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THE SENSITIVITY OF MODELED HURRICANES TO THE DISTRIBUTION OF VERTICAL SIGMA LEVELS

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1. INTRODUCTION

In the course of studying the development of idealized modeled hurricanes, a correlation between vortex evolution and vertical resolution became apparent. This has led to a study into the sensitivity of the intensification of a hurricane (as measured by minimum sea-level pressure, or PSMIN) to the spacing of the model's vertical levels. Unlike the horizontal grid spacing which has to remain constant in space, most models allow for sigma level spacing to vary in the vertical dimension. Conventionally, higher concentrations of sigma levels are chosen in meteorologically active regions, such as the planetary boundary layer (PBL), and the upper levels where the jet stream occurs. While studies have been performed as to sensitivity of hurricane evolution to horizontal resolution, less has been done regarding the vertical spacing of the vertical levels.

2. MODEL CONFIGURATION

The Penn State/NCAR mesoscale model, MM5, is used with a two-way nested grid configuration. The coarse grid (200 x 200 points) horizontal resolution is 15 km; that of the inner grid (103 x 103 points) is 5 km. Convection is modeled explicitly on the inner mesh, while on the outer mesh the Betts-Miller scheme is used. Micro-physics is modeled using the Reisner graupel scheme and includes snow, super-cooled water, graupel, and ice number prediction equations. Time dependent boundaries are used on the nested grid and relaxation boundaries are used on the large scale grid. The distribution of the 24 vertical levels is varied (section 3). An artificial vortex is constructed via the method described in Kimball and Evans (2002). The boundary temperature, moisture values, and sea level pressures are based on a 12 UTC 19 July 1997 Gulf of Mexico sounding. The sea surface temperature (SST) is constant and uniform and has a value of 28^0C. An f-plane, defined at 20^0N, is used. The initial vortex has a radius of maximum winds (RWM) of 135 km and a maximum wind value of 20 ms^{-1}.

3. SIMULATIONS

Figure 1 shows the sigma distributions used in this study. The o experiment clustered the sigma levels at the lower and upper regions of the troposphere. Three other distributions (c, s, and d) were based on the assumption that the sigma values would be best utilized in the PBL. Additional distributions were created to test various hypotheses as to the importance of sigma clustering in the jet stream layer (u), the middle region (m), and an even distribution throughout the field (e). One additional distribution using constant height intervals, from which sigma values were determined, (z) was also tested.

4. RESULTS

Figure 2 shows the evolution of PSMIN for the eight cases. In all cases, asymmetries developed over time leading to the eventual demise of the storms. This issue will be investigated at a later date.

Using the initial thermodynamic state of the model atmosphere, a theoretical maximum potential intensity (MPI) of 907mb was calculated (Emanuel, 1988). None of the simulations made it to the MPI except the two distributions where most of the sigma levels were concentrated in the upper atmosphere near the hurricane outflow layer (u and z). These storms deepened beyond the MPI to 895 mb. A strong outflow layer helps to maintain atmospheric instability and thunderstorm formation in hurricanes, the latter providing the storm's fuel. Therefore, this result seems consistent with hurricane physics. However, it is believed that hurricanes also need a strong inflow layer to supply warm, moist air to maintain the thunderstorms. It would seem logical, then, that simulations with high concentrations of sigma levels in the PBL would also produce intense hurricanes. Our results in Figure 2 showed that this did not hold true. A simulation with a reasonable concentration of sigmas in both the lower and upper levels (o) came closer to the MPI than ones with more sigmas concentrated in the lower levels, but a low concentration in the upper levels (c and s). Therefore, a well-resolved outflow would seem more important than a well-resolved inflow, but the distribution that had few values in either of the two layers but many in the middle of the field (m) matched the o distribution intensity. The d distribution clustered more sigmas in the PBL than the o case and had an even distribution through the remainder of the field, but its MPI was higher than that of the o or m distributions. Lastly, the e distribution with a similar sigma distribution in the PBL as o but with values distributed evenly through the middle of the field did better than the c and s simulations, but not as well as the m or o simulations. These results seem very contradictory to the theory that high equivalent potential air is imported via the inflow layer to fuel the storm.
Figure 3 shows the 8 sigma distributions transformed to altitude in meters. This changes the image of the

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distribution. It spreads out the upper levels and compresses the levels in the PBL. With the vertical levels displayed in this manner, the MPI behavior seen in Figure 2 seems more consistent with hurricane intensification theories. When both the outflow and the inflow are resolved adequately (u and z) the storm intensifies to its MPI. When only the inflow is well resolved (c, s, d, and e), the storm does not develop to its MPI. The o distribution has clustering in the PBL and a reasonable distribution in the upper atmosphere, yet the storm does not reach the MPI. The m distribution seems to be an anomaly; the distribution in the lower half of the troposphere is similar to u or z, but it would seem to be inadequate in the upper reaches. Yet the storm intensity is the same as the o distribution, and neither reached the predicted MPI.

The secondary circulation and the thermal structure in the eye seemed to agree with the intensity rankings. The outflow jet was very strong in both the u and z simulations; the o and the m cases were weaker but still reasonable during the development period, although the outflow weakened over time for the m results. The d simulation developed a weaker outflow. The c and e simulations had very weak outflows, and the s simulation showed minimal outflow development. The development of the inflow layer followed a similar pattern: the inflow layer was very strong in the u case. The development of the inflow layer in the z storm was slower, but it eventually had nearly the same strength as the u simulation. The inflow layers in the d and o simulations were initially stronger than those in the m and z simulations but in time all reached approximately the same values. The e and c computations barely showed the development of an inflow layer, and the s inflow layer was the weakest of all 8 storms. The warm core structure was consistent with the intensity of the secondary circulation in each case.

The preliminary conclusions to this study would appear to go against conventional wisdom. The distribution of vertical levels should be viewed with respect to altitude rather than sigma levels. Good resolution in both the jet stream layer and the PBL seems to be conducive to strong intensification (u and z), although the number of levels in the PBL is less than the convention. There appears to be a problem when there are too many points in the PBL with respect to height when coupled with few levels aloft (c, s, e, and d). This problem can be partially offset by more levels in the upper atmosphere (see o and to a lesser extent d). The m distribution remains something of an anomaly; it has good coverage in the mid-troposphere without too many PBL levels, but few levels aloft. Yet its intensity is closer to the MPI than most of the other computations. A new question is raised: are too many points in the PBL detrimental to storm development and, if so, why? A possible explanation might be that dry air intrusion is exacerbated by an overly resolved inflow.

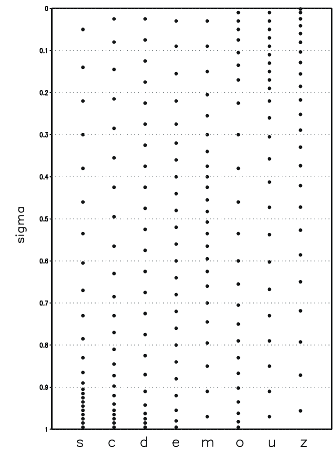

Figure 1: Sigma distributions.

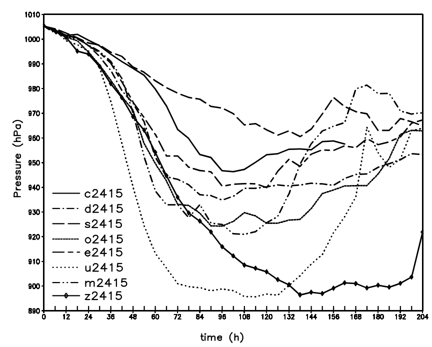

Figure 2: PSMIN timeseries.

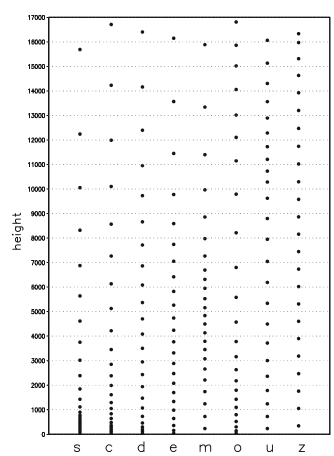

Figure 3: Altitude distributions.

5. REFERENCES

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