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The eternal vertical coordinate issue: sigma, eta, sloping steps eta update, and a severe downslope wind case study

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In spite of extraordinarily numerous efforts to gain understanding of and/or address the problems of the terrain-following (sigma) coordinates as well as those of a number of other choices the issue remains controversial. Arguments were advanced that none of various sigma system schemes designed to remedy its perhaps main difficulty, that of the pressure gradient force, do so satisfactorily. In addition, early tests of the Eta model benefits from its quasi-horizontal coordinate surfaces as opposed to sigma were all very much eta-favorable. Yet, a poor 10-km Eta result for a severe 1997 Wasatch downslope windstorm, pointed out by Staudenmaier and Mittelstadt, and the experiment and arguments of Gallus and Klemp, led numerous authors to believe that the eta is "ill suited for high resolution prediction models". This was compounded by findings of Colle, Westrick and Mass that the 1997 10-km Eta exhibited greater errors in placing precipitation over mountainous terrain than the sigma system MM5. All of this had contributed to the NCEP's decision to use the sigma system when moving for its "Weather Research and Forecasting" (WRF) model to be, "Nonhydrostatic Mesoscale Model" (NMM), early this decade.

The conspicuous step-topography eta problem referred to above is the separation of the flow downstream of a mountain, associated with weak winds along and at the foot of its lee slope. Mesinger, and Mesinger and Jovic in a number of conference papers (e.g., http://www.jamstec.go.jp/frcgc/eng/workshop/pde2004/agenda.html) offered a simple explanation of the problem, and presented a refinement of the eta discretization allowing for sloping steps, that successfully addresses the problem. Their

eta refinement represents a discretized version of the Adcroft, Hill, and Marshall's "shaved cells" system, and has been extensively tested and further improved since. At the same time, NCEP continued the work on its WRF-NMM model and mounted a 5-month parallel comparing the WRF-NMM coupled to its newly developed Gridpoint Statistical Interpolation (GSI) data assimilation code, against the operational Eta coupled to its 3D-Var code. The comparison was found WRF-NMM system favorable and was thus followed by the operational implementation of the WRF-NMM/GSI system in June 2006.

In the meantime, in several conference papers Mesinger has presented results of efforts to detect the loss of skill of the operational Eta compared to its driver global model (Avn, now GFS), as one would expect should take place at some forecast time due to the inflow of the older GFS lateral boundary condition (LBC) data used, and the notorious LBC error. To the contrary, within the Eta 3.5 days forecast range, even a slight increase in the Eta relative skill could be noticed. Mesinger has pointed out that the nature of this increase is consistent with the hypothesis of the eta coordinate being a significant contributor to this resistance of the Eta to the loss of relative skill. Interestingly, in comparing the Eta system precipitation scores vs those of the WRF-NMM system as a function of time (http://www.emc.ncep.noaa.gov/WRFinNAM/) once again a steady increase in the Eta system relative skill can be seen, with the two being competitive only in the first verification period when the difference in assimilation schemes may have mattered most. Note that the choice of the vertical coordinate is perhaps the main difference between the two models. Two other major modeling groups are recently reporting substantial improvements in precipitation skill resulting from the use of eta-like and/or horizontal coordinate surfaces.

Continuing our tests of the sloping steps eta approach, we here present results of a case-study of a hurricane-strength downslope "zonda" windstorm that occurred 11-12 July 2006 at about 31-33°S in the lee of the Andes. This is a section of the Andes with a mean altitude of about 4500 m, including many peaks over 6000 m, such as the Aconcagua Peak (6959 m), and a mean width of only 200-300 km. The event was very severe, with, for example, temperature and dew point at the San Juan synoptic station in 6 hours changing from 9 and 0, to 33 and -16°C, respectively! Using a 15-km Eta, we obtain downslope winds all along the very steep lee side of the main obstacle, with no flow separation. With sloping steps add-on code activated, we have a considerable increase in the downward velocity, on the order of 20-30 %. Further experiments are in progress and intend to be reported on at the time of the presentation of the paper.