15C.1 THE RELATIVE ROLE OF WIND VS. PRESSURE IN THE INITIALIZATION OF TROPICAL CYCLONES–OBSERVING-SYSTEMS SIMULATION EXPERIMENTS

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1. INTRODUCTION

Based on 4-dimensional variational (4D-VAR) data assimilation, a bogus data assimilation (BDA) method has been developed recently by Zou and Xiao (2000) to improve the initial condition for tropical cyclone simulation. Given a specified sea level pressure (SLP) distribution, the BDA process can lead to a better initial typhoon structure. Xiao et al. (2000, hereafter, XZW) expanded their work by assimilating the wind field data into the model. By comparing simulations with different data used for BDA, their result indicates that the assimilation of only the pressure field is more effective than the assimilation of only the wind field. However, adopting a similar approach, Pu and Braun (2001, hereafter, PB) showed that the assimilation of wind field would be more useful than that of pressure field, while assimilating both the wind and pressure fields would provide the best results. To gain more insights into the above conflicting results, we employ the Observing-Systems Simulation Experiments (OSSEs) to study the relative role of the wind and pressure fields in the initialization of tropical cyclones.

2. EXPERIMENT DESIGN

A nature run is performed to create the best initial condition (BIC) for Typhoon Zane (1996) using MM5. Then the BIC is downgraded to create a faked initial condition (FIC), which mimics what a typical global analysis can resolve on Zane. A series of OSSEs have been conducted to assess the potential impact of different variables on BDA. By taking different "observed" data [e.g., 3-dimensional wind (u, v), and/or surface pressure perturbation (p_s') fields from the BIC] for data assimilation, each experiment produces its own initial condition and the ensuing 60-h simulation to examine the track and intensity of the simulation.

The experiment of V-BIC (P-BIC; VP-BIC) represents a simulation started with an initial condition after the u and v (p_s'; u, v, and p_s') from BIC are taken as the observations for the 4D-VAR data assimilation, i.e., the initial condition [$x(t_0)$] is obtained by minimizing the following cost function:

$$J = \frac{1}{2}[x(t_0) - x_b]^T B^{-1}[x(t_0) - x_b] + \sum_{r=0,R} \frac{1}{2}\{h[x(t_r)] - y_o\}^T O^{-1}\{h[x(t_r)] - y_o\},$$

where x_b represents the background field taken from the FIC, and y_o is the observation field from the BIC, the **B** and **O** are the background error covariance matrix and the observation error covariance matrix, respectively, **h** is the observation operator, and t_R is the time window for data assimilation.

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3. RESULTS

3.1 Intensity

When only the sea level pressure (SLP) field is assimilated (P-BIC), the minimum central SLP (MSLP) of the storm (969 hPa, Fig. 1a) is well recovered at the initial time. But the initial wind field is severely underestimated (by about 30 m s^{-1}, Fig. 1b). Due to such dynamic imbalance between the wind and mass fields, the geostrophic adjustment occurs quickly in the first few hours of the integration in P-BIC, and the minimum central SLP fills immediately after the integration starts, thus larger intensity errors are induced.

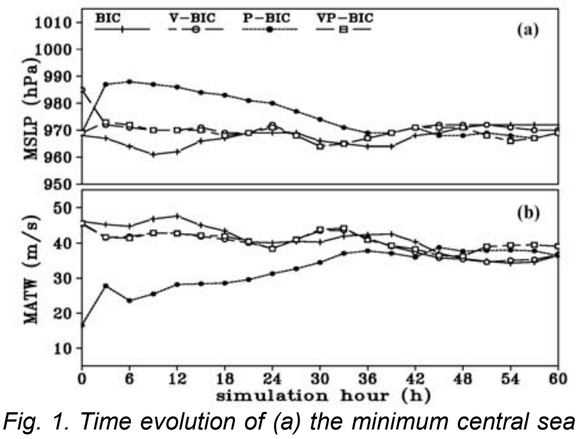

Fig. 1. Time evolution of (a) the minimum central sea level pressure (MSLP, hPa) and (b) the maximum azimuthally-averaged tangential wind (MATW, m s^{-1}) at the model level of σ=0.87.

For V-BIC, the maximum azimuthally averaged tangential wind at σ=0.87 (MATW) is identical to BIC of 45 m s^{-1} at the initial time, while the MSLP is higher than that of BIC by 17 hPa (see Fig. 1a). The evolution of the MATW of V-BIC (Fig. 1b) agrees well (within 5% error) with the BIC throughout the integration period, while the MSLP adjusts quickly toward the value of BIC (though still few hPa higher) and remains close to BIC for the rest of the simulation.

The result shows that the wind field is critical for maintaining a correct initial vortex structure of a TC. On the other hand, the model's memory on the pressure field is relatively short. Therefore when only the pressure field is assimilated, due to the imbalance between the pressure and wind fields, the pressure adjusts to wind field and fills up quickly, while the assimilation of wind field is more effective in maintaining the vortex structure than the assimilation of pressure field.

3.2 Issues on the geostrophic adjustment

The conventional understanding of the geostrophic adjustment (Blumen 1972) shows that the initial mass (wind) field tends to adjust rapidly (slowly) to the initial wind (mass) field for subsynoptic/mesoscale (synoptic or larger-scale) motions and at low (high) latitudes, where the ratio of the horizontal scale of motion (L) to the Rossby radius of deformation (L_R) is much smaller (larger) than 1. Extending this geostrophic-adjustment concept to an axisymmetric vortex, Schubert et al. (1980) indicated that a large-scale initial pressure disturbance would experience little change in the adjustment process (i.e., wind adjusts to pressure). Meanwhile, if the radius of maximum wind (L) is small compared to the radius of deformation (L_R), i.e., L/L_R << 1, the initial tangential wind and vorticity fields would have little change (i.e., pressure adjusts to wind). For a highly rotating fluid system, such as a TC, the natural scale in the symmetric vortex, i.e., the local L_R, can be better defined (Shapiro and Montgomery 1993) as

$$L_R = \frac{NH}{(\overline{\eta}\,\overline{\xi})^{1/2}}, \qquad (1)$$

where N is the static stability, H is the vertical scale, $\overline{\eta}\,\overline{\xi}$ represents the inertial stability, $\overline{\eta} = f + \overline{\zeta}$ is the absolution vorticity, $\overline{\xi} = f + 2\overline{v}/r$ is the inertia parameter, f is the Coriolis parameter, $\overline{\zeta} = [\partial(r\overline{v})/\partial r]/r$ is the relative vorticity of the azimuthal mean vortex, $\overline{v}$ is the azimuthal mean tangential wind, and r is the distance from the vortex center.

For P-BIC, as the vortex in FIC is rather weak (with the MATW of 13 m s^{-1} at the radius of about 330 km), while located at 22.4°N, it has a relatively large L_R of about 1120 km [estimated according to (1), with an estimated average N of 0.015 s^{-1} and H of 10 km] and the horizontal scale (L) of about 330 km (estimated based on the radius of the MATW). Thus the ratio of L/L_R is about 0.29 (see Table 1), and favors a geostrophic adjustment from the pressure field toward the wind field. Therefore, even the SLP is assimilated in P-BIC, the wind field cannot be fully recovered during the assimilation time window. In V-BIC, the MATW is increased to 45 m s^{-1} with the radius of MATW reduced to 150 km, which leads to an L_R of 230 km and L/L_R of 0.65 (Table 1), still favoring the adjustment of pressure field toward the wind field.

We also estimated the Rossby radius of deformation in both XZW's and PB's experiments, it is found that the scale of a TC vortex is generally much smaller than the radius of Rossby deformation (see Table 1). Therefore the geostrophic adjustment should favor the pressure field to adjust to the wind field and thus a better initial condition in the wind field is critical to the BDA and simulation/prediction of TCs.

In summary, the above analysis indicates that the different results between XZW and PB possibly arise from the different setup of the numerical experiments. We believe that as far as the geostrophic adjustment is concerned, based on the framework of Schubert et al. (1980) and Shapiro and Montgomery (1993), with the small value of L/L_R in all the analyses above, the wind field should play a more important role than pressure for the initialization of TCs using BDA technique.

Table 1: Estimation of Rossby radius of deformation.

	XZW	PB-George	P-BIC	V-BIC
Latitude	23°N	18°N	22°N	22°N
N	0.015 s^{-1}	0.015 s^{-1}	0.015 s^{-1}	0.015 s^{-1}
H	10 km	10 km	10 km	10 km
V_{max}	12 m s^{-1}	20 m s^{-1}	13 m s^{-1}	45 m s^{-1}
RMW(L)	280 km	230 km	330 km	150 km
L_R	1050 km	680 km	1120 km	230 km
L/L_R	0.27	0.34	0.29	0.65

REFERENCES

Blumen, W., 1972: Geostrophic adjustment. Rev. Geophys. Space Phys., 10, 485–528.

Schubert, W. H., J. J. Hack, P. L. Silva Dias, and S. R. Fulton, 1980: Geostrophic adjustment in an axisymmetric vortex. J. Atmos. Sci., 37, 1464–1484.

Shapiro, L. J. and M. T. Montgomery, 1993: A three-dimensional balance theory for rapidly rotating vortices. J. Atmos. Sci., 50, 3322–3335.

Pu, Z. -X. and S. A. Braun, 2001: Evaluation of bogus vortex techniques with four-dimensional variational data assimilation. Mon. Wea. Rev., 129, 2023–2039.

Xiao, Q., X. Zou and B. Wang. 2000: Initialization and simulation of a landfalling Hurricane using a variational bogus data assimilation scheme. Mon. Wea. Rev., 128, 2252–2269.

Zou, X. and Q. Xiao, 2000: Studies on the initialization and simulation of a mature hurricane using a variational bogus data assimilation scheme. J. Atmos. Sci., 57, 836–860.