Development of the Typhoon Initialization in a Mesoscale Model — Combination of the Bogused Vortex and the Dropwindsonde Data in DOTSTAR

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Abstract

Issues on the initialization and simulation of tropical cyclones by integrating both the dropwindsonde data and the bogused vortex into a mesoscale model have been studied. A method is proposed to combine the dropwindsonde data with the bogused vortex for the tropical cyclone initialization and to improve the track and intensity prediction. Clear positive impact of this proposed method on both the tropical cyclone track and intensity forecasts in a mesoscale model is demonstrated in three cases of typhoons, Meari (2004), Conson (2004) and Megi (2004). The effectiveness of the proposed method in improving the track and intensity simulations are also demonstrated in the evaluation of all 10 cases of DOTSTAR (Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region) missions in 2004. This method provides a useful means to improve the tropical cyclones prediction with the dropwindsonde observations.

Introduction

Since 2003, the research program of "Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region" (DOTSTAR, Wu et al. 2005, 2007) started to conduct targeted dropwindsonde observations of typhoons in the western North Pacific. Three operational global and two regional models were used to evaluate the impact of the dropwindsonde on tropical cyclone track forecasting (Wu et al. 2007). Based on the results of 10 missions conducted in 2004, the use of the dropwindsonde data from DOTSTAR on average improve the 72-h ensemble forecast of three global models, i.e., the Global Forecasting System (GFS) of NCEP, the Navy Operational Global Atmospheric Prediction System (NOGAPS) of the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the Japanese Meteorological Agency Global Spectral Model, by 22%.

However, Wu et al. (2007) showed that the average improvement of the dropwindsonde data made by DOTSTAR to the 72-h typhoon track prediction in the Geophysical Fluid Dynamics laboratory (GFDL) hurricane models is an insignificant 3%. It is very likely that the signal of the dropwindsonde data is swamped by the bogusing procedure used during the initialization of the GFDL hurricane model. This result is consistent with Tuleya and Lord (1997) where they showed that the bogusing system retarded the positive impact of dropwindsonde for as long as two days, although the overall positive impact was quiet large (20%). Wu et al. (2007) suggested that an optimal way of appropriately combining the dropwindsonde data with the bogused vortex in the mesoscale model needs to be developed in order to further boost the effectiveness of dropwindsonde data.

In short, it has been shown that either the bogusing of the initial storm vortex (Kurihara et al. 1998) or the assimilation of the dropwindsonde data (Aberson 2004; Wu et al. 2007) alone can improve the track forecast of the typhoons. However, as noted above, when both issues are taken into account, how to optimally combine the bogused vortex with the dropwindsonde data becomes a critical problem worthy of further study. Therefore, to maximize the use of the dropwindsonde data in the storm environment while inserting a suitable vortex into the numerical model, in this paper we investigate a method to appropriately combine the dropwindsonde data with the bogused vortex during the initialization procedure.

Methodology and experiment design

A single nest with 15-km resolution (301 x 301 grid points; 23 sigma vertical levels) of the latest version (V3.7.2) of the Penn State/NCAR nonhydrostatic mesoscale model (MM5) is adopted to examine the role of the dropwindsonde data and the bogused vortex on the TC forecasts and simulations. The model physics include the mixed-phase microphysics scheme, the Grell cumulus parameterization scheme, the MRF planetary boundary layer scheme, and the cloud-radiation interaction scheme. The detailed descriptions of the model can be obtained from Grell et al. (1995). Typhoons Meari, Conson and Megi (2004), in which cases the global models [such as NCEP Global Forecast System (GFS)] show rather positive impact on the 72-h track prediction when 17, 16 and 16 dropwindsonde data corresponding to each storm are assimilated (Wu et al. 2007). The model's initial and lateral boundary conditions and sea surface temperature are obtained from the denial runs (without using the dropwindsonde data) of the NCEP GFS model.

As practiced in the surveillance observations of the Atlantic TCs using the G-IV aircraft (Aberson and Franklin 1999, Aberson 2004), the DOTSTAR makes the dropwindsonde observations at the targeted areas surrounding the TC (generally more than 300 km away from the storm center). Such kind of special observations on the TC environment in DOTSTAR has shown positive impact on the track forecasts in global models (Wu et al. 2007). However, since DOTSTAR is still lacking in the inner-core storm observations, the dropwindsonde data provides very limited impact on the analysis of the inner storm structure, as well as on the storm intensity prediction.

The purpose of this work is to design a method to suitably combine the dropwindsonde data (in the storm environment) with the implanted bogused vortex (in the inner few hundred-km core of the storm), and to improve both the track and intensity predictions. The detailed descriptions below discuss the way that the bogused vortex is implanted and the way that dropwindsonde data are assimilated to the model:

a. Implanting the bogused vortex in the inner core region

Due to the lack of observations in the storm region and the limited horizontal resolution in global models, the global analyses generally do not well resolve the detailed structure of TCs. For example, the storm intensity in global analyses is often underestimated. Therefore when these global analyses are used to drive the mesoscale or hurricane models, a bogused vortex spun up from a separate simulation or prediction is generally adopted in the initialization process in order to obtain a more reasonable initial storm structure (Kurihara et al. 1995; Wu et al. 2002). In the method proposed here, a Rankin vortex using the bogusing scheme of Low-Nam and Davis (2001) with the strength analyzed from Joint Typhoon Warning Center (JTWC) is implanted 6 h prior to the model's initial time. Taking Typhoon Meari as an example, the DOTSTAR mission for Meari was conducted at 1200 UTC 25 September, 2006. Since the maximum sustained wind of Meari was estimated at 57 m s^{-1} (110 knots) by JTWC at 1200 UTC, the Rankin vortex, with a 60 m s^{-1} maximum wind was first created at 0600 UTC. Then the 6-h model integration is performed to produce a spun-up vortex at 1200 UTC. Following Wu et al. (2002), this study replaces the data in the storm core region with the above spun-up vortex as the new initial condition at 1200 UTC for Meari.

The choice of the size of the region for the above vortex replacement depends on where the dropwindsonde data are deployed. To avoid the conflict of the bogused vortex information with the dropwindsonde data, the replacement domain is purposefully chosen to be inside the region where dropwindsonde data are available. By doing so, the observed dropwindsonde data would not be seriously contaminated by the artificially-bogused vortex. For the case of Meari, the dropwindsonde data are generally taken at least about 400 km away from the storm center. Therefore, the circular region with a radius of 400 km (R_2) is selected for vortex replacement. Specifically, inside the inner 200-km radius (R_1), the model data are completely replaced by the spun-up vortex, while a linear transition zone between the 200- and 400-km radius is used to smoothly blend the spun-up vortex with the original global analysis.

For the case of Conson, the DOTSTAR mission was conducted at 1200 UTC 8 June, 2004. Since Conson was located close to Luzon at the time of the flight mission, to avoid releasing the dropwindsondes over the landmass of Luzon, the dropwindsondes were deployed at the location about 150 to 200 km from the storm center. Therefore, the implantation of the bogused vortex is within the 150 km-radius region (i.e., R_1 = 75 km and R_2 = 150 km). And for the Megi case, the R_1 and R_2 are the same as those of Meari, which are 200 and 400 km, respectively.

b. Assimilating the dropwindsonde data after the bogused vortex implanted

The MM5-3DVAR system was used to assess the impact of the dropwindsonde data on this study. The system is designed for the use in real-time applications and is available to the data assimilation community for general research. Its configuration is based on an incremental formulation, producing a multivariate incremental analysis for pressure, wind, temperature, and relative humidity in the model space. The background error covariance matrix allows for a separate definition of the vertical and horizontal correlation functions. The climatological background error covariances and statistical regression coefficients are estimated via the National Meteorological Center (NMC) method of averaged forecast differences (Parrish and Derber 1992). A detailed description and application of the MM5-3DVAR system can be found in Barker et al. (2004).

The MM5-3DVAR system is used to assimilate the dropwindsonde data in our experiments, e.g. BNDY and BYDY. Note that in BYDY (BNDY), the dropwindsonde data are assimilated into the model's analysis field from the NCEP GFS where the bogused vortex has (has not) been implanted.

Result - Evaluation of all DOTSTAR cases of the year 2004

Wu et al. (2007) have shown that the average 6-72-h track error from the operational global model of NCEP can be reduced by 14% when the dropwindsonde data are assimilated. To understand the overall impact of the above-proposed method, same experiments (i.e., BNDN, BNDY, BYDN, and BYDY) are conducted for all ten DOTSTAR cases of the year 2004.

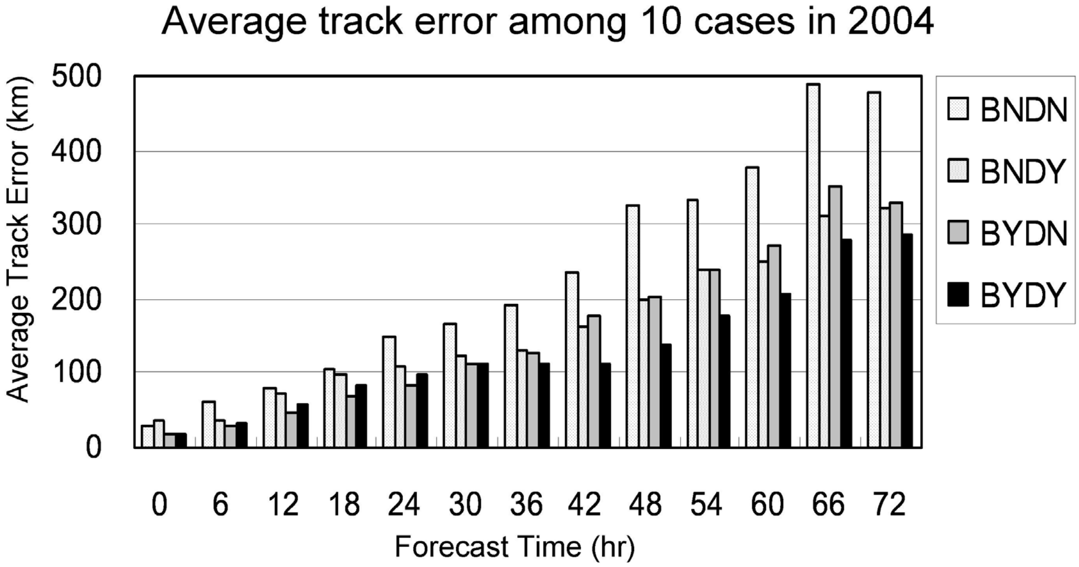

Figure 1. The overall average track errors relative to JTWC analysis in 10 evaluation cases of 2004 (unit: km). The numbers along the bottom axis are the number of the cases at each forecast time.

Figure 1 shows the comparison of the average track errors verified against the best track of JTWC from each experiment. It can be shown that the average 6-72-h track error is reduced by about 30% either with the dropwindsonde data assimilated or with the bogused vortex implanted. When both the dropwindsonde data and bogused vortex are used in the newly-proposed method, the average track error is reduced by 40%. Statistical examination by the paired test with one-sided distribution (Larsen and Marx 1981) for BNDN and BYDY indicates that the track improvement at 6, 42, 48, 60 and 66 h are statistically significant at the 90% confidence level.

Meanwhile, for all ten cases, the evolution of the average intensity error (in terms of the minimal sea level pressure) is also evaluated for simulations with and without the bogused vortex. Overall, the statistical examination for BNDN and BYDY shows that improvement of the intensity forecast by the proposed method is statistically significant at the 90% confidence level in the first 48 h.

In all, the substantial track and intensity improvement from the above 10 cases demonstrates the benefit of the proposed method of combining the dropwindsonde data and the bogused vortex to improving the TC simulation in the mesoscale model.

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