4A.1 TROPICAL CYCLONES IN COMPLEX VERTICAL SHEARS

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1. Introduction

It is well known that the intensity and structure of a tropical cyclone is modulated by the environment in which it is embedded. Large-scale factors that include high mid-level moisture and weak vertical wind shear are well-known, necessary conditions for a tropical cyclone to form (Gray 1968). Whereas high vertical wind shear and intrusion of dry air into an incipient tropical cyclone is likely to inhibit further development, the effects of adverse environments on mature storms is less obvious although it is generally presumed that they would be detrimental to maintenance of intensity.

Numerical studies have clearly documented a relationship between simple structured, environmental vertical wind shear and subsequent simulated tropical cyclone intensity change (Frank and Ritchie 1999; 2001). These studies show that when unidirectional shear is applied to a simulated mature storm, weakening occurs (measured by a rise in the central pressure). Furthermore, the amount of and time lag until weakening occurs is directly related to the strength of the shear.

Preliminary calculations indicate that the environmental shear is rarely unidirectional, nor is it pointing in the same direction as the tropical cyclone motion vector. More complicated vertical shear structure may have a more radical effect on the development of convection in the eyewall that appears to be so important for maintaining the tropical cyclone intensity.

In this study we examine the interactions between the tropical cyclone core and an environmental wind that either changes direction with height, or is pointed in a direction other than that along the motion vector. Specifically, we examine the case where the vertical wind shear is 90 degrees to the track of the tropical cyclone and compare that with previous results of shear cases where the shear vector is at an arbitrary angle to the motion vector.

2. Experimental Setup

The numerical model used in this study is the PSU/NCAR Mesoscale Model, Version 5 (MM5). The idealized environment includes a uniform sea surface temperature of 28.5 deg C and variable f. The initialization procedure is described in Frank and Ritchie (2001). Briefly, a tropical-depression-like vortex is allowed to develop for 48 hours in a zero-flow environment until it reaches hurricane intensity. At that point the vertical wind shear environment is added and the pressure and temperature fields are adjusted to balance the winds and pressure gradients. The vertical shear pattern is as used by Frank and Ritchie (2001), and the shears used in this study have a total wind velocity change of 15 m/s. The run illustrated below is for 90 degree cross-track shear. The results of this run are compared with previous cases of easterly and westerly shear (Frank and Ritchie 2002), where the total shear vector is at an arbitrary angle (10 – 30 deg for easterly and 70 – 90 deg for westerly) to the motion vector. The shears used in this study have a total initial wind velocity change of 15 m/s.

3. Results

The conceptual model developed in Frank and Ritchie (2001) was that the response of a tropical cyclone to shear results primarily from the tendency for the shear to advect potential vorticity (PV) downshear at higher levels. The dynamic response of the vortex causes convergence directly downshear of the center, and this leads to upward motion and rainfall downwind (i.e., to the left of the shear vector). Thus, a storm moving toward the west, with easterly shear over the center would tend to have maximum rainfall on the south side.

One result noted by Frank and Ritchie (2002) was that there was a link between the strength of shear, the resulting asymmetry of the rainfall pattern, and the tendency of the tropical cyclone to intensify or weaken. Figure 1 shows schematically the net shear and shear-induced vertical velocity patterns in the lower troposphere that would be expected for the beta-induced shear, easterly, westerly, and cross-track cases. For cross-track shear the net shear vector (beta-shear plus cross-track shear) points towards the southwest (Fig. 1a) and should induce maximum convection and rainfall on the south to southeast side of the storm. In general, the location of the rainfall maximum tends to occur about 45 degrees counterclockwise (downwind) of the location of the maximum updraft and cloud water areas. However, the locations of the rainfall maxima vary with time within a broader area covering about half of the eyewall cloud. The single most stationary feature of the asymmetry of the secondary circulation in the eyewall is the weak-echo region, which often appears as a break in the eyewall cloud. The beta-induced case (Fig.1b), easterly (Fig.1c) and westerly (Fig.1d) cases are as discussed in Frank and Ritchie (2002).

Figure 2 shows the minimum central pressure on domain 2 for the easterly, westerly, and cross-track shear cases. The pressure trends follow the above reasoning. The westerly shear case has the largest shear and strongest rainfall asymmetries (Fig. 3a), and weakens the most in 48 hours of integration. The beta-induced shear case has the least shear, the smallest asymmetry (not shown), and the greatest intensification. The cross-track and easterly shear are very similar in both their asymmetry strengths (Figs 3b and 3c respectively) and their intensification trends (Fig. 2).

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4. References

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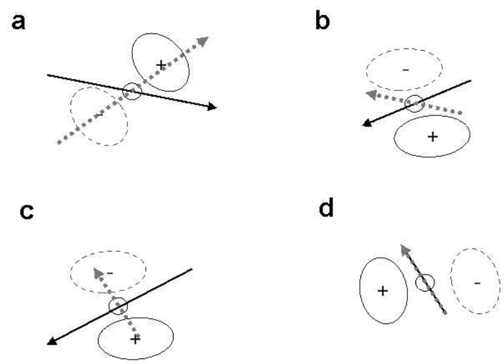

Figure 1. Expected shear and vertical motion patterns for a) the westerly shear case; b) the easterly shear case; c) the crosstrack shear case; and d) the beta-induced case. The solid black arrows indicate the direction of shear, and the green dashed arrowa indicate the direction of motion of each tropical cyclone.

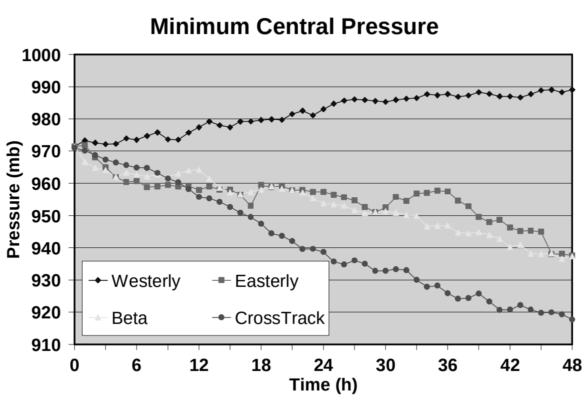

Figure 2. Time series of the minimum surface pressures for all four shear-induced cases.

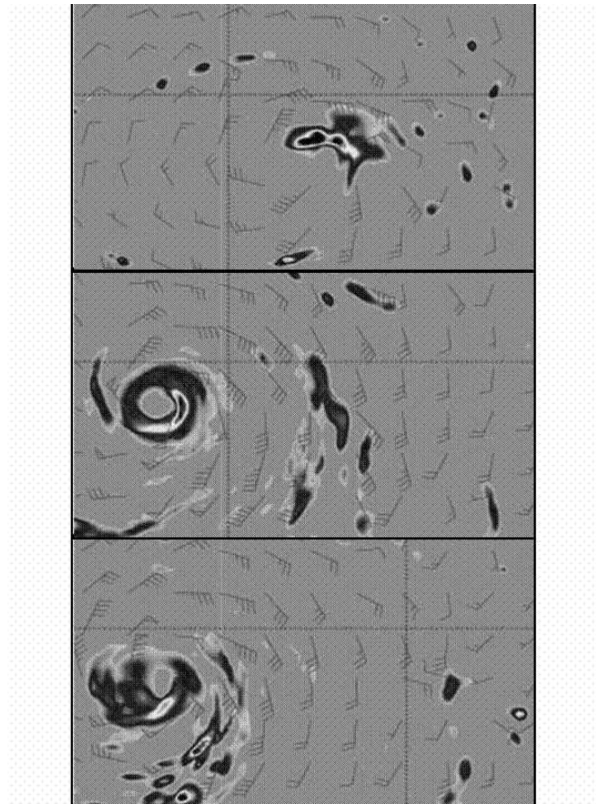

Figure 3. Three-hourly rainfall pattern at 24-h of integration for a) the westerly shear case; b) the crosstrack shear case, and c) the easterly shear case.