4A.3 ASYMMETRIC EYEWALL VERTICAL MOTION IN A HIGH-RESOLUTION SIMULATION OF HURRICANE BONNIE (1998)

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1. Introduction

Reasor et al. (2004) examined the tilting of a vortex by shear and found that a damping mechanism intrinsic to the dry adiabatic dynamics suppresses departures from an upright state. This realignment occurs through projection of the tilt asymmetry onto two types of vortex Rossby waves: sheared vortex Rossby waves, in which the radial shear of the swirling flow axisymmetrizes tilt asymmetries, and a quasi-mode, or discrete, vortex Rossby wave that, in the absence of damping, causes precession of the upper vortex until it realigns with the lower one (thereafter undergoing repeated cycles of tilting and realignment). With damping, the vortex achieves a downshear-left equilibrium tilt. This paper examines the role of a damped quasi-mode in producing asymmetric vertical motions in a high-resolution simulation of Hurricane Bonnie (1998).

2. Methodology

The MM5 model is used with nesting to 2 km. The simulation is started at 12Z 22 August 1998 and run for 36 hours. Physics options include the Blackadar boundary layer scheme, the Grell cumulus scheme (on the 36- and 12-km grids only) and the Goddard cloud microphysics. Radiative processes are calculated every five minutes. Initial and boundary conditions are obtained from ECMWF analyses and a bogusing technique using 4D-VAR assimilation is used.

3. Wavenumber 1 asymmetry in the eyewall

Figure 1 shows the 6-h (24-30 h) averaged fields of vertical motion and total precipitation mixing ratio at the 5 km level. Significant wavenumber 1 asymmetry is seen with maximum precipitation on the eastern side and maximum upward motions on the southeastern side of the storm. To investigate the effects of shear-induced vortex tilt, the center position at 8 km was determined at each time by estimating the centroid of the pressure field. The movement of the center at 8 km relative to that at the surface is shown in Fig. 2. An initially large tilt of ~12 km at 18 h is gradually reduced by half by 26.5 h as the upper center moves through two cyclonic loops. After 26.5 h, the tilt remains relatively small as the storm center at 8 km continues to loop in a generally cyclonic fashion downshear and slightly to the left of the shear vector. Figure 3 shows the azimuthal distributions of the radially averaged (30-60 km) wavenumber 1 upward motion and potential temperature anomaly at 5 km as well as the tilt azimuth at 8 km as a function of time for the period 18-36 h. The vertical motion and temperature asymmetries are determined with respect to the center location at 5 km. The maximum wavenumber 1 upward motion occurs on the east-southeastern side of the storm, is coincident with a cold anomaly, and is clearly occurring in the direction of tilt. Variations in the tilt of the vortex at 8 km are generally aligned with variations in the axis of peak wavenumber 1 upward motion and cold potential temperatures at 5 km. This alignment of the tilt, cold anomaly, and upward motion, as well as the damped looping motion of the upper vortex suggests that the vortex is approximately balanced and that the asymmetry is governed by the dynamics of the quasi-mode.

Many studies of adiabatic vortices in shear have shown that the maximum upward motion tends to occur 90° to the right of the tilt direction. Frank and Ritchie (1999) found that in diabatic vortices the maximum upward motion shifts to the downshear-left side. They suggested that grid-scale latent heating eliminates the downtilt temperature anomaly so that upward motion cannot be sustained to the right of the tilt. In the Bonnie simulation, however, temperature anomalies consistent with the tilt do form. It appears that the interaction of the mean vortex flow with these temperature anomalies produces weaker forcing for vertical motion than the more direct effects of the tilt. For example, assuming that the magnitude of the temperature anomaly is strongest at midlevels, the mean vortex flow moving through this anomaly field will produce vertical motion that peaks at those levels. Since this vertical motion is relatively far removed from the boundary layer, deep convection is less likely to occur. In contrast, if the tilting of the vortex produces low-level convergence and upper-level divergence in the downtilt direction, then deep convection with roots in the boundary layer can occur that results in strong upward motion in that direction.

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References

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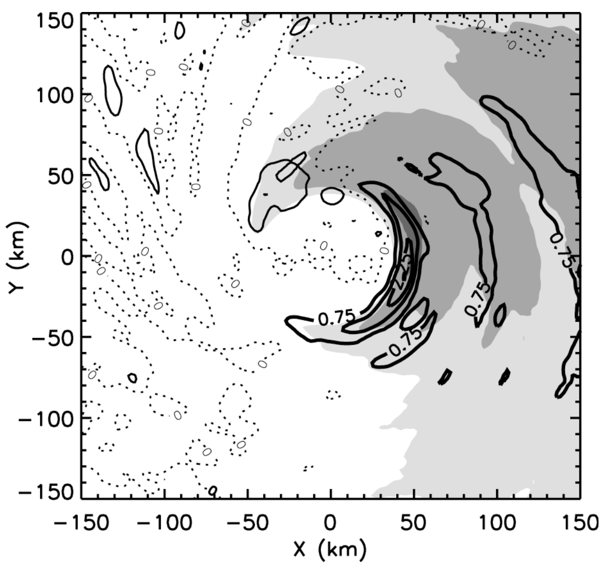

Figure 1. Time-averaged total precipitation mixing ratio (q_p, shading) and w (contours) at 5 km MSL. Contours for q_p at 0.5, 1, 2, 3, and 4 g kg^{-1} and w at intervals of 0.75 m s^{-1} for updrafts (thick solid lines) and 0.25 m s^{-1} for downdrafts (thin solid lines). The zero contour is indicated by dotted lines.

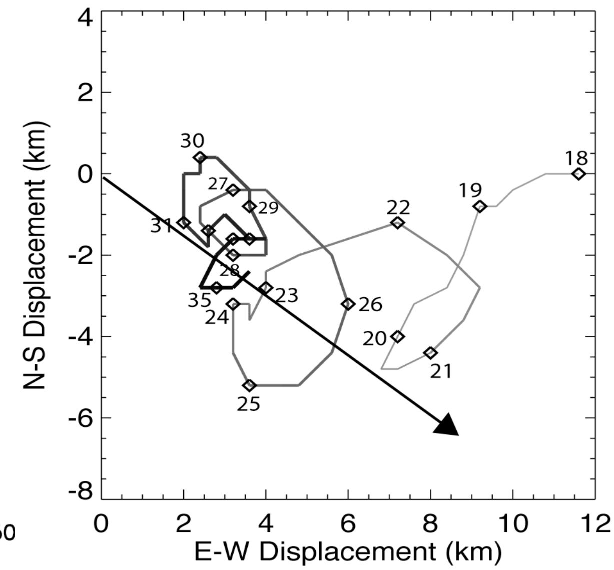

Figure 2. Displacement of the storm center at 8.2 km from the surface center for the period between 18-36 h. Time is indicated by the numbers while the line gets thicker and darker with time. The arrow indicates the direction of the 850-200 mb shear vector .

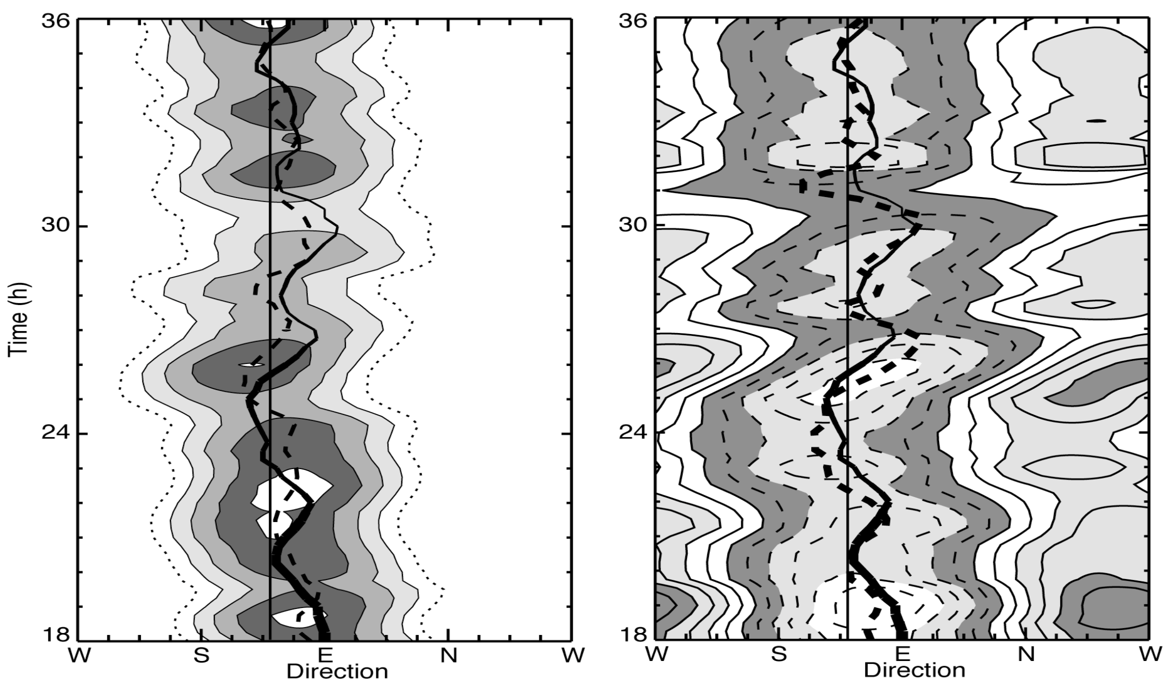

Figure 3. Time-azimuth distributions of wavenumber-1 (a) vertical motion and (b) potential temperature anomaly averaged between radii of 30-60 km. In (a), updraft contours are drawn at an interval of 0.25 m s^{-1} with the zero contour indicated by the dotted line. The dashed line shows the axis of peak wavenumber 1 upward motion or cold temperature anomaly. In (b), the contour interval is 0.3 K with positive (negative) values indicated by solid (dashed lines). The solid curve in (a) and (b) shows the direction of vortex tilt, with the thickness of the line proportional to vortex tilt (thicker for larger tilt). The solid vertical line indicates the direction of the 850-200 mb shear vector.