6.8 IMPACT OF DROPWINDSONDE DATA ON HURRICANE TRACK FORECASTS

Seon K. Park[1] and Da-Lin Zhang[2]

[1]Dept. of Environmental Sci. & Eng., Ewha Womans University, Seoul, Korea
(E-mail: spark@ewha.ac.kr)

[2]Dept. of Meteorology, University of Maryland, College Park, MD 20742

1. INTRODUCTION

Accurate forecasting of tropical cyclone track and intensity using numerical prediction models is a challenging problem due to lack of observational data over tropical oceans as well as errors in both model and observations. Although the model deficiencies have significantly reduced during the last two decades, initial uncertainties (i.e., analysis errors) still remain as a major source of forecast errors (e.g., Reynolds et al. 1994). The major improvement in observing systems for tropical cyclones over oceans has been achieved through dropwindsondes (e.g., Burpee et al. 1996; Aberson and Franklin 1999) and satellites (e.g., Velden et al. 1992; Leslie et al. 1998). Langford and Emanuel (1993) discussed the potential of using unmanned aircraft for deploying dropwindsondes. During the past few years, a series of field campaigns, the Convection and Moisture Experiment (CAMEX), has been conducted in the Atlantic basin collecting in-situ aircraft and ground measurements as well as remote sensing observations to study hurricanes – their structure, development, intensification, motion, and impact on landfall (see NASA 2002).

These unconventional and high-resolution data can bring about significant improvement in numerical prediction of tropical cyclones through *data assimilation* by increasing the accuracy of initial representation of the dynamical and thermodynamical structures of tropical cyclones (e.g., Velden et al. 1992; Shi et al. 1996; Leslie et al. 1998). However, not many studies have been done to investigate the impact of such data on forecast and assimilation for tropical cyclones using nonhydrostatic mesoscale models with sophisticated microphysics.

In the present study, the impact of dropwindsonde data on the numerical forecast of tropical cyclone track is investigated, especially in terms of the number and distribution of data, using a mesoscale numerical model. Implications of our results for data assimilation are also discussed. Although forecasting tropical cyclone intensity is an important problem, this study focuses more on the track forecast at this stage. For this study, the observing-systems simulation experiments (OSSEs; Arnold and Dey 1986) are performed based on the simulated dropwindsonde observations.

2. CASE AND MODEL DESCRIPTION

Hurricane Bonnie (1998) began as a tropical depression on 1200 UTC 19 August 1998 and reached the state of tropical storm on 1200 UTC 20 August and the state of hurricane around 0000 UTC 22 August. Bonnie hit the coast of North Carolina on 27 August 1998, turned northeastward and weakened afterwards. It recorded a maximum wind of 100 knots and a minimum pressure of 954 hPa. Operational models produced significantly different forecast on the track of Bonnie, thus making the forecast very difficult and highly uncertain.

Our experiments are performed for Hurricane Bonnie (1998) using the PSU/NCAR MM5 (version 2) – a three-dimensional, non-hydrostatic mesoscale model with full physics (Grell et al. 1995). For this preliminary study, a rather coarse grid domain is employed with horizontal resolution of 54 km (79 by 99 grids). A total of 15 σ-layers in the vertical is used with higher resolution in the PBL (half σ levels are: 0.98, 0.94, 0.92, 0.88, 0.85, 0.81, 0.77, 0.71, 0.6, 0.55, 0.45, 0.35, 0.25, 0.15, and 0.05). For physics options, Dudhia's simple ice microphysics, Grell's cumulus scheme and high-resolution Blackadar PBL scheme are employed. Zhu et al. (2003) have shown a 5-day cloud-resolving simulation of this storm with the finest grid size of 4km and more sophisticated cloud microphysics processes.

The initial forecast time is set to 0000 UTC 22 August 1998 where the tropical depression center was located near 20º N, 67º W. Control simulations are made for 120 hrs (5 days) up to 0000 UTC 27 August, based on two different initial data – the NCEP and ECMWF/TOGA global analysis data. The two forecasts depict very different aspects in hurricane track (see Fig. 1). The forecast based on the NCEP analysis data shows quite a good match with the best track especially near the landfall. Using the ECMWF/TOGA analysis data, the model forecasted Bonnie to stay out the sea and never make landfall, as most operational models did.

3. EXPERIMENT DESIGN

To investigate the impact of dropwindsonde observations on the track forecast of Hurricane Bonnie (1998), we have employed the OSSEs approach. Since the forecast track based on the NCEP analysis data matches the observed track (including landfall) quite well, we consider this forecast as the *simulated observation*. That is, the forecast variables (i.e., three-dimensional wind components, temperature and water vapor mixing ratio) at each grid are considered as the observed fields through dropwindsondes. The forecast based on the ECMWF/TOGA data, which shows much worse track forecast, is now considered as the *control forecast*. Our strategy is to assimilate a part of the simulated dropwindsonde observations in the vicinity of the tropical depression at the initial time of the control forecast and to see how the forecast tracks are modified due to the incorporation of the dropwindsonde data. With this approach, the "identical twin" problem is no longer an issue.

The dropwindsonde soundings are selected from the simulated observations at various numbers and locations around the storm center. Experiment C9 takes one dropwindsonde sounding near the storm center (C1) and additional eight data from the adjacent grids which are two grids apart from the center, thus showing a square-type distribution of data around the storm center. Experiment C5 takes four data out of C9 from the grids on the sides of the square. Experiment C13 adds four more data into C9 on the grids halfway between the vertices of the square and the center. Additional four data are added inside (Exp. C17-I) or outside (Exp. C17-O) to investigate the effect of highly dense observation network.

To assimilate these data into the preexisting analysis of the control forecast, we tried to avoid direct insertion (i.e., simple replacement of data at the same grid). We have used several MM5 analysis routines to achieve this task. First, the sounding data are extracted from the simulated observations. Then these data are blended using the bogusing technique. Finally the initialization is performed again.

4. RESULTS

Data impact experiments are performed by incorporating various numbers of the simulated dropwindsonde data around the storm center into the initial conditions (i.e., based on the ECMWF/TOGA analysis data). Here dropwindsonde observations are assumed to be provided at all vertical levels.

The major difference in the initial pressure fields between the NCEP data (i.e., simulated observation; hereafter NCEP) and the ECMWF/TOGA data (i.e., control forecast; hereafter TOGA) occurs in both location and intensity of the low pressure center. Their initial central location for NCEP and TOGA are (67.70º W, 20.18º N) and (67.21º W, 20.18º N), respectively. Their initial center pressures differs by 3 hPa with a lower pressure in NCEP. Wind fields are generally similar in circulation patterns; however, NCEP has stronger low-level winds and weaker high-level winds around the storm center.

Analyses of the wind difference fields between the control forecast and simulated observation (i.e., TOGA − NCEP) depict that, compared to NCEP, TOGA has relatively stronger westerly (easterly) at northern (southern) part of the storm center at lower level, while it has relatively stronger easterly (northwesterly) at northern (southern) part of the storm center at upper level. This implies that TOGA has stronger anticyclonic (cyclonic) circulation at lower (upper) level, which generates a weaker cyclonic vortex than NCEP does. In other words, to make the track forecast close to the observation (NCEP), the wind fields need a cyclonic (anticyclonic) correction at lower (upper) level.

Figure 1 depicts the forecast tracks from various experiments for different numbers and locations of dropwindsonde soundings. Adding just one dropwindsonde observation near the storm center (C1) makes little change in the forecast track. With more observations, such as C5 and C9, track forecasts are improved at least during the first 24 hrs; however, track forecasts near the landfall are still far from the observation (NCEP). Incorporating thirteen dropwindsonde data (C13) results in a large amount of correction in the forecast track, especially near the landfall. In general, more dropwindsonde observations in the vicinity of the storm center result in better track forecast.

To investigate the factors causing these differences in track forecasts, some differenced fields are analyzed (not shown). For example, the wind difference fields for Exp. C13 (i.e., C13 − TOGA) show that adding thirteen dropwindsonde data induces strong cyclonic (anticyclonic) correction in the lower (upper) level wind fields. This is consistent with dynamical features observed in the difference fields between TOGA and NCEP, as discussed above.

Figure 2 compares Exp. C13 with more dropwindsonde data – C17-I (C17-O) with four more soundings within (outside) the square made by the C13 soundings. Both experiments with more data demonstrated worse track forecasts than C13. Even a denser observation network near the storm center (C17-I) did not improve the track forecast. This implies that assimilation of excessively high-resolution dropwindsonde data around the storm center may not necessarily result in better track forecasts.

Another set of experiments is performed by dividing the area surrounding the storm center into four quadrants, each possessing thirteen dropwindsonde data. Track forecasts based on dropwindsonde soundings added in different quadrants are shown in Fig. 3. Generally, at least during the last 72 hrs, adding dropwindsonde soundings in front semicircle (NW13 and SW13) results in better track forecast than adding the soundings in rear semicircle (NE13 and SE13). In some sense, this is consistent with Franklin and DeMaria (1992) who showed that observations in front semicircle of the cyclone were more effective in improving barotropic model forecasts than those in the rear semicircle. Our results indicate that enhancing observations in each quadrant results in improved forecast tracks in general. However, dropwindsonde data distributed with uniform distance around the storm center, as in C13, exerted better effect than those in any quadrant (i.e., front or rear semicircle).

5. CONCLUSIONS

In this study, the potential impact of dropwindsonde observations on track forecasting of Hurricane Bonnie (1998) is investigated in terms of data number and distribution around the storm center using the MM5 model and the OSSE approach. Overall, increasing the number of dropwindsonde observations around the storm center improved track forecast; however, excessively dense data did not give further improvement. In addition, enhanced observations in any semicircle in the vicinity of storm center resulted in less improvement than those distributed with uniform distance from the storm center. Our results indicate that appropriate number and distribution of dropwindsonde soundings around the storm center make necessary corrections in the wind fields at all levels for better track forecast, as demonstrated by the analyses of difference fields.

Although current study demonstrates the impact of dropwindsonde data on improving hurricane track forecasts, for more complete understanding of the mechanisms of data impact, a detailed study on the evolution of dynamical and thermodynamical structure of the tropical cyclone in each experiment should be followed.

In terms of data assimilation, our results imply that proper observational network and density are important in numerical track forecast of tropical cyclones. Therefore, the flight routes for deploying dropwindsondes should be carefully planned. The results also address the importance of conducting adaptive observation studies to find more effectively where and how we should deploy dropwindsondes and enhance other observing systems (e.g., Zhang and Krishnamurti 2000).

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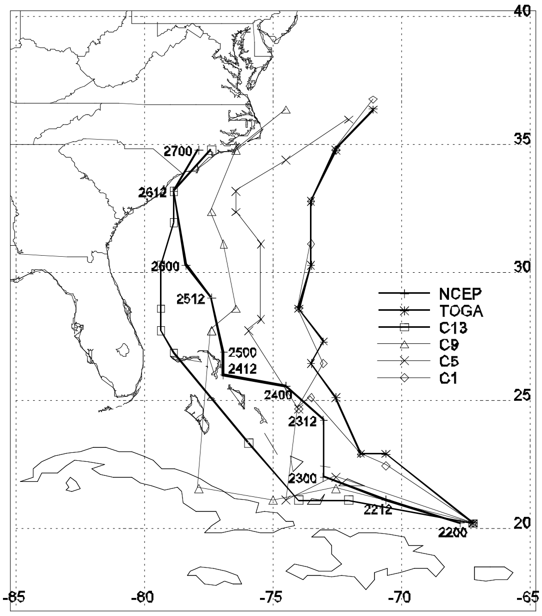

Fig. 1. Forecast tracks of Hurricane Bonnie (1998) based on the NCEP and TOGA analyses, and on incorporation of various setups of dropwindsonde data around the storm center (e.g., C13 indicates a forecast with 13 dropwindsonde data). Symbols on the lines represent the locations of storm center and the numbers beside the centers describe day and time (in UTC).

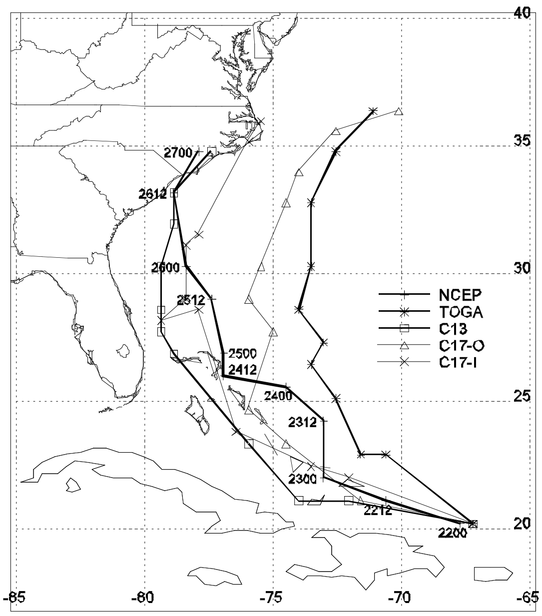

Fig. 2. As in Fig. 1 except for forecasts with more dropwindsonde data (13 vs. 17) around the storm center.

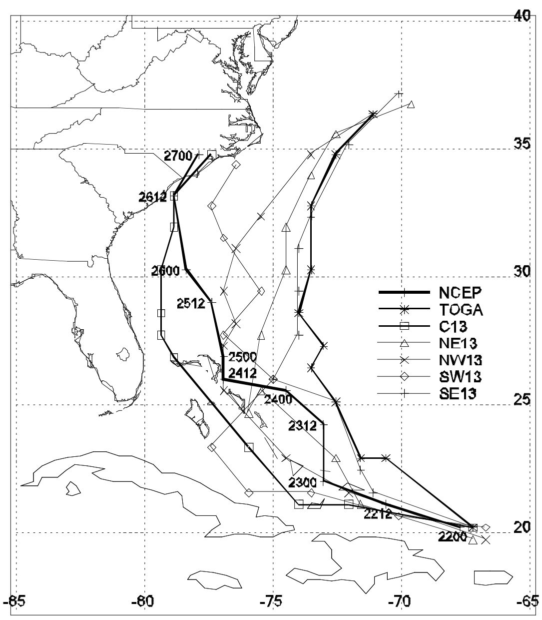

Fig. 3. As in Fig. 2 except for forecasts based on incorporation of 13 dropwindsonde data at different areas around the storm center (e.g., NW13 indicates a forecast with 13 dropwindsonde data located at the northwest quadratic domain).