A Numerical Study of Typhoon Xangsane (0615) Development by Weather Research and Forecasting Model

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Received: 15 March 2013 Accepted: 15 June 2013

Abstract

This research simulates the development of typhoon Xangsane (0615) in terms of vertical vorticity of the storm. The Weather Research and Forecasting (WRF) model is used in the simulations. The Rankine vortex wind bogussing is used to enhance the weak observed wind speed before input into WRF model. Results show that with bogus wind, the simulation provides accurate timing of the intensification of Xangsane from tropical to typhoon.

Keywords: component, Wind bogussing, WRF model, Typhoon Xangsane

Introduction

Tropical cyclones have great effects on long shore or offshore structures and frequently cause losses of lives and properties. Thus, it is of great importance to simulate tropical cyclone development. In this research, the development of typhoons Xangsane (0615) is used in a model simulation. The vortex bogussing is a method to improve the initial data by increasing weak observed wind speed of tropical storm before input into the model. The Rankine vortex is used in[1] to bogus tropical cyclone wind in a single level primitive equation (SILEPE) model. A rankine vortex is applied in bogussing tropical cyclone forecasts by MM5 model in[2] which results in better wind speed forecast.

Methodology and data

A. Rankine Vortex Equations

Assuming the initial position, the central sea level pressure, the maximum tangential wind speed c_m, and the radius at which the maximum tangential wind speed occur R_m, the tangential wind of a typhoon can be calculated according to[1] and[4]. This wind can be described as a function of the radial distance of the storm r as

$$c = c_m \frac{r}{R_m} \qquad for \quad r \le R_m \tag{1}$$

$$c = c_m \left(\frac{r}{R_m}\right)^{-\alpha} \qquad for \quad r > R_m \tag{2}$$

where c is the tangential wind speed and the value of α has been determined empirically from observed tropical cyclones. In this paper α is 0.6.

The tangential wind speed of a typhoon can be calculated in the west–east direction or zonal wind (υ) and the north–south direction or meridional wind (ϖ) as

$$u = c \cos\theta \tag{3}$$

$$v = c \sin\theta \tag{4}$$

where θ is the angle between the wind speed and the north direction.

The geopotential height is defined as $z=gh$, and assumed to be related to the wind field by the gradient wind relationship[5]

$$\frac{\partial z}{\partial r} = fc + \frac{c^2}{r} \tag{5}$$

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After replacing c from Eq. (1) and Eq. (2) into Eq. (5) and integrating,

$$\int dz = \left(fc_m + \frac{c_m{}^2}{R_m} \right) \int \frac{r}{R_m} dr \qquad ,r \le R_m$$

$$\int dz = fc_m \int \left(\frac{r}{R_m} \right)^{-\alpha} dr + c_m^2 \int \frac{r^{-1-2\alpha}}{R_m{}^{-2\alpha}} dr \qquad ,r > R_m$$

We have

$$z(r) = \frac{c_m}{2}\left(fR_m + c_m \right)\left(\frac{r}{R_m} \right)^2 + c_1 \qquad ,r \le R_m \tag{6}$$

$$z(r) = \frac{fR_m c_m}{1-\alpha}\left(\frac{r}{R_m} \right)^{1-\alpha} - \frac{c_m^2}{2\alpha}\left(\frac{r}{R_m} \right)^{-2\alpha} + c_2 \qquad ,r > R_m \tag{7}$$

Assuming continuity of geopotential height at the radius of maximum of wind, c_1 and c_2 can be eliminated from both of the equations. This will lead to the geopotential height at the distance r from the storm center, $z(r)$, which is calculated from the following equations[2]

$$z(r) = z(R) - \left[\frac{fR_m c_m}{2(1-\alpha)} \left\{ 2\left(\frac{R}{R_m} \right)^{1-\alpha} - (1+\alpha) - (1-\alpha)\left(\frac{r}{R_m} \right)^2 \right\} - \frac{c_m{}^2}{2\alpha} \left\{ \left(\frac{R}{R_m} \right)^{-2\alpha} - (1+\alpha) + \alpha \left(\frac{r}{R_m} \right)^2 \right\} \right] \qquad r \le R_m \tag{8}$$

$$z(r) = z(R) - \left[\frac{fR_m c_m}{(1-\alpha)} \left\{ \left(\frac{R}{R_m} \right)^{1-\alpha} - \left(\frac{r}{R_m} \right)^{1-\alpha} \right\} - \frac{c_m{}^2}{2\alpha} \left\{ \left(\frac{R}{R_m} \right)^{-2\alpha} - \left(\frac{r}{R_m} \right)^{2\alpha} \right\} \right] \qquad r > R_m \tag{9}$$

***B. Weather Research and Forecasting (WRF) Mode*l**

The WRF model is used to simulate vertical vorticity at the 850 hPa. The WRF model is developed primarily by the National Center for Atmospheric Research (NCAR) and the National Centers for Environmental Prediction (NCEP). Other contributors include the Forecast Systems Laboratory (FSL), Center for Analysis and Prediction of Storms (CAPS), the Air Force Weather Agency (AFWA), the Federal Aviation Administration (FAA) and the Naval Research Laboratory (NRL). This is a fully-compressible, nonhydrostatic model, and is conservative for scalar variables[6].

C. Vorticity

The vertical component of vorticity is defined as the circulation about a closed contour in the horizontal wind components u and v.

The expressions for the vertical component of vorticity is

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \tag{10}$$

The central-difference approximation for computation of vorticity at grid point *(i, j)* transforms Eq. (10) into

$$\zeta_{i,j} = \left[\frac{v_{i+1,j} - v_{i-1,j}}{2dx} \right] - \left[\frac{u_{i,j+1} - u_{i,j-1}}{2dy} \right] \tag{11}$$

D. Experiment Case

The experiment case (Table 1) in this paper is tropical cyclone Xangsane (0615). Data for this storm are obtained from the Joint Typhoon Warning Center (JTWC)[7] and the initial condition from[8] at 850 hPa. The initial time of simulation is 26/09/2006 00UTC and the ending time of simulate is 27/09/2006 06UTC. The domain in this study between latitude $0^\circ N$ to $23^\circ N$ and longitude $95^\circ E$ to $125^\circ E$.

Table 1 Observed data of typhoon xangsane[7].

Date and Times	*Latitude*	*Longitude*	*Maximum Wind Speed (m/s)*	*Type*
2006 09 26 00UTC	15.3 °N	112.5 °E	18.01	Tropical Storm
2006 09 26 06UTC	15.6 °N	111.6 °E	25.72	Tropical Storm
2006 09 26 12UTC	15.7 °N	110.7 °E	30.86	Tropical Storm
2006 09 26 18UTC	15.6 °N	109.7 °E	33.44	Typhoon
2006 09 27 00UTC	15.6 °N	108.6 °E	38.58	Typhoon
2006 09 27 06UTC	15.7 °N	107.4 °E	43.72	Typhoon

The steps for the simulation of typhoon Xangsane development are shown in Figure 1

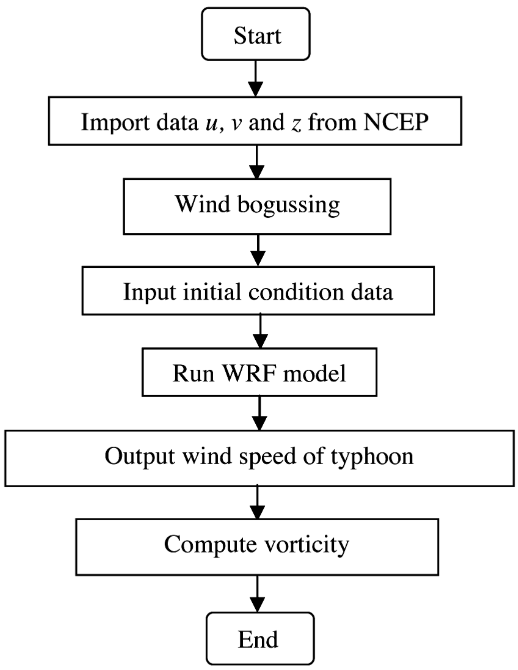

Figure 1 Steps of the simulation.

Results and discussion

Wind speeds from the simulations of the typhoon development with and without bogus at 850 hPa on 26/09/2006 at 18 UTC are shown Figures 2 and 3, respectively. Wind speed patterns in both figures are similar. However, the vorticity development in bogus case is better than that of no bogus case.

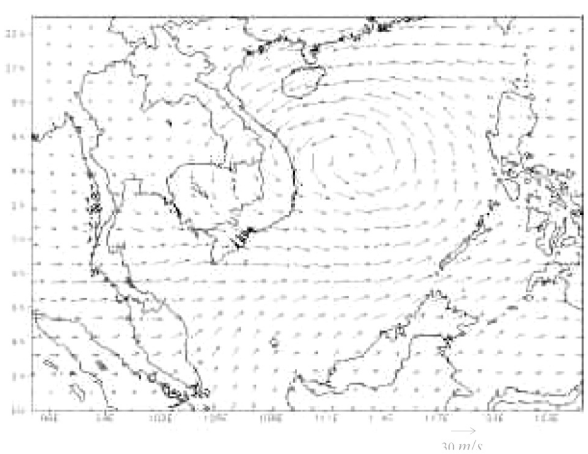

Figure 2 The simulated wind of typhoon Xangsane with no bogus wind on 26/09/2006 at 18UTC.

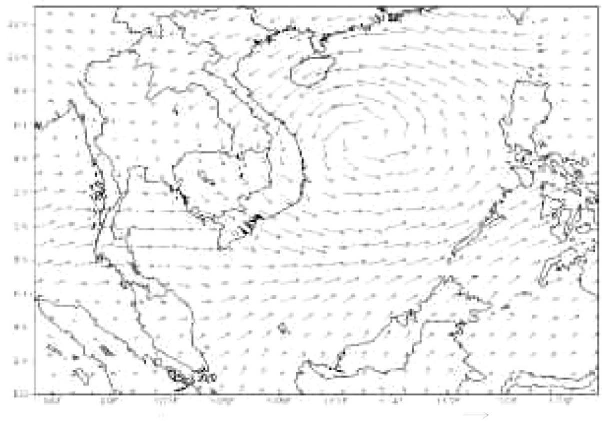

Figure 3 The simulated wind of typhoon Xangsane with bogus wind on 26/09/2006 at 18UTC.

The vorticity of typhoon Xangsane as simulated with no bogus, bogus wind and vorticity computed from JTWC data are shown in Table 2 and Figure 4.

Table 2 The vorticity of the typhoon xangsane.

Date and Times	ζ_{JTWC} ($\times10^{-5}s^{-1}$)	*Type*	$\zeta_{No\ bogus}$ ($\times10^{-5}s^{-1}$)	*Type*	ζ_{Bogus} ($\times10^{-5}s^{-1}$)	*Type*
2006 09 26 00UTC	0.60	Tropical Storm	0.42	Tropical Storm	1.29	Tropical Storm
2006 09 26 06UTC	0.68	Tropical Storm	0.56	Tropical Storm	1.81	Tropical Storm
2006 09 26 12UTC	1.67	Tropical Storm	1.31	Tropical Storm	2.71	Tropical Storm
2006 09 26 18UTC	3.21	Typhoon	2.03	Tropical Storm	3.45	Typhoon
2006 09 27 00UTC	3.77	Typhoon	2.47	Typhoon	3.98	Typhoon
2006 09 27 06UTC	4.03	Typhoon	2.92	Typhoon	4.34	Typhoon

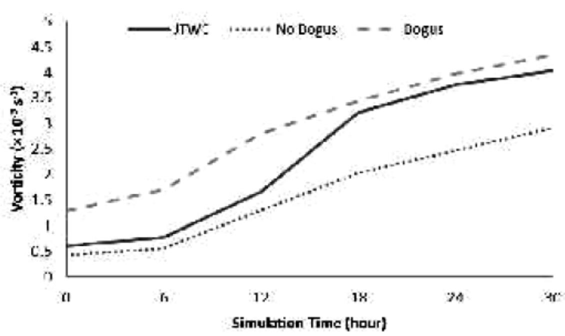

Figure 4 Comparison of the simulated vorticity for typhoon Xangsane.

Results from the simulations show that the bogus wind can provide realistic values of vorticity when compare with the JTWC data.

Conclusions

Observed wind speeds from satellites are usually weaker than real wind speed around a tropical cyclone. To correct this problem, a wind bogussing method is applied to the observed wind speed before input into the WRF model. Simulation of vorticity during the development of typhoon Xangsane shows that the simulation with bogus wind provides better results than without bogus wind.

Acknowledgment

The first authors would like to thank the Rajamangala University of Technology Krungthep (RMUTK) for the scholarship and the Mathematical Department of King Mongkut's University of Technology Thonburi (KMUTT) for computer facilities.

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