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The sloping steps eta: An unconditionally stable monotonic horizontal diffusion scheme, and the Gallus-Klemp experiment

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With little basic guidance available in choosing the dependence of the horizontal diffusion coefficient on resolution, the choice made in the Eta model was to have the coefficient change so as not to affect the scheme's linear stability condition. But even so in runs at 1-km resolution over rough São Paulo–Rio Janeiro coastal region topography blow-ups occurred that were traced to instability in horizontal diffusion. The reason was that with the second-order nonlinear Smagorinsky-like scheme used the effective diffusion coefficient is a product of the diffusion coefficient and the local deformation rate, with the latter's dependence on resolution and topography roughness not being easy to foresee. Thus, high values of the product were at times occurring, leading to instabilities.

The problem was addressed by limiting the diffusion changes not to alter the sign of the five-point Laplacian involved. This simple step not only results in the scheme's unconditional stability but also prevents generation of new extrema making the scheme monotonic. The attention focused on the diffusion code in addition serendipitously led to the discovery of the omission of making the code aware of the sloping steps refinement of the eta discretization (Mesinger et al., Meteor. Atmos. Phys., 2012). With this awareness implemented, the Gallus and Klemp (Mon. Wea. Rev., 2000) experiment of flow over a bell-shaped mountain was rerun with all parameters the same as used to obtain the step-coordinate panels of Fig. 6 of Gallus and Klemp. Recall that the result of that figure is largely responsible for a wide-spread opinion in NWP community that the eta is "ill suited for high resolution prediction models", with these specific words or similar written in a number of papers citing Gallus and Klemp. The emulation of the Gallus, Klemp experiment using the arrived at sloping steps Eta code led to a flow pattern looking at the lee side remarkably similar to that Gallus and Klemp obtained after modifying advection schemes at points adjacent to the step corners using an assumed condition of the y-component vorticity being zero at the step corners, plot (c) of their Fig. 6. Thus, the Gallus-Klemp based concern over the eta coordinate's suitability for high resolution prediction models would seem demonstrated as not warranted provided the sloping steps discretization is used.