Observing Strategy and Observation Targeting for Tropical Cyclones using Ensemble-based Sensitivity Analysis and Data Assimilation

BaoguoXie[1,2], FuqingZhang,[1] QinghongZhang[2], and Jon Poterjoy[1]
1. Department of Meteorology, Penn State University, University Park
2. Department of Atmospheric and Oceanic Science, School of Physics, Peking University, Beijing, China

Abstract

An ensemble Kalman filter (EnKF) data assimilation system for the Weather Research and Forecast (WRF) model is used with ensemble-based sensitivity analysis to explore observing system design and observation targeting for tropical cyclones. The case selected for this study is Typhoon Morakot (2009), a Western Pacific storm that brought record-breaking rainfall to Taiwan. Forty-eight hours prior to making landfall, ensemble sensitivity analysis using a 50-member convection-permitting ensemble, predicts that observations located in the southwest quadrant of the typhoon will have the highest impact on reducing the forecast uncertainty of the rainfall. A series of observing system simulation experiments (OSSEs) using the WRF-EnKF to assimilate synthetic dropsonde observations suggest that the effectiveness of this targeting strategy is rather limited, though some positive correlation exists between the predicted observation impacts provided by the ensemble sensitivity and the simulated impacts based on the OSSEs. The limitations may be due to strong nonlinearity in the governing dynamics of the typhoon system, the accuracy of the ensemble background covariance, and the projection of individual sounding observations to the complex targeted sensitivity vectors from the ensemble.

1. Ensemble sensitivity

$$\mathbf{P}^{f|b} - \mathbf{P}^{f|a} \approx (\mathbf{X}^{f|b} \cdot \mathbf{Y}^T)([\mathbf{Y} \cdot \mathbf{Y}^T + \mathbf{R}]^{-1}[\mathbf{Y} \cdot (\mathbf{X}^{f|b})^T]$$

Y is a vector of background state variables (e.g., u, v, or T)
X is the forecast metric.
P(f|a) and **P(f|b)** are the error covariance matrices for the analysis and background.
The location of maximum ensemble sensitivity indicates the targeting region
Regional averaged rainfall and sea level pressure (SLP) in Taiwan are selected as the forecast metric.

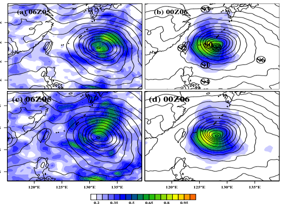
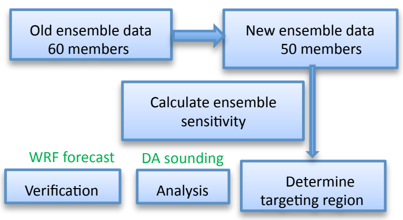


Fig. 1. The impact factor of 72-h average rainfall in (a-b) and average sea level pressure at 0000 UTC August 8 in Taiwan (c-d) to initial condition at 0600 UTC 5 August and 0000 UTC 6 August. The S0-S6 markers show the sample sounding locations.

2. Experiment design



	Horizontal resolution	West-East	North-South	Vertical Levels
D1	13.5 km	603	539	34
D2	4.5 km	603	539	34

Microphysics scheme	WSM 6-class graupel scheme
Longwave radiation	rrtm scheme
Shortwave radiation	Dudhia scheme
cumulus option	No cumulus

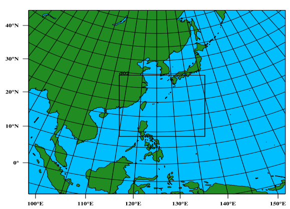


Fig. 2 Domain design for experiment

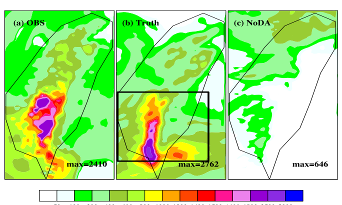


Fig. 3 72-h accumulated rainfall for observation (a) Truth (b) and NoDA (c) experiment in Taiwan.

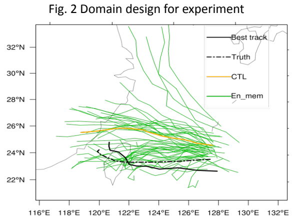


Fig. 4 Forecast track for each of the 50 members.

3. OSSE experiment

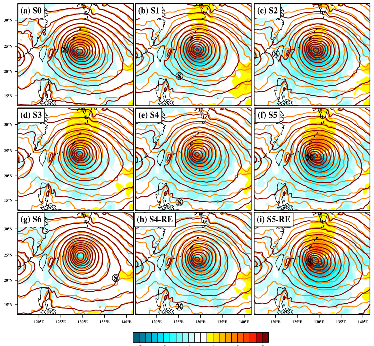


Fig. 4. Increments (posterior minus prior) in sea level pressure (hPa) after assimilating single sounding (indicated by circled cross and S symbol) for 7 soundings and two soundings with random error. Black, orange and brown dots represent the typhoon positions in the truth, prior and posterior positions, respectively.

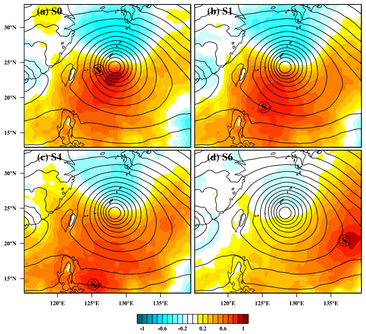


Fig. 5. Correlations between sea level pressure (at S) and 850 hPa height for 4 selected soundings.

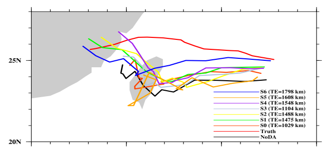


Fig. 6. Track forecasts after assimilating each of the 7 soundings indicated in Fig. 4

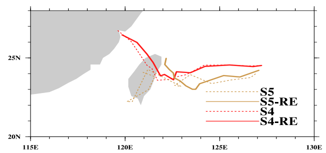


Fig. 7. Track forecasts after assimilating single soundings with (S4-RE, S5-RE) and without (S4, S5) random errors.

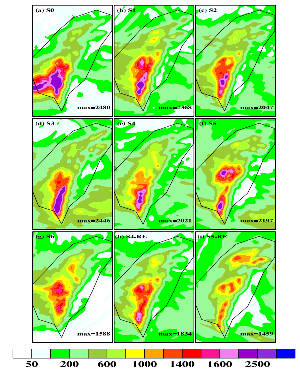


Fig. 8. 72-h accumulated precipitation for forecasts initialized from the 7 single-sounding experiments (a-g), and two soundings with random errors (h and i).

72-h model forecast show that she individual sounding observations can greatly improve both the rainfall and track forecast, thus reduce the forecast error variance as predicted by ensemble sensitivity. However, the effect is limited on some of the sounding experiments.

4. Verification

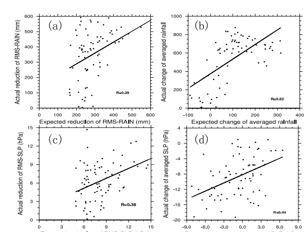


Fig. 9. Scatter plots and linear regression between expected and actual reduction in root mean square error (RMSE) of average rain (a) and average SLP (c), expected changes versus actual changes in average rainfall (b) and average SLP (d).

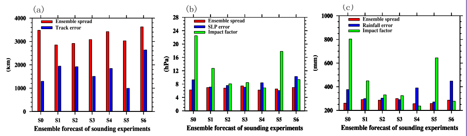


Fig. 10. Error and ensemble spread of track (a), SLP (b) and rainfall (c) for each ensemble forecast with respect to each sounding experiment.

5. Conclusion

(1) Ensemble sensitivity analysis and the WRF model, combined with the EnKF data assimilation method are used to study the targeting strategy on a TC in the northwestern Pacific.

(2) Ensemble sensitivity is effective in determine the targeting region with maximum impact factor, however, little correlation was found between the predicted and actual error reduction.

(3) OSSE experiments show that single sounding observations can reduce the forecast error variance greatly with respect to different locations.

(4) Random error in observations are important in TC targeting due to the strong non-linear development of TC.

(5) The usefulness of ensemble sensitivity in recognizing the targeting region is reduced by the non-linear error (observation error and model error) growth.

(6) The non-linear mechanism of orographic rainfall associated with typhoon Morakot in Taiwan may have degraded the effectiveness of ensemble sensitivity.