Sloping steps Eta: Monotonic horizontal diffusion and Gallus-Klemp test

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“Sloping steps” Eta. A number of Eta dynamical core features following NCEP operational code. **CPTEC version** ([http://etamodel.cptec.inpe.br/](http://etamodel.cptec.inpe.br/)):

- **Nonhydrostatic option** (Janjić et al. MWR 2001), as in NCEP’s “Workstation Eta”, same as in NCEP’s WRF/NMM;

Subsequently:

- **Finite-volume vertical advection of dynamic variables,** $v, T$; (van Leer-type scheme of Mesinger and Jović, NCEP Office Note 2002)
Over the years, five documented tests eta vs sigma; in all of them eta did better. Used at NCEP in near-real time for North American Regional Reanalysis (NARR).
However: “Eta Gallus-Klemp problem” (MWR 2000)

Bell-shaped (“Witch of Agnesi”) mountain:

Gallus-Klemp (2000) Fig. 6:

Gallus-Rančić Eta code

Modified by G-K next to step corners

Also: poor Eta performance for a case of a downslope windstorm
Gallus and Klemp (2000), Abstract:

“The simulations reveal that for inviscid flow over a mountain using the step-terrain coordinate, flow will not properly descend along the lee slope. Rather, the flow separates downstream of the mountain and creates a zone of artificially weak flow along the lee slope. This behavior arises due to artificial vorticity production at the corner of each step and can be remedied by altering the finite differencing adjacent to the step to minimize spurious vorticity production”.
Eta: bad press for quite some time:

“ill suited for high resolution prediction models”


... more

In addition:

A 2002 announcement of the replacement of the 10-km Eta, run at NCEP on the so-called HiResWindow nests, by an 8-km NMM, among other points stated: “This choice [of the vertical coordinate] will avoid the problems . . . with strong downslope winds and will improve placement of precipitation in mountainous terrain“ (Geoff DiMego, personal communication, 19 July 2002).
Upgrade of the eta discretization: The sloping steps

Vertical grid: The central $v$ box exchanges momentum, on its right side, with $v$ boxes of two layers:
In the 2012 *Meteorol. Atmos. Phys.* paper:

An upgraded version of the Eta model

**Fig. 3** Gallus–Klemp experiment, with parameters chosen so as to mimic the results shown in Gallus–Klemp (2000) Fig. 6. Control, *left panel*; code using sloping steps eta discretization, *right panel*
Subsequently, in running nonhydrostatic version of the Eta code, at 1-km resolution over a region of very rough topography, considerable noise was seen, and blow-ups occurred. E.g. paper presented Wednesday, Chou et al.: High-resolution forecasts over complex topography of Southeast Brazil
In the Eta, Smagorinsky-like scheme, diffusion change proportional to

\[ \left\langle \delta_x \left( \Delta^y \delta_x' u \right) + \delta_y \left( \Delta^x \delta_y' u \right) \right\rangle \Delta t \]

\( \Delta \) standing for finite-difference velocity deformation
Thus: diffusion change cannot be controlled by a simple change of the diffusion coefficient!
Thus: diffusion change cannot be controlled by a simple change of the diffusion coefficient!

Blue $\rightarrow$ red $\rightarrow$ green each time “diffusion coefficient” doubled

Top panel: measure of noise in sea level pressure

Fig. 1. Upper panel: Average absolute sea level pressure difference between model output points and four-point averages of their nearest surrounding points, as a function of time, in hours, for three values of the coefficient $\alpha$ in (3), and for the first of six experiments performed. Values of $\alpha$ used are equal to 0.04, 0.08, and 0.16, for the blue, red, and green curves, respectively. Lower panel: Average precipitation, in mm/hr, at model output points, for the same experiment and with the same colors used as in the plots of the upper panel.
To refine the diffusion scheme / prevent blow-ups:

Limit diffusion change not to change the sign of the finite-difference Laplacian used

Unconditionally stable and monotonic Smagorinsky-like horizontal diffusion scheme
Looking at the diffusion code, it was noted that the horizontal diffusion code was not made aware of the sloping steps discretization:
Simulation of the Gallus-Klemp experiment with the Eta code allowing for velocities at slopes in the horizontal diffusion scheme, right hand plot. The plot (c) of Fig. 6 of Gallus and Klemp (2000), left hand plot.
“Sloping steps”: improved eta discretization, corrected for an oversight, removes the Gallus-Klemp problem of flow separation in the lee of a bell-shaped mountain
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A feature of some concern: highest velocities on top of mountain. Possible further refinements: slopes extending over more than one grid point, and/or along cliffs of more than one step.
Some of the references that might have been used:


