A New Approach to Diagnose Tropical Cyclone Track Prediction Error

Munehiko Yamaguchi*, Tetsuo Nakazawa, and Kazumasa Aonashi
Meteorological Research Institute, Japan Meteorological Agency
Tsukuba, Japan

1. INTRODUCTION

There are many sources of error in numerical weather prediction (NWP) system such as the imperfection of NWP models and the uncertainties in initial and boundary conditions. In general, it is difficult to identify the cause of prediction error because it results from a combination of those factors and the extent of contribution of each factor changes from one initial time to another.

Recent research projects such as The Observing System Research and Predictability Experiment (THORPEX) have made it possible to distinguish between prediction errors attributable to the initial conditions from those attributable to the NWP model to some extent. This separation is achieved by running one NWP model from the initial conditions of another NWP system with higher prediction performance. The initial conditions are thought to be essential for accurate predictions in cases where the prediction is significantly improved by replacement of the original initial conditions. Meanwhile, we may gain insight into modifications that will improve an NWP model by analyzing those cases where replacing the initial conditions with those of another NWP system yielding accurate predictions does not reduce the prediction error in the assessed model.

In this study, the Japan Meteorological Agency's global spectral model (JMA/GSM) was run from the European Centre for Medium-range Weather Forecasts (ECMWF) initial conditions to separate TC track prediction errors associated with the initial conditions from those inherent in the NWP model. The separation of the two error sources, the initial conditions and the NWP model, is helpful from a standpoint of developing the NWP system since developers of initial conditions can avoid spending much of their time in trying to improve prediction cases where the NWP model is considered as a major error source, and vice versa.

2. Data and Methodology

In this study, we used the JMA's global forecasting system, which consists of the 4-dimensional variational (4DVAR) data assimilation scheme and the JMA/GSM [*JMA*, 2007]. The resolution of the JMA/GSM used in this study was TL319L60, although that of the operational system is TL959L60. First, the JMA/GSM was run from the initial conditions created during a 6-hourly data assimilation cycle of the 4DVAR to obtain the reference track predictions (hereafter, the JMA model and JMA initial conditions: JM-JI). The predictions were initiated at 1200 UTC only. Second, the JMA/GSM was run from the ECMWF initial conditions (hereafter, the JMA model and ECMWF initial conditions: JM-EI). We used the following method to create initial conditions for the JMA/GSM from the ECMWF analysis data. We downloaded the ECMWF analysis data with a horizontal resolution of 0.5625º (equivalent to TL319) from the Year of Tropical Convection (YOTC) database. JMA/GSM uses 60 vertical layers up to 0.1 hPa, but only 25 vertical levels from 1000 hPa to 1 hPa are available in the YOTC data set. Therefore, we adopted a linear interpolation technique in the vertical direction to create the initial conditions from the YOTC data set. The predictions of the ECMWF model and its initial conditions (hereafter, EM-EI) were obtained from the TIGGE database, which provides the forecast fields of the ECMWF high-resolution deterministic forecasting system as well as those of the EPS.

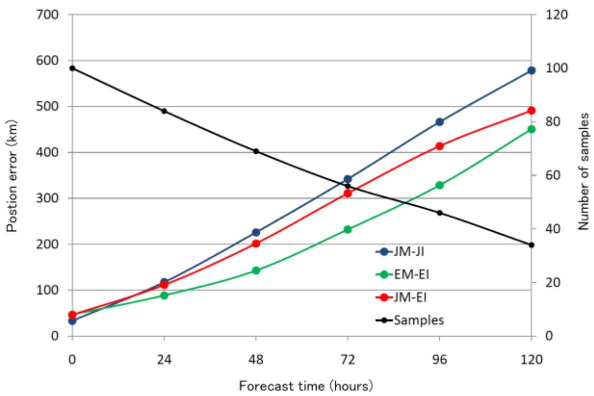

Figure 1. Position errors (left vertical axis) from 0 to 5 days of JM-JI, EM-EI, and JM-EI, and the number of samples (right vertical axis).

We verified 16 TCs that occurred in the western North Pacific basin from August to November 2009 using the best-track data analyzed by the Regional Specialized Meteorological Center (RSMC) Tokyo–Typhoon Center. Only TCs that were of tropical storm or stronger intensity at the initial time were selected for verification. TCs of tropical depression intensity at the initial time were not included in the verification, but if the TC intensity was reduced to tropical depression status during the prediction period (up to 5 days), the prediction was verified, including the times when the TC was categorized as a tropical depression.

* *Corresponding author address: Munehiko Yamaguchi, Meteorological Research Institute, Typhoon Research Department, Nagamine 1-1, Tsukuba, Ibaraki 305-0052, Japan*
email: myamagu@mri-jma.go.jp

3. RESULTS

The position errors of JMA/GSM were reduced by replacing the JMA/GSM initial conditions with those of ECMWF (JM-EI in Figure 1). The improvement rate of JM-EI with respect to JM-JI was 5%, 11%, 9%, 11%, and 15% on days 1 to 5, respectively. Thus, the replacement of the initial conditions accounts for 20%, 29%, 29%, 38%, and 68% of the difference between JM-JI and EM-EI on days 1 to 5, respectively. The difference between JM-JI and JM-EI was statistically significant at the 90% level on days 4 and 5.

Comparison of observed TC tracks and the tracks predicted by ECMWF and JMA/GSM showed that TC track prediction was significantly improved by the initial condition replacement (Figures 2a and b). For Typhoon Dujuan, the recurvature of the JM-JI track occurred earlier than the observed track or the EM-EI track recurvature, and the TC's subsequent movement with the westerly jet stream was faster, resulting in a position error of 595 km on day 3. The replacement of the initial conditions improved both the timing of the recurvature and the subsequent movement speed, reducing the error to 122 km. For Typhoon Lupit, JM-JI failed to predict the recurvature and predicted that Lupit would make landfall in the Philippines, whereas EM-EI successfully predicted the recurvature, though the track showed a slow bias after the recurvature. After replacement of the initial conditions in JMA/GSM, the model was able to predict the recurvature of Lupit, thus reducing the position error from 720 km to 280 km.

Additional experiments were conducted in which the initial conditions were created by blending the low-wavenumber component (≤T42, ~300 km) of the ECMWF analysis with the higher one of the JMA analysis (JM-EI2). The horizontal resolution of T42 was equal to that of the ensemble initial perturbations in the ECMWF EPS. Even this change in initial conditions improved the track (Figures 2a and 2b, orange lines), which indicates that the representation of the steering flow formed by the synoptic environment around the TC is important for accurate TC track prediction. It also shows the validity of adopting low-resolution singular vectors to create the ensemble initial perturbations in the ECMWF and JMA EPSs, which have horizontal resolutions of T42 and T63, respectively.

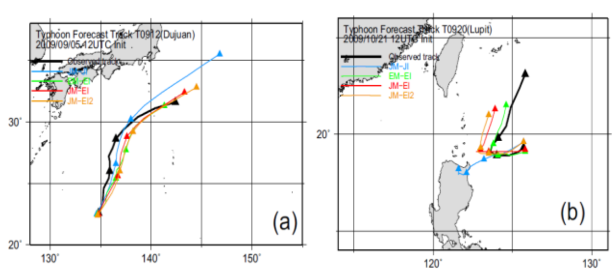

Figure 2. Track predictions by JM-JI, EM-EI, JM-EI, and JM-EI2 and the observed track for (a) Typhoon Dujuan, initiated at 1200 UTC on 5 September 2009, and (b) Typhoon Lupit, initiated at 1200 UTC on 21 October 2009. The triangles are plotted along each track every 24 hours.

Figures 3a and b show two examples where replacement of the initial conditions did not improve TC track prediction even though the EM-EI position error was small. Typhoon Morakot made landfall in Taiwan, where it caused torrential rainfall and catastrophic damage. Typhoon Parma made landfall in the Philippines and added to the damage caused by Typhoon Ketsana, which had struck the previous week. In both cases JM-JI showed a northward bias and failed to predict the landfalls. Moreover, the northward bias remained even after replacement of the initial conditions with the ECMWF initial conditions. The insensitivity of these predictions to changes in the initial conditions indicates that modifications of JMA/GSM would be needed to predict the observed tracks more accurately.

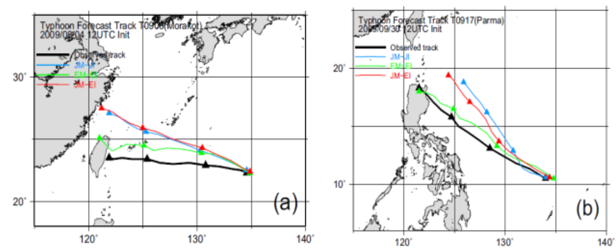

Figure 3. Track predictions by JM-JI, EM-EI, and JM-EI and the observed track for (a) Typhoon Morakot, initiated at 1200 UTC on 4 August 2009, and for (b) Typhoon Parma, initiated at 1200 UTC on 30 September 2009.

4. Conclusions

The JMA's Global Spectral Model (JMA/GSM) was run from the initial conditions of ECMWF, which are available in the YOTC data set, to distinguish between TC track prediction errors attributable to the initial conditions and those attributable to the NWP model. The average position error was reduced by about 10% by replacing the initial conditions, and in some cases, the predictions were significantly improved. In these cases, the low wavenumber component of the ECMWF analysis was found to account for most of the improvement. In addition, the observed tracks were captured by the JMA Typhoon Ensemble Prediction System (TEPS), which deals with initial condition uncertainties (not shown). In some cases, however, the replacement of the initial conditions did not improve the prediction even when the ECMWF forecast was accurate. In these cases, TEPS could not capture the observed track either (not shown), implying the need for dealing with uncertainties associated with the NWP model.

REFERENCES

JMA (2007), Outline of the operational numerical weather prediction at the Japan Meteorological Agency. Appendix to WMO Numerical Weather Prediction Progress Rep., JMA, Tokyo, Japan, 194 pp. [Available online at http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline-nwp/index.htm.]