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

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EMS 2016,Trieste, Italy

"Sloping steps" Eta. A number of Eta dynamical core features following NCEP operational code. CPTEC version (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)

"Step-topography" Eta:

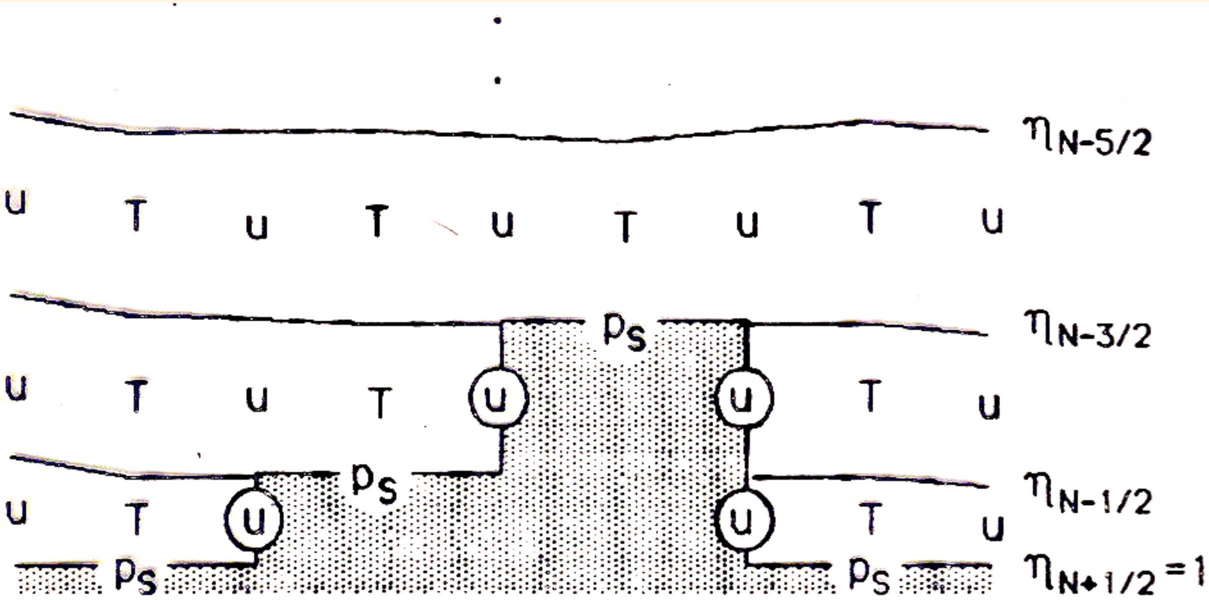
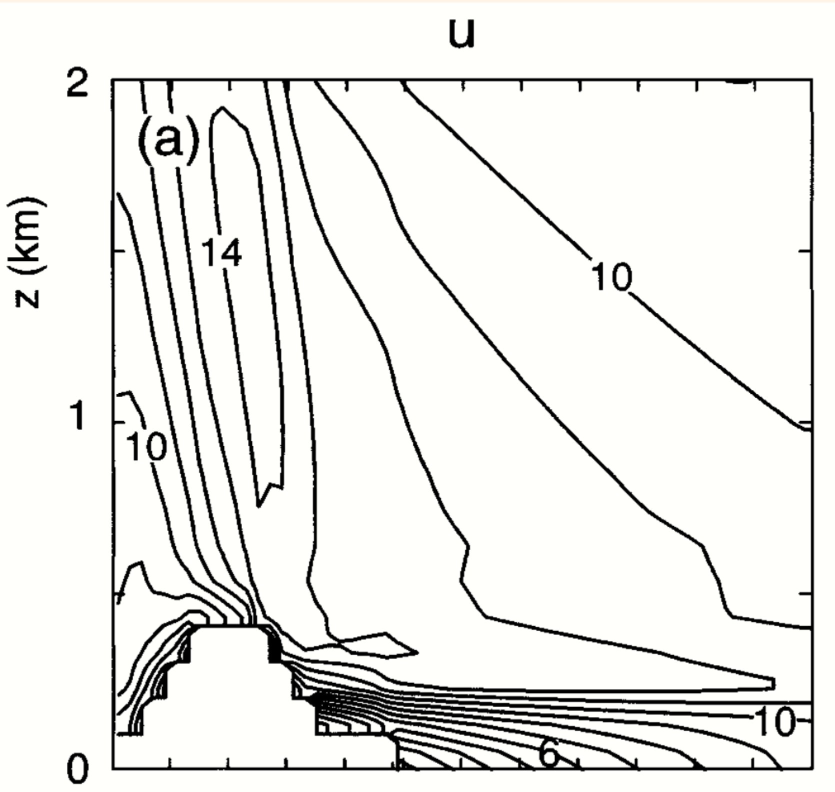


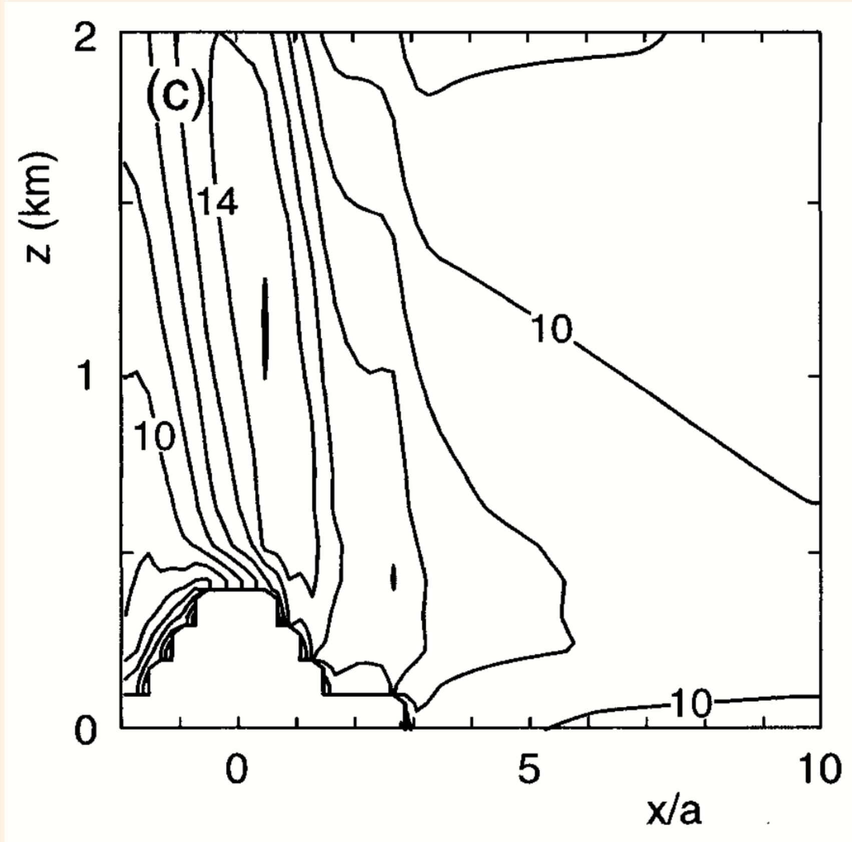
FIG. 1. Schematic representation of a vertical cross section in the eta coordinate using step-like representation of mountains. Symbols u, T and p_s represent the u component of velocity, temperature and surface pressure, respectively. N is the maximum number of the eta layers. The step-mountains are indicated by shading.

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"

Schär et al., *Mon. Wea. Rev.*, 2002;
Janjic, *Meteor. Atmos. Phys.*, 2003;
Steppeler et al., *Meteor. Atmos. Phys.*, 2003;
Mass et al., *Bull. Amer. Meteor. Soc.*, 2003;
Zängl, *Mon. Wea. Rev.*, 2003;

. . . more

In addition:

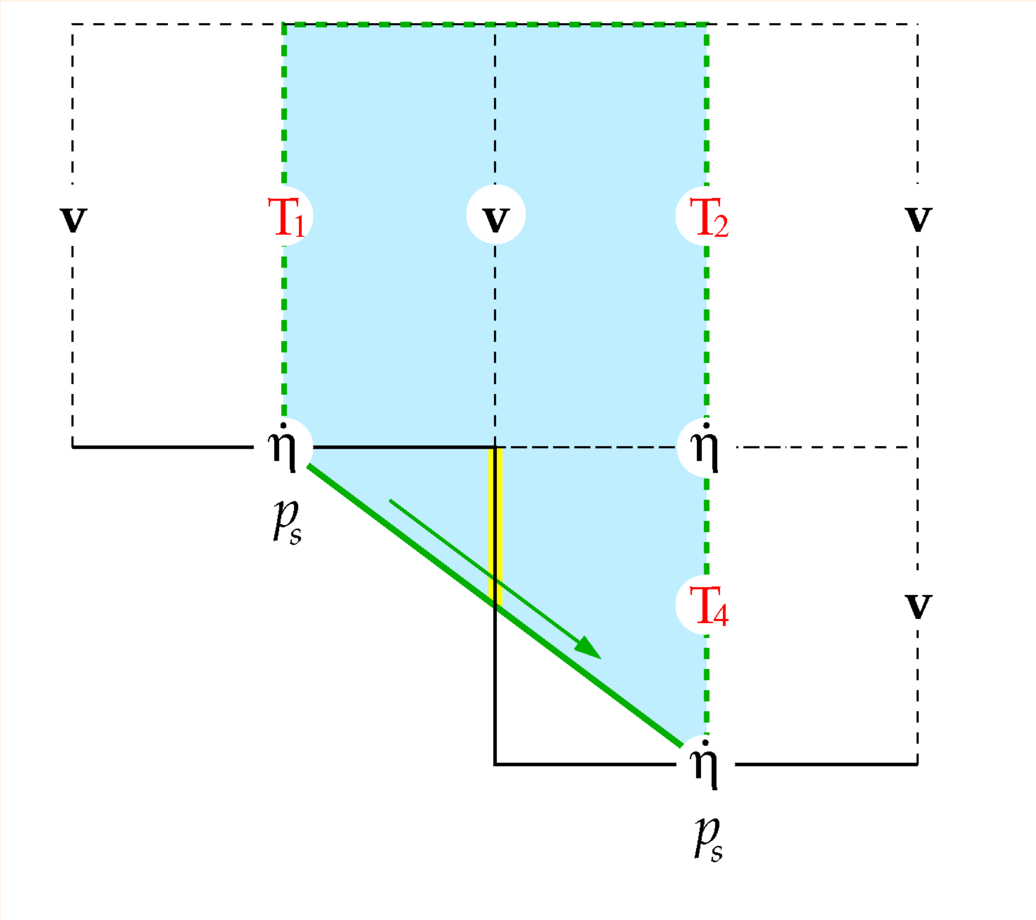
Colle, B. A., K. J. Westrick, and C. F. Mass, 1999: Evaluation of MM5 and Eta-10 precipitation forecasts over the Pacific Northwest during the cool season. *Wea. Forecasting*, **14**, 137-154.

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

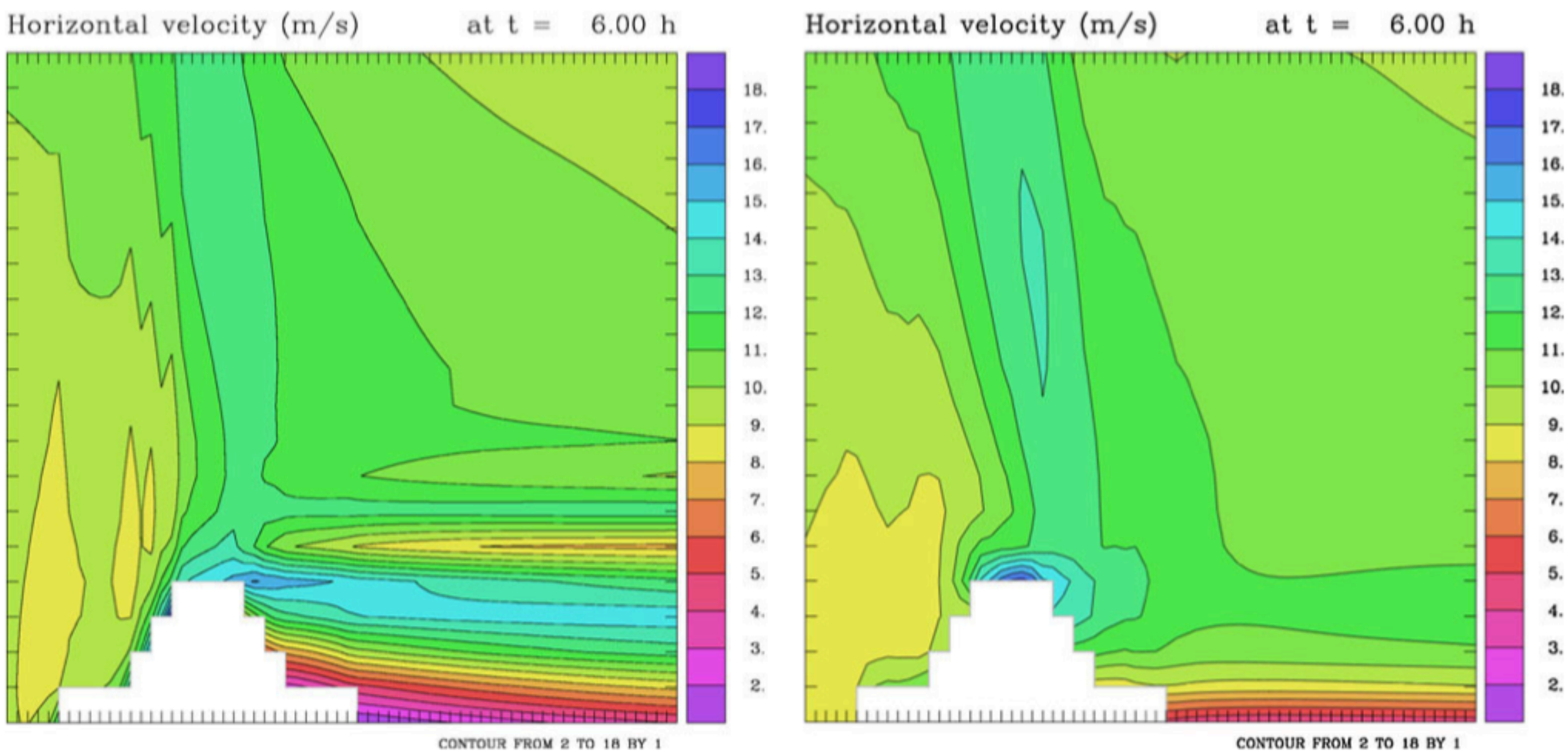
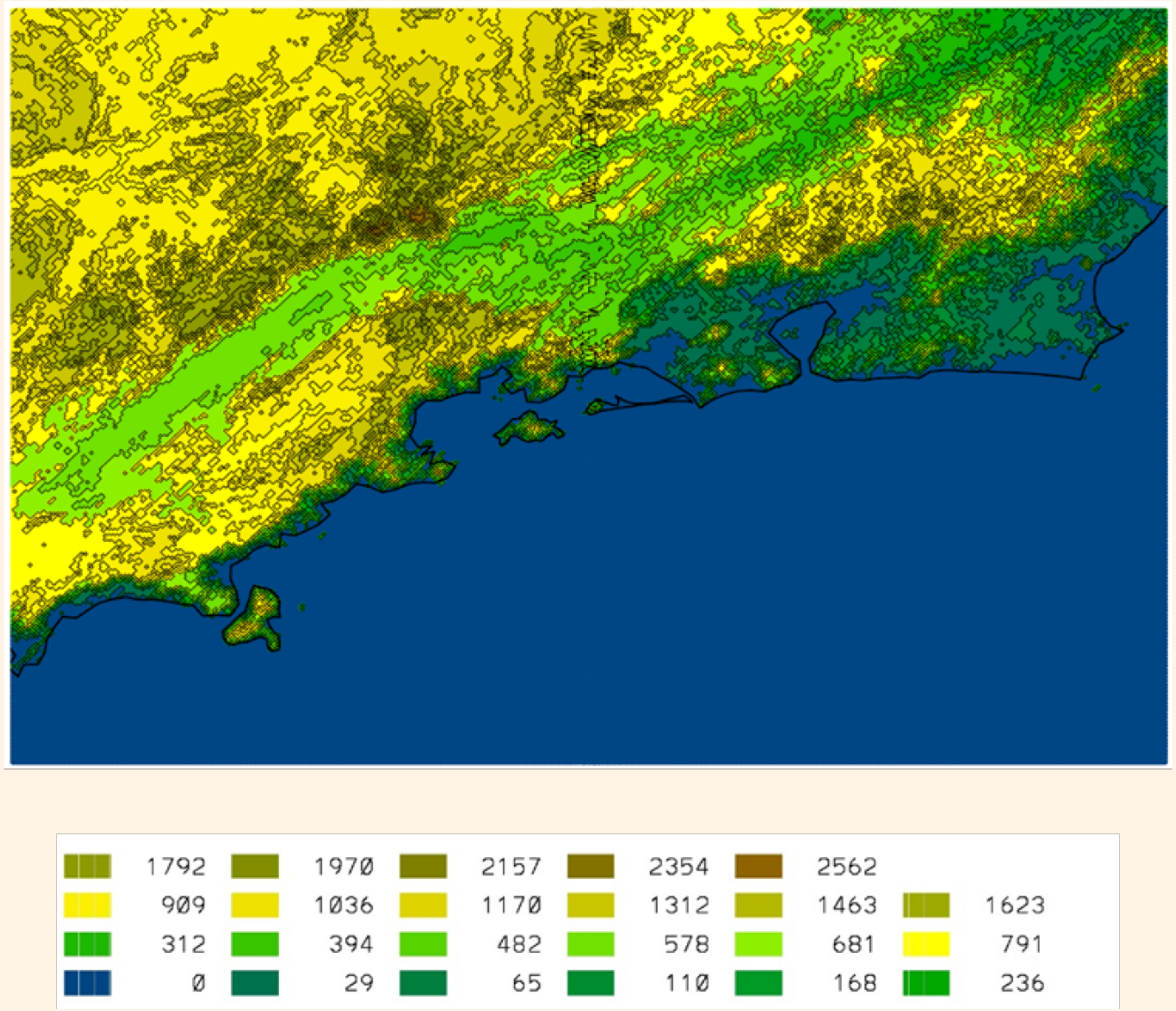


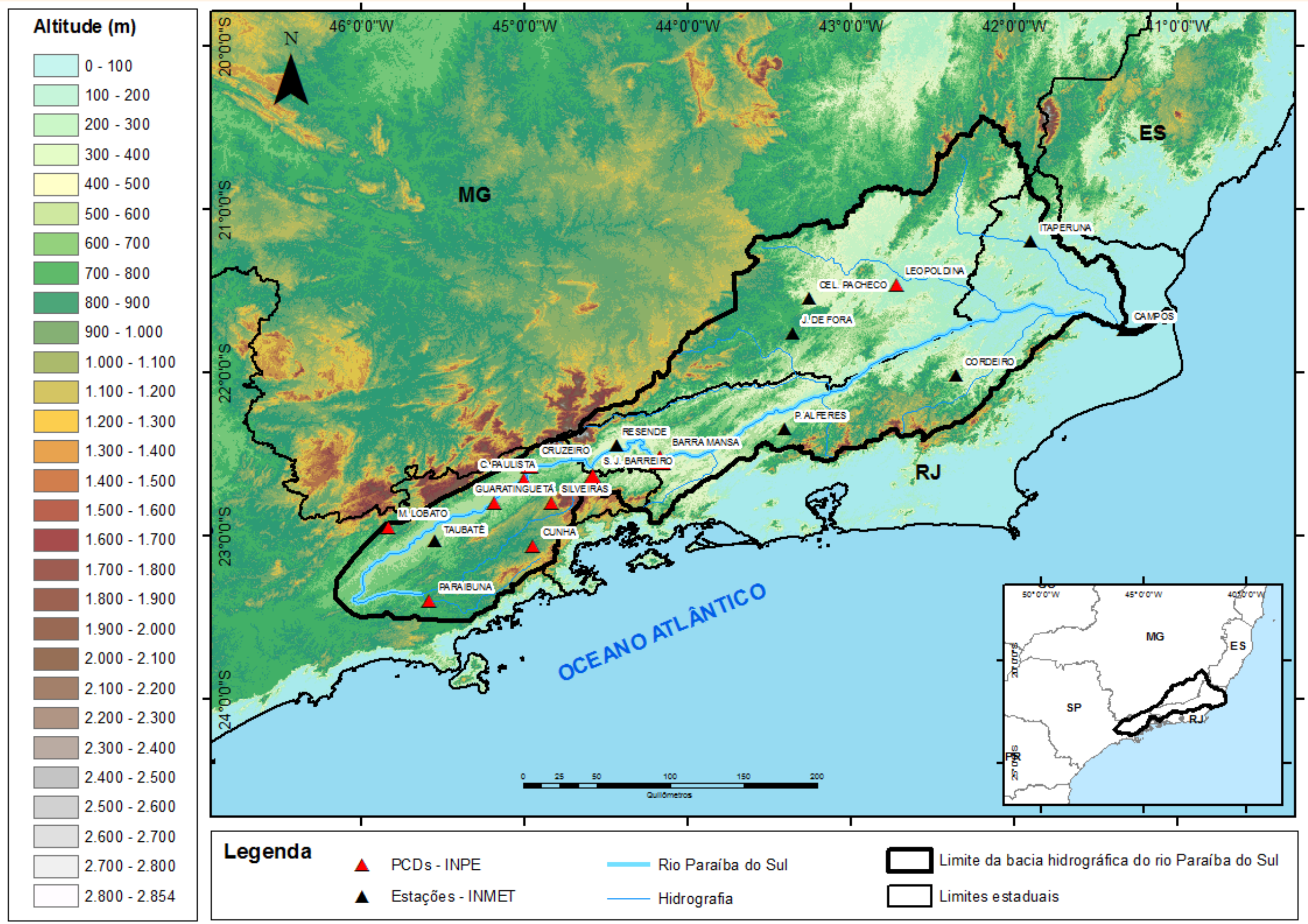
Fig. 3 Gallus–Klemp experiment, with parameters chosen so as to mimic the results shown in Gallus–Klemp (2000) Fig. 6. Control, *left panel*; code using sloping steps eta discretization, *right panel*

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



1792
1970
2157
2354
2562
909
1036
1170
1312
1463
1623
312
394
482
578
681
791
0
29
65
110
168
236



Altitude (m)
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1.000
1.000 - 1.100
1.100 - 1.200
1.200 - 1.300
1.300 - 1.400
1.400 - 1.500
1.500 - 1.600
1.600 - 1.700
1.700 - 1.800
1.800 - 1.900
1.900 - 2.000
2.000 - 2.100
2.100 - 2.200
2.200 - 2.300
2.300 - 2.400
2.400 - 2.500
2.500 - 2.600
2.600 - 2.700
2.700 - 2.800
2.800 - 2.854
46°0'0"W
45°0'0"W
44°0'0"W
43°0'0"W
42°0'0"W
41°0'0"W
20°0'0"S
21°0'0"S
22°0'0"S
23°0'0"S
24°0'0"S
N
MG
ES
RJ
ITAPERUNA
LEOPOLDINA
CEL. PACHECO
J. DE FORA
CAMPOS
CORDEIRO
P. ALFERES
RESENDE
BARRA MANSA
CRUZEIRO
S. J. BARREIRO
C. PAULISTA
GUARATINGUETÁ
SILVEIRAS
M. LOBATO
TAUBATÉ
CUNHA
PARAIBUNA
OCEANO ATLÂNTICO
0 25 50 100 150 200
Quilômetros
50°0'0"W
45°0'0"W
40°0'0"W
MG
ES
SP
RJ
PR
Legenda
PCDs - INPE
Estações - INMET
Rio Paraíba do Sul
Hidrografia
Limite da bacia hidrográfica do rio Paraíba do Sul
Limites estaduais

In the Eta, Smagorinsky-like scheme, diffusion change proportional to

$$\left\langle \delta_{x'}\left(\overline{\Delta}^{y'}\delta_{x'}u\right)+\delta_{y'}\left(\overline{\Delta}^{x'}\delta_{y'}u\right)\right\rangle \Delta t$$

Δ standing for finite-difference velocity deformation

Thus: diffusion change cannot be controlled by a simple change of the diffusion coefficient !

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Blue —> red —> green

each time "diffusion coefficient" doubled

Top panel: measure of noise in sea level pressure

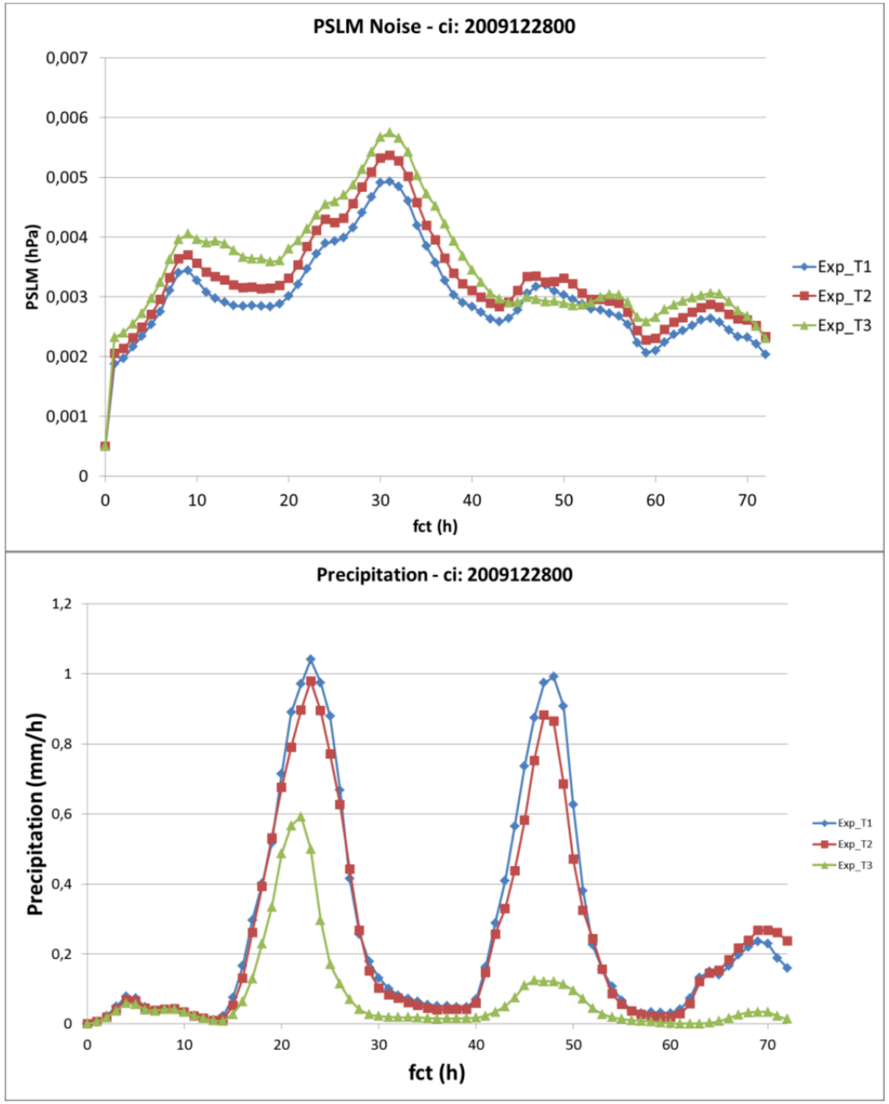


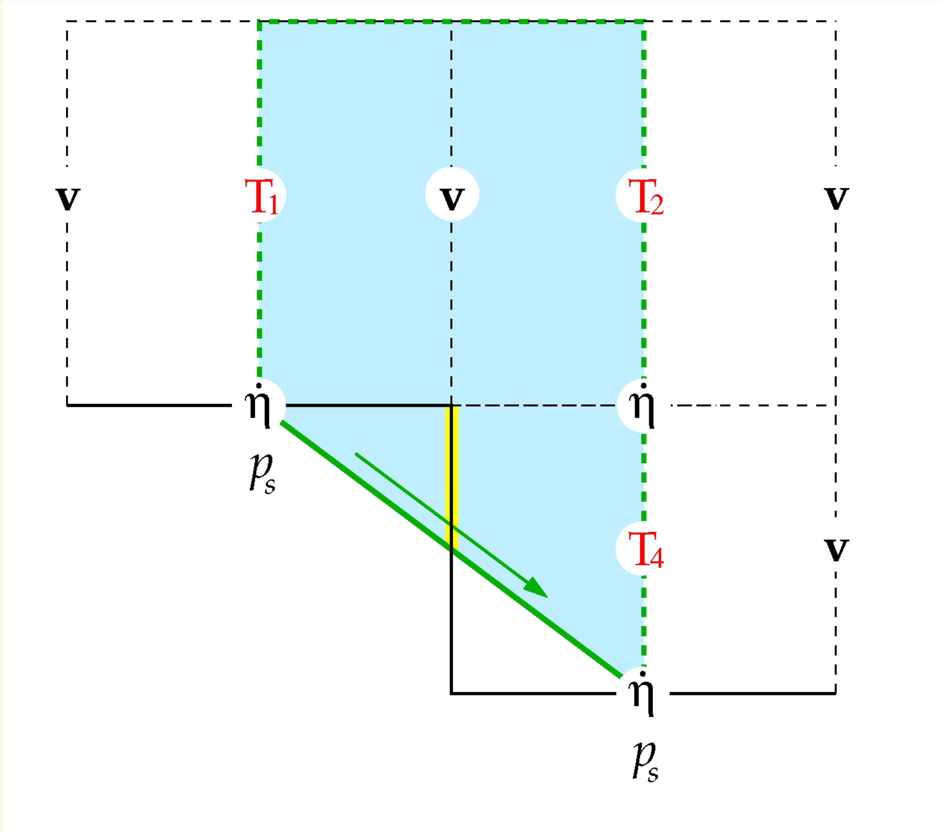
Fig. 1. Upper panel: Average absolute sea level pressure difference between model output points and four-point averages of their nearest surrounding points, as a function of time, in hours, for three values of the coefficient α in (3), and for the first of six experiments performed. Values of α used 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.

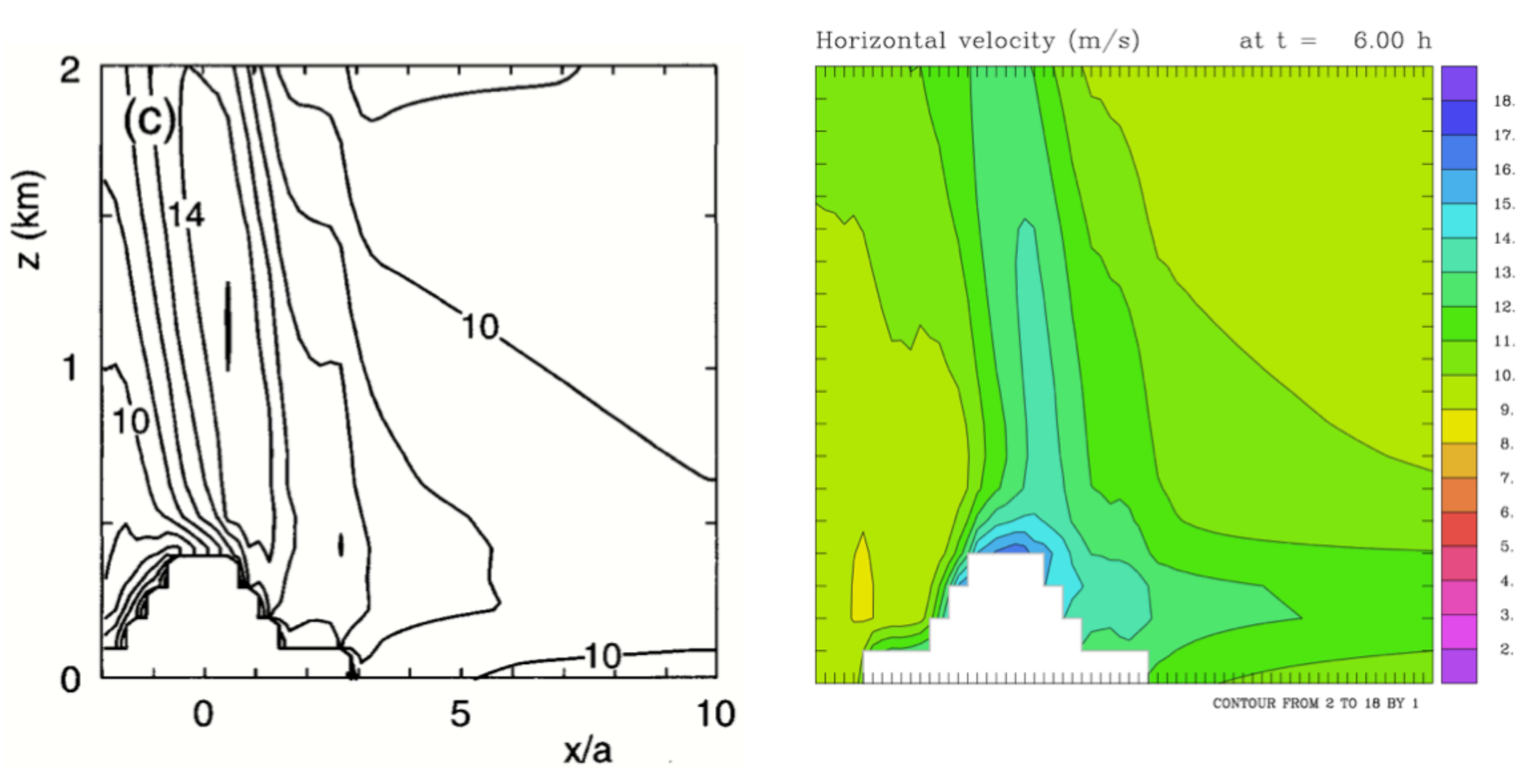
To refine the diffusion scheme / prevent blow-ups:

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:

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Zhang, H., and M. Rancic: 2007: A global Eta model on quasi-uniform grids. *Quart. J. Roy. Meteor. Soc.*, **133**, 517-528.