The sensitivity of hurricane simulations to the distribution of vertical levels

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A study completed for an idealized hurricane simulation using MM5, over water, at a constant surface temperature (SST), showed that the storm developed very differently as a function of the vertical spacing of the model sigma levels. The distribution of vertical levels in the inflow, outflow and middle layers of the atmosphere clearly affected the intensity, size and structure of the storms, causing certain processes to be under- or over-resolved. Eight different simulations with the same set number of vertical levels but different distributions were compared with the theoretical Maximum Potential Intensity (MPI) and a baseline calculation. The baseline case had more levels (35 half-sigma levels), and the levels were clustered in meteorologically active regions such as the Planetary Boundary Layer (PBL) and the hurricane outflow layer (o35). A similar distribution with 24 half-sigma levels was also tested (o24). Concerned that more levels were necessary in the PBL, several distributions were created to test this hypothesis: s24 (severely clustered), c24 (clustered), d24 (distributed evenly outside the PBL), and e24 (evenly distributed throughout). Two additional distributions were also created to test the importance of the middle region (m24) and the upper troposphere (u24). One final distribution was created using constant height intervals (z) converted to sigma levels (z24). All of the distributions had smooth transitions from clustered to less clustered regions.

Table 1 gives the rankings of all nine simulations as a function of the peak Minimum Sea Level Pressure (MSLP). The magnitude of the ultimate intensity at the mature stage is clearly dependent on the distribution of the vertical levels in each simulation. Cases with many levels in the outflow layer (roughly above =0.25) deepened more rapidly and reached a lower MSLP (o35, o24, u24, z24). The u24 and z24 cases, which have the fewest levels in the PBL (roughly below =0.95), actually became too intense, dropping below the theoretical MPI of 907 hPa for these idealized conditions. The cases with more levels concentrated in the PBL, at the expense of the outflow layer, did not become as intense. In fact, the s24 case, with a very strong inflow layer and a very weak outflow layer, resulted in the weakest storm intensity. These results show that the storm intensities can be ranked according to the number of levels above =0.25 and the number below 0.95, where more levels aloft and fewer levels below meant a more intense storm. This is quantified in the next-to-last column of Table 1; a larger number represented a more intense storm. Exceptions were u24 and z24 which were similar in intensity but had a different number, and m24, which despite having a lower number, was as efficient as o35 and o24 in producing an intense storm.

Varying the vertical distribution of the sigma levels in a model had a net effect of changing the model's physical parameterizations because certain important processes may not have been adequately resolved. Surface fluxes in the PBL were over-estimated in the u24 and z24 cases, allowing these storms to intensify too much. The cases with poorly resolved outflow layers (s24, c24, d24, and e24) displayed restricted secondary circulations, since convection was confined to low and mid-tropospheric levels and too little latent heating occurred at the middle levels to facilitate the formulation of a strong secondary circulation. These storms developed into much weaker systems than the baseline case o35. In the m24 case, where both the inflow and outflow layers had too few levels, the inadequately resolved outflow layer and a subsequent weak secondary circulation were compensated for by the over-estimated surface fluxes.

The ultimate goal of these studies is to provide recommendations for an optimal number of sigma levels and their distribution. The recommendations may be sensitive to the choice of physical parameterizations. These results have important implications to hurricane forecasting. If such models are sensitive to the distribution and number of vertical levels, then forecasts may not accurately represent the real situation with serious consequences to life and property.

Case	**Intensity Rank**	**No. of levels above =0.25**	**No. of levels below =0.95**	**Levels above =0.25 – levels below =0.95**	**Average intensity (hPa). Saffir-Simpson cat. in parentheses.**
s24	9 (weak)	3	5	-2	963.5 (3)
c24	8	4	5	-1	952.3 (3)
e24	7	4	3	1	942.2 (4)
d24	6	5	4	1	940.2 (4)
o24	5	8	3	5	928.8 (4)
o35	4	11	5	6	924.7 (4)
m24	3	5	1	4	924.6 (4)
z24	2	12	1	11	899.7 (5)
u24	1 (intense)	11	1	10	899.4 (5)

Table 1: For each case the following quantities are shown: intensity ranking in terms of minimum sea level pressure attained, number of half sigma levels above =0.25 (outflow) and below =0.95 (inflow), the difference between the number of levels above and below these levels, and the average intensity (hPa) attained during the mature period. Saffir-Simpson categories are shown in parentheses.