Assimilation IASI observation in WRFDA and its impact on typhoon Hongxia

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Abstract. This study evaluates the impact of assimilating Infrared Atmospheric Sounding Interferometer (IASI) radiance observations in the WRFDA system on the numerical weather prediction of typhoon Hongxia (2015). The IASI observations are quantity controlled and variational bias corrected in the assimilation procedure and the RTTOV fast radiative transfer model is applied as the IAS I observation operator. Two groups of assimilation and forecast experiments are conducted. The analysis fields and track forecasts are verified against the real observations. The results show that, compared with the control experiment, assimilating IASI observations has improved the forecast of typhoon Hongxia. The IASI data assimilation reduces the track errors for 72-h forecasts and improves the accuracy of the path forecast.

Introduction

As one of the most important observation instruments on the Metop series of polar orbiting operation meteorological satellites operated by EUMETSAT, the hyper-spectral Infrared Atmospheric Sounding Interferometer (IASI) provides observations on atmospheric temperature and humidity with high accuracy and resolution [1]. This high spectral resolution instruments measures the 8461 radiance channels covering the spectral range between 3.7 μm to 15 μm at a resolution of 0.5 cm^{-1} (apodized) and with a footprint of 12 km at nadir[2].

Recently, IASI is already one of the most important observations within the assimilation system, it is still haven't been made full use of in regional model [3], while the assimilation of observations in global model is more and more mature. There are many challenges for the assimilation of IASI observations in regional model, as the regional assimilation procedure needs the initial fields from the forecast model and lateral boundary conditions. Also limited to the observation time and frequency, the number of the IASI observations could be applied in the regional model is small. Also in area affected by typhoon, the observations are still insufficient for various factors as the satellite infrared data affected by cloud, the initial vortex in large scale analysis fields always too small and so on. Xu et al. assimilated the IASI radiance observation for Hurricane Maria (2011) and typhoon Megi (2010), and derived the results that the assimilation of IASI observations improved the typhoon forecast and additional studies with more cases over extended periods are need [4]. Liu et al. assimilated the Advanced Infrared Sounder (AIRS) on satellite AQUA in regional model provides us some experiences about assimilation the infrared hyper-spectral radiances in regional areas affected by typhoon [5].

Here, we attempt to assimilate the IASI observations in the 3-dimesional variational (3DVAR) component of WRFDA [6], and access the impact of IASI radiance assimilation for typhoon Hongxia (2015). In contrast to the Xu et al. (2014) study we pay particular attention to the role of bias correction, and contrast the use of variational bias correction and apply the Radiative Transfer model for advanced TOVS (RTTOV) as the observation operator for IASI radiances [7].

The structure of the paper is as follow. We first provide an overview of IASI instrument in section 2. In section3 introduces radiance assimilation method in the WRFDA system and the vatiational bias correction investigated in the present study. Section 4 gives the introduction of typhoon Hongxia and the experimental setting. Finally access the impact of the assimilation IASI observations on the forecast of typhoon Hongxia and derive the overall conclusions in section 5.

IASI instrument

IASI is an infrared observation instrument with 8461 spectral sampling, and has a swath around 2200 km, and 120 FOVs in each scan line. The IASI instrument can record data from the following ranges: carbon dioxide strong absorption around 15 μm, ozone absorption v_2 around 9.6 μm, water vapour v_3 strong absorption and methane absorption up to the edge of the thermal infrared. IASI is flown on the METOP series of polar orbiters which complete the whole ground observations two times per day, and pass sky over the east Asia at nearly 00 (UTC) and 12 (UTC) every day.

In the present study, up to 165 IASI channels are assimilated from the instrument on board METOP-A satellite, and the channels are summarised in Table 1. They include temperature-sounding and window channels.

Table 1. Groups of IASI channels.

Group	Number of channels	Channel numbers	Wave-numbers cm^{-1}
Upper temperature souding	80	16-241	648.75-705.00
Mid temperature souding	28	246-306	706.25-721.25
Lower temperature souding	33	308-386	721.75-741.25
Window	24	389-921	742.00-875.00

Assimilation method and variation bias correction

For assimilation IASI radiance data, the 3DVAR system of WRFDA (3.7) is employed in the study and the RTTOV (11.2) fast radiative transfer model compiled in WRFDA is used as the IASI observation operator for computing radiance from the model profiles. Radiances are prone to systematic biases between the observed radiances and those simulated from the model first guess which must be corrected [8]. The bias correction can be expressed as the linear combination of N_p bias predictors $P(x)$ with the correction coefficient β as the follows:

$$BC(x,\beta)=\sum_{i=1}^{N_p}\beta_i P_i(x) \tag{1}$$

This results in the observation operator $H(x)$ in the assimilation system modified by the bias correction as follows:

$$\tilde{H}(x,\beta)=H(x)+BC(x,\beta) \tag{2}$$

The new observation operator $\tilde{H}(x,\beta)$ is applied in the cost function $J(x,\ \beta)$ of assimilation method, and the optimal correction coefficients suitable for background field x_b and IASI observations field y_o through the minimization algorithm.

$$J(x,\beta)=(x_b-x)^T B^{-1}(x_b-x)+[y_o-\tilde{H}(x_b,\beta)]^T R^{-1}[y_o-\tilde{H}(x_b,\beta)] \tag{3}$$

Here, B and R are the background and observation error covariance matrices, respectively, and the superscript T means transposition. The predictors of Eq. (2) include eight parameters: the constant component of biasβ_0 (always set to be 1), 200-50 hPa and 1000-300 hPa layer thickness, surface skin temperature, the total column water vapor, the scan position, the square and the cube of scan position.

Experiment design

Typhoon Hongxia formed as a tropical depression on May 4, 2015 in the north-west Pacific Ocean and moved north-westward steadily intensified. Then the system was upgraded to be a typhoon at 0200 UTC 6 May and soon further grew in size to be a super typhoon at the afternoon on May 9. Hongxia landed at Luzon in Philippines at 0450 UTC 10 May, and moving north-east gradually weakening and was last noted on May 12 near the Japan' coast.

Two sets of experiments were performed for the study the impact of the assimilation IASI observations on typhoon Hongxia. These runs are considered as control (CNTL) and experimental (WRFDA) runs are respectively by excluding and including IASI observations. In the WRFDA runs, the IASI L1C radiances at the 0000 UTC 10 May 2015 are assimilated. Instead of directly using the fnl reanalysis data provided by the USA National Centers for Environmental Prediction (NCEP) as the first guess in the 3DVAR experiments, a WRF simulation was first integrated from 1800 UTC 9 May for 6h to provides a 3DVAR first guess. For all the experiments, the model was integrated for 48h starting from 0000 UTC 10 May to 0000 UTC 12 May. The model initial conditions are at 0000 UTC so that the cyclone is fully covered by METOP-A satellite passes.

Experiment results and conclusions

Figure 1 depicts the bias correction of IASI channel 170. The mean bias, standard deviation and root mean square decrease largely especially for the upper temperature channels and decrese a certain extent for lower temperature channels. This illustrates the variation bias correction method is effective for IASI channels.

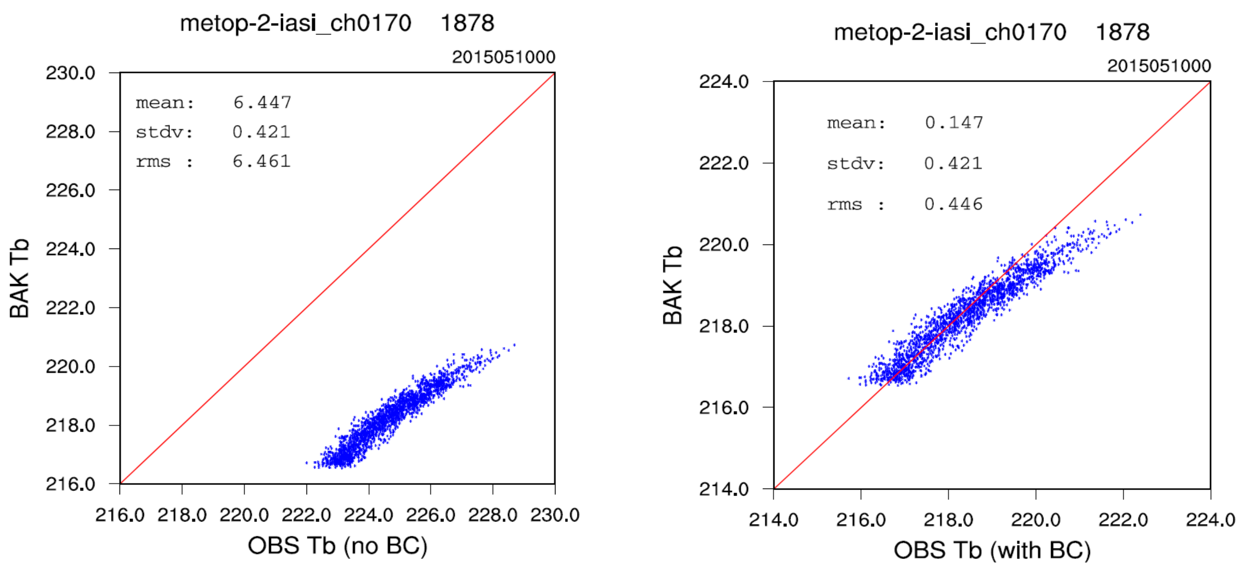

Fig. 1. The scatter diagrams of IASI channel 170 before (left) and after (right) bias correction.

Figure 2 shows the typhoon tracks from the CNTL and the WRFDA data assimilation experiments. Both tracks are compared with the observed track. The track from the assimilation IASI experiment is more close to the observed track than the CNTL experiment and the development tendency matches better to the real observation than the CNTL experiment. These results are largely attributed to general advancements in typhoon initialization brought by the analysis derived from the IASI assimilation. Future work will likely address using refined observation errors and cloud-detection scheme to potentially improve the impact of IASI observations.

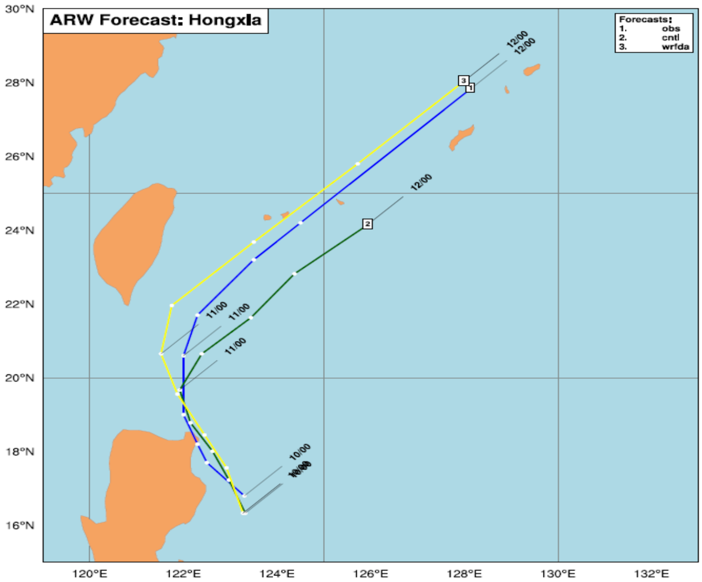

Fig.2. The forecast tracks of typhoon Hongxia.

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