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A DYNAMIC MODEL FOR BAROTROPIC VORTEX MOTION OVER TOPOGRAPHY ON A β PLANE

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1. INTRODUCTION

Strong barotropic cyclones over topography on a β-plane were investigated by a joint analytical and numerical approach. The motion of the vortices shows complicated track deflections associated with meandering Rossby wave wakes. The track deflections can be further explored by a dynamic model which predicts similar results to those observed from the numerical calculations and some historical typhoon trajectories encountering the Island of Taiwan.

2. THE DYNAMIC MODEL

For strong cyclonic vortices, i,e., Ro~O(1-10), assuming that there exist small variations of surface depression η^* and bottom topography h_B^*, a non-dimensional PV conservation relationship for strong cyclonic vortices can be written

$$D/Dt\left(\beta_0 y + \beta_B h_B - \beta_v \eta + \varsigma\left(1 + Ro\left(\beta_B h_B - \beta_v \eta\right)\right)\right) = 0 \quad (1)$$

where the non-dimensional beta parameters β_0, β_B and β_v, respectively, account for the planetary beta effect, elliptical-shape topography and the vortex depression. The proposed dynamic model predicts that at any instant, the velocity of the vortex

$$\vec{V} = \vec{V_c} + \vec{V_y} + \vec{V_B} \quad (2)$$

consists of three contributions: $\vec{V_c}$, the component without planetary beta and topographic effect, and two other component $\vec{V_y}$ and $\vec{V_B}$ as explained below. During a small time instant, assume that the surface depression and the relative vorticity *at the vortex core* are approximately unchanged. From Eq. (1), we can derive a *meridional adjusting velocity (MAV)* $\vec{V_y}$ of the vortex moving across the topographic gradient

$$\vec{V_y} = -\alpha\left(dh_B/dt\right)\vec{e_y} \ \textit{along the direction of } \vec{V_c} \quad (3)$$

where the topography-adjusting factor α is defined to be $\alpha = \left(1 + Ro\varsigma_c\right)\beta_B/\beta_y$, where ς_c is the relative vorticity at the vortex core. In the meanwhile, another *topographic-adjusting velocity (TAV)* $\vec{V_B}$ of the vortex is also induced while the vortex moving meridionally with an adjusting $\vec{V_y}$

$$\vec{V_B} = \frac{1}{\left|\nabla h_B\right|}\left(dh_B/dt\right)\vec{e_B} \ \textit{along the direction of } \vec{V_c} \quad (4)$$

where $\vec{e_B}$ represents the non-dimensional unit vector along the topographic gradient.

3. SHALLOW WATER SIMULATIONS

The numerical method used in the present study closely related to Helfrich et al. (1999). The rotating shallow water model (SWM) was numerically integrated using a public-domain, finite-volume code CLAWPACK by LeVeque (1998). The main feature of CLAWPACK is a Godnov-type finite volume method in which the Riemann problems are solved at cell interfaces to properly resolve the wave structure. The SWM calculations were performed with a grid of size 320×320. All the calculations were performed on a Cray J916 machine at a non-dimensional time

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step 0.016 and approximately 11.6 CPU seconds were required for a single time step.

4. RESULTS AND DISCUSSION

Figures 1(a)-(d) show a sequence of vorticity contours of the numerical simulation for a typhoon-like Rankine vortex on a beta-plane impinging upon a bell-shaped mountain with 2500 m height. The vortex moves to northwest due to the planetary beta effect and sheds secondary wakes at the downstream. Fig. 1(e) shows the comparison of the vortex tracks obtained from the SWM (circles) and the dynamic model (solid lines); the results are in close agreement with each other. Figure 2(a) shows a so-called *continuous- track* type of historical typhoons that encountering the Island of Taiwan as reported by Wang (1980). Fig. 2(b) shows that qualitatively similar tracks were observed from the dynamic model calculations. From the time series plots of the vortex drifting speed $\vec{V}$ as shown in Fig. 2(c), we discover an unsteady motion of *D-A-D-A* alternative type of motion, where ‘D’ denotes deceleration and ‘A’ represents acceleration.

5. CONCLUDING REMARKS

In summary, this study proposes a dynamic model which predicts the vortex speed under the influence of the planetary and topographic beta effects. The drifting speed $\vec{V}$ of the vortex in the proposed model consists of (i) the component without two kinds of beta effects $\vec{V_c}$, (ii) the meridional adjusting velocity (MAV) $\vec{V_y}$ and (iii) the topographic adjusting velocity (TAV) $\vec{V_B}$. The results predicted by the model compare very well with numerical calculations based on the SWM. Further application of the proposed model to typhoon vortices encountering the Island of Taiwan also shows very promising similarity in the vortex trajectories.

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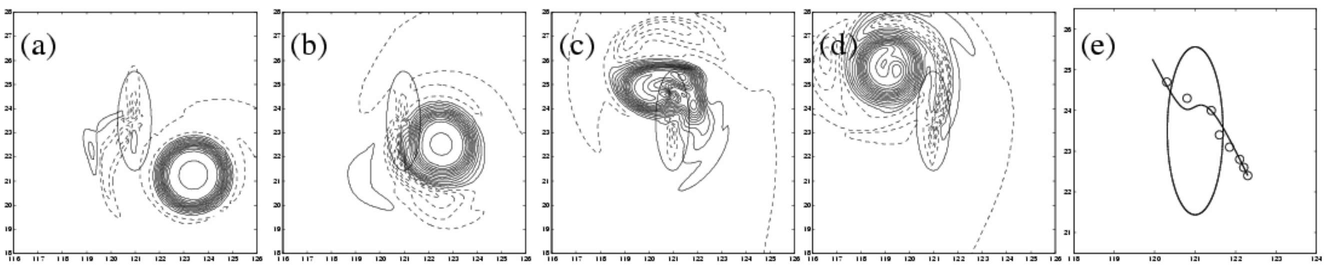

Figure 1 Comparison of shallow water simulation and the dynamic model results of vortex evolution over topography.

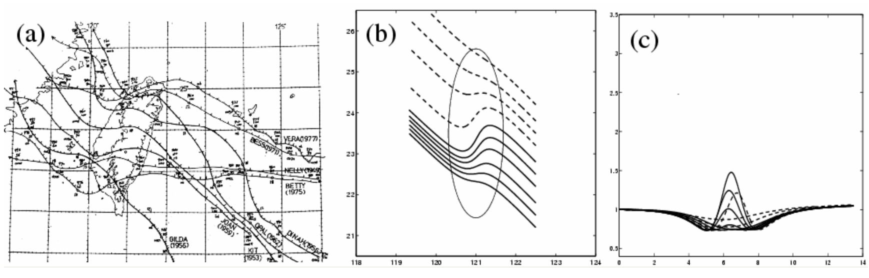

Figure 2 (a) Historical typhoons, (b) dynamic model results and (c) time series plots of the drifting speed of the vortex.