541 Evaluation of WRFDA 4D-Var System through Month-long Run and Case Study

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1. Introduction

WRFDA (The Weather Research and Forecasting Data Assimilation) 4D-Var has been developed since 2004 by NCAR/MMM Data Assimilation Group. The WRFDA 4D-Var algorithm takes the incremental 4D-Var formulation that is commonly used in operational systems. It uses the WRF model as a constraint to impose a dynamic balance on the assimilation. The original tangent and adjoint models were developed based on the WRF model dynamic core version 2.02 in May 2005. 4D-Var system keeps being updated and optimized year by year. So far, it has included the simplified PBL, microphysics (Kessler scheme) and cumulus (Kain-Fritsch) scheme physical package; it has the digital filter and lateral boundary control options. It is capable of assimilating conventional data, radar data, and satellite radiance data. The following section will present the performance of monthly experiment with 4D-Var.

In 2010, both the framework and code were upgraded largely. First of all, tangent and adjoint models were re-coded based on the latest ARW WRF model repository codes. Secondly the framework was re-designed by modifing the previous three executables (wrfvar, wrfnl, wrfplus) a single executable, which is similar as WRFDA 3D-Var run currently. Significant computational performance will be improved due to the elimination of disk IO and the new parallelization design.

2. Experiment Design

2.1 Month-long Experiment

In order to evaluate the performance of WRFDA 4D-Var, T8 domain (Fig.1) was selected to run monthly, where the horizontal grid spacing was 45km with 140x94 grid size, and vertical levels were 57 with the model top of 50 hPa. The experiment design is showing at Fig.2, which is cool-start (no cycling) of both WRFDA 4D-Var and WRFDA 3D-Var over a one-month period beginning 1200 UTC 15 August 2007 and ending 1200 UTC 15 September 2007. Most GTS conventional data were assimilated for each cool-start experiment, which include the SYNOP, SOUND, METAR, PROFILER, QSCAT, BUOY, SHIP, PILOT, AIREP, SATLLITE WIND, GPS. There is no satellite radiance data used in this experiment. Averagely, one 4D-Var job on NCAR bluefire (IBM) computer with 64 processors can be done within 4 hours. WRFDA 3D-Var experiment was conducted too for comparison. In the 4D-Var run, the 3-h forecast from 0.5x0.5 FNL analysis at 0600 and 1800 UTC served as the 'background' (or first-guess); while, the 'first-guess' for 3dvar run was the 6-h forecast. The time window for both 4D-Var and 3D-Var are 6 hours, but which for 4D-Var is 0-6 h, and 3D-Var is '-3' – '+3' h. In this case, the analysis of 4D-Var was produced at 0900 and 2100 UTC, and 3D-Var is at 0000 and 12000 UTC. For comparison, two 48-h forecasts were employed based on the analysis of both 4D-Var and 3D-Var starting from 0000 and 1200 UTC. So the experiments of 4D-Var need an extra 3-h forecast from the analysis time (0900 and 2100 UTC) to get the initial at same time (0000 and 1200 UTC) as 3D-Var. Figure 1 is an example (1200 UTC 15 August 2007) of the experiment configuration for 4D-Var and 3D-Var. We made the cool-start (no cycling) runs as shown in figure 2 twice a day during 15 August to 15 September 2007.

2.2 Case Study for Upgraded 4D-Var System

Typhoon Morakot (August, 2009, Fig.6) case was selected to test the new upgraded 4D-Var system in 2010. Experiment setup followed Fig.2, but start from 1800 UTC 5 August 2009. Since the parallelization is not ready yet for the new upgraded system, serial 4D-Var run was conducted on 108km resolution domain (Fig.7: d01) with 74x47x36 grid size, and the model top was 20hPa. The first-guess used here is ERA-Interim data, which is improved reanalysis data with an improved atmospheric model and assimilation system. The resolution is 0.703125 degrees. The detailed description about this data refers to http://dss.ucar.edu/datasets/ds627.0/. In this experiment, only the following conventional data was assimilated: SYNOP, SOUND, METAR, PROFILER, QSCAT, BUOY, SHIP, PILOT, AIREP, SATLLITE WIND, GPS PW. 72-h forecast was performed on triple nested domain (Fig.7) with ARW WRF model. The 1^{st} domain initialized from 4D-Var and 3D-Var was interpolated to the 2^{nd} (36km) and 3^{rd} (12km) domain when the forecast started in WRF model. 3D-Var and CTRL (no data assimilation) are the compare experiments for 4D-Var. CTRL means no data assimilation made in the initial condition.

3. Results

3.1 Month-long Experiment

The high frequency surface observation, for example synop, ingested by 4D-Var is more than 3dvar. Statistically, the OMB of 4D-Var has the lower RMSE than 3dvar (Fig.3 left panel), and which also benefit to the OMA (Fig.3: right panel). The reason is the 4D-Var calculate the OMB distributed on 7-time slots within the time window; however, 3dvar is a fixed background at the analysis time in the middle of time window. The impressive improvement obviously presented in the 3-D wind field from the verification profiles against ECMWF in Fig.4 at analysis time. The verification of 24-h forecast also presented slightly improvement from 4D-Var comparing with 3D-Var, especially wind fields in the upper level. Here, ECMWF analysis data was used to do verification, since ¾ of T8 domain covers ocean where no enough conventional data for verification.

3.2 Morakot Case

All the results of this case came from upgraded WRFDA 4D-Var system. In Fig.8, the verification for analysis was made against ERA-Interim data. Significantly, 4D-Var generated a much better initial condition for the following forecast than 3D-Var. 72-h forecast for the track of Morakot is shown in Fig.9. Both 4D-Var and 3D-Var produced the improved track forecast comparing with CTRL, which moved much slower than observed, and did not make a landfall. The calculation of track forecast error (Fig.10) presented that 4D-Var reduced more error than 3D-Var, especially after 36-h forecast. The 72-h forecast verification against ERA-Interim data showed in Fig.11. The 72-h entire forecast RMSE of 4D-Var presented the slightly improvement comparing with 3D-Var. The intensity forecast was omitted here because the low-resolution set-up was not able to improve it neither by 4D-Var or 3D-Var.

4. Conclusions and Future Work

The upgraded WRFDA 4D-Var system keep the consistent performance as the previous version, but more efficient in framework and penalization design. Both month-long experiment with previous version and case study with new upgraded version present WRFDA 4D-Var is better fitting the observation than 3D-Var. This advantage also benefits to the following forecast. 4D-Var improved the track forecast to some extent for this typhoon case.

In the next, we will evaluate the upgraded 4D-Var with the same month-long run study as previous; utilize higher resolution to investigate the typhoon Morakot precipitation and intensity forecast; investigate the performance with the simplified PBL and microphysics schemes.

5. References

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Zhang, Fuqing, Yonghui Weng, Ying-Hwa Kuo, Jeffery S. Whitaker, Baoguo Xie, 2010: Predicting Typhoon Morakot’s Catastrophic Rainfall with a Convection-Permitting Mesoscale Ensemble System. *Wea. Forecasting*, **25**, 1816–1825.

Zhang, Meng, Fuqing Zhang, Xiang-Yu Huang and Xin Zhang, 2010: Inter-comparison of an ensemble Kalman filter with three- and four-dimensional variational data assimilation methods in a limited-area model over the month of June 2003. Mon. Wea. Review, Early Online Release.

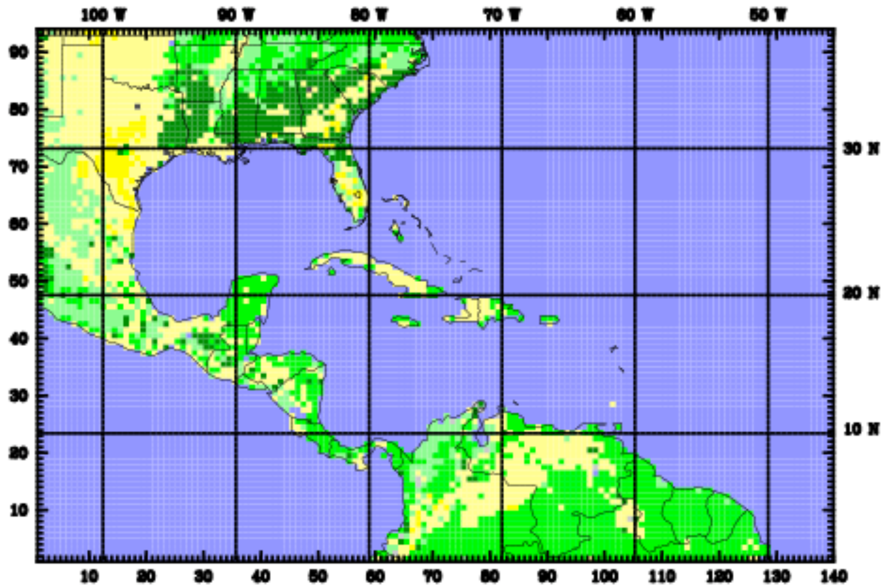

Fig.1: Month-long experiment domain – T8

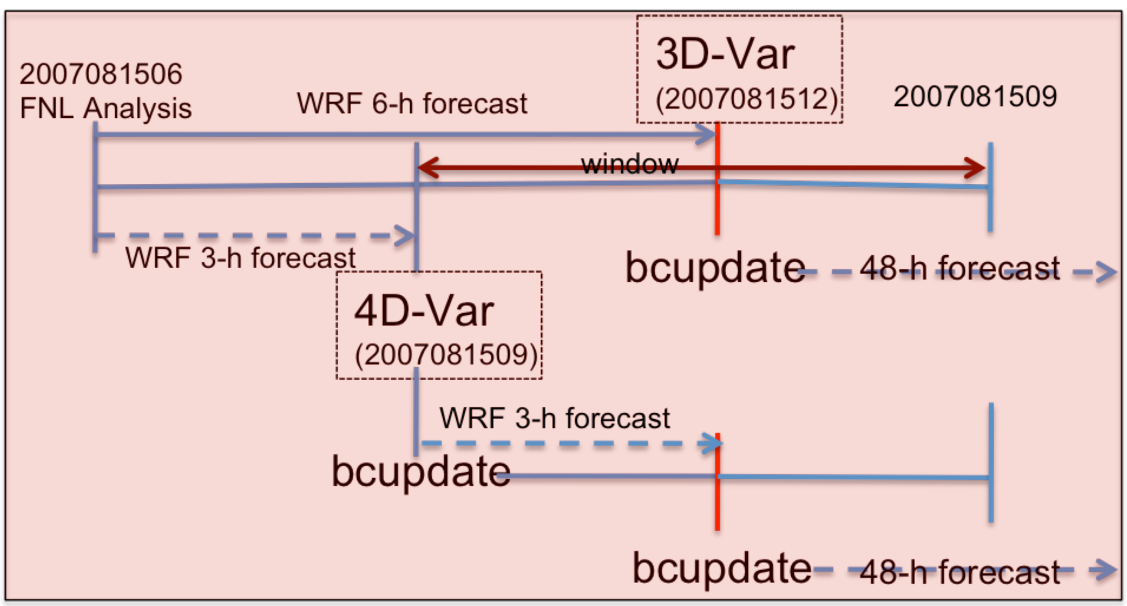

Fig.2: Experiment design flow chart

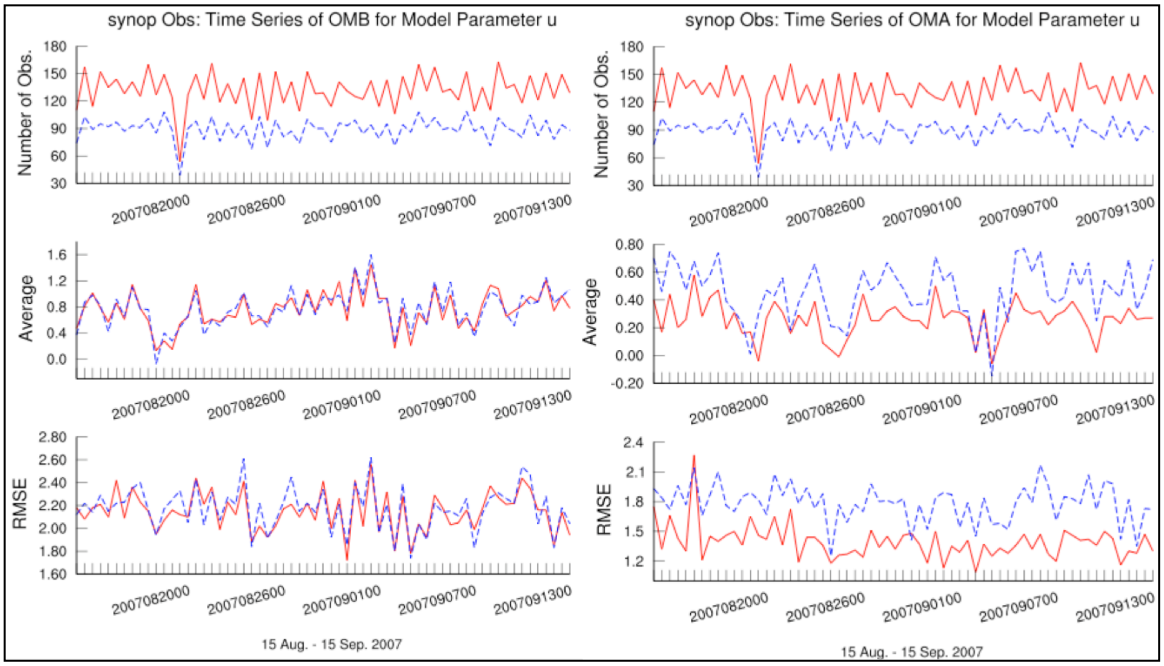

Fig.3: The comparison of OMB (left) and OMA (right) between 4D-Var and 3D-Var at the analysis time

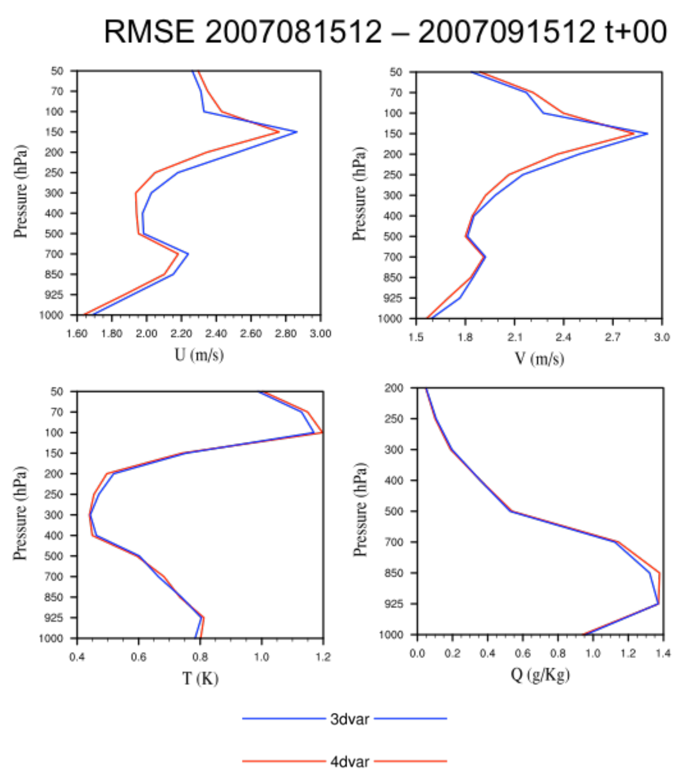

Fig.4: Statistics RMSE Profiles of the verification against the ECMWF at analysis time

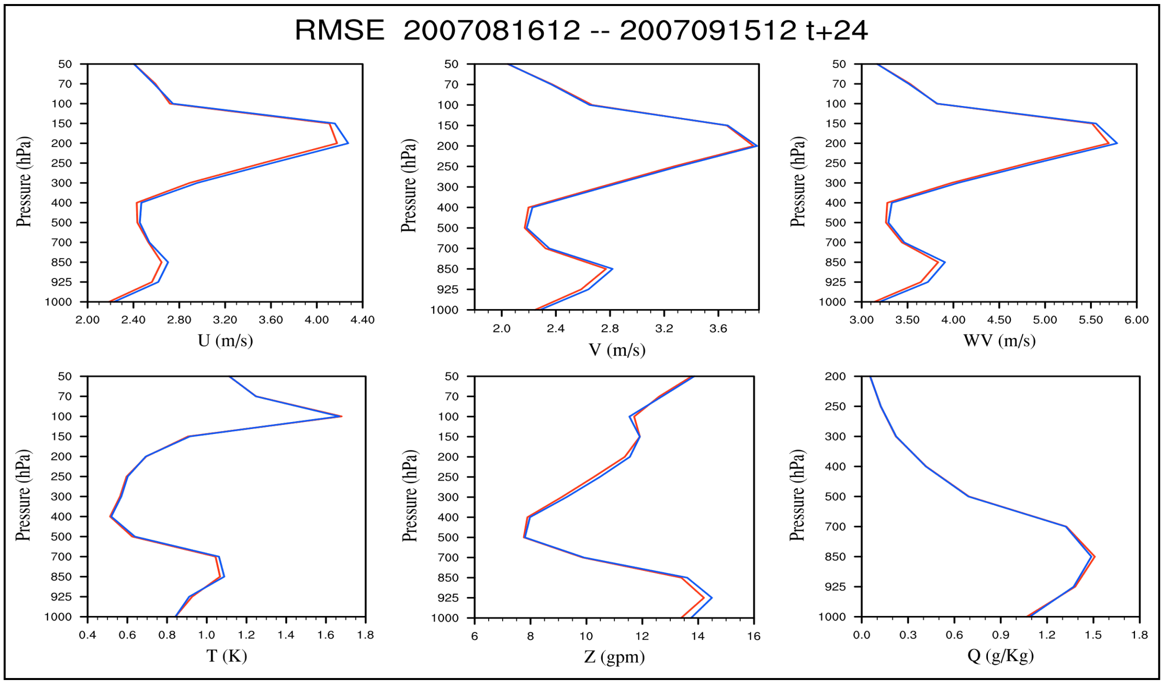

Fig.5: RMSE profiles of verification against ECMWF at 24-h forecast

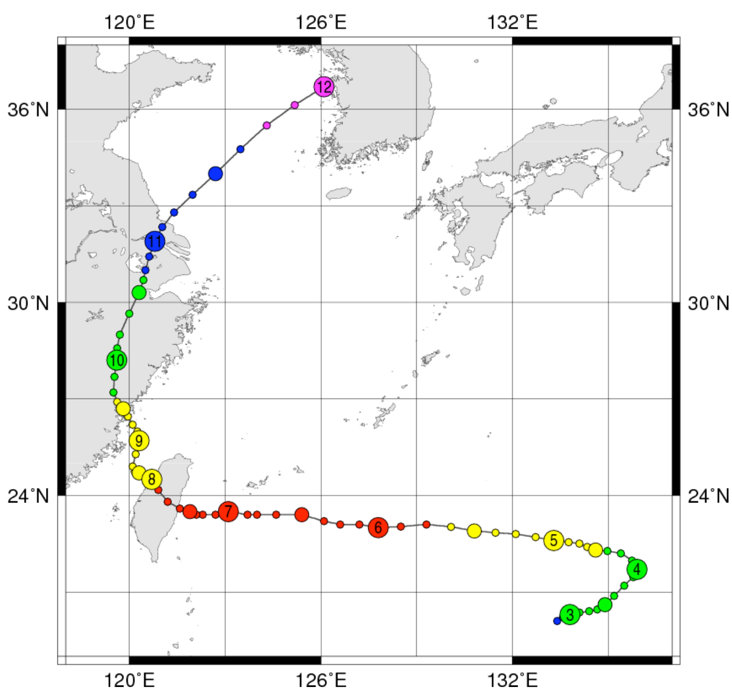

Fig.6: Typhoon Morakot track (copied from http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/l/200908.html.en)

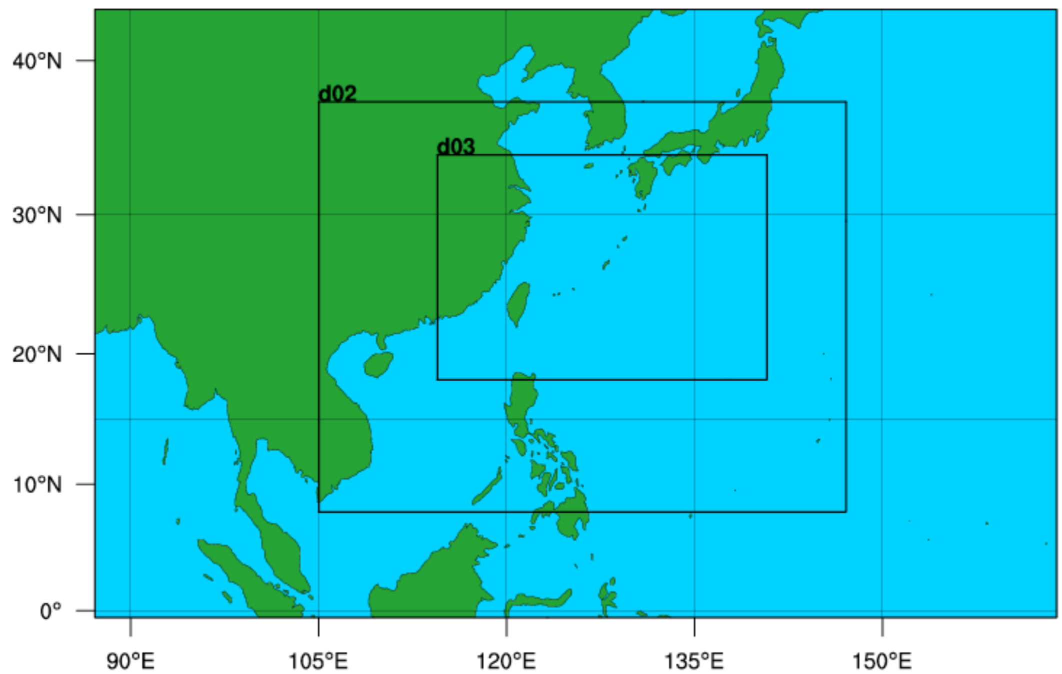

Fig.7: Selected domain for the simulation of typhoon Morakot

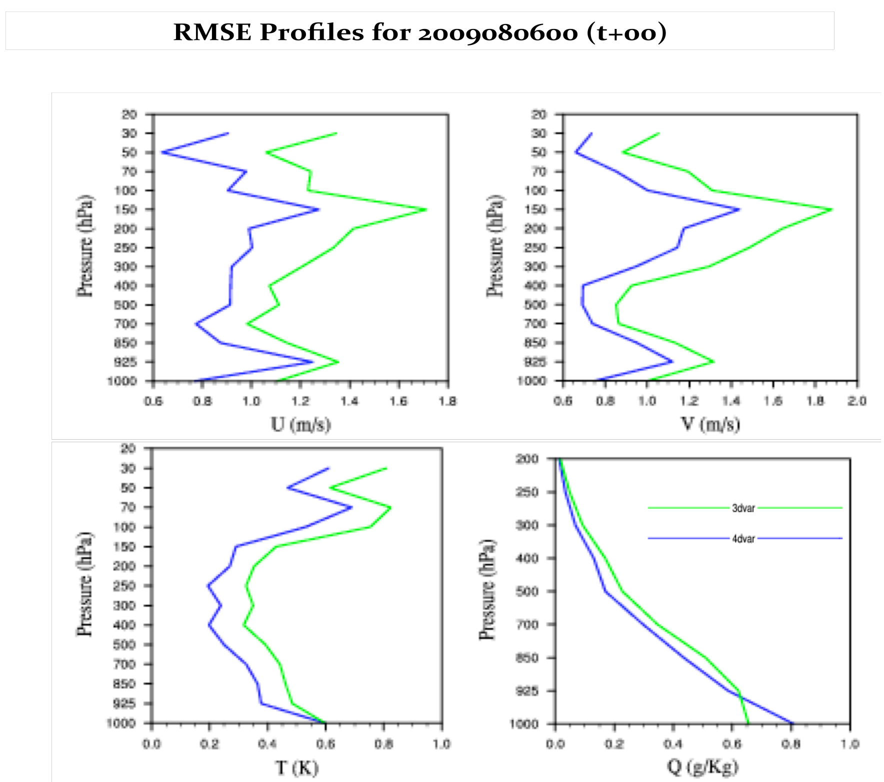

Fig.8: RMSE profiles of the verification for analysis against ERA-Interim data

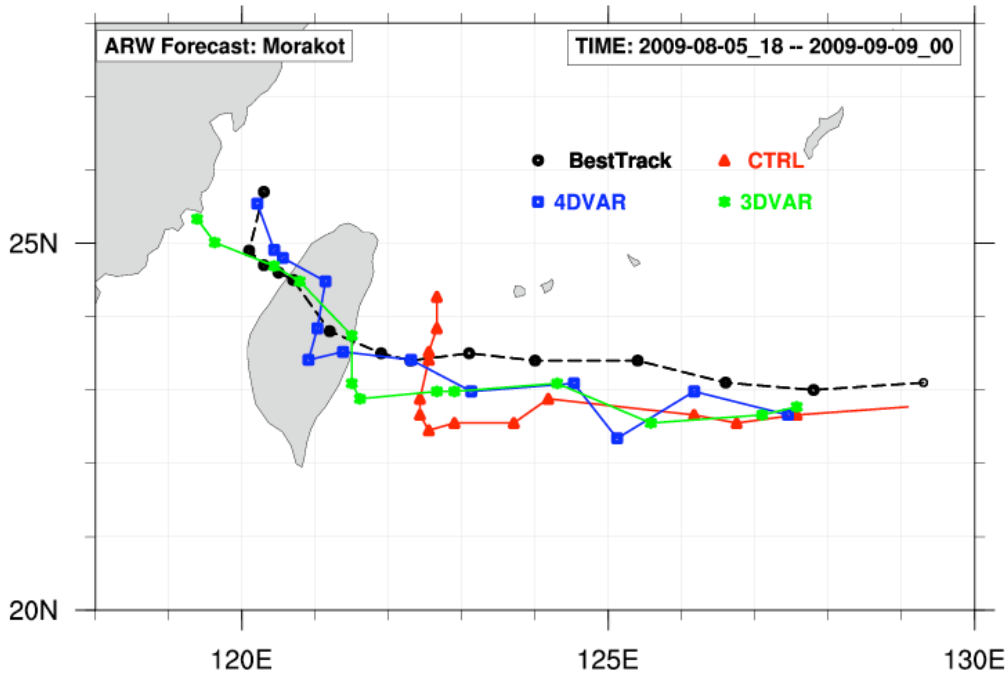

Fig.9: 72-h Track forecast for typhoon Morakot starting from 00 UTC August 6, 2009

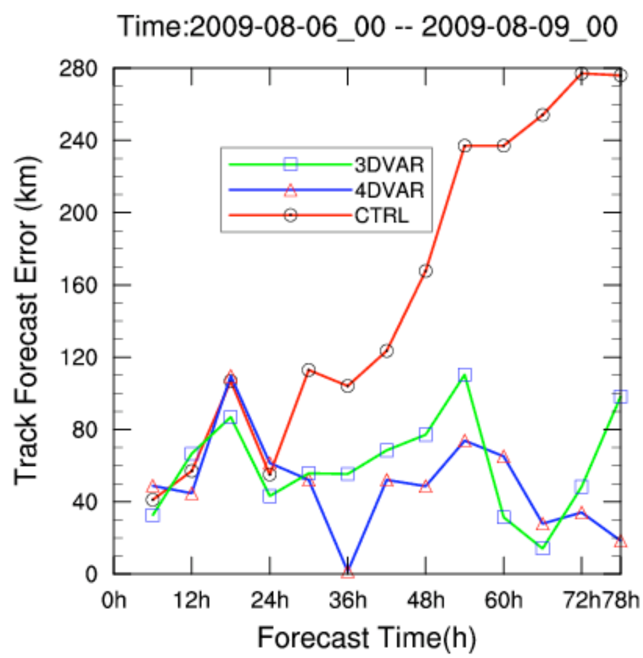

Fig.10: 72-h forecast error of track corresponding with Fig.9

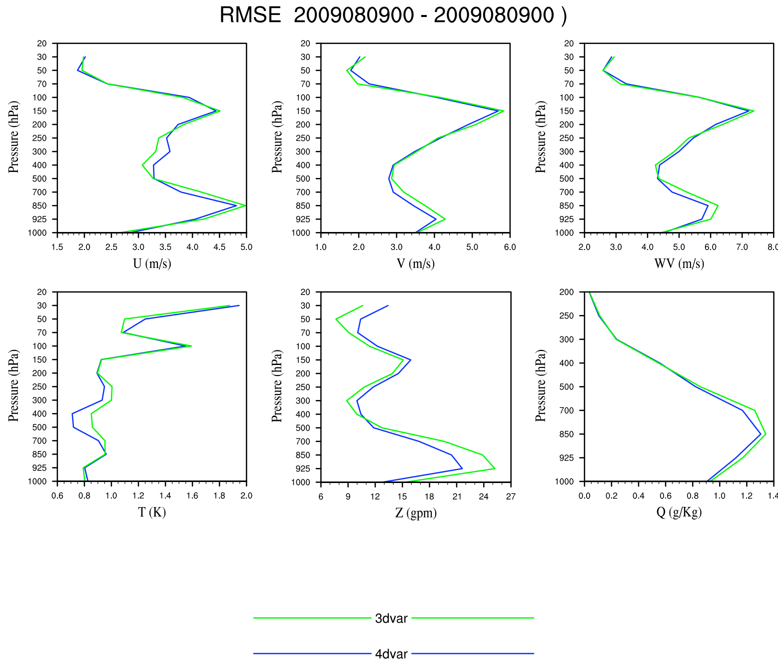

Fig.11: RMSE profiles of the verification for 72-h forecast against ERA-Interim data