6D.6 A NUMERICAL INVESTIGATION OF SLABULAR CONVECTION AND MOIST ABSOLUTE INSTABILITY IN HURRICANE ISABEL

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1. INTRODUCTION

Observational and modeling studies have shown that the atmosphere sometimes convectively overturns in a manner resembling mesoscale slabs or sheets of air as opposed to individual convective cells (Thorpe et al. 1982, Rasmussen and Rutledge 1993, Liu and Moncrieff 1996, Bryan and Fritsch 2000, and James and Fritsch 2003). These slabs are associated with strong mesoscale ascent, typically caused by dynamic forcing such as that found along mid-latitude surface-based outflow boundaries and fronts. The slabs appear on radar as contiguous swaths of uniformly high reflectivity and often extend for tens (hundreds) of km in the along (cross)-flow directions. In some instances, the mesoscale forced ascent can create moist absolutely unstable layers (MAULs) that extend for hundreds of km horizontally and several hundred hPa vertically (Kain and Fritsch 1998, Bryan and Fritsch 2000, and Rogers and Fritsch 2001). Bryan and Fritsch (2000) have shown that, in these situations, dynamically forced mesoscale vertical motions exceed those produced by buoyancy, causing the rate of moist convective overturning to be too slow to remove the instability.

Unlike the typical mid-latitude squall line, a tropical storm may not contain a powerful cold-pool lifting mechanism. Nevertheless, strong mesoscale ascent can still occur owing to low-level convergence into the spiral bands and the eyewall. Moreover, since temperature differences between the ascending parcel and the environment are typically smaller than in mid-latitude squall line situations, the potential for the mesoscale ascent to exceed the vertical motions produced by buoyancy is enhanced. Therefore, it is hypothesized that slab convection and moist absolute instability exist in the spiral bands and eyewall region of tropical systems. To examine this possibility, a high resolution (Δx = 250m) simulation of Hurricane Isabel was performed.

2. MODEL CONFIGURATION

A multi-nested and multi-model configuration is used to produce a high-resolution simulation of Isabel during the 14th and 15th of September 2003. The outermost domains are provided from the real-time MM5 tropical storm forecasts made by the Penn State Center for High-resolution Applied Regional Modeling (CHARM). The MM5 is configured with 30 vertical levels and includes four nested domains over the tropical region of interest with horizontal grid spacing of 135, 45, 15, and 5 km. Using the 5 km domain provided by CHARM, an additional higher resolution (Δx = 1 km) domain was generated and a 15-hour simulation over a 1000 by 1000 km region encompassing Isabel was conducted.

The 1 km output from the MM5 was used to provide initial and lateral boundary conditions (10 minute intervals) for the highest resolution simulation, performed using the compressible cloud model (CM1) developed and described by Bryan and Fritsch (2002). The idealized model was modified to include surface fluxes and to ingest initial and lateral boundary conditions from the MM5. The model was configured with a horizontal grid spacing of 250 m extending over 2200 x 2200 grid points (550 km), and vertical grid spacing of 250 m up to approximately 10 km and 500 m up to 20.5 km (60 vertical levels). The fine resolution is desirable since Bryan et al. (2003) have shown than grid spacings on the order of 100 m are necessary for the turbulence closures to be appropriate. The model was integrated for six hours starting at 2200 UTC 14 September 2003.

3. RESULTS

Figure 1 shows the simulated reflectivity at the lowest model layer (125 m) four hours into the simulation. The storm is asymmetric with several swaths of reflectivity greater than 40 dBZ along the eyewall and spiral bands. Figure 2 illustrates a model sounding located in the primary band at 0200 UTC 15 September. The sounding shows a deep saturated environment with approximately 1500 J of convective available potential energy. A deep layer of saturated absolutely unstable air extends from just above the surface to 635 hPa. This 3500 m deep MAUL is generated and maintained by low level mesoscale vertical velocities ranging from 3-7 m/s through the layer. Similar soundings can be found in all quadrants of the storm, with MAULs often found upstream of the areas with the deepest convection.

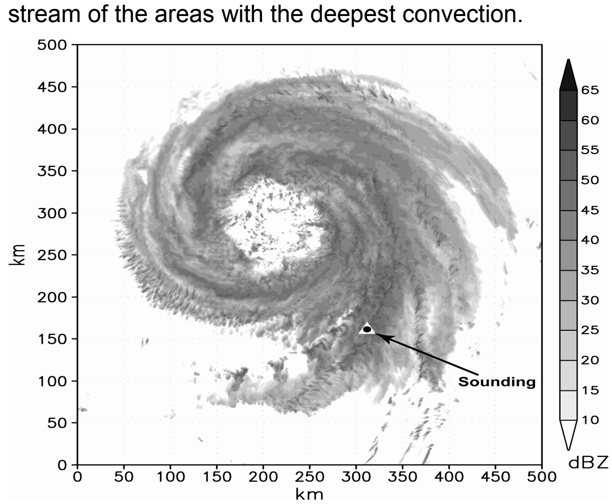

Figure 1. Simulated lowest level (125 m) reflectivity (dBZ) in hurricane Isabel at 0200 UTC September 15 2003.

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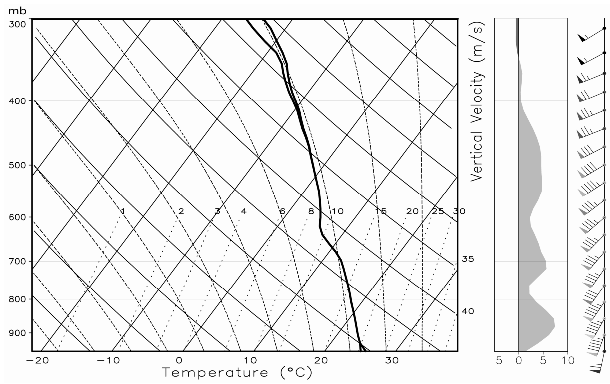

Figure 2. Model skew *T*-log *p* sounding and vertical velocity at 0200 UTC September 15 2003. The sounding location is shown in Fig. 1.

In order to examine the mean mesoscale extent of the MAUL regions, it is advantageous to filter the primitive variables in time and space. The data are averaged every 15 minutes from 0000 to 0100 UTC 15 September while maintaining a continuous frame of reference relative to the center of the hurricane. A Fourier transform and a wave cutoff filter are used to remove all wavelengths less than 4 km. From the filtered output, the equivalent potential temperature θ_e is calculated (Bolton 1980), and the moist absolutely unstable layers found. A layer is considered moist absolutely unstable if the vertical gradient in θ_e is negative and there is saturation (cloud water > 0.1 g/kg). Figure 3 illustrates the depth of the deepest MAUL within the column. Not surprisingly, MAULs exist in the core region of the hurricane as well as in the outer spiral bands, but they are deep over a far more extensive area than is observed in mid-latitude convective systems. The largest region of instability is located southwest of the storm center, where the MAUL depths frequently exceed 2 km. To better examine this region, a cross section (white line in Fig. 3) was extracted (Fig. 4). It is clear that MAULs (extending from 1 to 4 km) are present over much of the cross section.

The depth of MAULs are substantially reduced if stability is diagnosed using the saturated Brunt Vaisala frequency (Durran and Klemp 1982). As in other tropical environments, the distinction between pseudo-adiabatic and reversible thermodynamics appears to be important (Xu and Emanuel 1989).

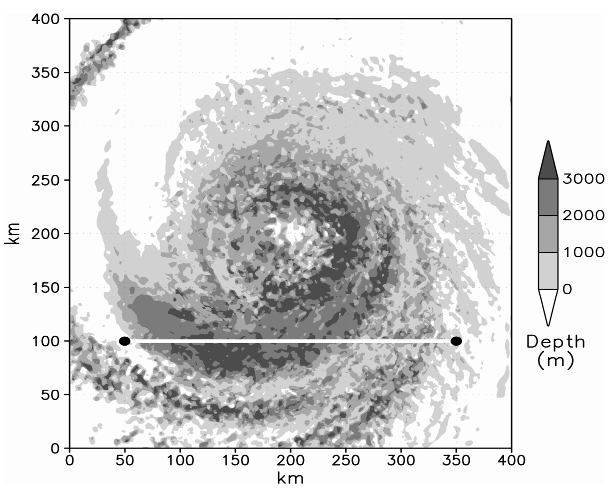

Figure 3. Depth (m) of the deepest moist absolutely unstable layer.

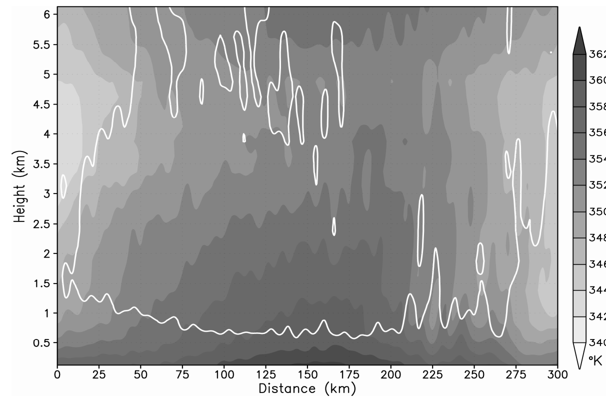

Figure 4. Cross section (see Fig. 3) of equivalent potential temperature θ_e (shaded) and cloud water (white line). The white contour encloses the saturated (>0.1 g/kg of cloud water) region.

The time evolution of the MAULs and corresponding reflectivity field (not shown) reveal what appears to be a correlation between MAUL development and deep convection, i.e., large regions of moist absolute instability precede the generation of new convective bands with reflectivities exceeding 50 dBZ. This occurs along the inner eyewall as well as along the outside of the spiral bands. While MAULs in mid-latitude convective systems require convection to initiate the cold-pool lifting mechanism, little or no convection is needed prior to the genesis of MAULs in tropical systems.

4. CONCLUDING REMARKS

Moist absolutely unstable layers were found in many portions of a high-resolution simulation of Hurricane Isabel. Most commonly, the layers formed in association with spiral bands and the eyewall, were typically from 1 to 3 km deep, and extended over much of the core region of the hurricane. Also, upstream regions of moist absolute instability appeared to precede the development of deep moist convection.

Although moist absolutely unstable layers have been observed in many mid-latitude mesoscale convective systems, little is known about how they affect the dynamics of the systems. Likewise, this simulation of Isabel suggests that MAULs exist over large mesoscale regions within tropical storms but their importance in tropical cyclogenesis and storm evolution is not well understood. It is important that research continue to examine the persistent nature of moist absolute instability in regions of strong low-level inflow in tropical systems. Comparing the strength and areal extent of MAULs between a strengthening and a weakening hurricane may provide the key to understanding the importance of moist absolute instability in the development of deep moist convection and quite possibly storm intensification.

5. REFERENCES

http://analog1.met.psu.edu/ross/hurricane/reference.html