effectiveness of using a high-resolution global EnKF analysis and perturbations in initializing cloud-resolving regional-scale ensemble forecast for hurricane prediction. The performance of such a system in predicting the record-breaking rainfall of Morakot (2009) is shown in Figures 1-3.

(3) *Transitioning the mesoscale ensemble data assimilation system to COAMPS.* This system was originally developed by the PI capable of assimilating in-situ and remote observations including radar data. The initial tests of the COAMPS-based system at NRL by Dr. Allen Zhao were very encouraging and we will continue to improve it for the Navy model. We have just received the approval from US Navy to use COMAPS directly at Penn State University through an Educational Partnership Agreement between Navy and PSU.

IMPACT/APPLICATIONS

Understanding of the limit of tropical cyclone predictability and the associated error growth dynamics is essential for setting up expectations and priorities for advancing deterministic forecasting and for providing guidance on the design, implementation and application of short-range ensemble prediction systems. Understanding the nature of tropical cyclone predictability is also crucial to the design of the efficient data assimilation systems for tropical cyclones. The advanced ensemble-based data assimilation system capable of assimilating both Doppler radar and satellite observations is very promising for the future cloud-resolving ensemble prediction of tropical cyclones.

TRANSITIONS

In collaborations with scientists at NRL Monterey, the WRF-based ensemble data assimilation system partially sponsored by this project is currently being transplanted to the Navy mesoscale prediction model COAMPS with the potential to be used in future operational forecasts.

The ensemble-based data assimilation system is also currently being transitioned to the Hurricane Research System (HRS model) at the Hurricane Research Division of NOAA.

PUBLICATIONS

1. **Zhang, F.**, and J. A. Sippel, 2008: Effects of moist convection on hurricane predictability. *Journal of the Atmospheric Sciences*, 66, 1944-1961 [referred, in print].
2. **Zhang, F.**, Y. Weng, J. A. Sippel, Z. Meng, and C. H. Bishop, 2009a: Cloud-resolving Hurricane Initialization and Prediction through Assimilation of Doppler Radar Observations with an Ensemble Kalman Filter: Humberto (2007). *Monthly Weather Review*, **137**, 2105-2125 [referred, in print].
3. Gao, S., Z. Meng, **F. Zhang**, and L. F. Bosart, 2009: Torrential Rainfall Mechanisms of Severe Tropical Storm Bilis (2006) after its Landfall: Observational Analysis. *Monthly Weather Review*, **137**, 1881-1897 [referred, in print].
4. Fang, J and **F. Zhang**, 2009: Initial development and genesis of Hurricane Dolly (2008). *Journal of the Atmospheric Sciences* [referred, in press].
5. Sippel, J. A and **F. Zhang**, 2009: Factor in forecast uncertainties of Hurricane Humberto (2007). *Journal of the Atmospheric Sciences* [referred, in review].

6. **Zhang, F.**, Y. Weng, Y.-H. Kuo, and J. S. Whitaker, 2009b: Predicting Typhoon Morakot's catastrophic rainfall and flooding. *Geophysical Research Letter* [referred, in internal review].

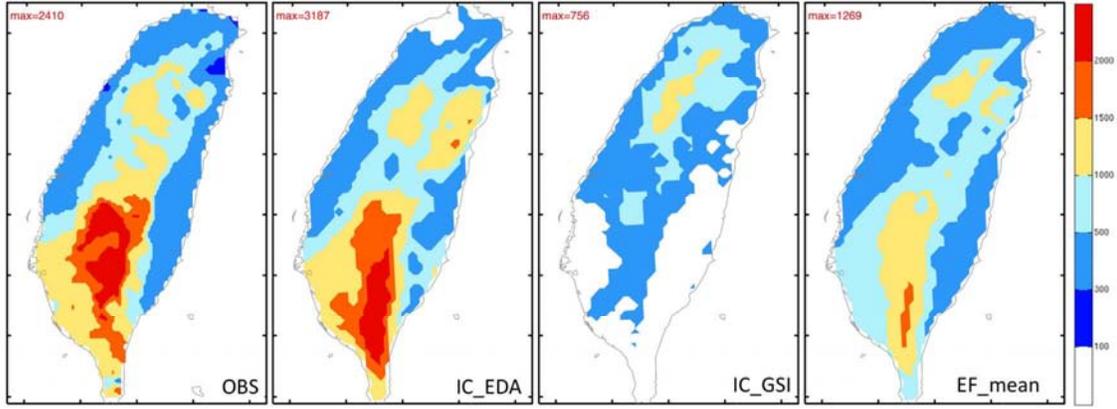


Figure 1. The 72-h accumulated rainfall total (00Z 6 to 00Z 9 August) over the Taiwan Island: (a) Observations from Taiwan Central Weather Bureau; (b) the 96-h 4.5-km cloud-resolving WRF forecast with the GFS realtime analysis using ensemble data assimilation (EDA) as initial conditions (“IC_EDA”); (c) the 96-h 4.5-km cloud-resolving WRF forecast with the GFS operation analysis using GSI as initial conditions (“IC_GSI”); and (d) ensemble mean of the 60-member 4.5-km cloud-resolving ensemble forecast using GFS EDA perturbations as initial conditions.

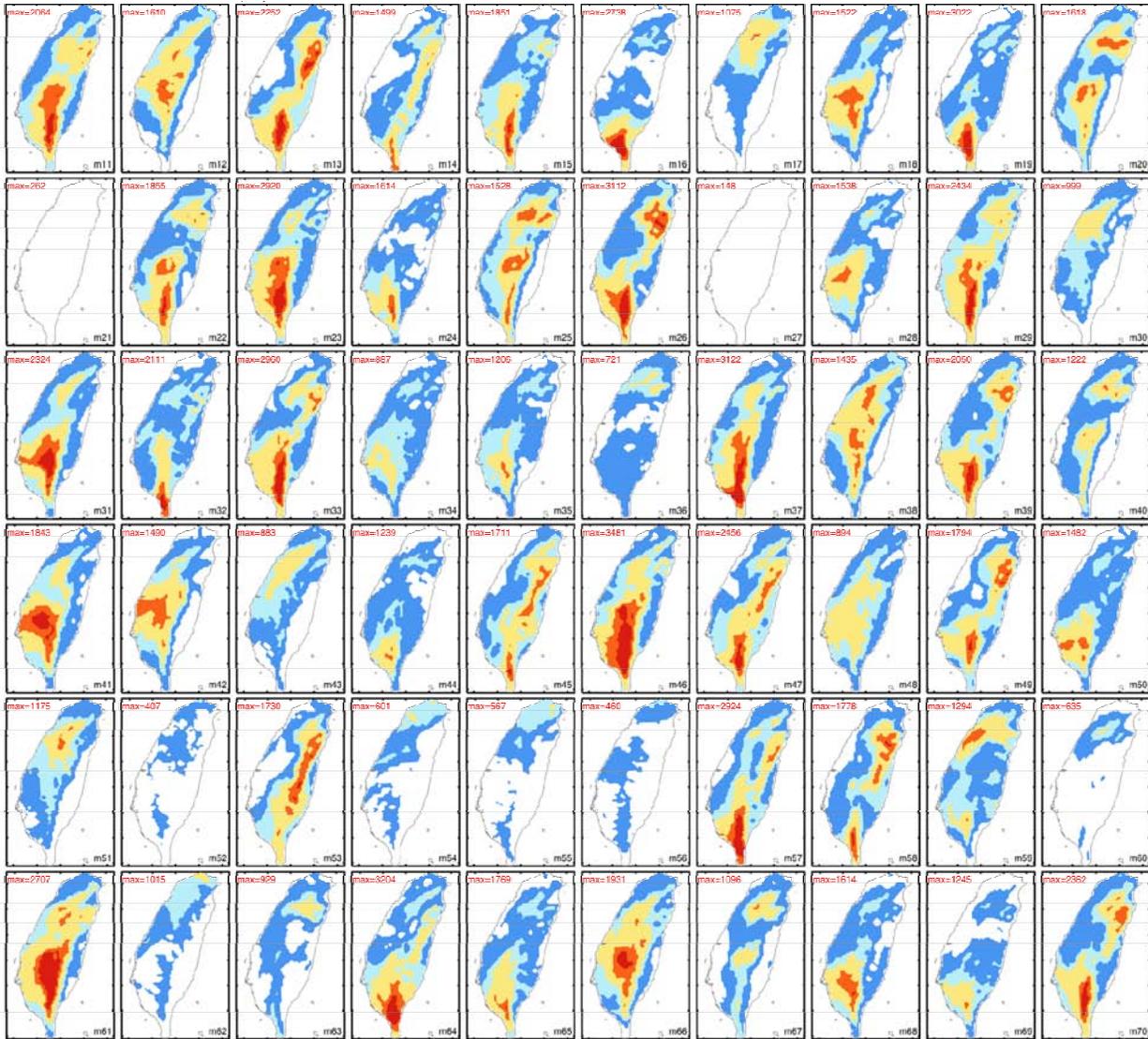


Figure 2. The 72-h accumulated rainfall total (in mm color scaled as in Figure 1) over the Taiwan Island forecasted by each of the 60 4.5-km cloud-resolving ensemble members.

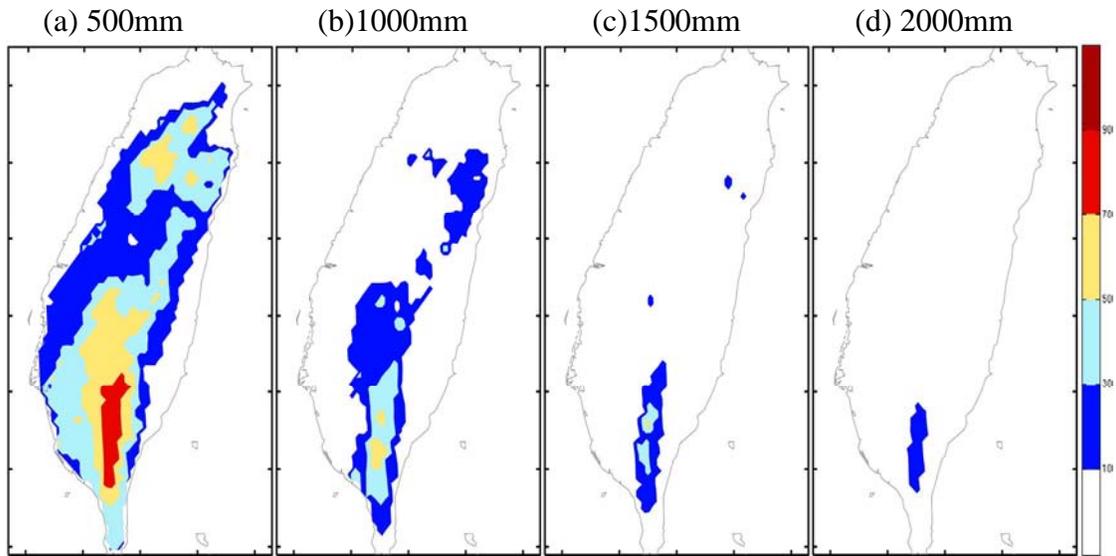


Figure 3. Probability distribution (%) of potential rainfall exceeding (a) 500, (b) 1000, (c) 1500 and (d) 2000 m calculated from the 4.5-km 60-member cloud-resolving ensemble forecasts initialized with EDA perturbations.