16.6 POTENTIAL VORTICITY DIAGNOSIS OF A SIMULATED HURRICANE

Xingbao Wang and Da-Lin Zhang
Department of Meteorology, University of Maryland, College Park, MD 20742

1. INTRODUCTION

Although the balanced dynamics of hurricanes have been well established by previous theoretical studies of inviscid, adiabatic flows, few has been done using real data due to the high non-ellipticity associated with intense anticyclonic shears outside the radius of maximum winds (RMW). In this study, the inner-core balanced dynamics of hurricanes is examined by applying a nonlinear balance (NLB) model to a high-resolution explicit simulation of Hurricane Andrew (1992) by Liu et al. (1997, 1999).

2. METHODOLOGY

Here, the non-ellipticity of the NLB system is alleviated by combining it with the potential vorticity (PV) equation. The axisymmetric tangential winds are first used to obtain the height field by solving the NLB equation, and the axisymmetric PV is then calculated from the balanced winds and heights. Since hurricanes are to a large extent axisymmetric, the perturbation PV, defined as a deviation from the axisymmetric PV, is one order of magnitude smaller than its axisymmetric component, the PV inversion algorithm of Davis and Emanuel (1991) is adopted to invert the three-dimensional perturbation wind and temperature of the hurricane. Finally, the divergent component of horizontal winds is obtained through the NLB Omega equation with incorporation of the diabatic heating and boundary layer effects.

3. RESULTS

Figs. 1a and 1b compare the vertical PV structures from the simulation to the inverted winds and geopotential heights. The small disparity, given in Fig. 1c, indicates that most of the simulated PV is well recovered by the inverted wind and height fields, even in the intense latent heating regions and in the boundary layer. This is in agreement with previous theoretical studies of the balanced flows associated with hurricanes.

Figs. 2a and 2b compare the tangential winds from the simulation to the PV inverted. Again, the PV-inverted recovers most of the features of the simulated, as shown by the small differences given in Fig. 2c. In both cases, there is a low-level jet in tangential winds (Figs. 2a,b). The low-level convergent inflow, upper level divergent outflow and strong updrafts in the eyewall are well described by the balanced dynamics. The magnitude of unbalanced winds is small and similar to that shown in Zhang et al. (2001). Relatively larger disparities occur in the boundary layer and between the 11-14 km altitudes due to the presence of strong friction and outflow divergence. The residual of removing the balanced component from the model-simulated shows that the centrifugal force in the vicinity of the maximum wind is unbalanced. Another important unbalanced feature is the compensating subsidence associated with latent heating. These unbalanced winds are more likely associated with inertial gravity and acoustic waves.

4. CONCLUSIONS

The above results show that most of the three-dimensional hurricane flows are quasi-balanced, and they can be recovered using the PV inversion technique. The divergent component, including the eyewall updrafts, the boundary-layer inflow, the upper-level outflow and descent in the eye are balanced to a fair degree. However, some unbalanced components are also present in the low-level jet, the boundary-layer inflow, the upper-level outflow, and the temperature inversion in the eye. The residual of removing the balance component from the model simulation is a good indication of such unbalanced features. In particular, the residual shows that the centrifugal force in the vicinity of RMW is unbalanced and obviously associated with the surface friction.

References

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Corresponding author address: Xingbao Wang, University of Maryland, Dept. of Meteorology, College Park, MD 20742;Email: xingbao@atmos.umd.edu

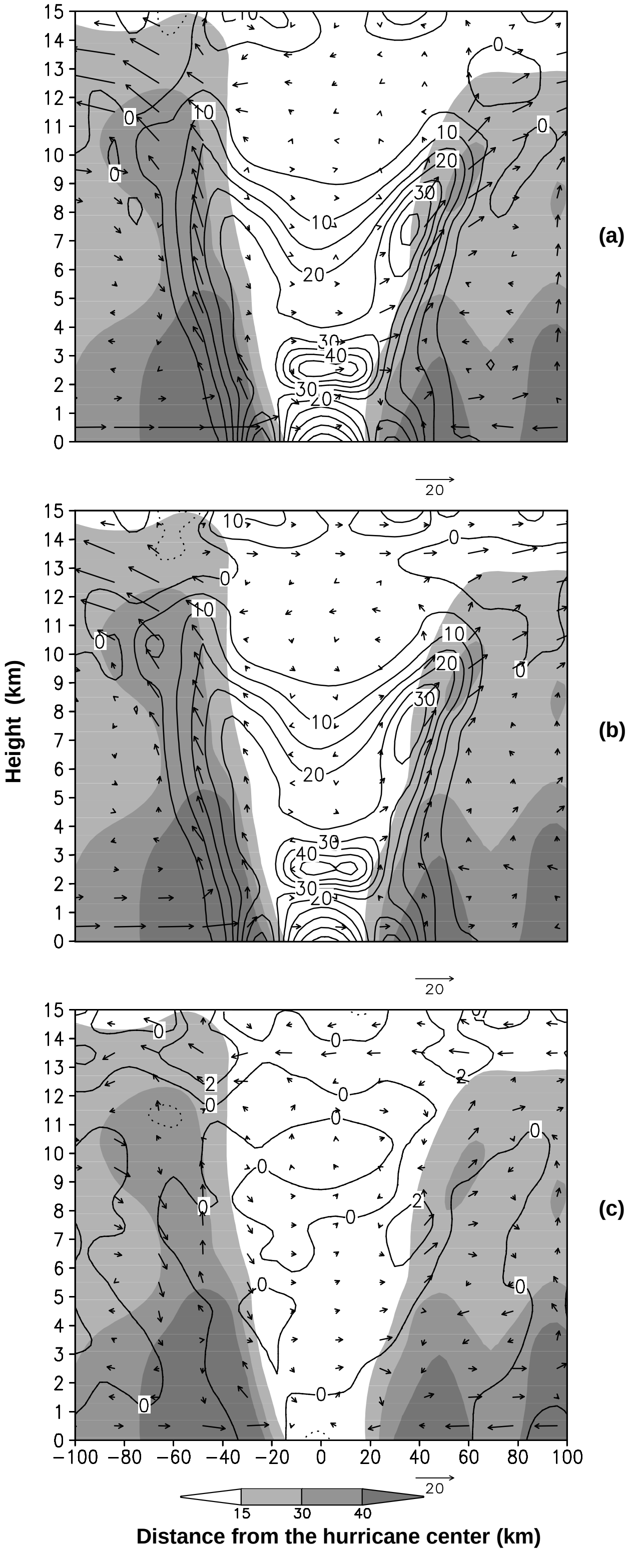

Fig. 1 West-east vertical cross sections of PV at intervals of 5 PVU, superposed with in-plane flow vectors and radar reflectivity (shaded with values larger than 15 dBZ) for (a) the simulated; (b) the NLB-retrieved; and (c) the difference between, i.e., (a) – (b). They are obtained by averaging 15 4-min. outputs from 60.5 to 61.5 h simulation.

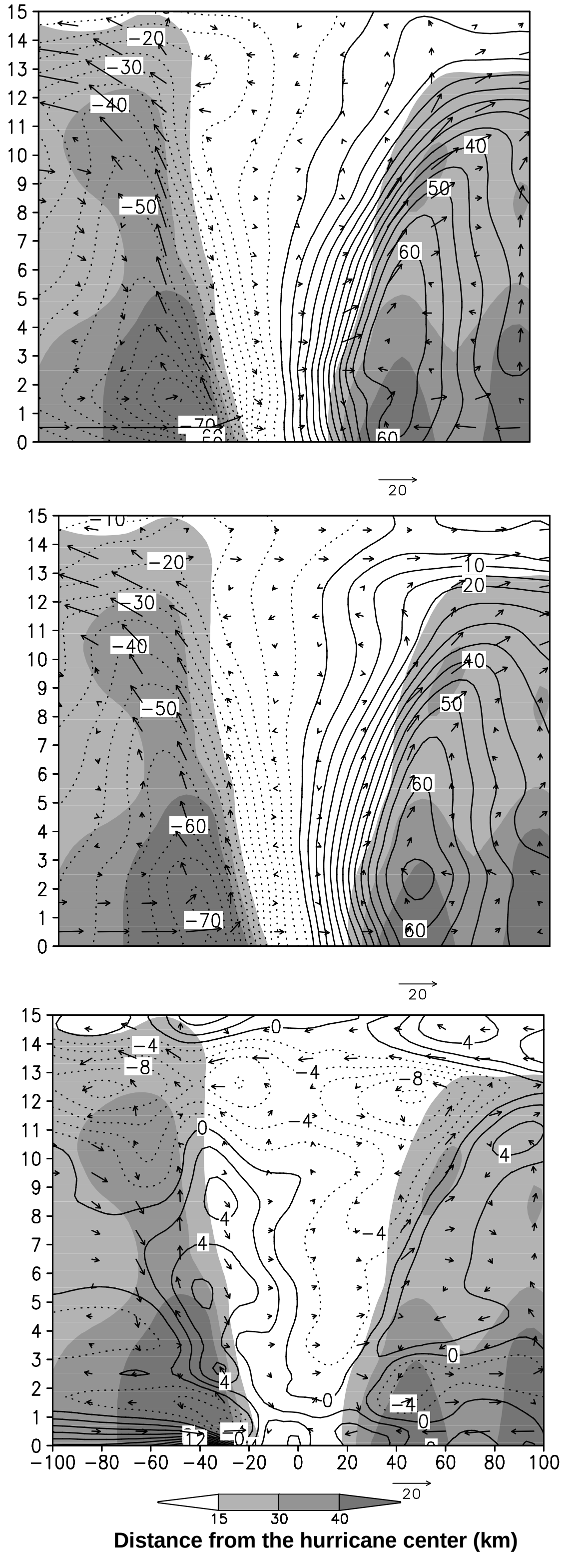

Fig. 2 As in Fig.1 except for tangential winds at intervals of 5 m s^{-1}. The contour interval in (c) is 2 m s^{-1}.