4C.6 A CLOSER LOOK AT VORTICAL HOT TOWERS IN A TROPICAL CYCLOGENESIS ENVIRONMENT

Andrea B. Saunders*
Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

Over the past several decades there has been considerable interest in determining what mechanisms are responsible for the transformation of a midlevel mesoscale convective vortex (MCV) into a tropical cyclone. It is a generally accepted fact that convection plays an important role in tropical cyclone intensification, yet convective-scale processes are absent from many current tropical cyclogenesis theories. Given the numerous observational studies indicating that deep convective blow-ups are a precursor to tropical storm formation (eg. Zehr 1992), we believe one must consider the role of emergent convective structures in the spin-up process.

2. A VORTICAL HOT TOWER PATH TO TROPICAL CYCLOGENESIS: AN OVERVIEW

Using the non-hydrostatic CSU RAMS, Montgomery et al. (2003, hereafter M03) ran near cloud-resolving experiments to investigate tropical cyclogenesis from a single initial midlevel MCV embedded within a moistened tropical environment. The time period before tropical cyclone formation ($t < 24$ h) was dominated by nearly continuous deep convective activity. Using a modified version of the Sawyer-Eliassen equations, M03 determined the toroidal circulation that would be induced by diabatic heat released by deep convection, as predicted by Eliassen's balanced vortex theory. This toroidal circulation consists of an azimuthal mean radial inflow at low- and mid-levels. This mesoscale inflow acts to converge planetary and MCV-related vorticity, leading to an increase in the azimuthal mean tangential wind field at low levels and thus the development of a surface concentrated mesoscale vortex. These predicted changes in the mesoscale wind fields are qualitatively and quantitatively similar to the changes observed in the model's azimuthal mean vortex fields.

M03 used quasi-balanced dynamics to describe the system-scale evolution. This theory, however, hinges on the assumption that convective latent heat release is occurring in a quasi-steady fashion on the system scale. Given the fact that the first 24 hours of the control simulation are dominated by nearly continuous deep convective activity, this is a reasonable assumption. However, a variety of sensitivity trials were run in which this is not the case. For example, an experiment was run without the initial MCV. This experiment ceased to have any convective activity after $t = 4$ h and failed to develop a mesoscale surface circulation after 72 h. Here we investigate which conditions, present in the control simulation yet absent in the experiment run without an initial MCV, are responsible for deep convective activity.

3. PRELIMINARY HYPOTHESES FOR VHT LONGEVITY

There are two factors that contribute to the continuous deep convective activity noted above: long-lived individual hot towers and/or continual convective redevelopment. Let us consider the first influencing factor. A typical hot tower lifetime in our control simulation is found to be on the order of an hour, with some individual VHTs being tracked for as long as 3 h. Upon hot tower formation, the updraft tilts the ambient horizontal vorticity of the initial MCV into the vertical, and a vorticity dipole is observed centered about the updraft core. As the hot tower intensifies, vortex tube stretching by the updraft core greatly intensifies the positive convective vorticity anomaly. Our model hot towers were found to have positive absolute vertical vorticity ($f + \zeta \approx$ 30–40 $\times 10^{-4}$ s^{-1}) values associated with them. These "vortical" hot towers, or VHTs, were also observed in the MM5 model simulations of Hurricane Diana documented in Hendricks et al. (2004).

M03 discusses several consequences that heightened vorticity can have on hot tower structure. First, the increased vorticity in the vicinity of the hot tower will increase to local inertial stability. This increased stability will help keep the latent heat released in the updraft core from propagating away via inertia-gravity waves, and hence should increase the effectiveness of the hot tower as a local heat source. The heightened inertial stability should also reduce midlevel entrainment of cooler, drier air. If these predicted impacts hold true, we would hypothesize that VHTs should experience longer lifetimes than their less vortical counterparts.

4. MESOSCALE ENVIRONMENT'S IMPACT ON VHT STRUCTURE AND LONGEVITY

We tested the above hypothesis that vorticity will increase a VHT's longevity through a series of sensitivity trials examining the first convective burst initiated at $t = 20$ min. The sensitivity trials were run with the same thermodynamic profiles as the control. The first trial omitted the initial MCV and the second omitted the MCV and increased planetary vorticity over the domain by a factor of 10 (ie, $f = 3.77 \times 10^{-4}$ s^{-1}) . The initial updraft in the control

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* *Corresponding author address:* Andrea B. Saunders, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371; saunders@atmos.colostate.edu

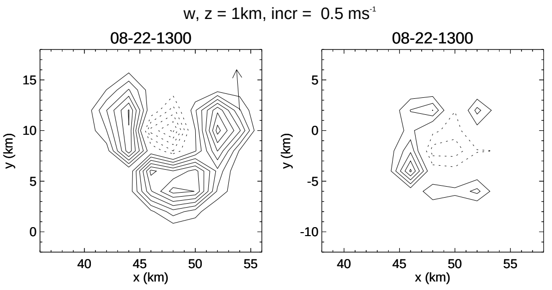

Figure 1: Vertical velocity at $z = 1$ km for initial updraft just after peak in control (left) and 2 sensitivity trial (right). Solid = positive, dashed = negative, contour intervals 0.5 ms^{-1}. Arrow in upper righthand corner is the average vertical shear vector (control only).

simulation experienced a significantly longer lifetime than in the first trial without and initial MCV. At first glance, this finding appears to confirm our hypothesis. The second trial developed a highly vortical hot tower, yet this VHT had a much shorter lifetime than either of the previous two hot towers. Hence, it appears that vorticity alone is actually detrimental to the updraft's longevity. Could it be that the same vorticity-induced stability that serves to protect the updraft core at midlevels is inhibiting low level inflow that the hot towers need to sustain themselves? These results suggest that the relationship between vorticity and hot tower longevity is not as simple as we had originally thought.

5. HOW DOES THE MCV ENVIRONMENT CONTRIBUTE TO QUASI-STEADY CONVECTIVE ACTIVITY?

The abundance of VHTs in the control simulation suggests that the combination of the horizontal wind and vorticity fields of the initial MCV is conducive to the formation and sustenance of long-lived VHTs. The most notable difference between the physical structure of VHTs in the MCV environment versus the still environments is the presence of a downshear tilting with height. This tilt displaces the downdraft downshear of the updraft core (Figure 1, left). The VHTs in the still environments appear to be vertically upright, so their downdrafts occur in the center of their updraft cores (Figure 1, right). The former orientation reduces contamination of the updraft core by the colder, drier air of the downdraft, and is thus the preferred scenario for increasing updraft lifetimes.

Until now, we have focussed on the effects of vorticity on individual hot tower lifetimes. Another factor contributing to quasi-steady convective activity is convective redevelopments. In the control, new convection is continually forming in the vicinity of existing convection. The still-environment sensitivity trials experience at most one convective redevelopment, with no further deep convection. The first theory as to why these developments occur in the MCV environment is coldpool lifting. The MCV wind field results in the relative flow across the VHTs at low levels, which may be converging at the coldpool boundary and spawning new convection. However, the coldpools in our study are relatively weak, with potential temperature deficits ranging from 0.6–1.0 K below the environmental value. In looking at a few cases early in the simulation, it appears that convective redevelopment is favored downshear-left of an existing updraft. Although on a much smaller scale, this observation is consistent with the preferred convective region for a hurricane-like vortex (Reasor et al. 2003, Braun et al. 2003). Further investigation is necessary to determine if these mechanisms are acting in our simulations.

6. CONCLUSIONS

The results presented here indicate that vorticity influences the structure of convective hot towers. The exact nature of this influence is complex, and dependent upon a number of other environmental factors. We have presented several ways in which the MCV environment may modulate deep convective activity, and thus alter its role in the tropical cyclogenesis process. Further investigation, through higher-resolution model simulations and an observational field campaign, is needed to test these hypotheses. Until we fully understand the role of deep convection, or more specifically the vortical hot tower, in the tropical cyclogenesis process, we cannot consider any theory complete.

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7. REFERENCES

Braun, S. A., M. T. Montgomery and Z. Pu: High-resolution simulation of Hurricane Bonnie (1998). Part I: The organization of vertical motion. *J. Atmos. Sci.*, , submitted Sept. 1, 2003

Hendricks, E. A., M. T. Montgomery and C. A. Davis, 2003: On the role of "vortical" hot towers in tropical cyclone formation. *J. Atmos. Sci.*, , to appear

Montgomery, M. T., M. E. Nicholls, T. A. Cram and A. B. Saunders: A vortical hot tower route to tropical cyclogenesis. submitted Dec. 4, 2003

Reasor, P. D., M. T. Montgomery and L. D. Grasso, 2004: A new look at the problem of tropical cyclones in vertical shear flow: vortex resiliency. *J. Atmos. Sci.*, , **61**, 3–22

Zehr, R., 1992: Tropical cyclogenesis in the western North Pacific. NOAA Tech. Rep. NESDIS 61, 181