The impact of assimilation of microwave radiance in HWRF on the forecast over the western Pacific Ocean

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Abstract

We investigated the impact of assimilating microwave radiances from the Advanced Microwave Sounding Unit-A (AMSU-A) and the Microwave Humidity Sounder (MHS) into the Hurricane Weather Research and Forecasting (HWRF) model on the forecast of typhoon tracks over the western Pacific Ocean. The assimilation of MHS observations has positive impacts on the track forecast, but the assimilation of AMSU-A leads to mixed results. In the forecast experiments, the bias correction coefficients created from the regional model data assimilation system are found to be superior to those produced by the global modeling system, even though the background fields in both cases are derived from the global model predictions.

1. Introduction

Typhoons are among the most severe natural hazards that cause damage to property and loss of life in Taiwan. Developing a more accurate forecast model for typhoons could potentially help to improve the preparedness and to decrease damage. The 2012 operational HWRF model adopts three layers of nesting with an enhanced 3-km horizontal resolution for the innermost domain. The improved resolution allows improved representations of the inner-core structure of a typhoon and its interaction with the environmental flow; both are important for the prediction of the intensity and track of the typhoon. In the HWRF system, the initial condition is generated with an advanced vortex initialization and data assimilation system (GSI), which assimilates both satellite radiances and conventional observations (Gall et. al. 2013). In this work we investigate the impact of incorporating the microwave observations of the AMSU-A and MHS radiances in HWRF for the prediction of typhoons over the western Pacific Ocean.

The HWRF is a coupled atmosphere-ocean model. Its atmospheric component is a non-hydrostatic mesoscale model with one parent domain and two nested domains. The area of coverage of the parent domain is determined by the position of a typhoon, whereas the two nested domains move with the typhoon and maintain a two-way interaction among the domains. The horizontal resolutions of the three domains, from the outermost to the innermost, are 27, 9 and 3 km. The model has 42 vertical levels with the top fixed at 50 hPa. The model physics originated from the Geophysical Fluid Dynamics Laboratory hurricane model. An initial field is created for the model in two steps. First, the original typhoon-like vortex in the background field from the Global Forecast System (GFS) analysis/forecast is removed and replaced with a new vortex reconstructed from information provided by the National Hurricane Center (NHC). Second, a 3DVAR data assimilation system is used to assimilate the observational data. The data assimilation system used in this work is the community Gridpoint Statistical Interpolation (GSI). Our forecast experiments do not use an interactive ocean model.

The AMAU-A has 15 channels with their central frequencies ranging from 23.8 to 89.0 GHz. The atmospheric temperature profiles are retrieved from channels 3 to 14 and other cloud parameters (Weng and Grody, 2000), whereas surface parameters are determined from channels 1, 2, 3 and 15. Each cross-track scan line contains 30 fields of view; the horizontal resolution is 48 km at nadir. Because microwaves can penetrate non-precipitating clouds, the AMSU-A observations provide more information under severe weather conditions over cloudy fields of view than the observations with infrared instruments. For example, Zhu et al. (2002) and Chou et al. (2008) used the AMSU-A retrieval temperature to determine the structure of the circulation associated with tropical cyclones and used the information for their predictions.

The measurements by the Microwave Humidity Sounder (MHS) on board NOAA-18, NOAA-19 and the METOP series of satellites can serve to determine the profiles of water vapor concentration. Five microwave-sounder channels of MHS are similar to those in the Advanced Microwave Sounding Unit–B (AMSU-B) with the change of channel 2 from 150 to 157 GHz and channel 5 from 183.31 to 191.31 GHz. The center frequencies of channels 1, 3 and 4 are 89.0, 183.31$\pm$1.00 and 183.31$\pm$3.00 GHz. Each scan line has 90 observations with a horizontal resolution 16 km at nadir. The error analysis in previous work indicated that the retrievals based on MHS might be more accurate than those based on AMSU-B, because of the decreased noise level for MHS (Thomas and Philip 2006).

2. Experiments and Data

The measurements taken by AMSU-A on board NOAA-15, 16, 18, 19 and MetOp-a that fall within a 3-h window about the initial time are assimilated using the GSI data assimilation system. The data from channels 9-14 are excluded because the maxima of the weighting functions of those channels are located above the top of the HWRF model (which is 50 hPa). The simulated brightness temperature from HWRF deviates from the observations. NOAA-15, NOAA-18 and NOAA-19 pass East Asia about 0600 and 1800 UTC and MetOp-a at about 0000 and 1200 UTC. The measurements from MHS on board NOAA-18, NOAA-19 and MetOp-a that fall within the aforementioned 3-h window are also assimilated with the GSI data assimilation system. Because the maxima of the weighting functions of the five MHS channels (Zou et. al. 2013, see their Figure 1) are all below our model top of 50 hPa, all channels are used in our experiments.

Bias correction is important to ensure the quality of retrieval and assimilation of satellite radiances (Eyre 1992; Chou and Huang 2004). The bias, defined as the difference between satellite observation and the simulation with a radiative transfer model using a weather forecast model output as its input, might be caused by (1) errors in the observational instruments and data preprocessing, (2) limitation of the radiative transfer model, and (3) bias in the weather forecast model output. In some cases, the bias might exceed the signal, so to impact negatively the results of data assimilation. In GSI, the bias in satellite observation is expressed as a linear regression of *N* state-dependent predictors, $P_i(x)$, with their coefficients β_i, which serve to modify the model of radiative transfer:

$$\mathcal{H}(x, \beta) = H(x) + \sum_{i=1}^{N} \beta_i \,.\, P_i(x) \quad , \qquad (1)$$

in which *H* is the radiative transfer model and *x* is the atmospheric state from the output of the weather forecast model. $\mathcal{H}$ in the left side would produces the modified radiances. Vector β is obtained on minimizing the following cost function:

$$J(\beta) = 1/2\, [\, y - \mathcal{H}(x,\beta)]^T [\, y - \mathcal{H}(x,\beta)] \quad , \qquad (2)$$

in which *y* is a satellite observation (Dee 2004). Of two components in the procedure for bias correction in the GSI system, one is a correction for air mass bias in which the predictors are associated with the model state; the other is an angle-dependent bias correction in which the predictors are functions of the scan position. In the following experiments, we tested the effects of using two sets of bias correction coefficients: one is generated from the NCEP global modeling system, and the other is generated by the HWRF itself.

The NCEP global six-hour forecast fields serve as the background fields for the GSI system. In the *control run*, only conventional observations are assimilated to create an initial field for the forecast of the typhoon. In the *experimental run*, both conventional observations and satellite data (AMSU-A and/or MHS) are assimilated.

3. Results

We select Typhoon Soulik for experiments that tested the impact of AMSU-A and MHS data on the forecast of the typhoon. Typhoon Soulik formed at 20^{o}N, 151^{o}E about north of Guam Island on 2013 July 7. It moved westward steadily and intensified, with its maximum wind speed attaining more than 51 m/s at 0600 UTC on 2013 July 10. It landed in northern Taiwan about 0030 UTC on 2013 July 13, although its intensity had decreased (from 50.9 to 32.7 m/s) before landing. The typhoon left Taiwan about 0800 UTC on 2013 July 13, eventually landing in mainland China before its final dissipation (see Figure 3). Our forecasts for the typhoon are made from a set of initial times that span from 2013 July 6 0600 UTC to July 9 1200 UTC, with the initial condition sampled every six hours.

The mean error in the track and the root-mean-square errors in the atmospheric fields are calculated for the control and experimental runs as a function of the forecast lead time. For the forecast of typhoon Soulik, our analysis revealed that the assimilation of the MHS observations leads to slightly decreased forecast errors for the track and atmospheric (geopotential height and wind) fields. Figure 1 shows the mean error in the typhoon track from six experimental forecasts with initial times sampled every six hours from 2013 July 8 0600 UTC to July 9 0600 UTC. Figure 1 (a) shows the result when the bias correction coefficients are obtained from the global forecast system; Fig. 1 (b) is its counterpart when the bias correction coefficients are calculated from the GSI data assimilation system in HWRF. The contrast between the two figures illustrates the benefit of estimating the bias correction coefficients from the HWRF system. In Fig. 1 (b), the inclusion of the MHS data improved the forecast of the track over the entire duration of the simulation; in Fig. 1 (a) the forecast with MHS data produced a larger error than the control run until after 55 h of forecast duration. The benefit of using the bias correction coefficients generated by HWRF/GIS is evident also when comparing the runs with the AMSU-A data in Figs. 1 (a) and 1 (b). When the runs with AMSU-A are compared to the control runs, the impact of the AMSU-A data is, nevertheless, found to be mixed or even negative (as in Fig. 1 (a)).

The assimilation of the MHS data improved the predictions of not only the typhoon track but also the general structures of the geopotential height, temperature and wind fields. The root-mean-square errors of those fields, calculated over the domain bounded by latitude 0 N and 50 N and longitude 100 E and 150 E, are shown in Fig. 2 as a function of pressure. Shown from top to bottom are the initial time and the forecasts at 24, 48, 72, 96 and 120 h. Green and red denote the errors for the control runs and the experimental runs with the MHS data, respectively. The decreased error because of the inclusion of MHS data is evident at 72 h, especially in the geopotential height. At greater forecast durations (96 and 120 h) this decreased error becomes even more significant in the geopotential height and it also becomes evident in the velocity fields. The overall results here demonstrate the potential of using the MHS data to improve the forecast of typhoons.

The reason that the AMSU-A data have a negative impact on the forecast in selected cases is still under investigation. Here, Figs. 3(a) and 3(b) show the predicted tracks of typhoon Soulik for two cases with separate initial times. While the incorporation of the MHS data slightly improved the forecast of the track for both cases, the inclusion of AMSU-A has a positive impact for one case (Fig. 3(a)), but a negative impact for another (Fig. 3(b)). The effects of the AMSU-A data on the forecasts of the geopotential height and temperature fields are also mixed (not shown). Because HWRF requires TCvital data to initiate the simulation, the usable period to create the bias correction coefficients decreased. A possible explanation of the mixed effects of the AMSU-A data is that the generation of the bias correction coefficients for AMSU-A might require more time to spin up than the case for MHS. Useful future work would be to perform additional runs with the AMSU-A data and to use the statistics from large samples to decrease noise in the bias correction coefficients.

4. Summary

We tested the impacts of assimilating the AMSU-A and MHS radiances in HWRF on the prediction of a typhoon track over the Western Pacific Ocean and found that the MHS data had an overall positive effect in improving the forecast of the track and the meteorological fields associated with a typhoon. We found also that the bias correction coefficients generated from the mesoscale model (HWRF) itself are superior to those generated from the global model in assisting to improve the outcome of assimilating the radiance data. Our experiments with the assimilation of AMSU-A data produced more mixed results, with improvement in forecast in some cases but degradation in others. This condition indicates that the outcome of our AMSU-A experiments is still strongly influenced by statistical noise. More simulations might be needed in future work to clarify the impact of the AMSU-A data on the high-resolution HWRF forecast of typhoons.

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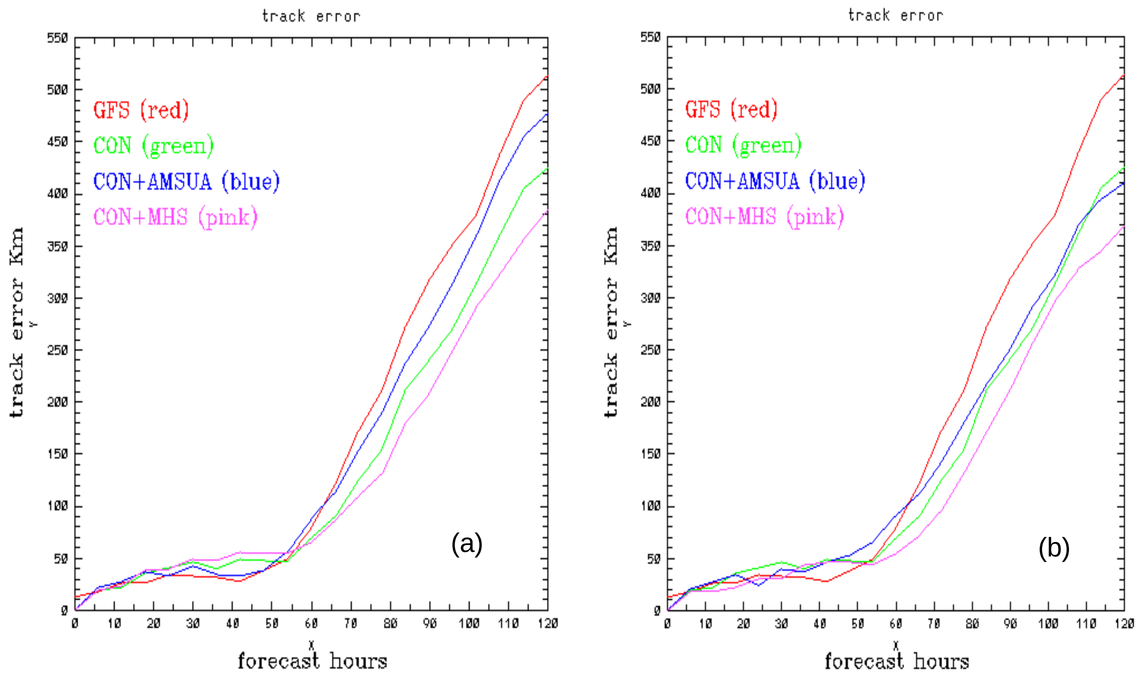

Fig. 1. Mean absolute errors in the forecast of the track for Typhoon Soulik as a function of forecast lead time (from analysis to 120-h forecast). Green denotes the control run; pink and blue indicate the runs with assimilated MHS and AMSU-A data, respectively. Red marks the GFS forecast. (a) The case when the bias correction coefficients produced with the global model are used. (b) The case when the bias correction coefficients generated with the mesoscale model itself are used.

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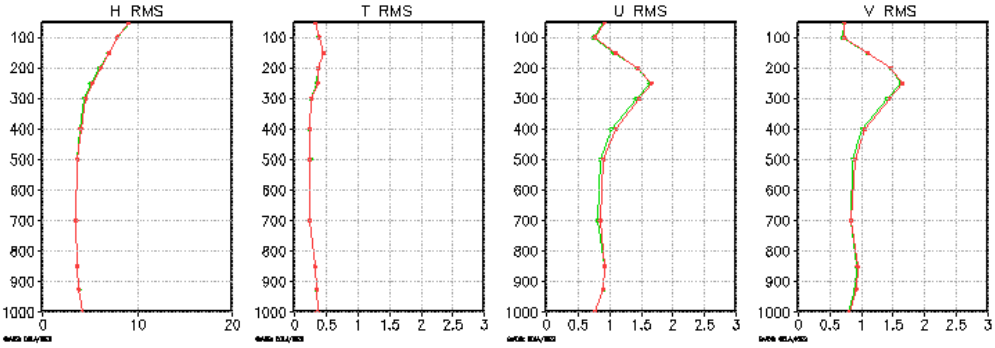

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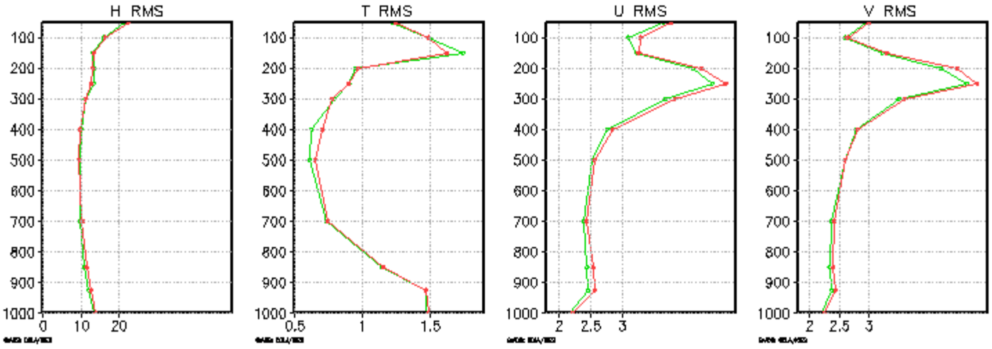

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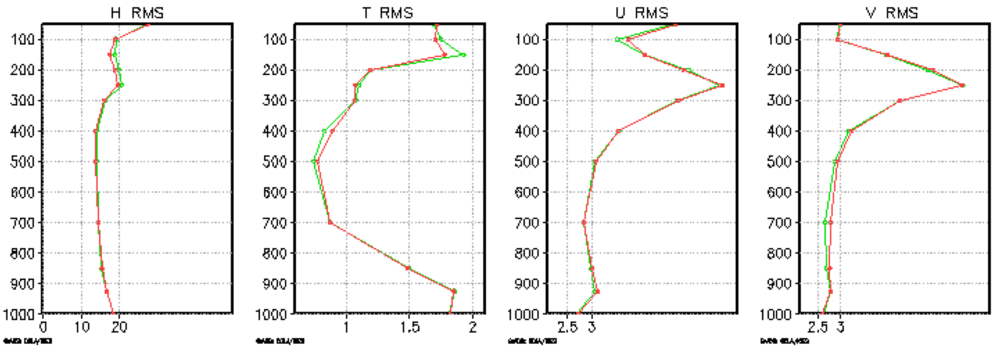

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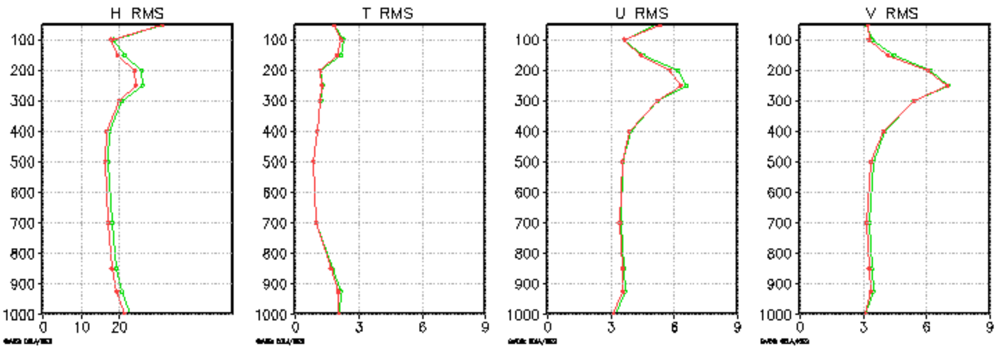

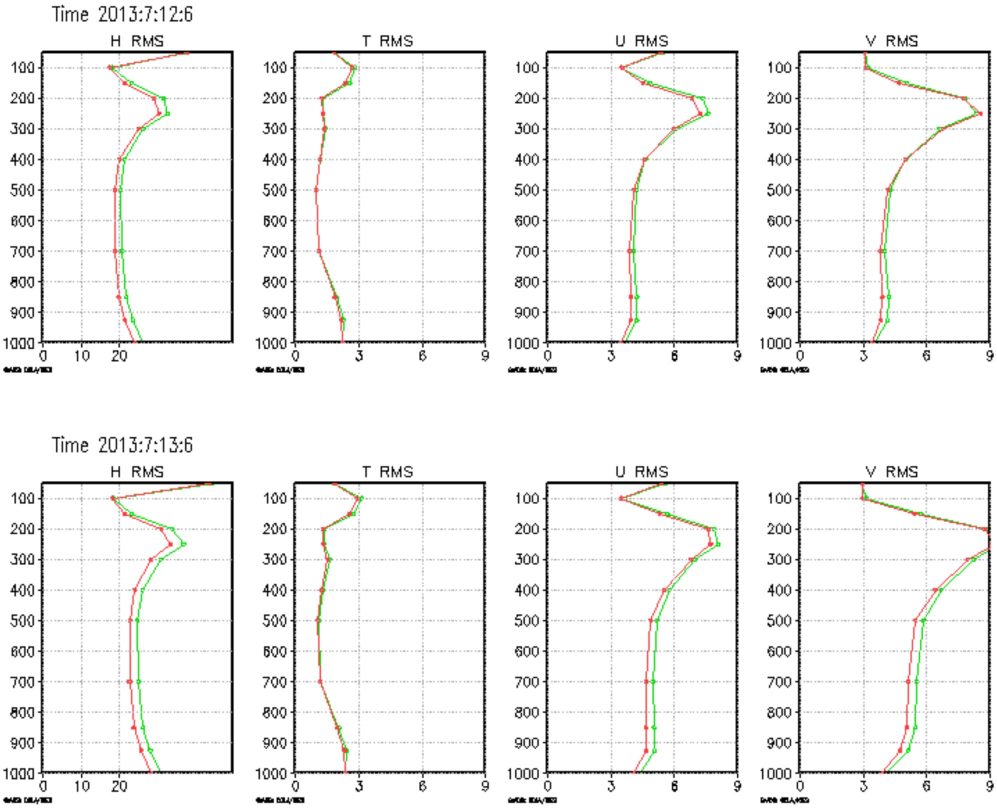

Fig. 2. Root-mean-square error over the domain bounded by 0 N-50 N and 100 E-150 E, as a function of pressure. Top to bottom are the initial time, followed by the forecast at 24, 48, 72, 96 and 120 h. Left to right are the errors in geopotential height, temperature, and *u* and *v* components of velocity. Green indicates the control run, and red the run with assimilated MHS data.

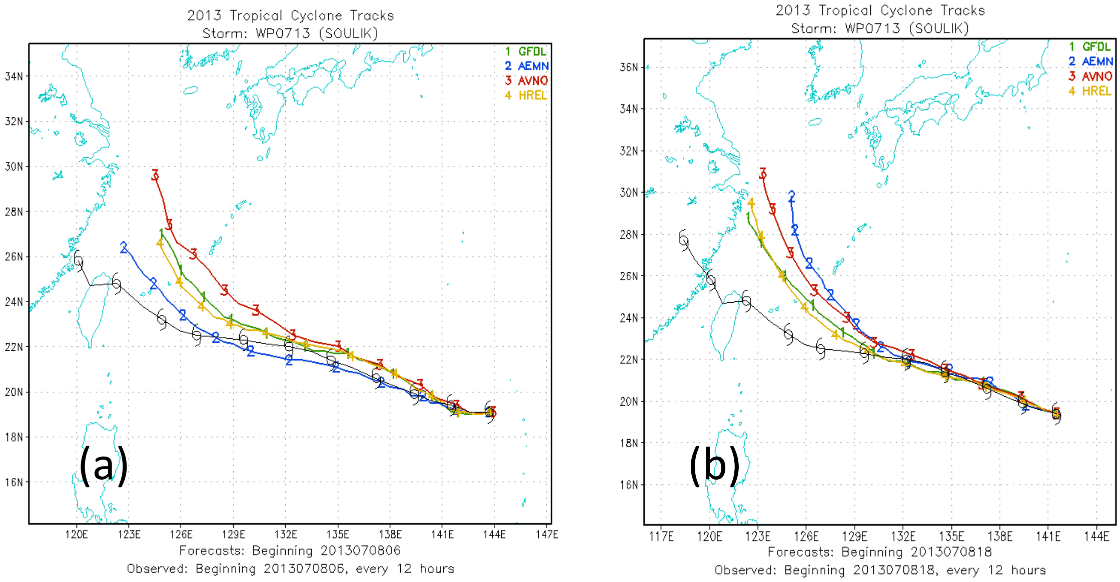

Fig. 3. Comparison of typhoon tracks. The black line with typhoon markers indicates the best track (observation); green marks the control run; blue and yellow indicate the runs with the AMSU-A and MHS data, respectively. The red line is the GFS forecast. (a) The case with initial time at 2013 July 8 0600 UTC. (b) The case with initial time at 2013 July 8 1800 UTC.