Eta vs sigma: Placement of storms, Gallus-Klemp test, and 250 hPa wind skill compared to ECMWF in ensemble experiments

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1) Introduction: summary of various documented eta vs sigma tests and other relevant results;

2) Eta topography

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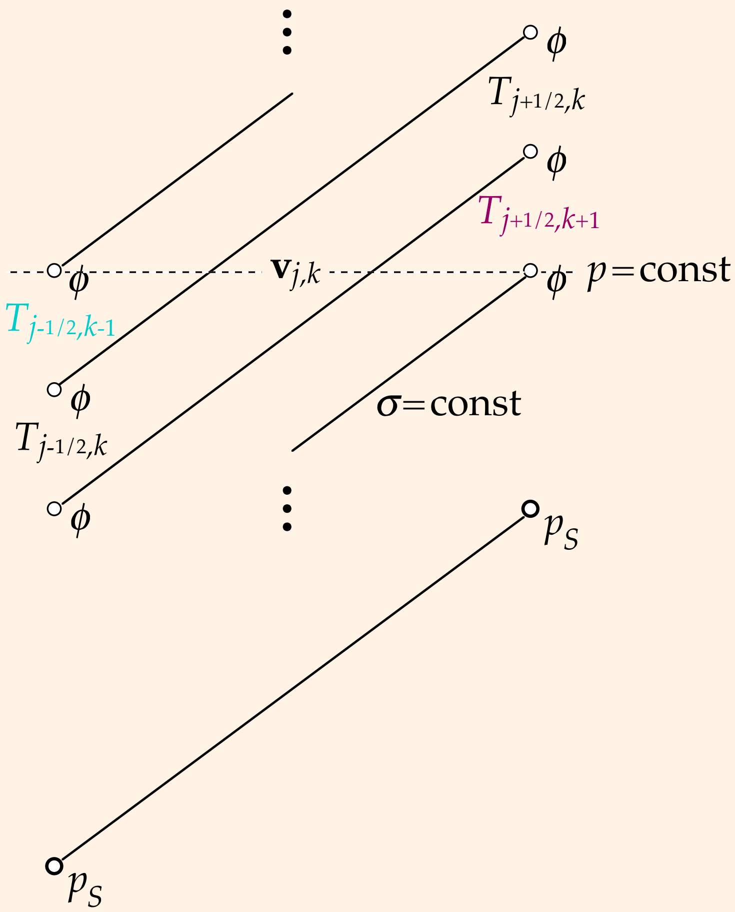
5) Concluding comments

1) Terrain-following coordinates: pressure gradient force



Continuous case:
PGF should depend on,
and only on,
variables from the ground
up to the p=const surface:

The best type of sigma scheme:
will depend on $T_{j+1/2,k+1}$, which *it should not*;
will *not* depend on $T_{j-1/2,k-1}$, which *it should*.

A straightforward sigma system scheme is not aware of all model variables it should be aware for physical reasons

The "eta" coordinate:

$$\eta = \frac{p - p_T}{p_S - p_T}\eta_S, \quad \eta_S = \frac{p_{rf}(z_S) - p_T}{p_{rf}(0) - p_T}$$

Setting $\eta_S = 0$ this becomes sigma: switch in the code !

Over the years, five documented tests eta vs sigma:

- Mesinger et al. (MWR, 1988): Noise with sigma !
- Black ("The step-mountain ...: A documentation", NMC, 1988):

  Geopotential height errors, 14 consecutive forecasts, as a function of height and time: NGM, Eta, Eta/sigma;
- Mesinger, Black (Met. Atmos. Phys., 1992):

  Cases of lows in the lee of Rockies, precipitation scores;
- Mesinger, Black, Baldwin (André Robert Mem. Vol., 1997)

  Precipitation scores, a detailed synoptic study of a case;
- Chuang, in Mesinger et al. (AMS, Orlando 2002); also in Mesinger (2004, 50th Anniversary of Oper. NWP Symp., College Park, MD): the case of the Mesinger paper of the Potsdam Symp. book, 2001, run as sigma

#1 Sigma Eta

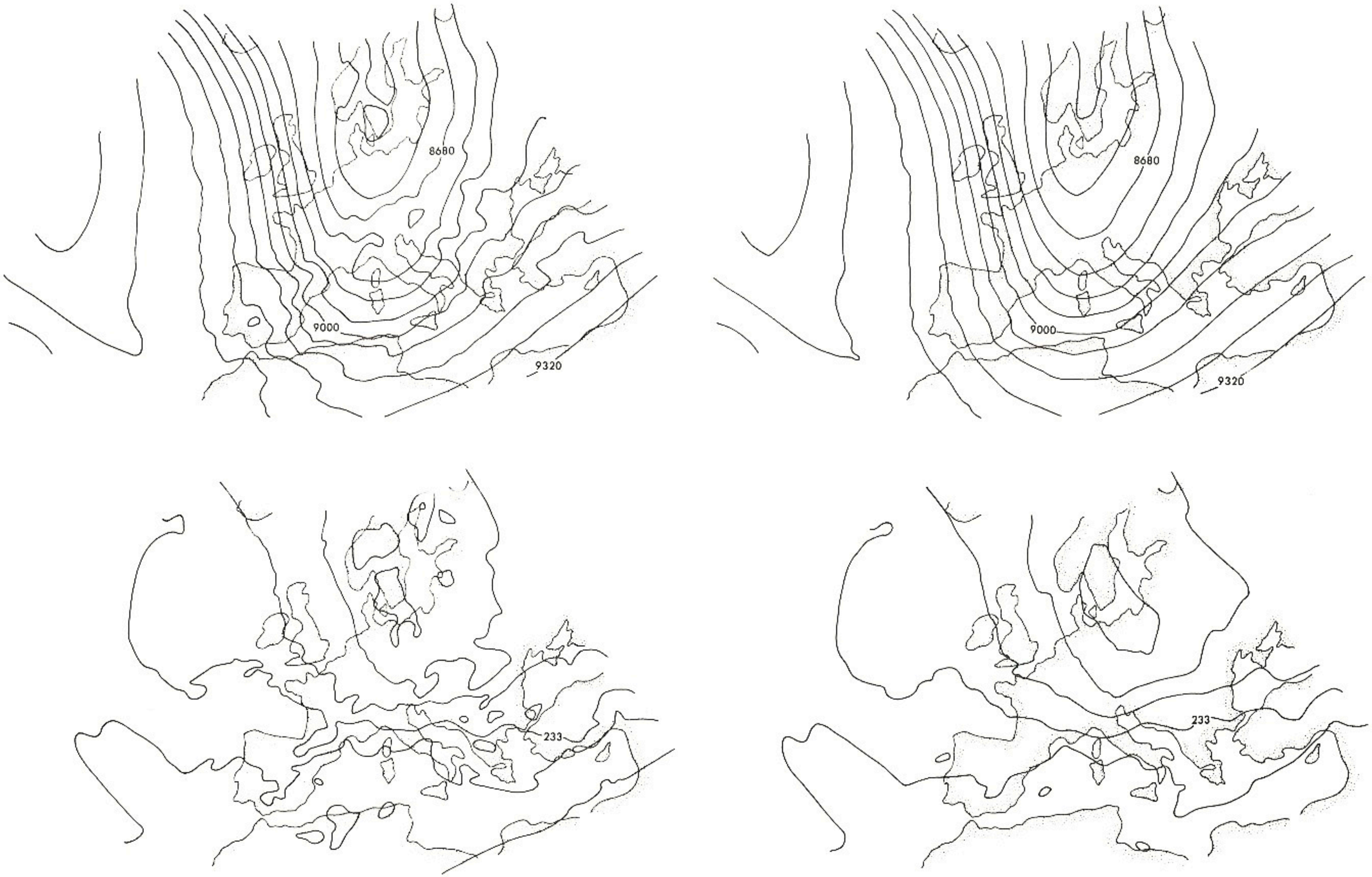
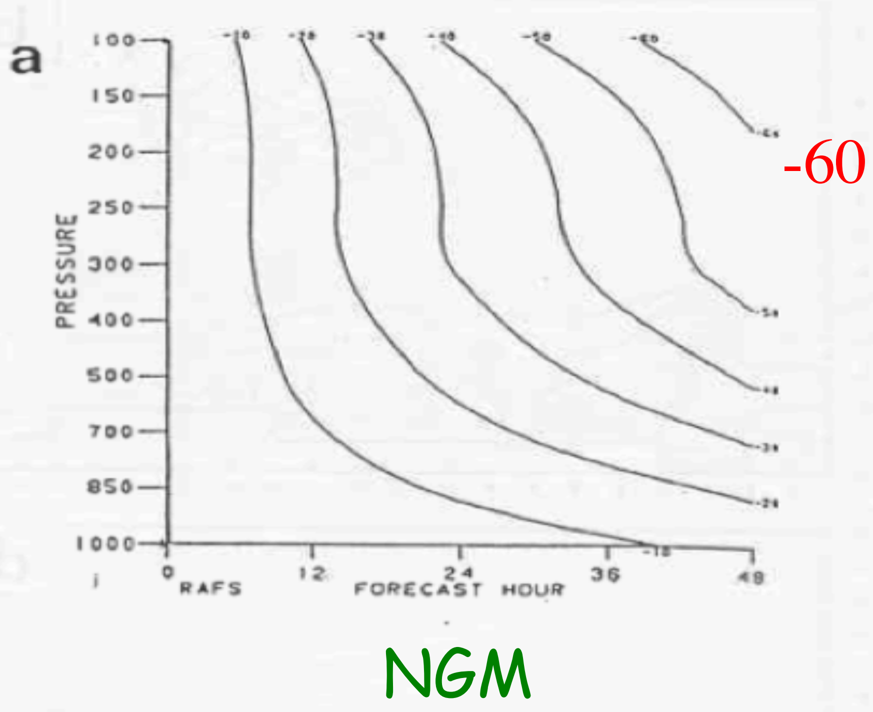
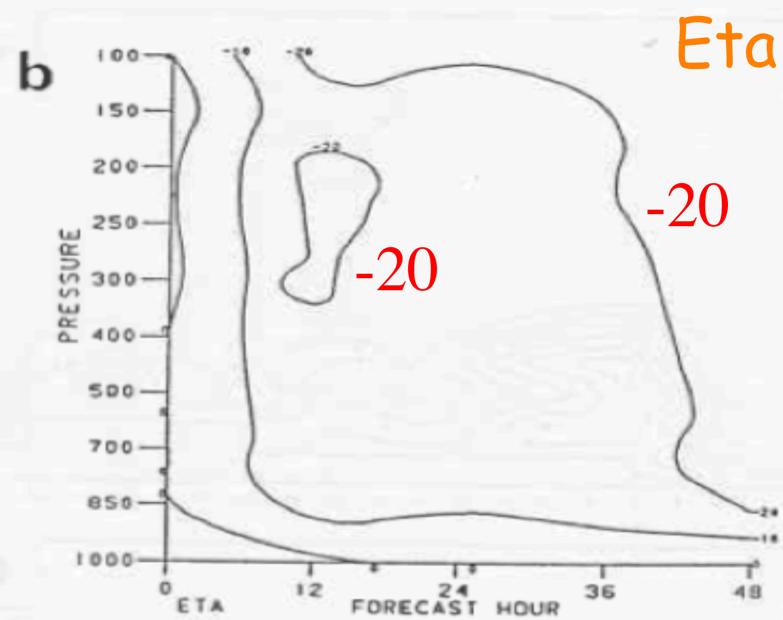


FIG. 6. 300 mb geopotential heights (upper panels) and temperatures (lower panels) obtained in 48 h simulations using the sigma system (left-hand panels) and the eta system (right-hand panels). Contour interval is 80 m for geopotential height and 2.5 K for temperature.

#2 Black, T. L., 1988: The step-mountain eta coordinate regional model: A documentation. NOAA/NWS National Meteorological Center, April 1988, 47 pp. [Available from NOAA Environmental Modeling Center, M-Square Research Park, 5825 University Research Court, College Park, MD 20740.]

"Cold bias" a well recognized problem of the operational NGM.





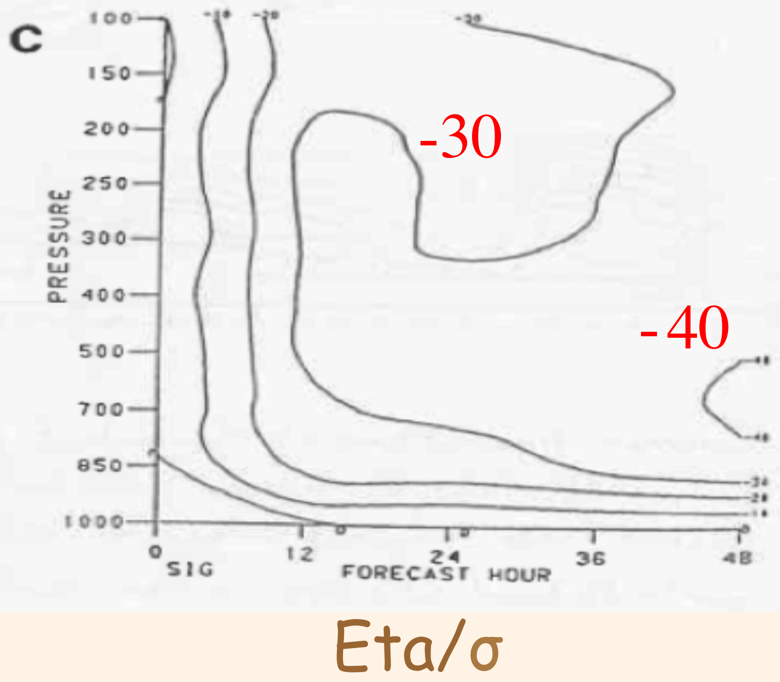
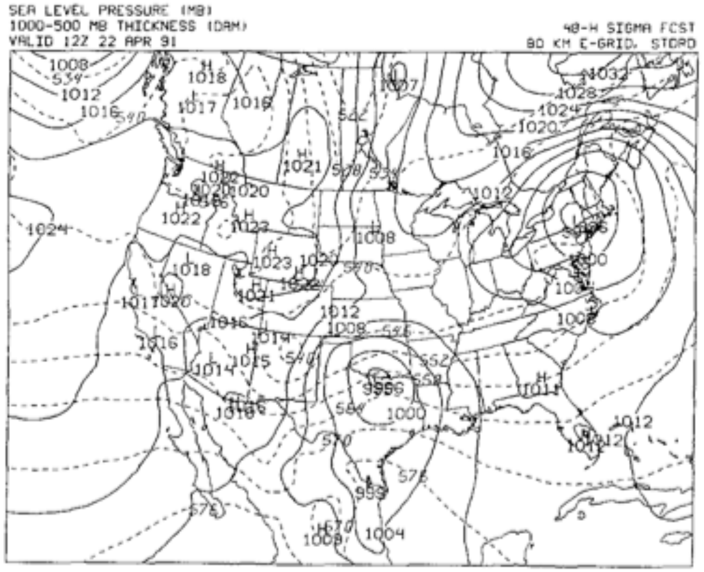


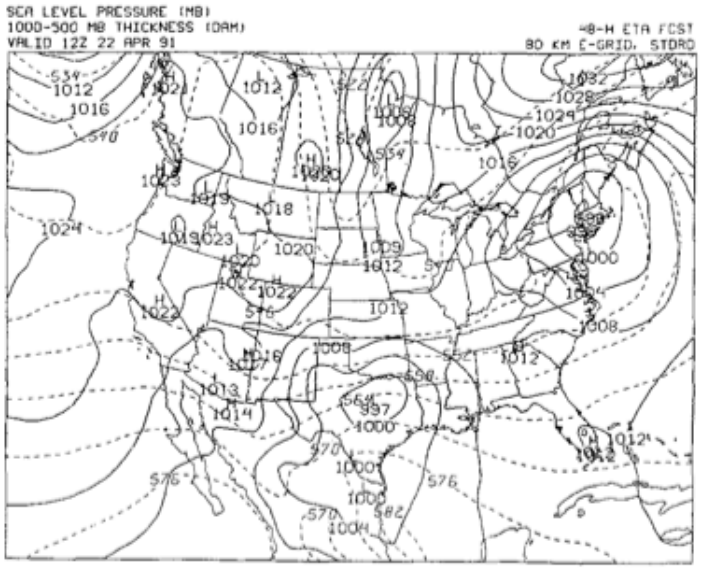
Fig. 9. Mean height errors (m) for 20-26 August 1987 including both 00Z and 12Z cycles: (a) NGM; (b) eta model; (c) sigma mode of eta model.

Geopotential height errors

#3

Eta run as sigma, 48 h

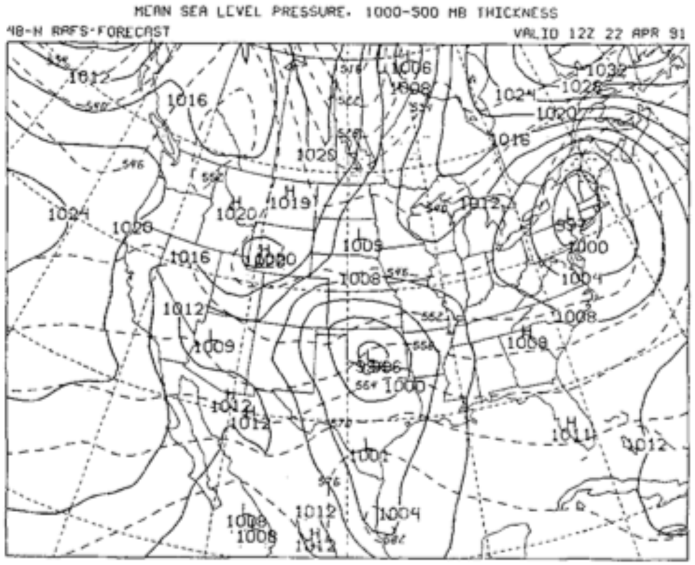




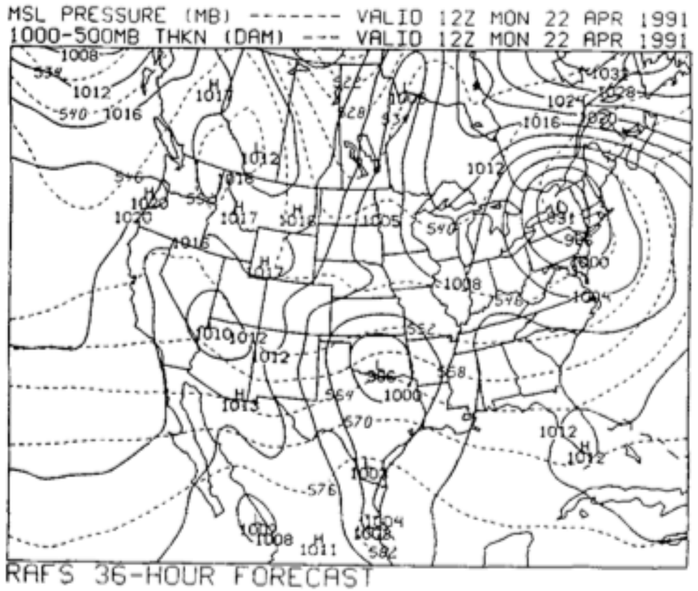
Eta
48 h

(80 km / 16 lyrs)

Fig. 7. As in Fig. 3 except for verifying at 1200 UTC 22 April 1991

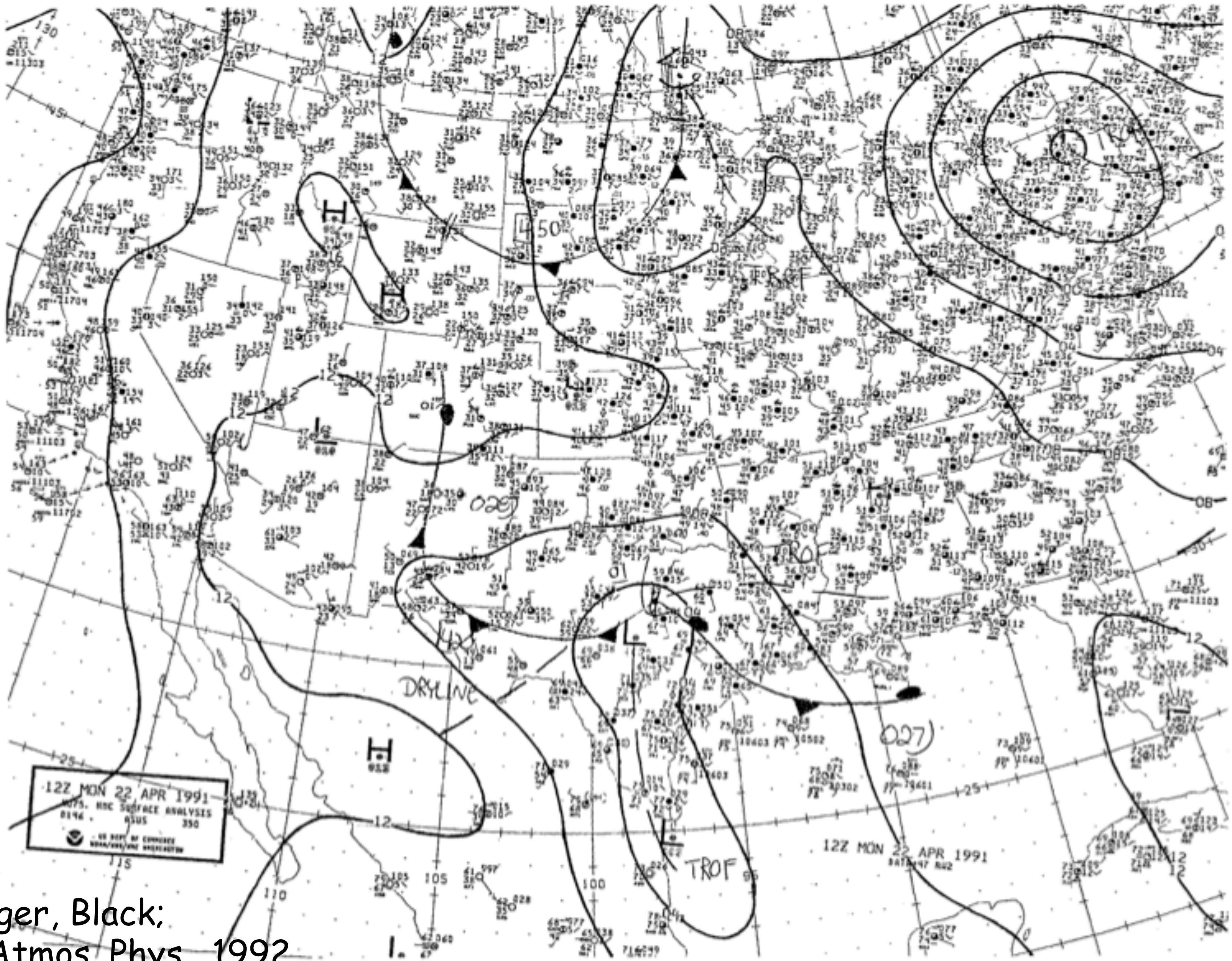


NGM
48 h



NGM
36 h

Fig. 8. U.S. operational regional model (NGM) forecasts of sea level pressure (mb, solid lines) and 1000–500 mb thickness (dam, dashed lines), verifying at 1200 UTC 22 April 1991. 48-h forecast is shown as the upper panel, and 36-h forecast as the lower panel



Mesinger, Black;
Met. Atmos. Phys., 1992

Fig. 6. A section of the NMC surface analysis for 1200 UTC 22 April 1991

Precipitation scores;
9 consecutive forecasts,
14 verifications

Because observations are at 1200 UTC only, each forecast will have either one or two 24-h periods which can be verified. Those beginning at 0000 UTC have just one, i.e., the 36-h forecast. Those beginning at 1200 UTC have both the 24-h and 48-h forecasts. With our nine forecasts we had a total of 14 verifications, over 6 verification periods. There were 5 verifications of 24-h forecasts, 4 verifications of 36-h forecasts, and 5 verifications of 48-h forecasts.

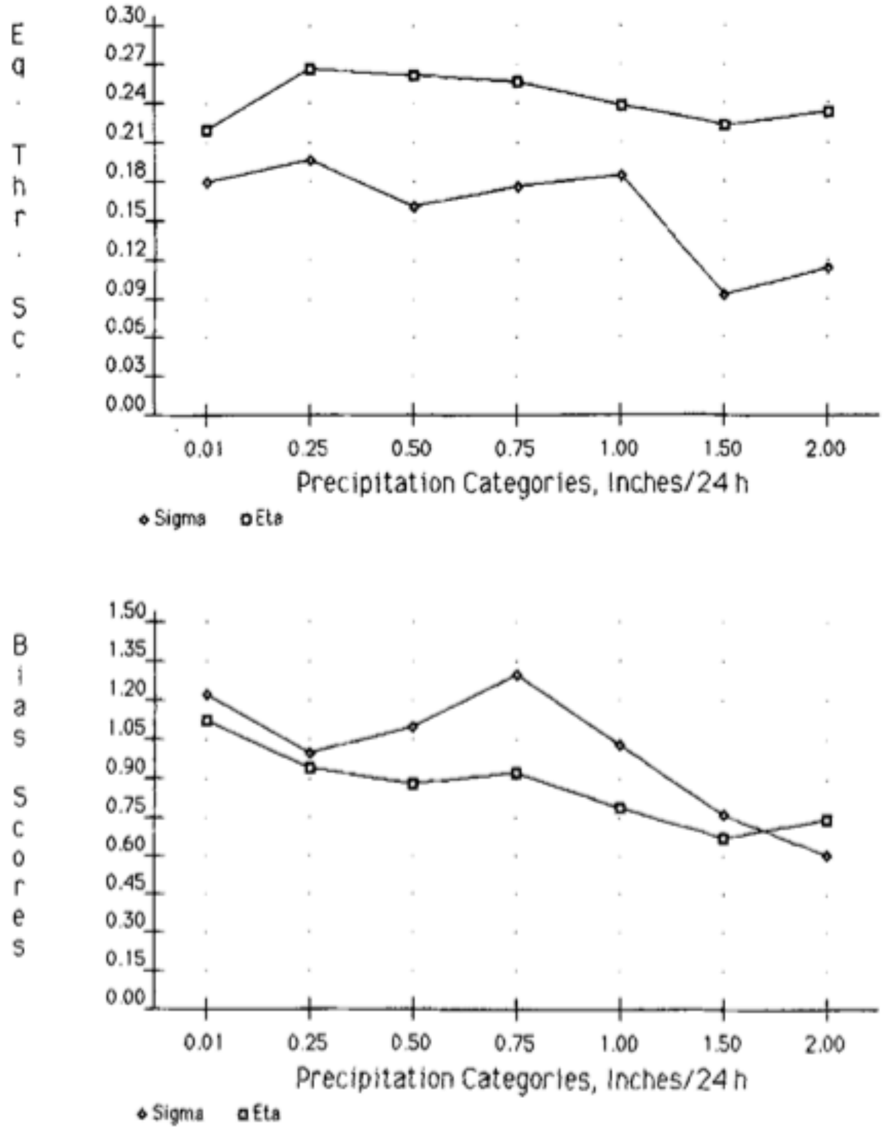


Fig. 12. Equitable threat scores for a total of nine consecutive forecasts of the NMC Eta Model, run in its sigma coordinate mode (diamonds) and in its eta coordinate mode (squares), upper panel. Bias scores for the same set of forecasts, lower panel. See text for further detail

#4

André Robert Memorial Volume:

Also a case study of a heavy precipitation event

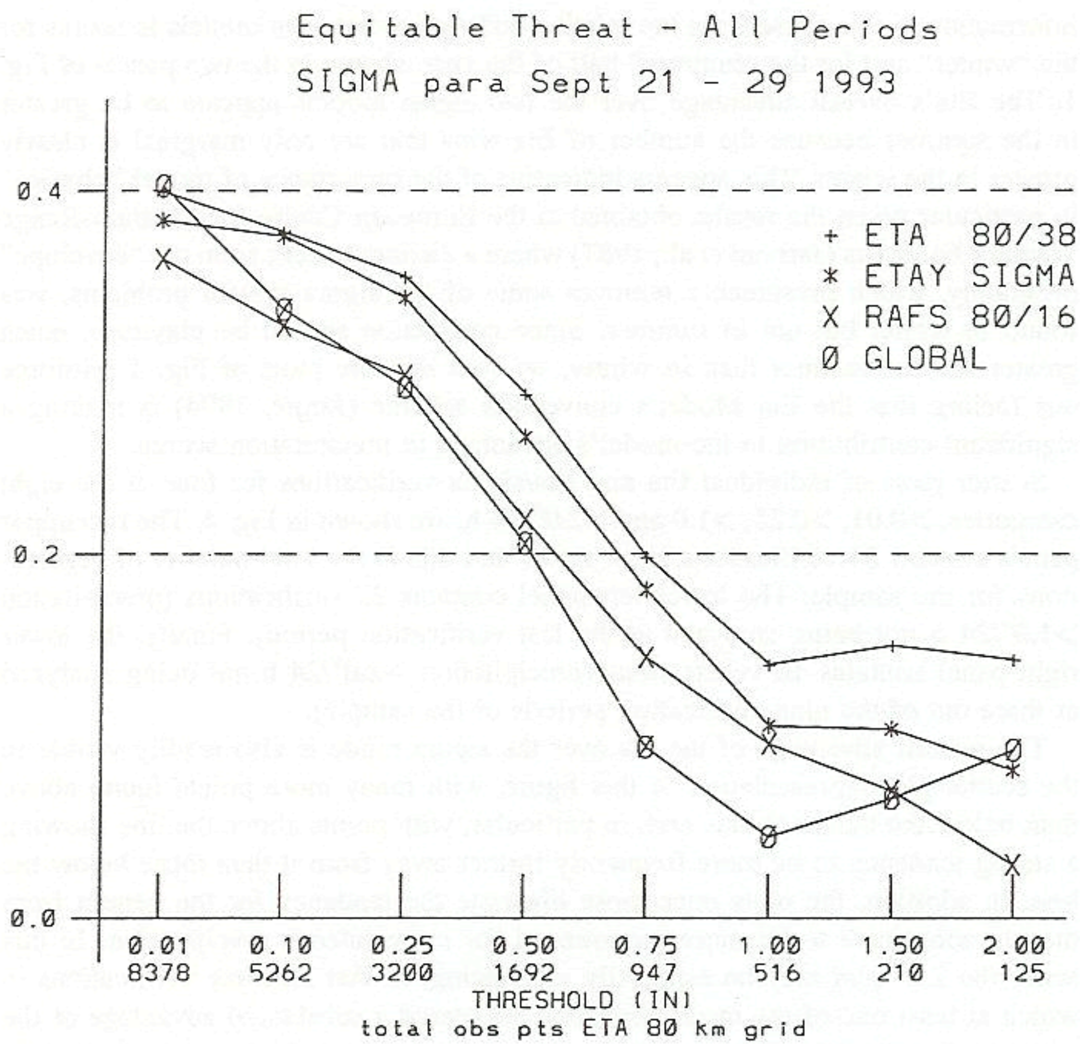
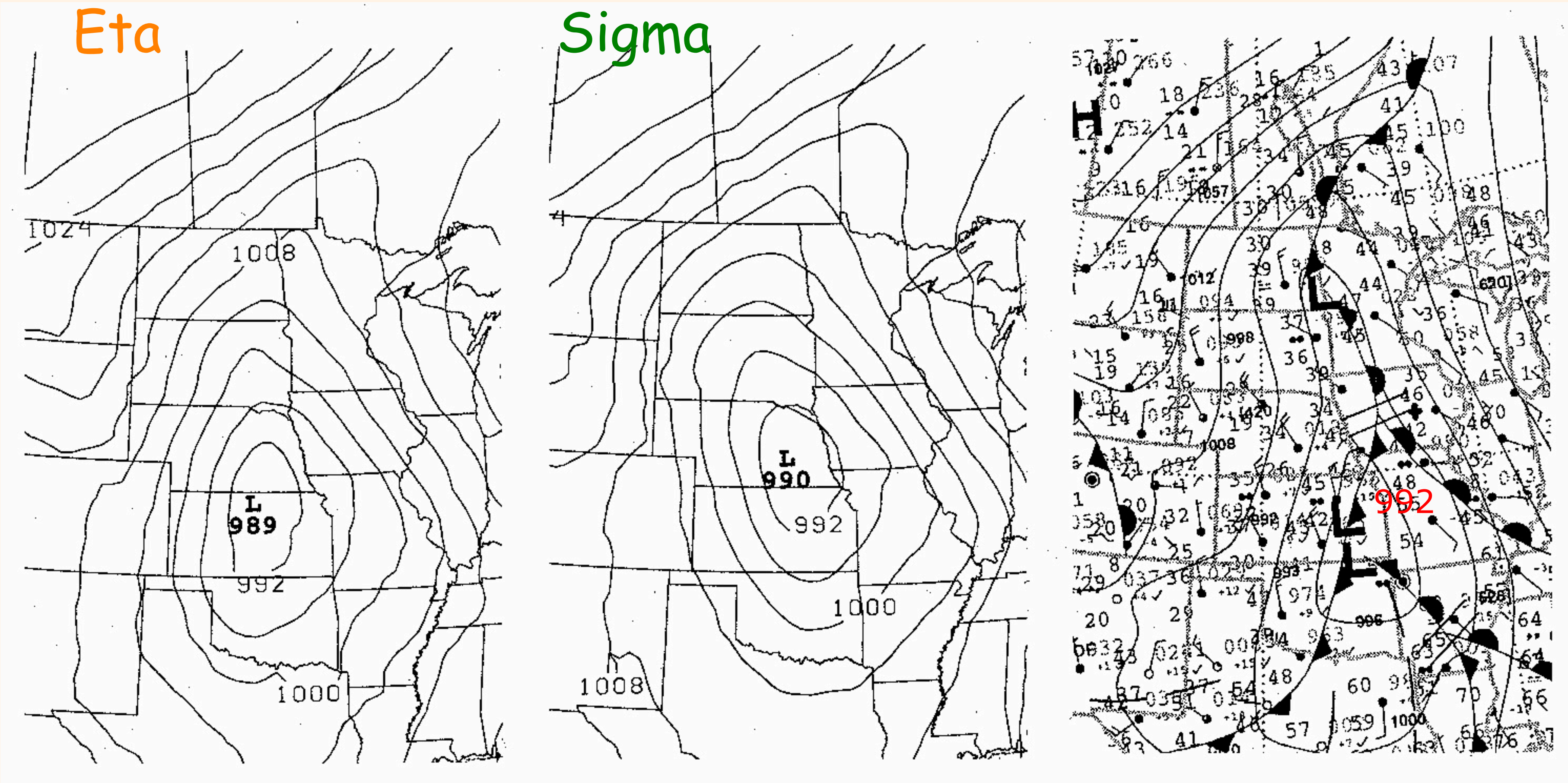


Fig. 3 Equitable precipitation threat scores for two versions of the Eta Model: Eta 80 km/38 layers ("ETA"), and the same version of the Eta Model but run using sigma coordinate ("ETAY"), and for the NGM (RAFS), and the Avn/MRF ("global") Model; for a sample of 16 forecasts verifying 1200 UTC 21 September through 1200 UTC 29 September 1993. Eight forecasts are each verified once, for 12–36 h, and the remaining eight each twice, for 00–24 and for the 24–48 h accumulated precipitation.

#5 Eta (left), 22 km, switched to use sigma (center), 48 h position error of a major low increased from 215 to 315 km :



Valid 6 Nov. 2000; similar to earlier experiments at lower resolution

Chosen because “Avn” / GFS, at 48 h, was forecasting a very deep low centered in North Dakota – favoring the more northerly center

Why ?

Motivated by #5: Eta vs Avn accuracy in forecasting positions of "Major lows":

On consecutive HPC analyses, at 12 h intervals, in the first verification,

i) the analyzed center has to be the deepest inside at least three closed isobars (analyzed at 4 mb intervals). A "closed isobar" is here one that has all of the isobars inside of it, if any, appear only once;

ii) must not have an "L" analyzed between the 1st and the 2nd of its closed isobars, counting from the inside;

iii) has to be located east of the Continental Divide, over land or inland waters (e.g., Great Lakes, James Bay); and

iv) must be stamped on "four-pane" 60-h forecast plots of both the Eta and the Avn.

In the second verification,

Same, except that at least two closed isobars are required

Done manually

(NCEP HPC analyses used for verification,
hand-edited, at 12 h intervals, not available electronically)

Table 1. Forecast position errors, at 60 h, of "major lows", east of the Rockies and over land or inland waters, Dec. 2000 - Feb. 2001

Valid at	HPC depth	Cl. isb.	Ctr.	Avn error	Eta error
12z 7 Dec.	1002 mb	3	SD	875 km	425 km
00z 12 Dec.	997 mb	4	In	125 km	275 km
12z 12 Dec.	988 mb	7	NY	325 km	150 km
12z 17 Dec.	1001 mb	4	Sk	100 km	75 km
12z 17 Dec.	990 mb	7	On	175 km	425 km
00z 18 Dec.	984 mb	7	Qc	450 km	575 km
12z 18 Dec.	963 mb	11	Qc	75 km	100 km
00z 18 Dec.	1001 mb	3	Co	100 km	25 km
02z 18 Dec.	1010 mb	2	Mo	650 km	500 km
12z 19 Dec.	1006 mb	3	Ab	425 km	175 km
00z 20 Dec.	997 mb	5	Sk	250 km	350 km
12z 20 Dec.	1002 mb	2	ND	175 km	175 km
12z 21 Dec.	1008 mb	3	Mi	100 km	175 km
00z 22 Dec.	1007 mb	3	Mi	100 km	50 km
12z 22 Dec.	1011 mb	2	On	125 km	375 km
12z 24 Dec.	1015 mb	3	On	325 km	150 km

etc.

Summary

Winter #1:
41 cases, 18 events;
Average errors: Avn 319 km, Eta 259 km
Median errors: Avn 275 km, Eta 275 km
# of wins: Eta 25, Avn 15, 1 tie

Winter #2:
38 cases, 16 events;
Average errors: Avn 330 km, Eta 324 km
Median errors: Avn 262.5 km, Eta 250 km
# of wins: Eta 19, Avn 17, 2 ties

Eta somewhat more accurate both winters, in spite of this being at 2.5 days lead time, plenty in winter for the western boundary error to make it into the contiguous U.S.!

Note in particular:

States where typically lows form in front of deep troughs crossing the Rockies:

Colorado, Kansas, and states sharing borders with these two: a total of 10 cases,

8 wins for the Eta, 2 wins for the Avn

An aside re eta vs sigma #5 (position of low over Kansas)

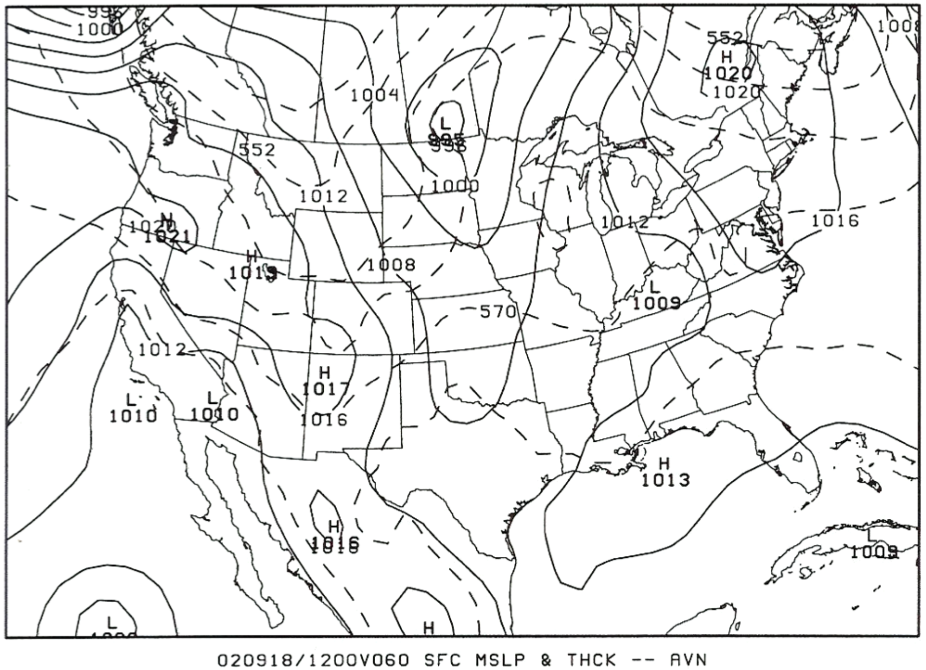
There were other cases in which the Eta did better in forecasting the detail of what was going to happen:

The three low centers case

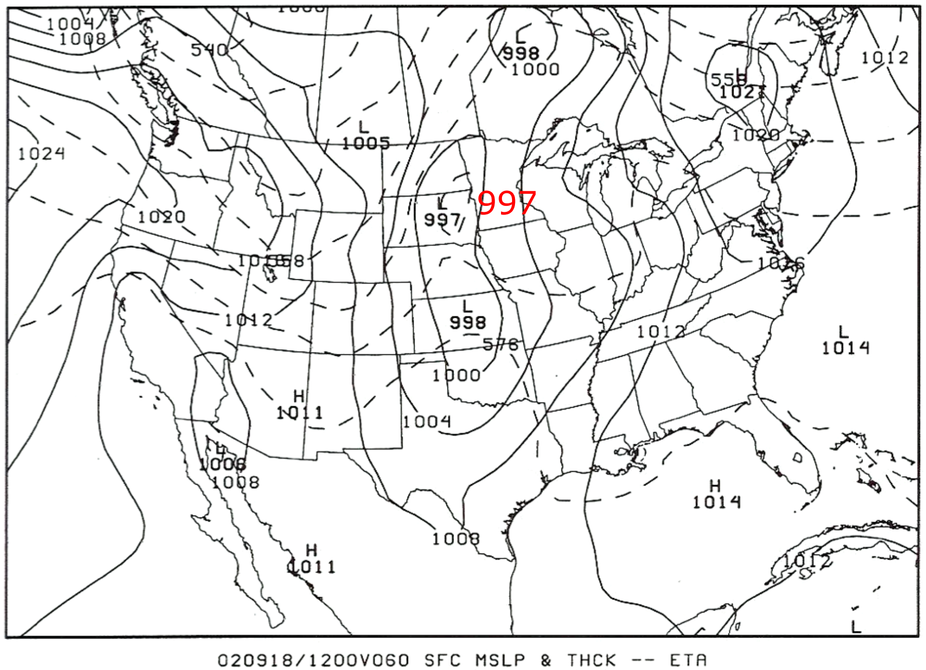
Valid at

12z 18 September 2002

Avn

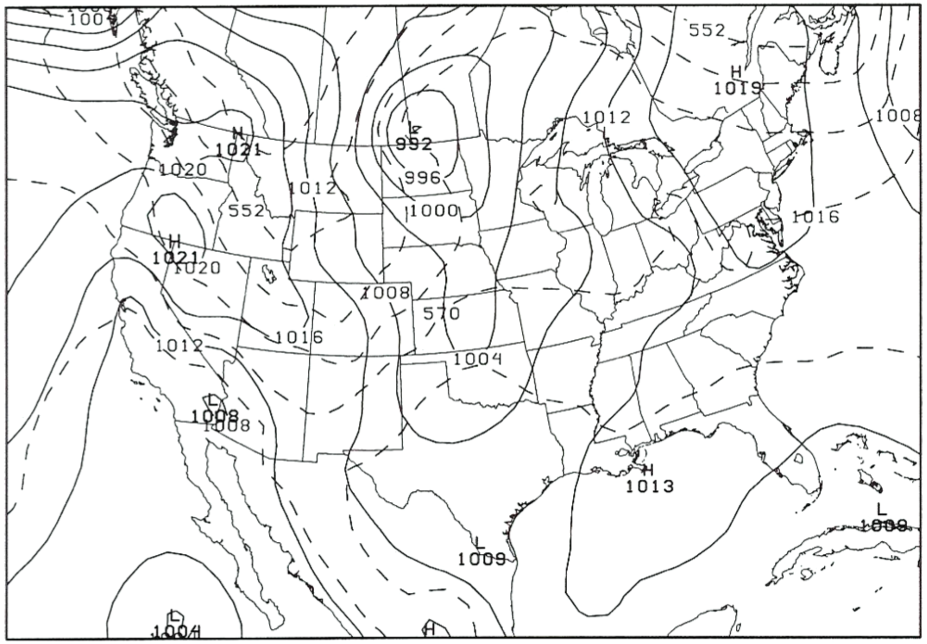


Eta



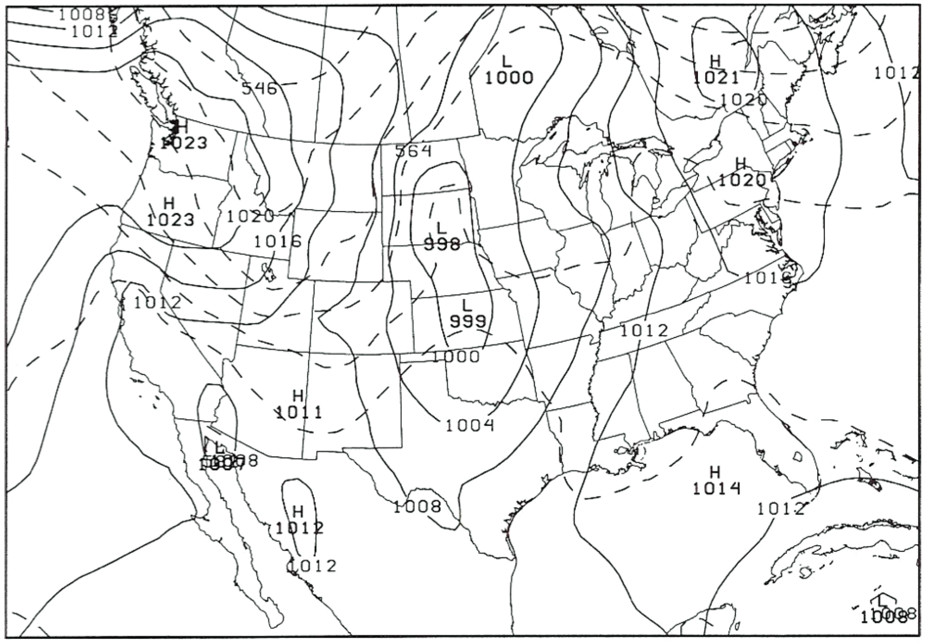
60 h fcsts

Avn



020918/1200V048 SFC MSLP & THCK -- AVN

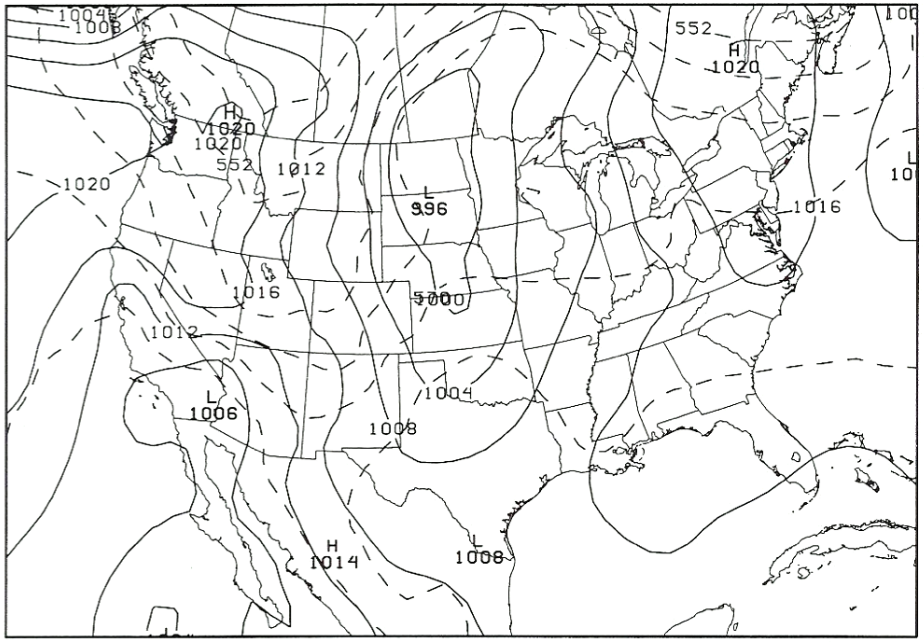
Eta



020918/1200V048 SFC MSLP & THCK -- ETA

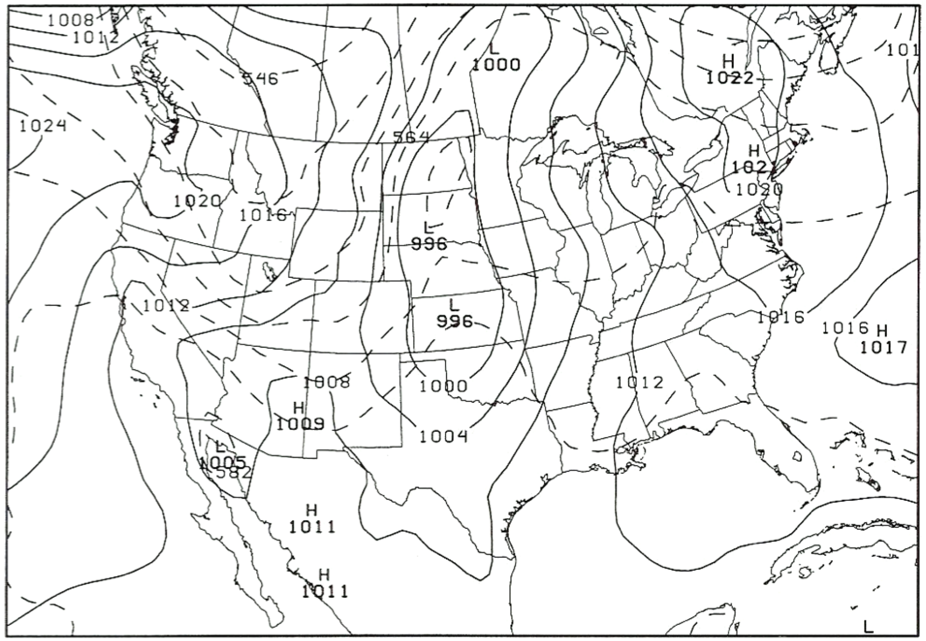
48 h fcsts

Avn



020918/1200V036 SFC MSLP & THCK -- AVN

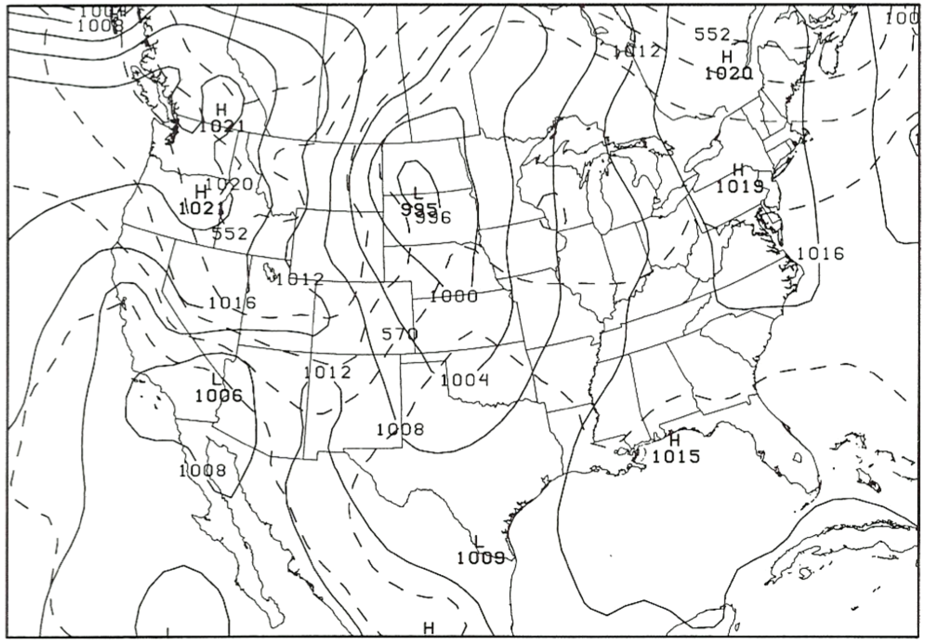
Eta



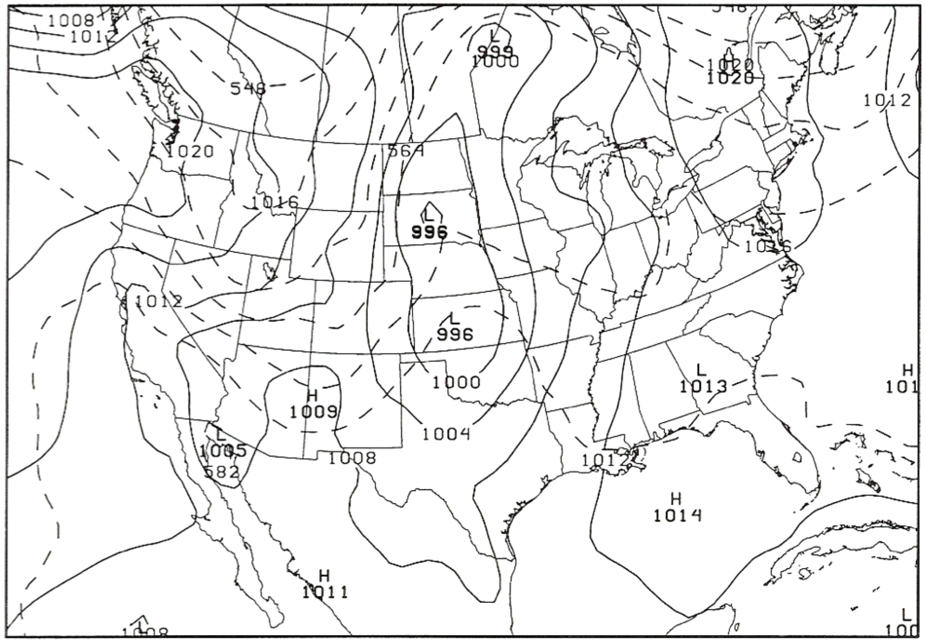
020918/1200V036 SFC MSLP & THCK -- ETA

36 h fcsts

Avn

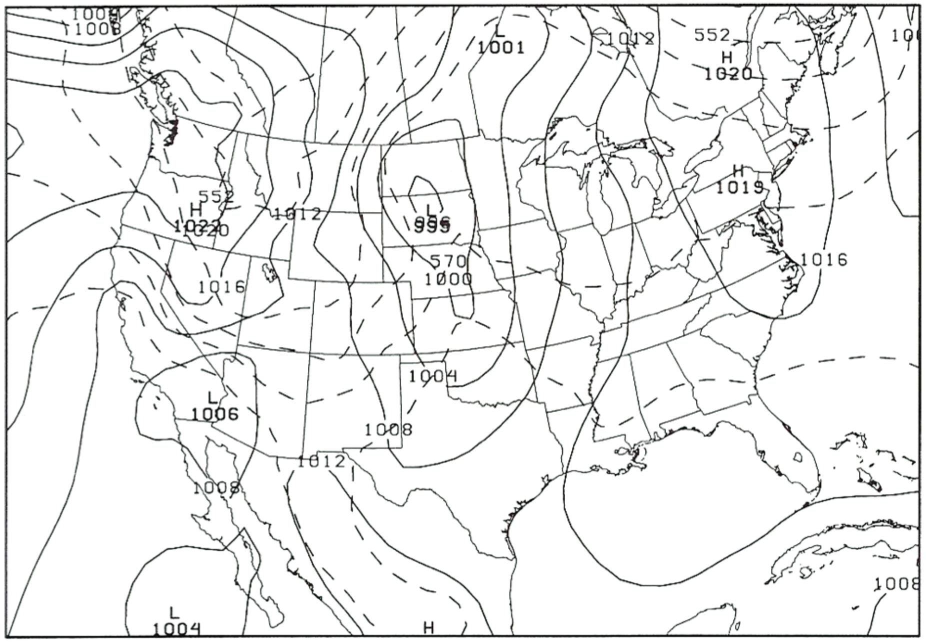


Eta

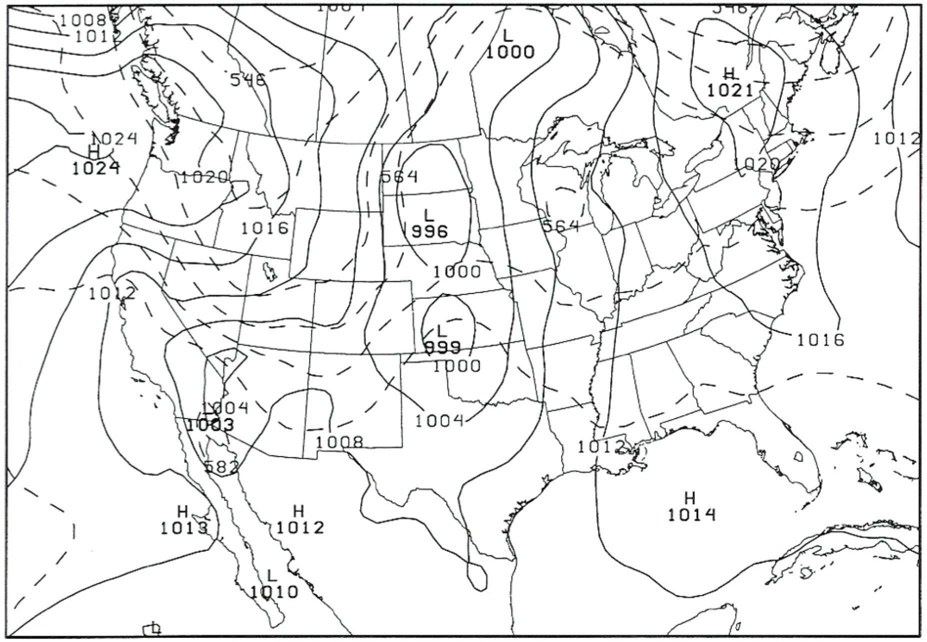


24 h fcsts

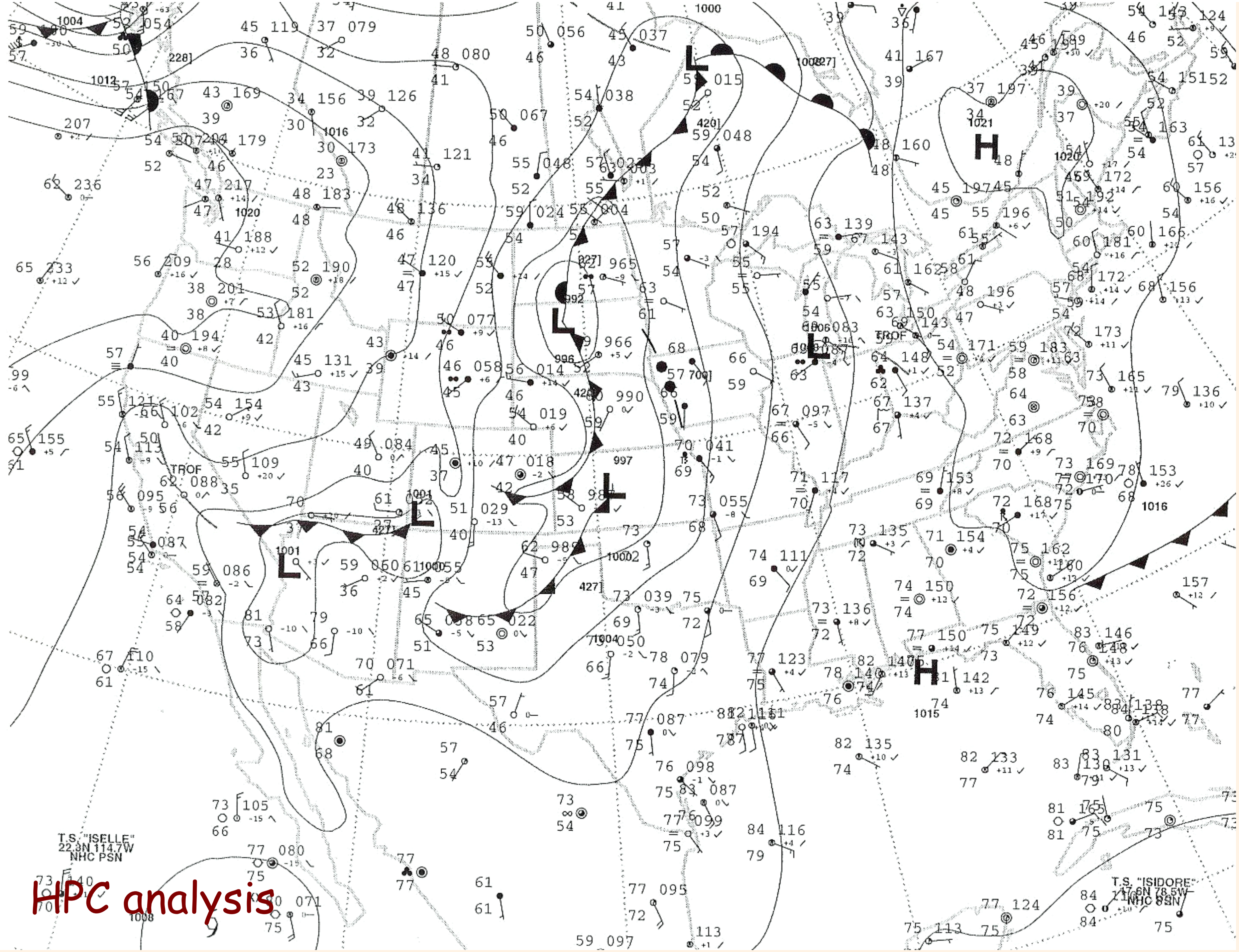
Avn



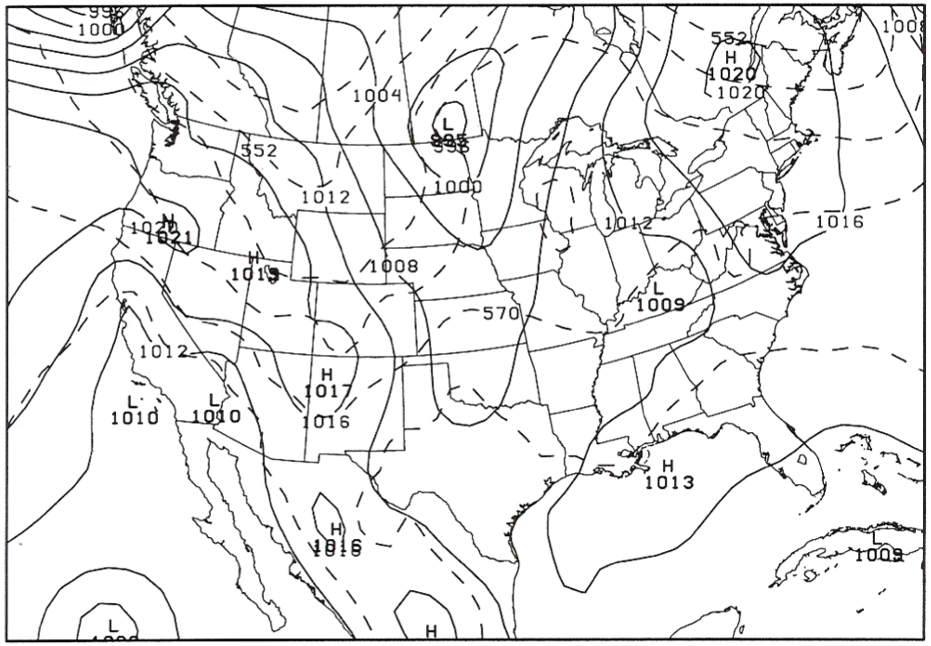
Eta



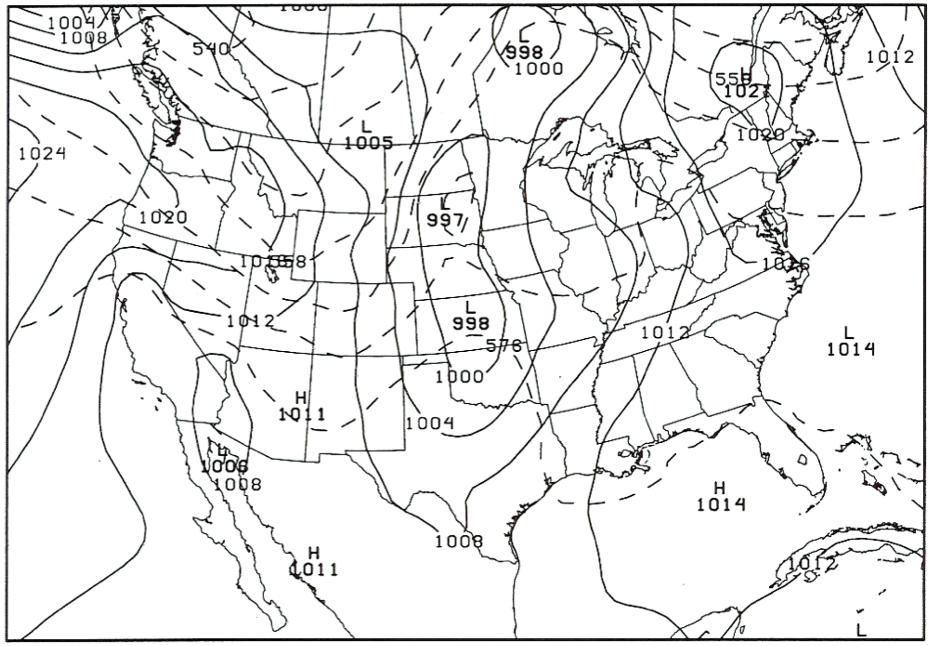
12 h fcsts



HPC analysis

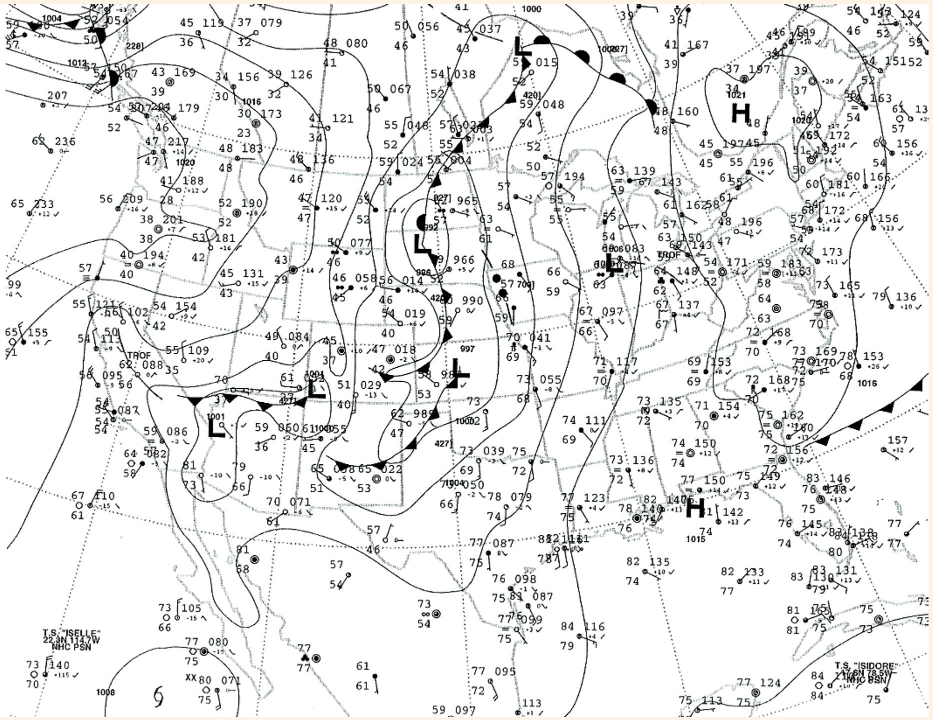


020918/1200V060 SFC MSLP & THCK -- AVN



020918/1200V060 SFC MSLP & THCK -- ETA

Avn, 60 h fcst



HPC analysis

Eta, 60 h fcst

However: Eta Gallus-Klemp (MWR 2000) problem, etc.:

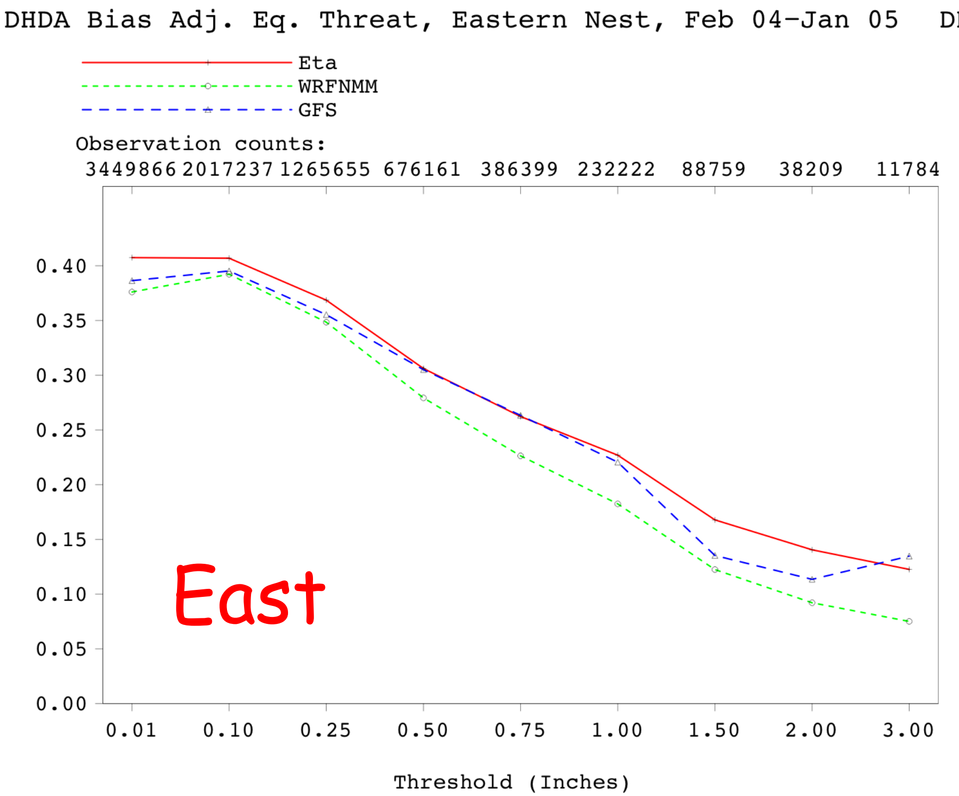
An NCEP decision to move toward implementation of NMM, NMM-WRF to be. NOAA-wide announcement summer of 2002, in support of the operational implementation of the NMM at NCEP, using terrain-following coordinate, stated

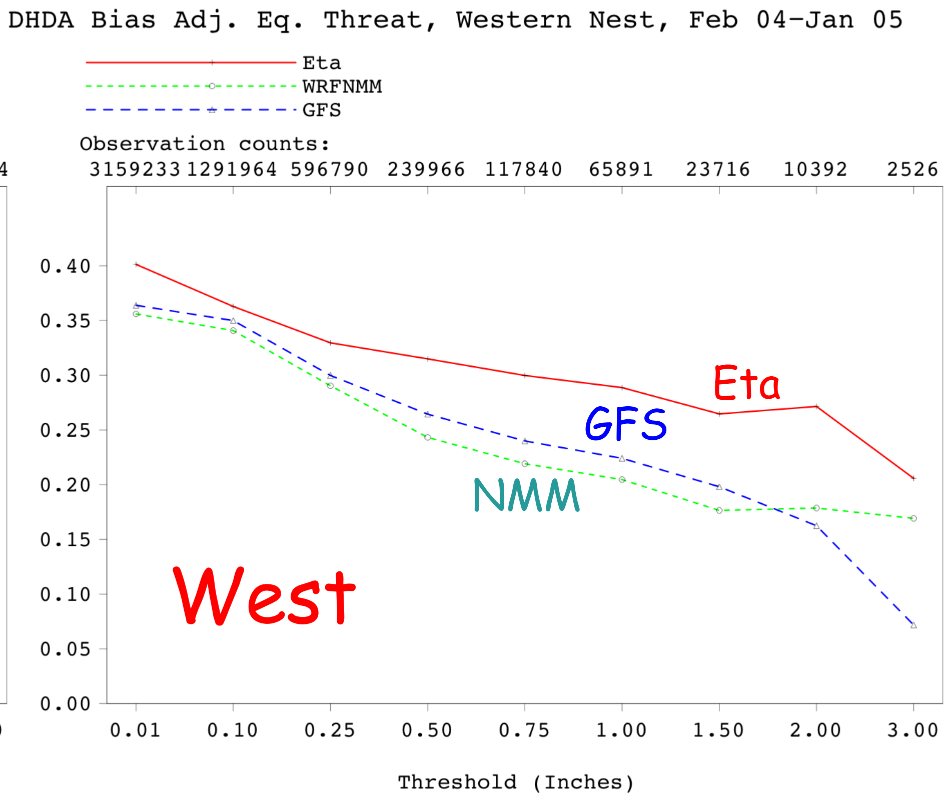
"This choice [of the vertical coordinate] will avoid the problems . . . with strong downslope winds and will improve placement of precipitation in mountainous terrain."

Consequently, the Eta "frozen" since spring of 2005; a single implementation after summer of 2003 in land-surface, and cloud/radiation

Last 12 months of the availability of three model scores:

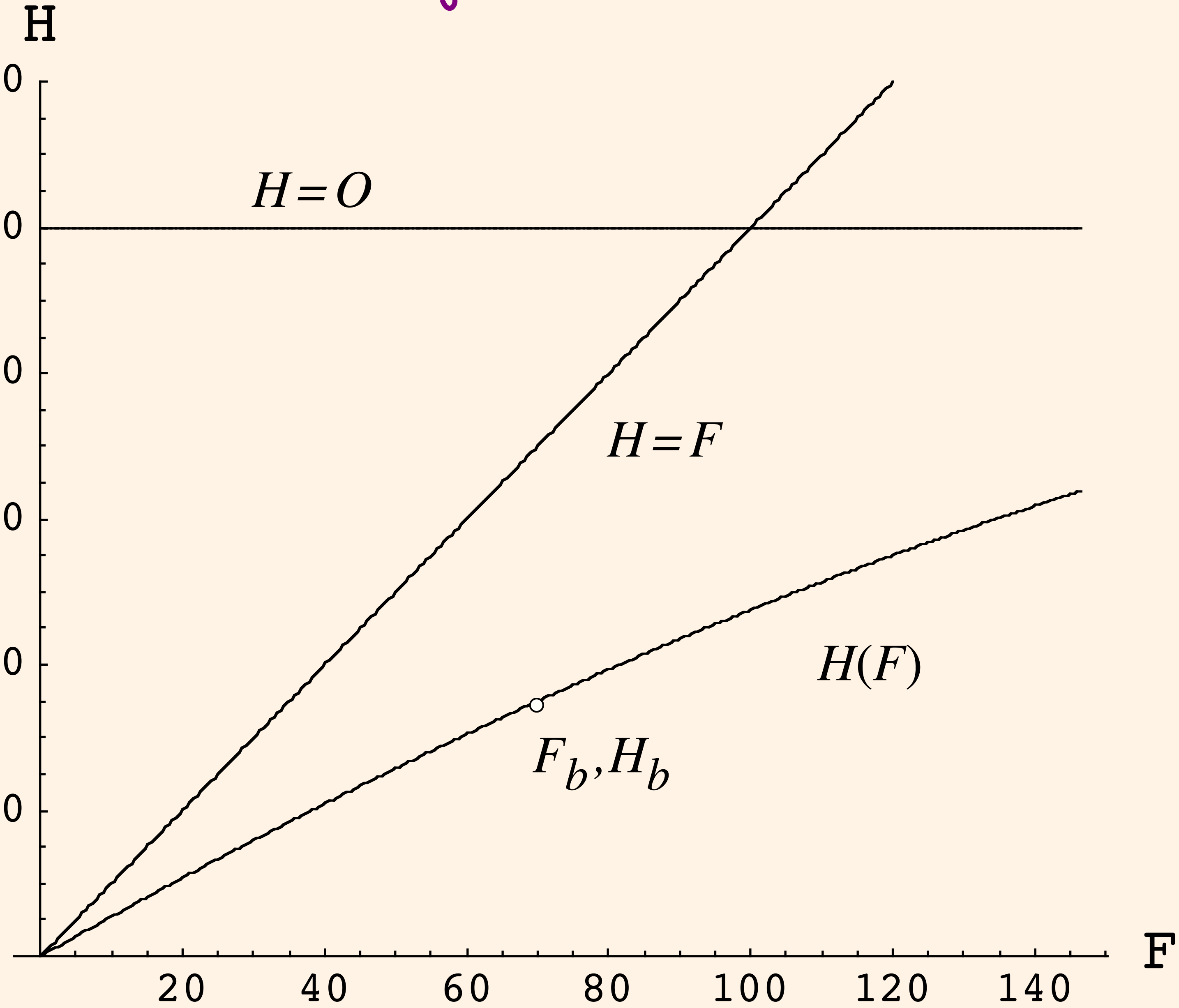
ETS corrected for bias, "hi-res nests" over ConUS:





Eta 12-km, NMM 8-km; correction for bias: Mesinger (Adv. Geosci. 2008): In order to obtain score that verifies placement of precipitation !

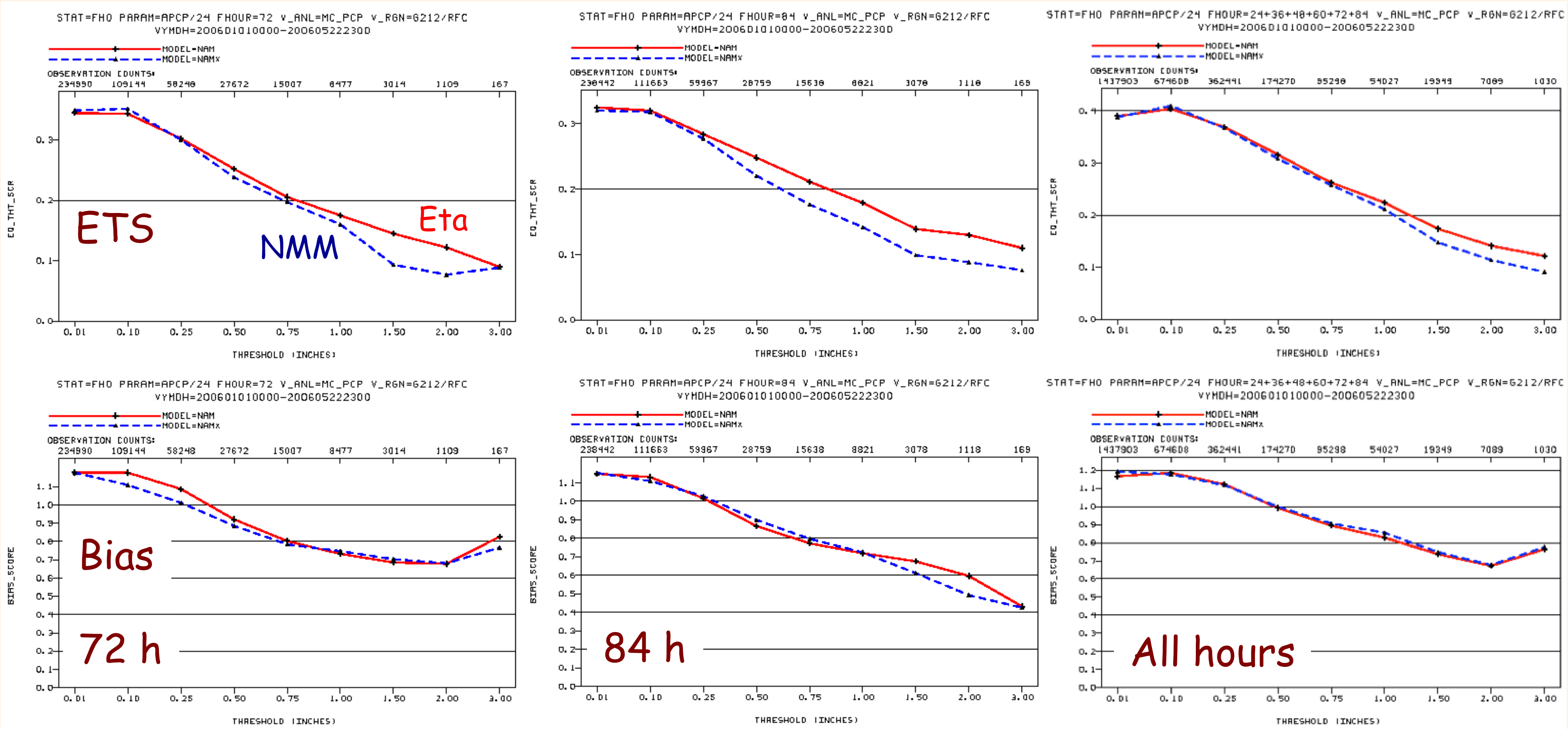
ETS adjustment for bias: dHdA method:



Precipitation scores of the parallel NMM/GSI vs Eta/EDAS, 1 January-22 May 2006:

Unfortunately, ETS not corrected for bias

(From DiMego 2006)



24-h precipitation Equitable Threat Scores (upper panels) and Bias Scores (lower panels) of the Eta model/EDAS (red) and NMM-WRF/GSI (blue), of the 1 January-22 May 2006 parallel, run at 12-km resolutions. 24-h precipitation thresholds are increasing from 0.01 to 3 in/24 hours along the abscissas of the plots. Verifications at 72 h (left), 84 h (middle), and combined 24, 36, 48, 60, 72 and 84 h (right). After DiMego (2006).

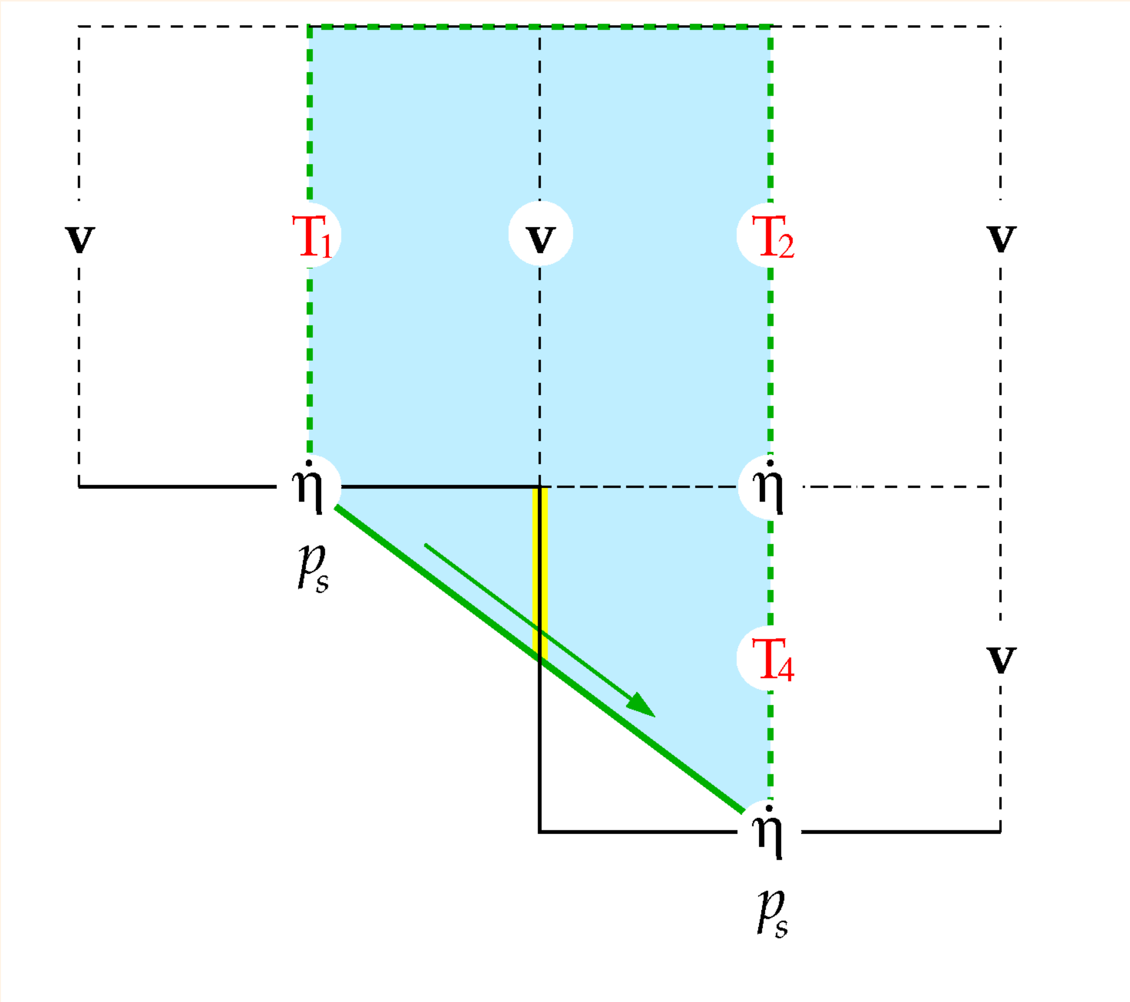
Eta developments subsequent to its NCEP "Workstation version":

Mesinger, F., S. C. Chou, J. Gomes, D. Jovic, P. Bastos, J. F. Bustamante, L. Lazic, A. A. Lyra, S. Morelli, I. Ristic, and K. Veljovic, 2012: An upgraded version of the Eta model. *Meteor. Atmos. Phys.*, **116**, 63-79.

Major new feature: "sloping steps" (Mesinger and Jovic, NCEP ON 439)

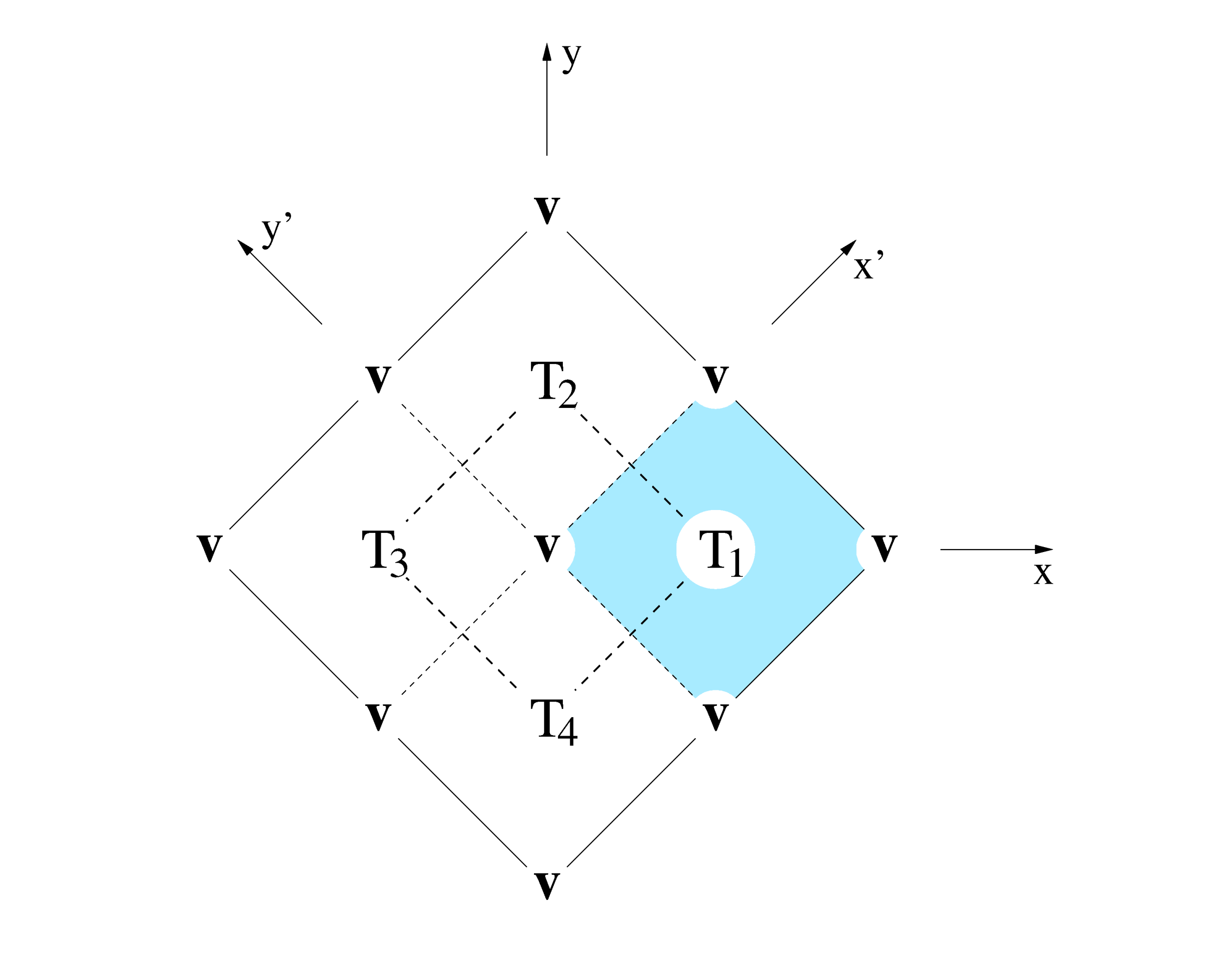
The sloping steps disretization, vertical grid

The central **v** box exchanges momentum, on its right side, with **v** boxes of two layers:



Horizontal treatment, 3D

Example #1: topography of box 1 is higher than those of 2, 3, and 4; "Slope 1"



Inside the central **v** box, topography descends from the center of T1 box down by one layer thickness, linearly, to the centers of T2, T3 and T4

A real data downslope windstorm test:

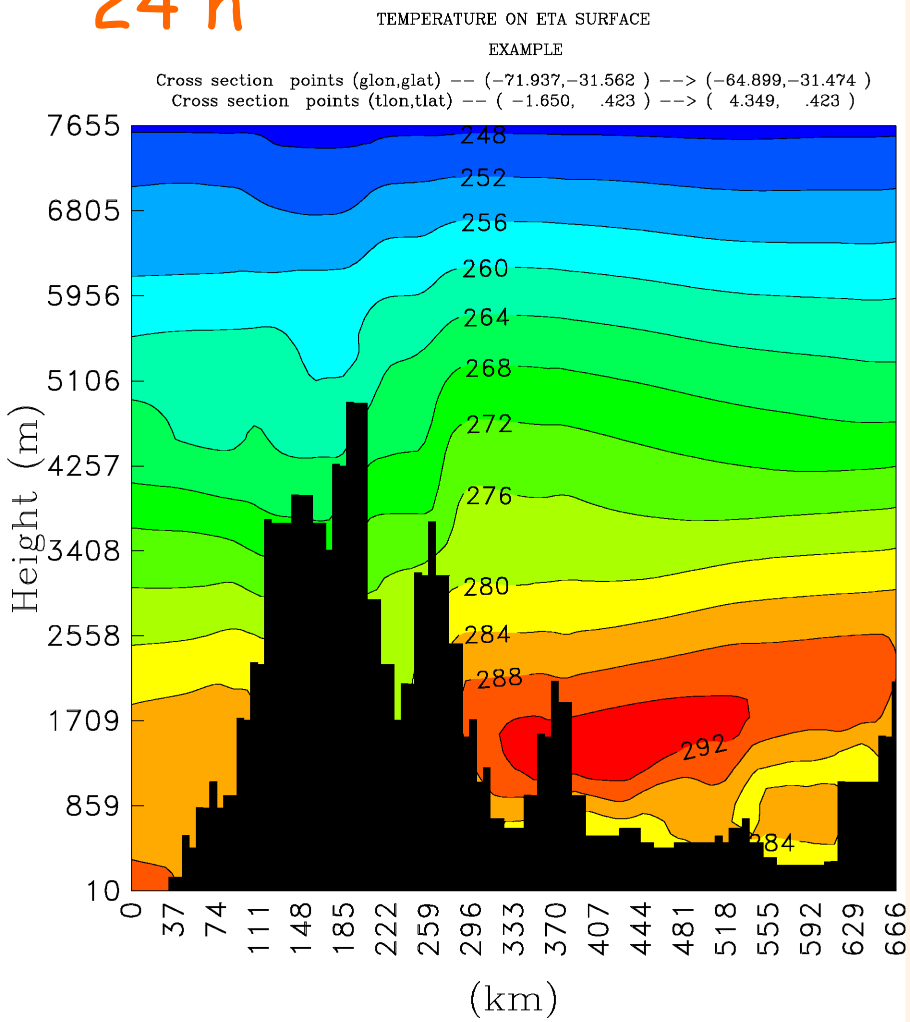
Zonda case of 11-12 July 2006

Acknowledgement:

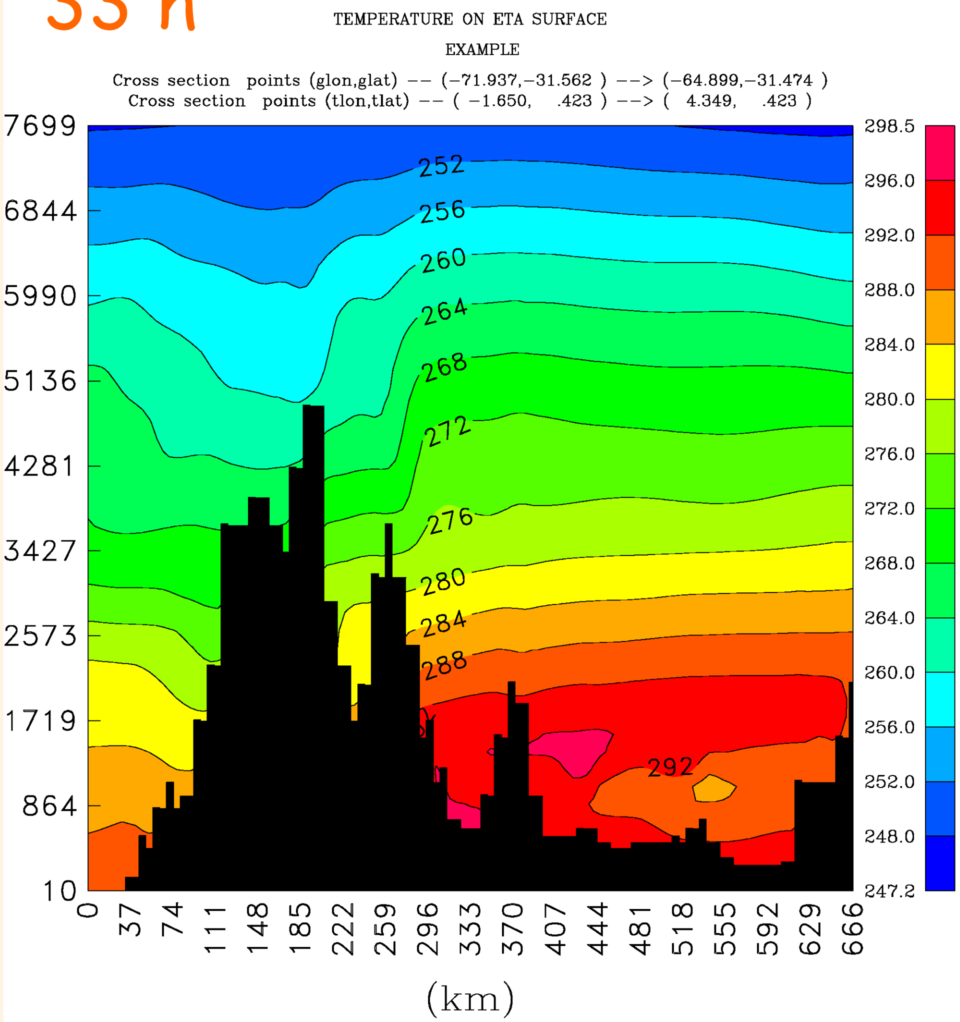
. . .

Initial condition: 1200 UTC 10 July 2006; 8 km/60 lyr resolution, nonhydrostatic switch on

24 h



33 h



T change in the San Juan area from < 284 K to > 296 K !

2) The Eta topography

NARR Q&A.   Summary:

Grid cell silhouette and mean topography values calculated;

Where Laplacian of the mean > 0, mean
Where Laplacian of the mean < 0, silhoutte

Followed by an effort to restore major mountain passes that may have been closed by silhouette.

Examples of treatment of topography in some other models / by other authors

Webser et al. QJ 2003:

SMOOTHING THE OROGRAPHY

(a) Motivation

A fundamental limitation of any numerical model is that features close to the grid-scale are poorly resolved; at these scales truncation effects (numerical errors) will dominate the true solution. As emphasized by Lander and Hoskins (1997), it is therefore desirable that these scales should not be forced directly as otherwise the well-resolved scales may very soon be contaminated by the errors forced at, or close to, the grid-scale.

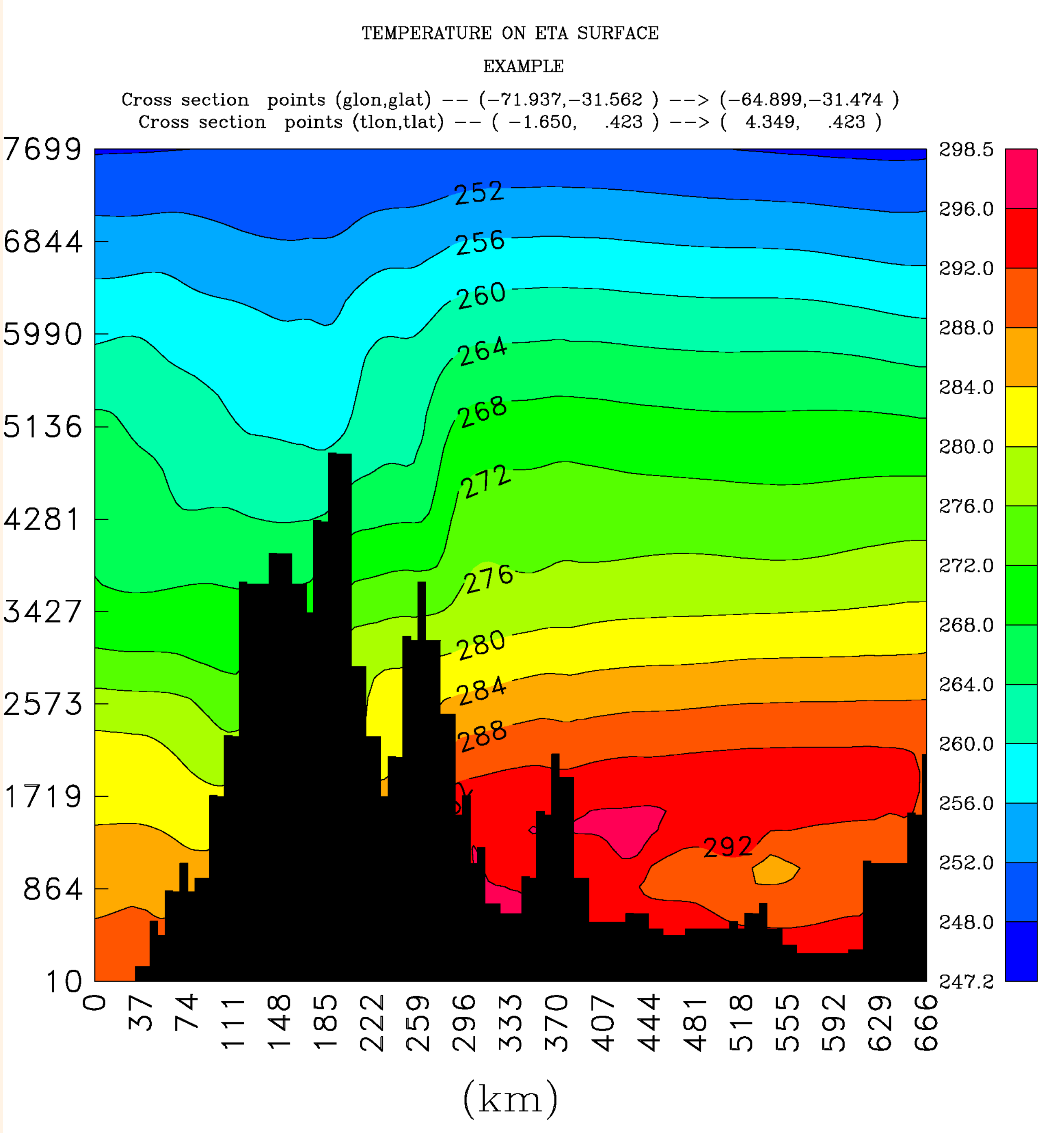
Weller, Shahrokhi, MWR 2014:

ABSTRACT
Steep orography can cause noisy solutions and instability in models of the atmosphere. A new technique for modeling flow over orography is introduced ….

....

NMM, DiMego 2006:

"Lightly smoothed, grid-cell mean everywhere"


TEMPERATURE ON ETA SURFACE
EXAMPLE
Cross section points (glon,glat) -- (-71.937,-31.562) --> (-64.899,-31.474)
Cross section points (tlon,tlat) -- (-1.650, .423) --> (4.349, .423)
7699
6844
5990
5136
4281
3427
2573
1719
864
10
252
256
260
264
268
272
276
280
284
288
292
0
37
74
111
148
185
222
259
296
333
370
407
444
481
518
555
592
629
666
(km)
298.5
296.0
292.0
288.0
284.0
280.0
276.0
272.0
268.0
264.0
260.0
256.0
252.0
248.0
247.2

3) Gallus-Klemp / Witch of Agnesi test

Falure of an experimental Eta to do well a Wasatch downlsope windstorm, and Gallus, Klemp experiments (MWR 2000) led to a widespread opinion that the eta coordinate was "ill suited for high resolution prediction models”

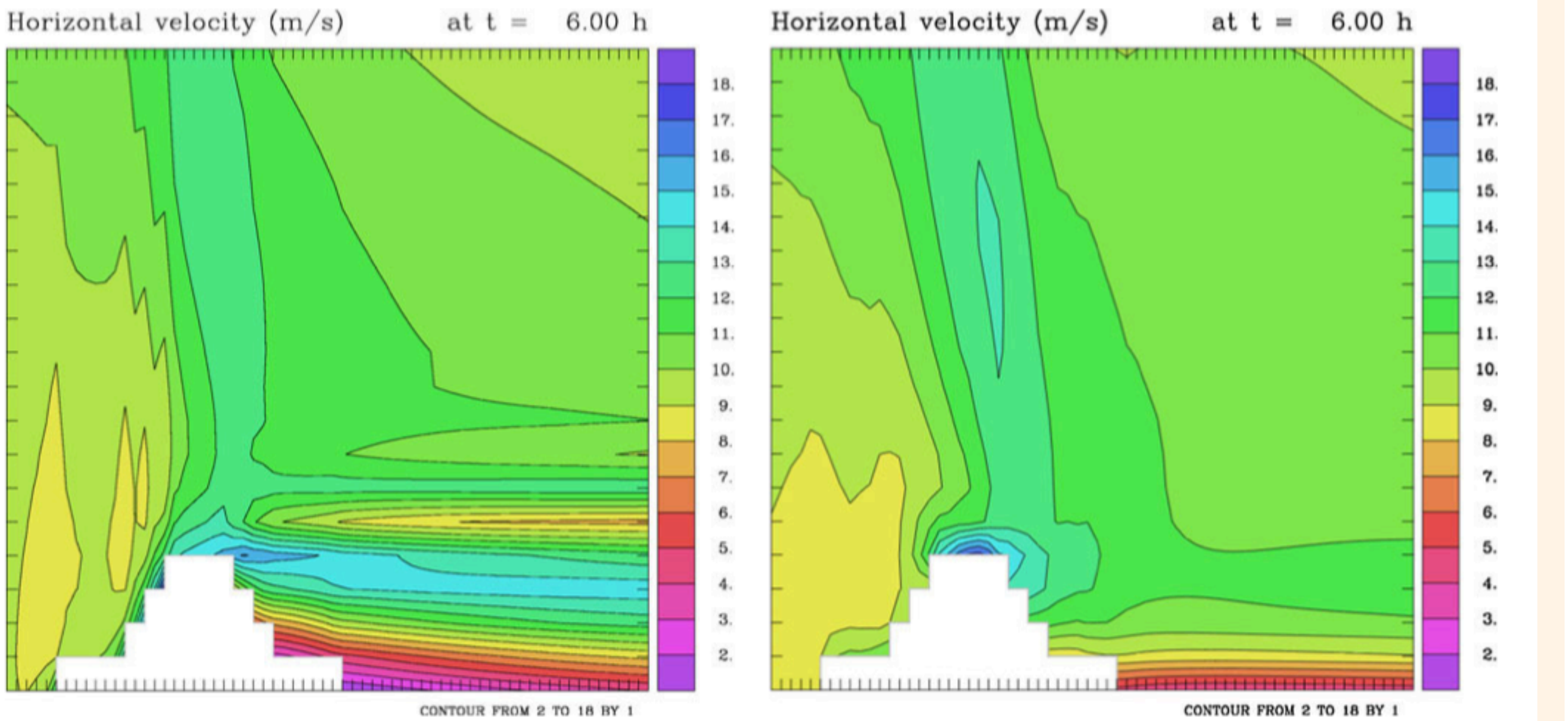


Fig. 3 Gallus–Klemp experiment, with parameters chosen so as to mimic the results shown in Gallus–Klemp (2000) Fig. 6. Control, *left panel*; code using sloping steps eta discretization, *right panel*

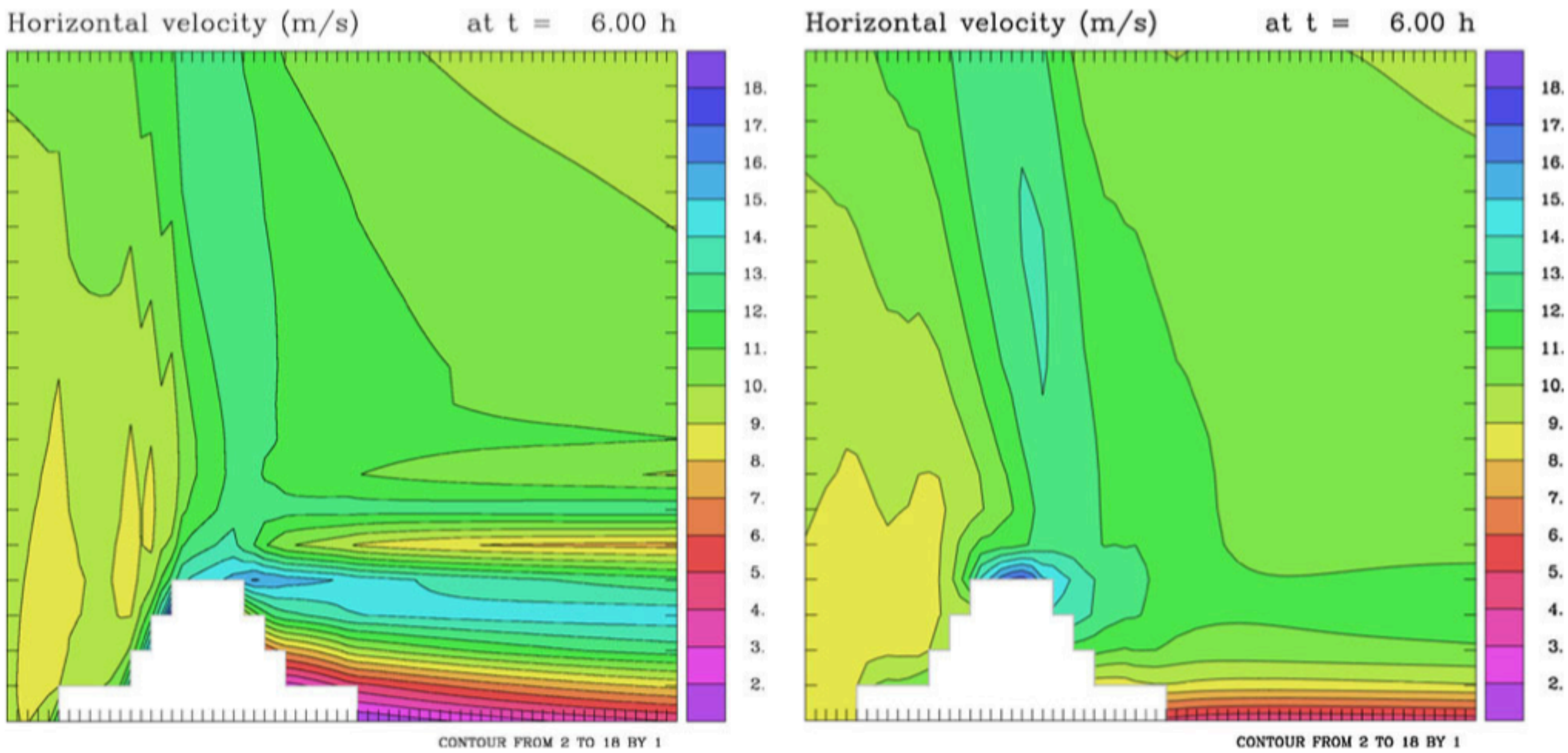
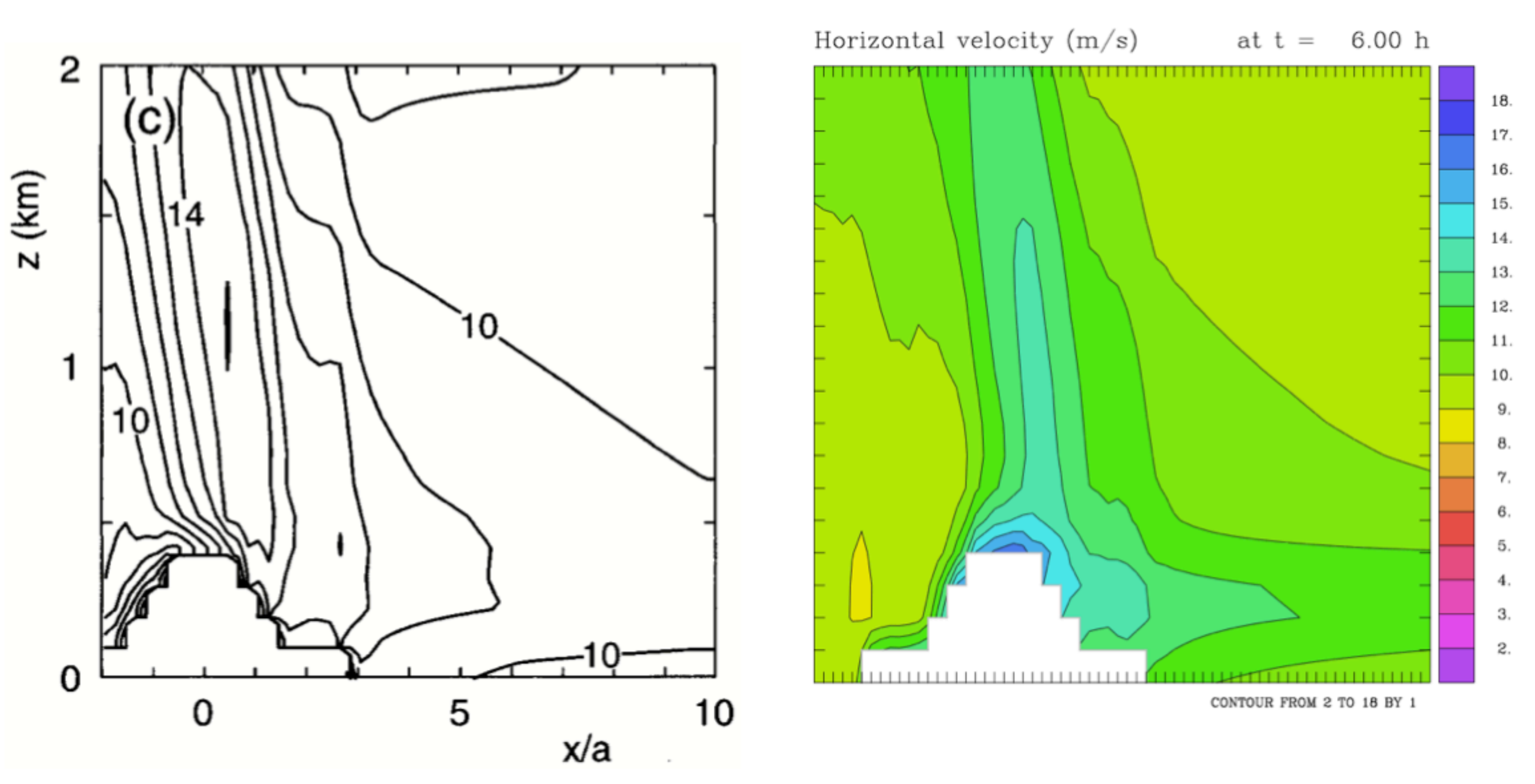


Fig. 3 Gallus–Klemp experiment, with parameters chosen so as to mimic the results shown in Gallus–Klemp (2000) Fig. 6. Control, *left panel*; code using sloping steps eta discretization, *right panel*

Recently, an ommision was noted of making the horizontal diffusion code aware of the sloping steps discretization. Attending to this issue an unconditionally stable and monotonic Smagorinsky-like horizontal diffusion scheme was put in place. Now:



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.

4) Skill in 250 hPa winds vs ECMWF in ensemble experiments

Veljovic et al. (M. Zeitschrift, 2010),

Eta 26 member ensemble driven by an ECMWF 32-day ensemble:

(Upgraded) Eta: ~31 km/45 layer, 12,000 x 7,580 km domain;

ECMWF: T399 (~50 km)/62 level to 15 days, lower resolution later;

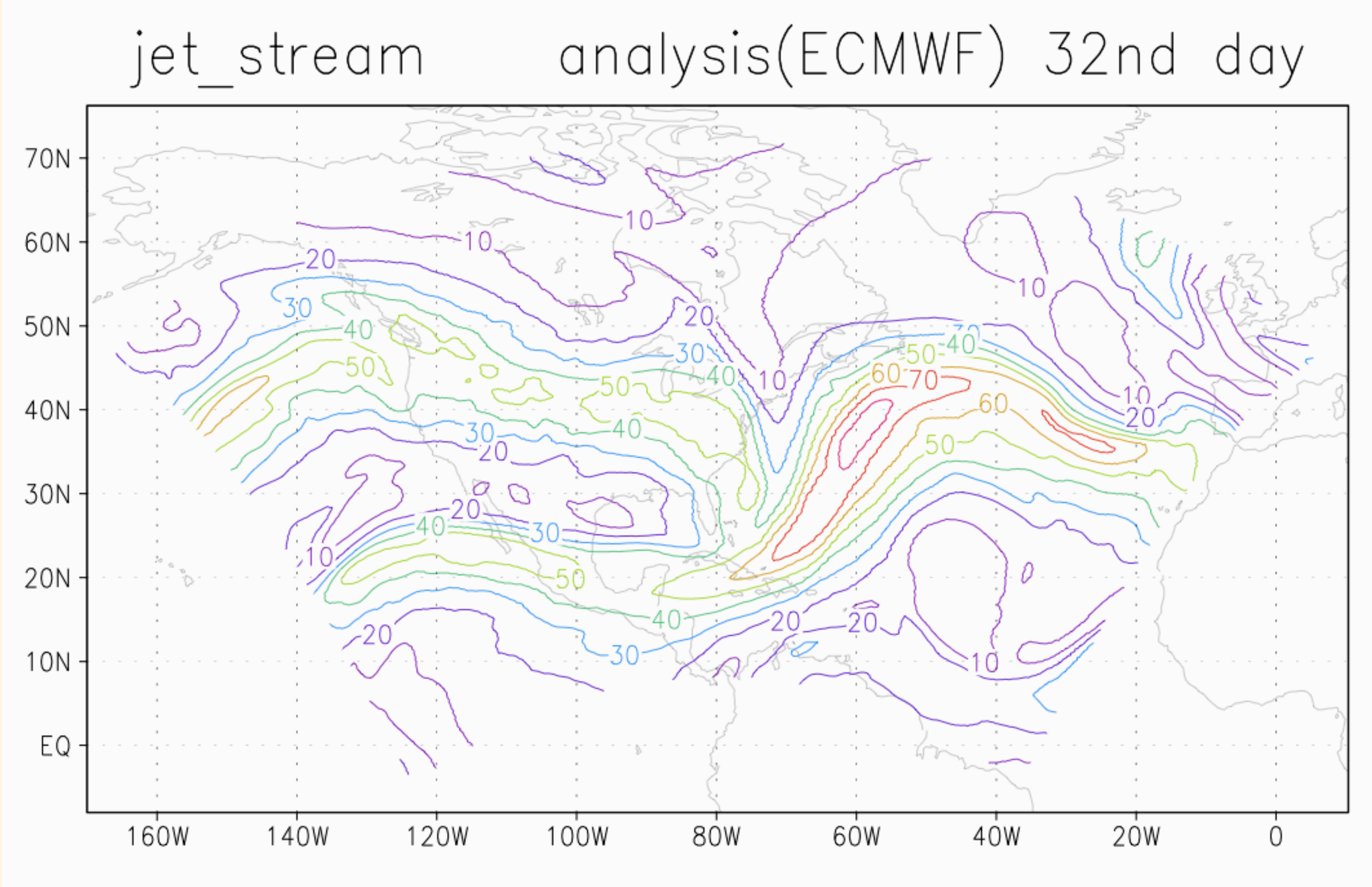
Verification against ECMWF analyses

Question #1 asked:

Can a nested model improve on large scales ?

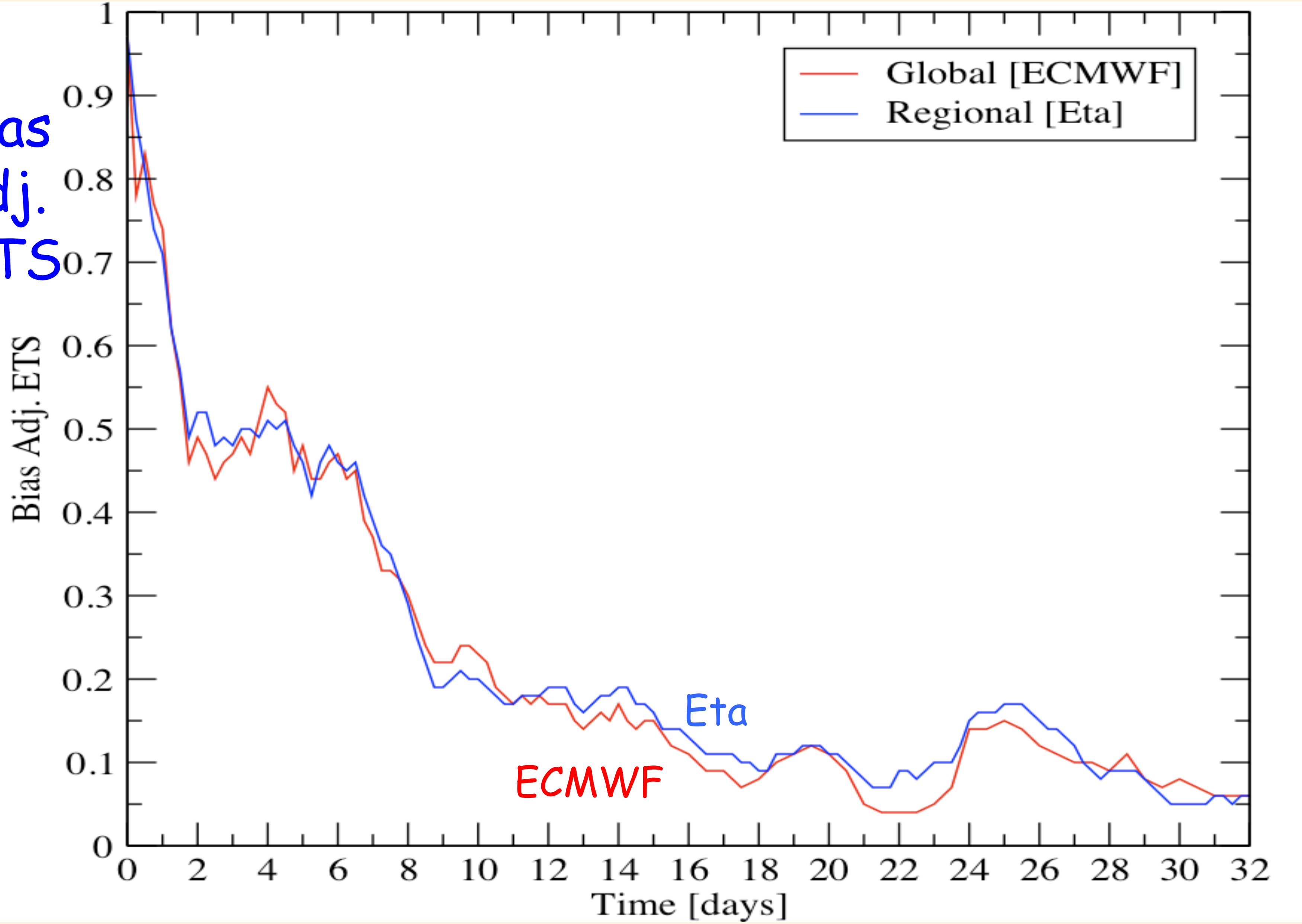
How do we look at "large scales" ?

Winds at 250 hPa, position of the jet stream !

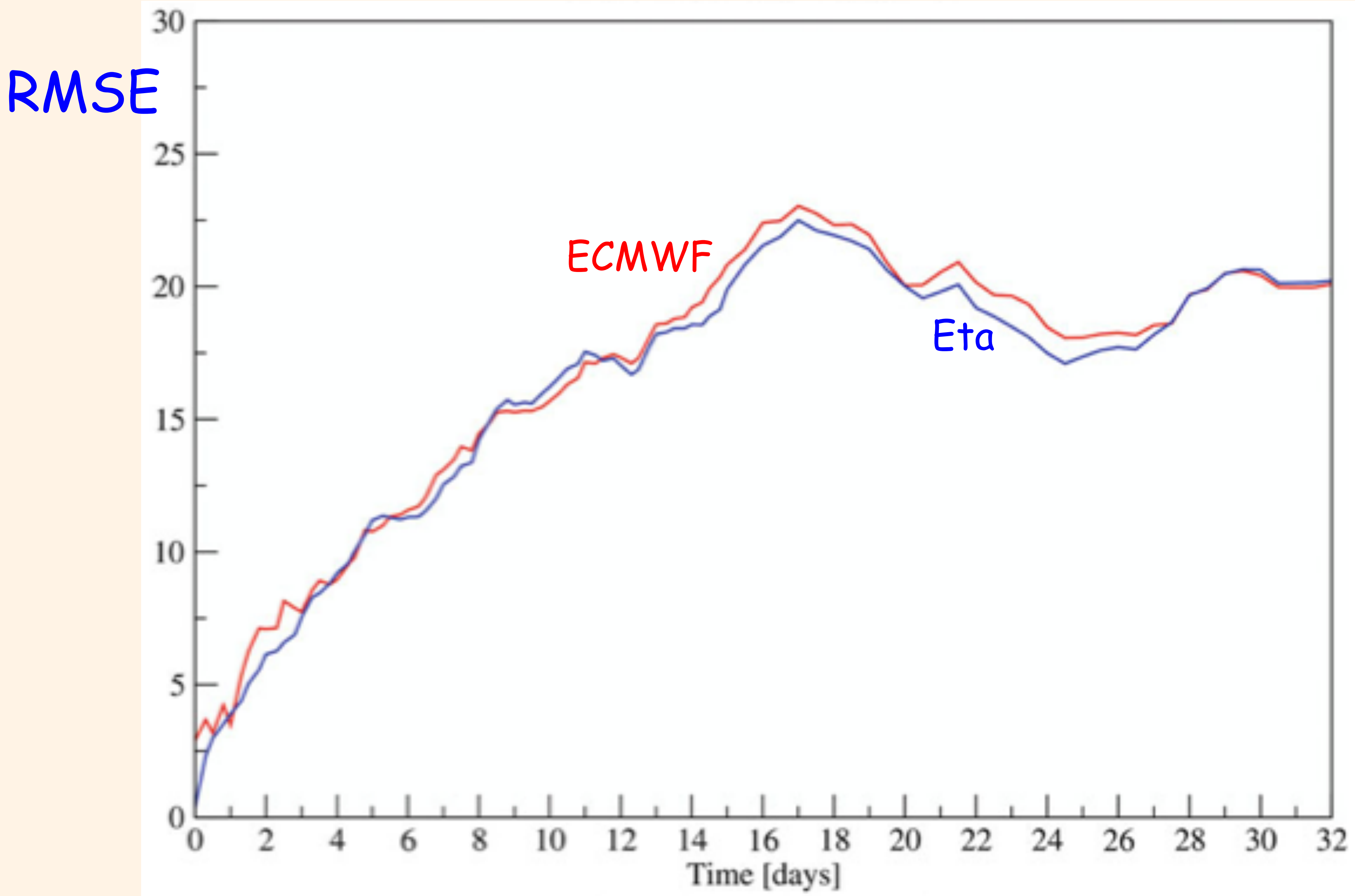

jet_stream analysis(ECMWF) 32nd day
70N
60N
50N
40N
30N
20N
10N
EQ
160W
140W
120W
100W
80W
60W
40W
20W
0

Results: 26 members 32-day forecasts, winds > 45 m/s:

Bias adj. ETS



Customary rms difference, m/s, all 26 forecasts:



What is/are the main contribution/s enabling the Eta, a regional model incurring LBC errors, to generate, more often than not, large scales better than its driver forecasts ?

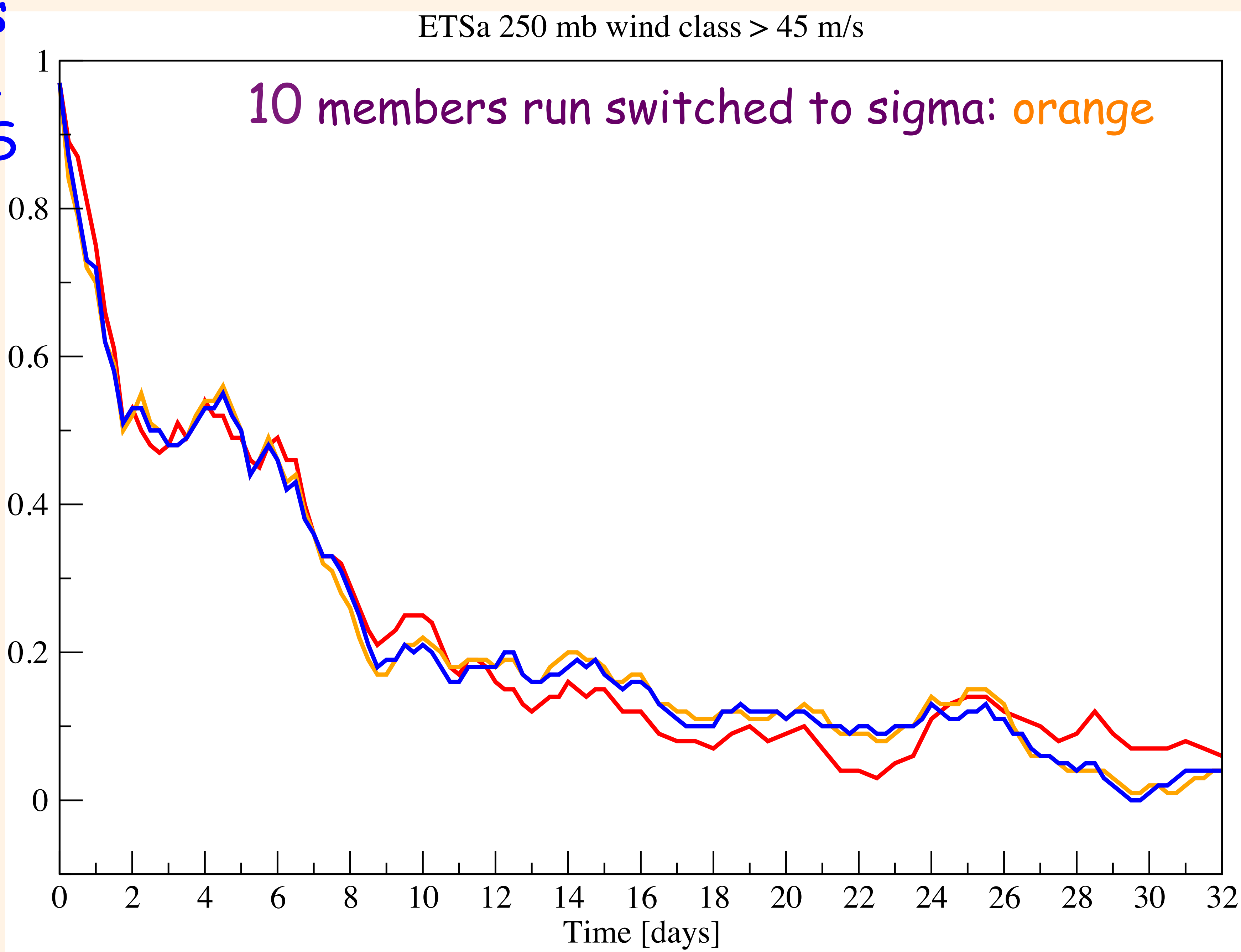
What is/are the main contribution/s enabling the Eta, a regional model incurring LBC errors, to generate, more often than not, large scales better than its driver forecasts ?

Specifically, why the Eta scores improve around day 12 compared to the ECMWF ones ?

Could it be the eta coordinate ?

10 members run switched to sigma

Bias adj. ETS



ETSa 250 mb wind class > 45 m/s
10 members run switched to sigma: orange
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
Time [days]

rms difference plot: almost identical message !

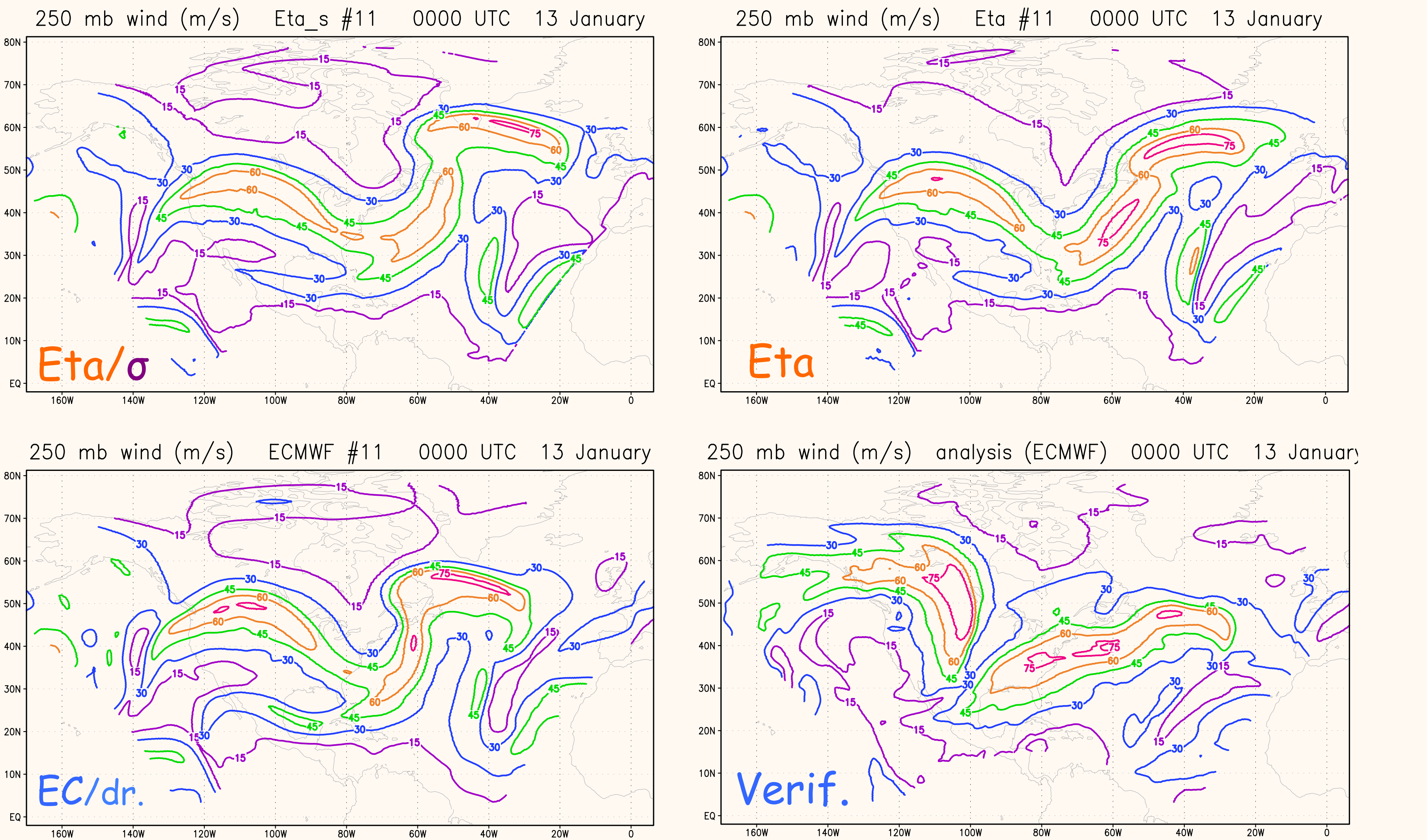
Thus: eta vs sigma not identified as the #1 reason for the success of the Eta against ECMWF in the 26-member ensemble result

What else could be the reason/s ?

We can only produce a list of possible candidates :(

However: Inspecting wind speed maps at 12 days we could see, synoptically, Eta tending to produce a more accurate tilt of the 250 hPa trough compared to both ECMWF, and the Eta run as sigma

Example, member 11:



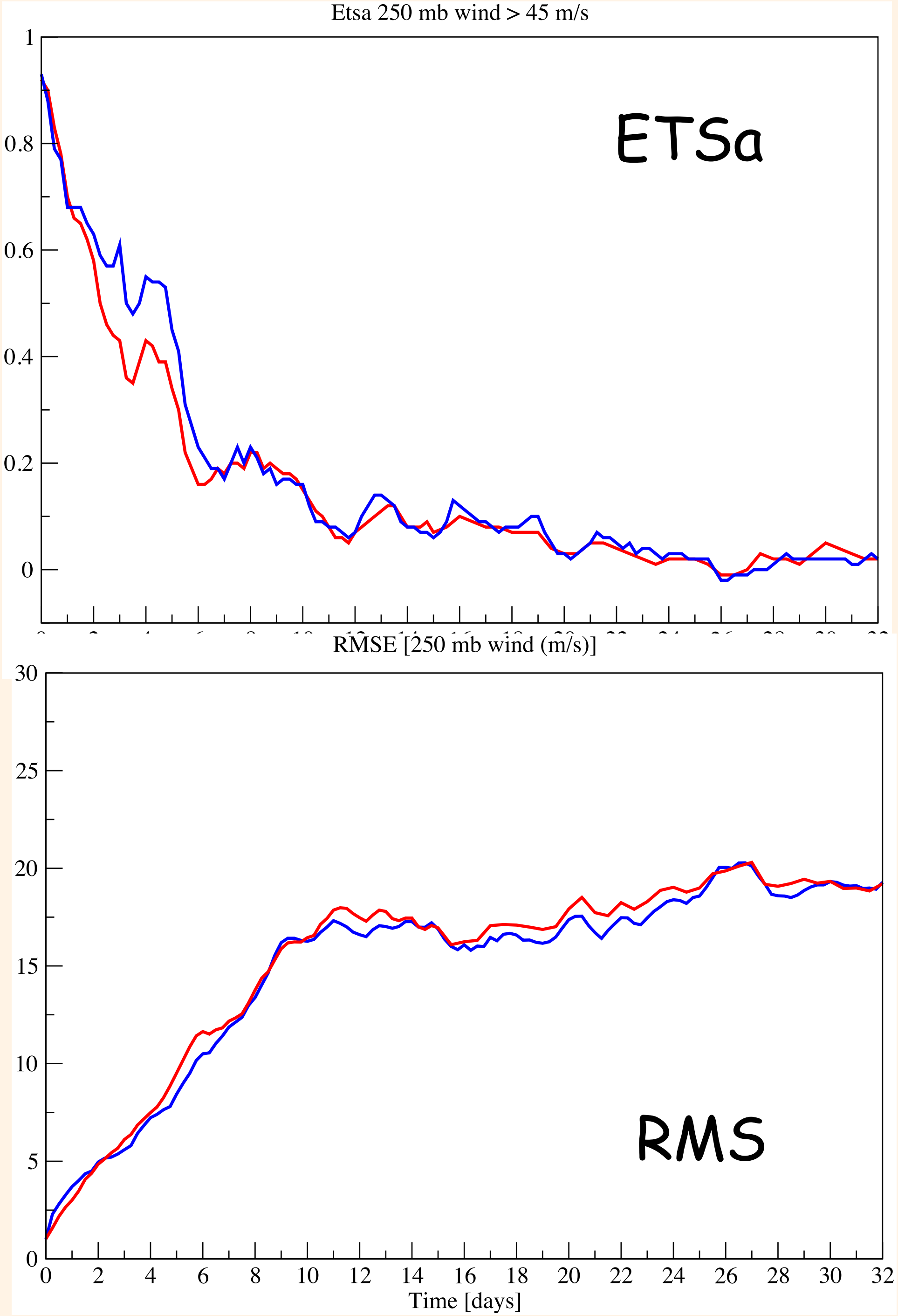
Speed contours of 250 hPa winds of 12 day forecasts, shown over the Eta members' domain: of the Eta member 11 but run using sigma coordinate, top left panel; same but using the eta, top right panel; same but of the ECMWF ensemble member 11 used to drive these Eta forecast, bottom left panel. Same except ECMWF analysis verifying at the same time, bottom right panel.

This kind of an advantage for Eta in 3 out of 10 members. In one member sigma had a more accurate tilt.

A 10-member Eta experiment rerun for a more recent ECMWF ensemble, one initialized 4 October 2012, when its resolution was higher than of that used previously:

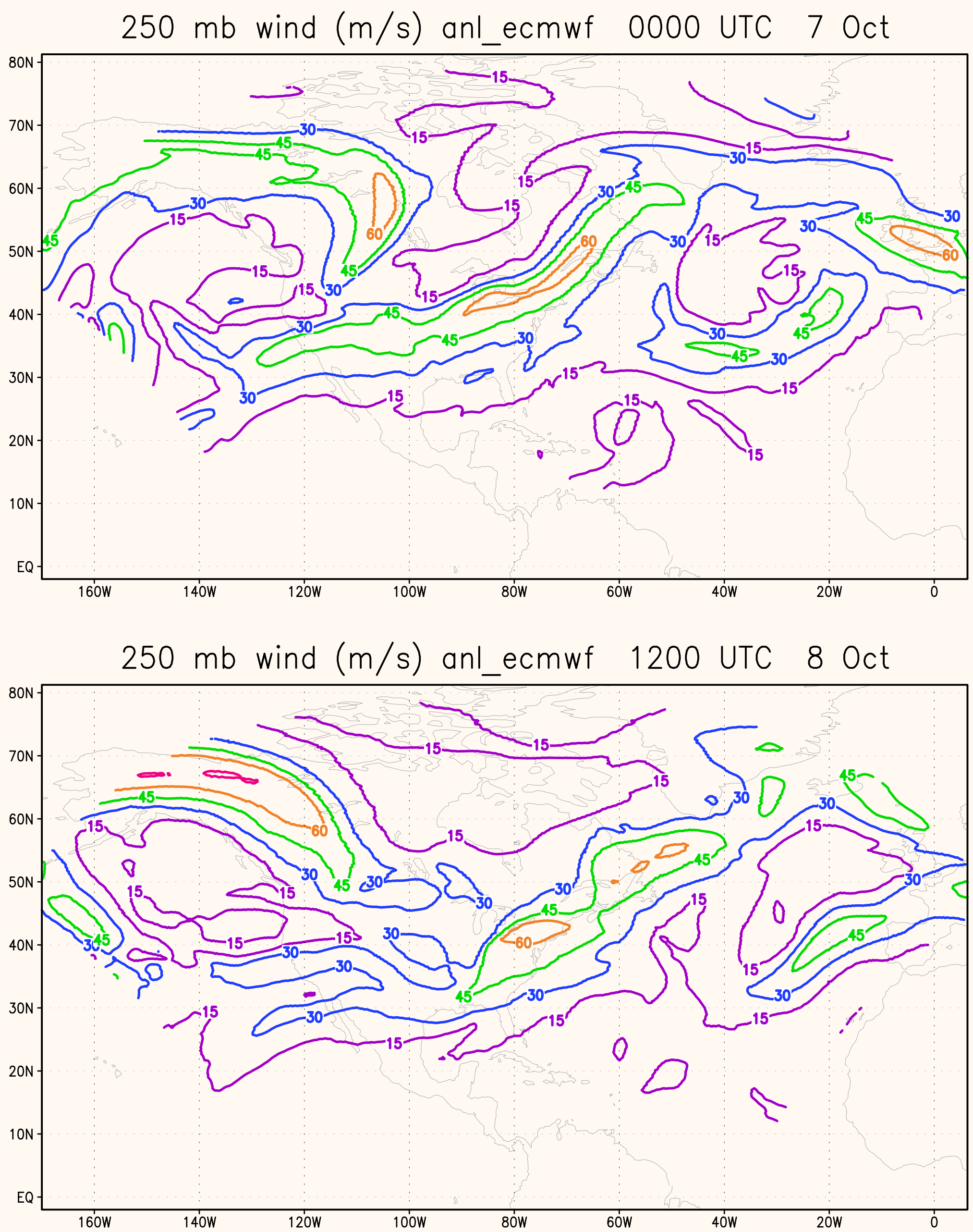
32 km the first 10 days, 63 km thereafter

Bias adjusted ETS scores of wind speeds greater than 45 m s^{-1}, upper panel, and RMS wind difference, lower panel, of the driver ECMWF ensemble members (red) and Eta members (blue), both at 250 hPa and with respect to ECMWF analyses. Initial time is 0000 UTC 4 October 2012.



Contours of the 250 hPa wind speeds, in m s^{-1}, of the ECMWF analysis valid at 0000 UTC 7 October 2012, upper panel, and of that valid at 1200 UTC 8 October 2012, lower panel.

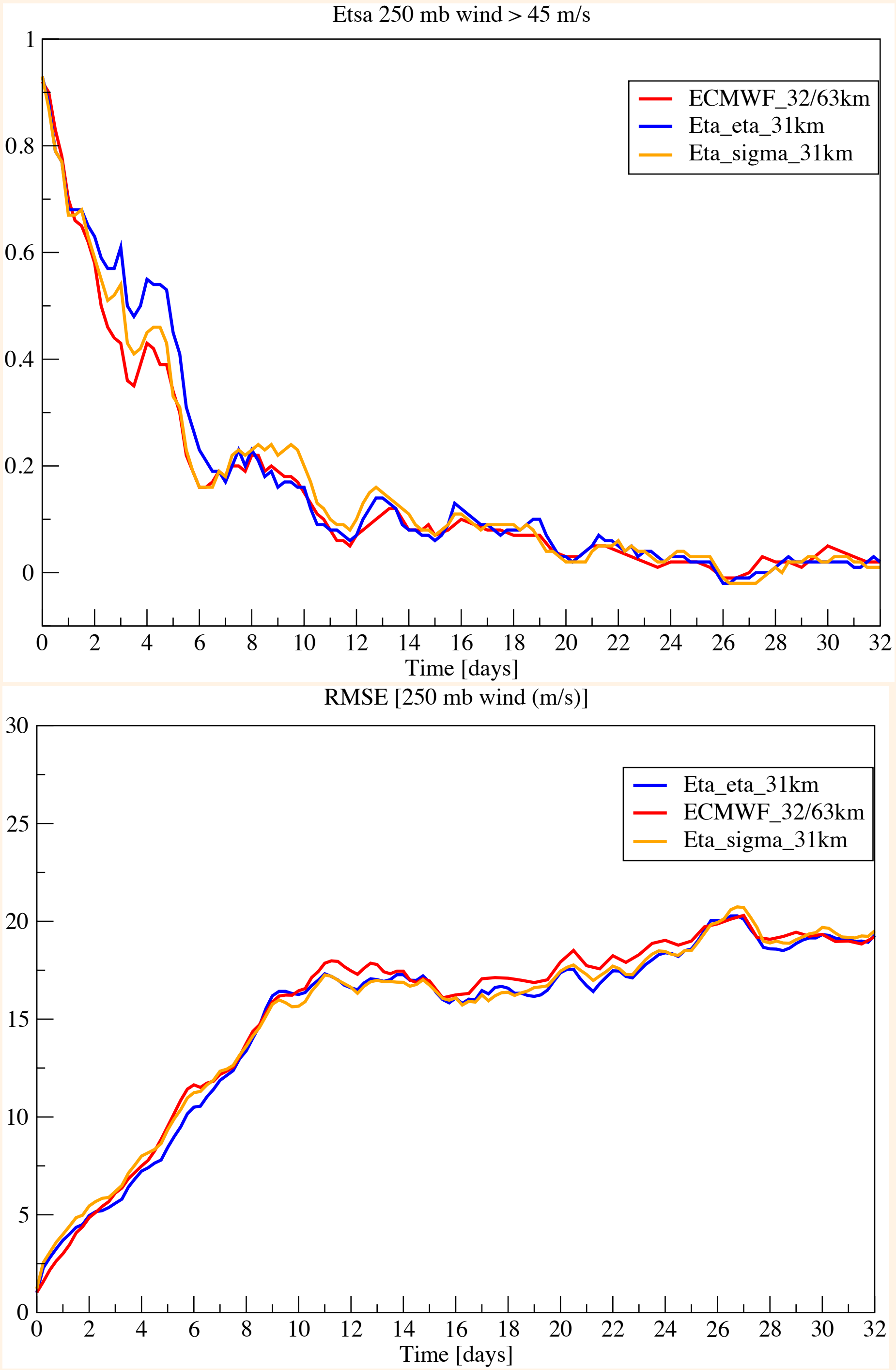
These times correspond to day 3.0, and 4.5, respectively, of the plots of the preceding slide



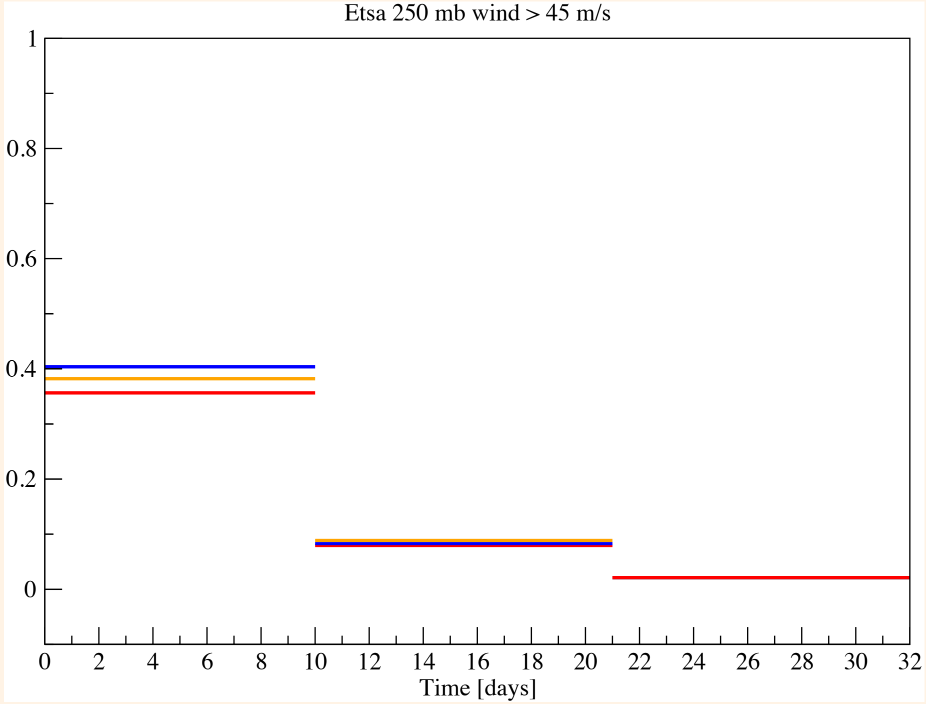
Eta coordinate ?

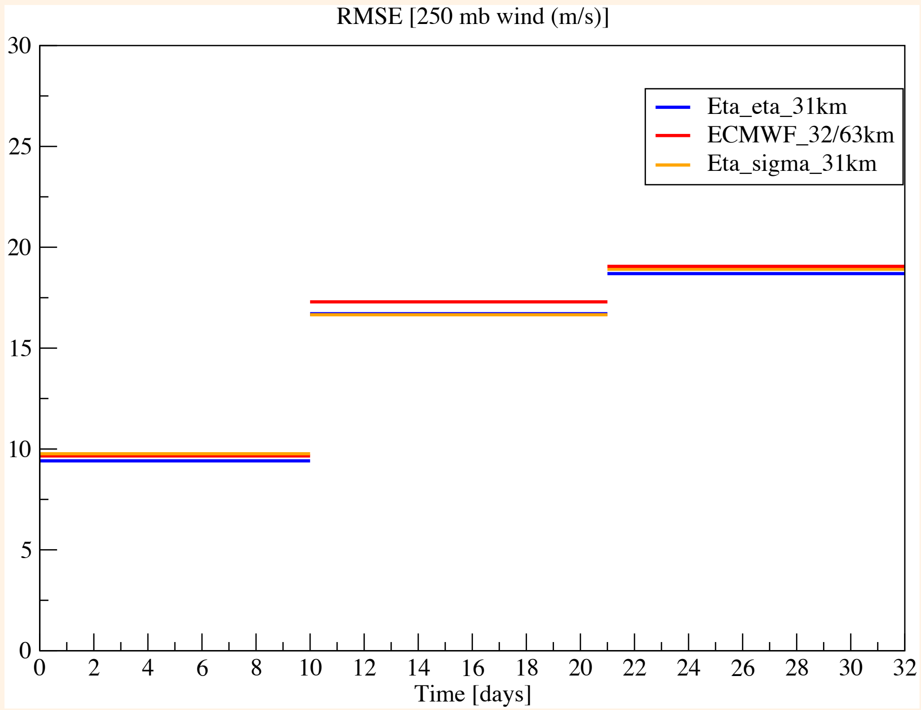
Eta switched to use sigma

Bias adjusted ETS scores of wind speeds greater than 45 m s^{-1}, upper panel, and RMS wind difference, lower panel, of the driver ECMWF ensemble members (red), Eta members (blue), and Eta members run using sigma (orange), all at 250 hPa and with respect to ECMWF analyses. Initial time is 0000 UTC 4 October 2012

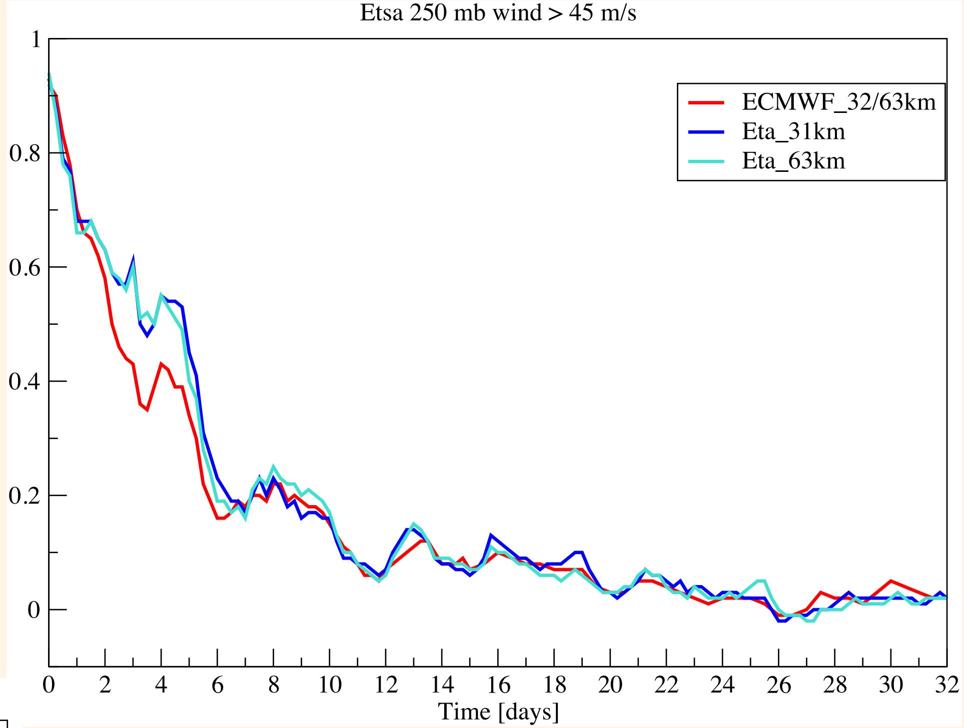


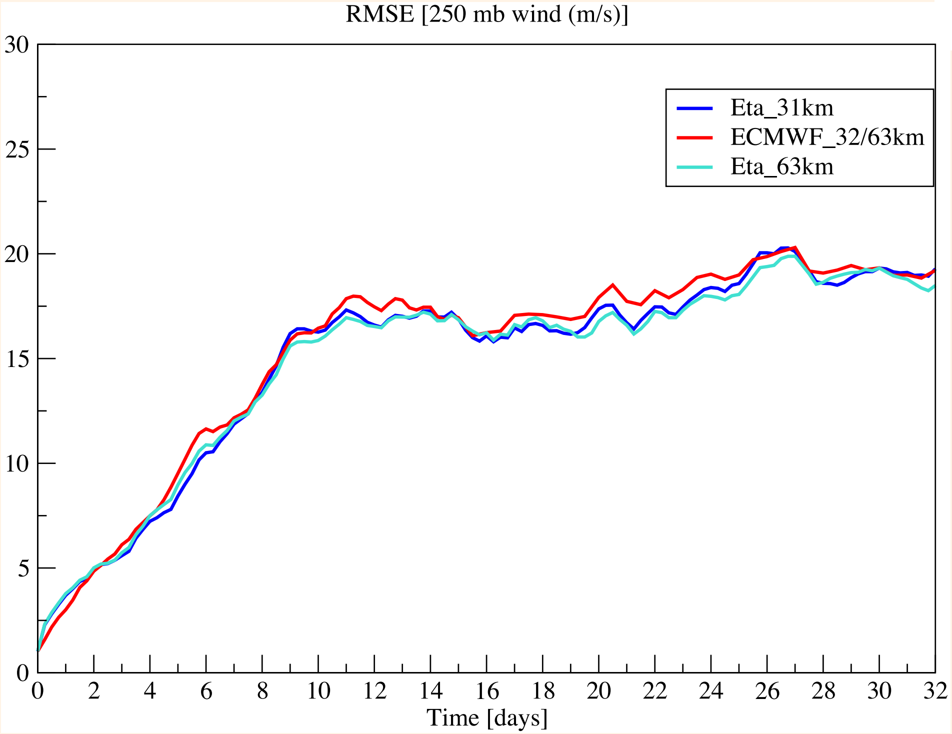
10, 11, 11 day averages:





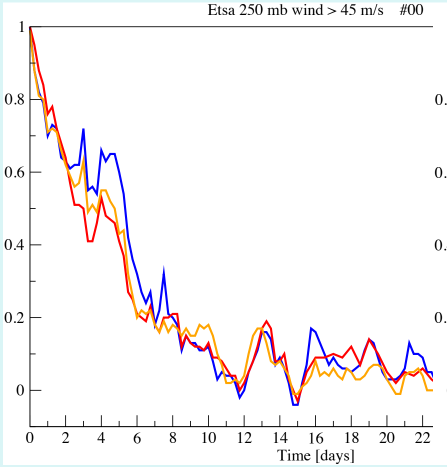
Resolution ?

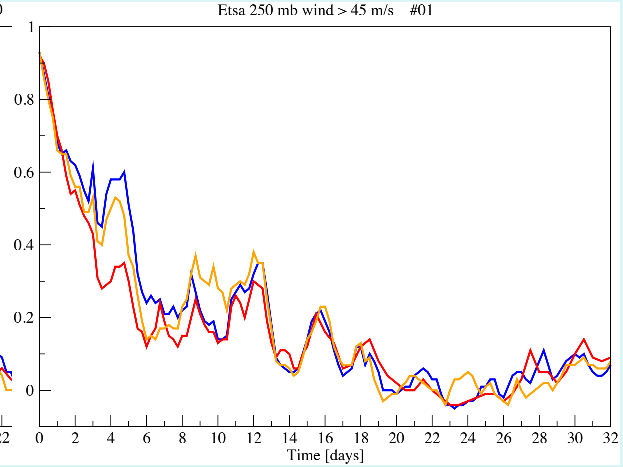


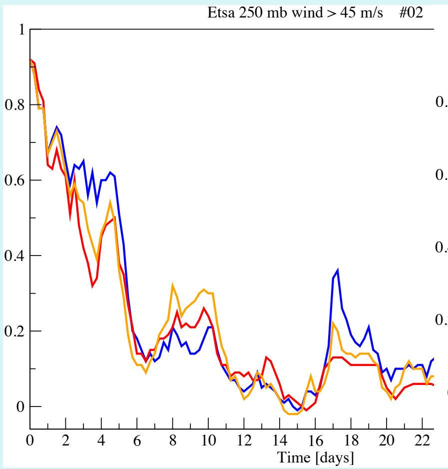


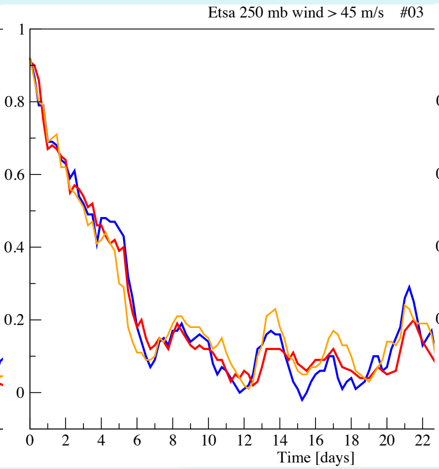
No visible impact !!

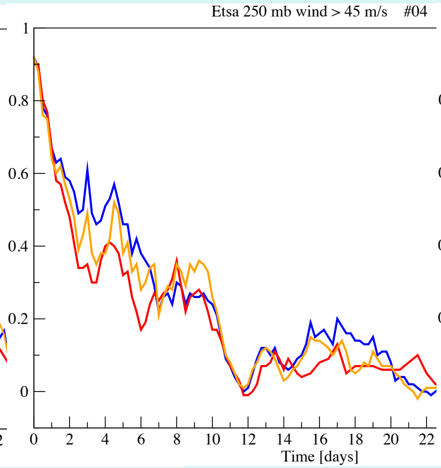
For insight into the advantage of the Eta/eta, also Eta/sigma consider plots for individual members:

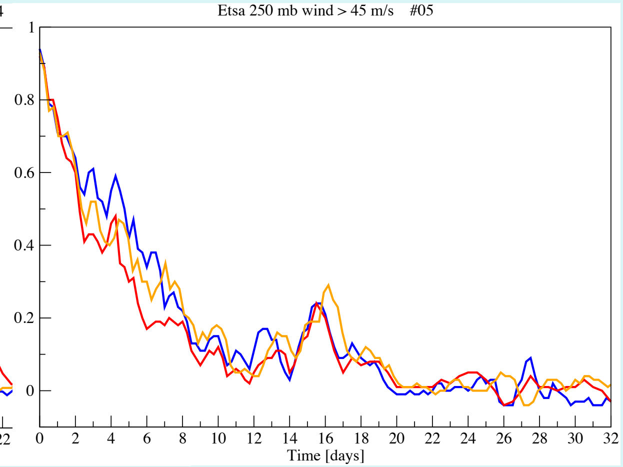


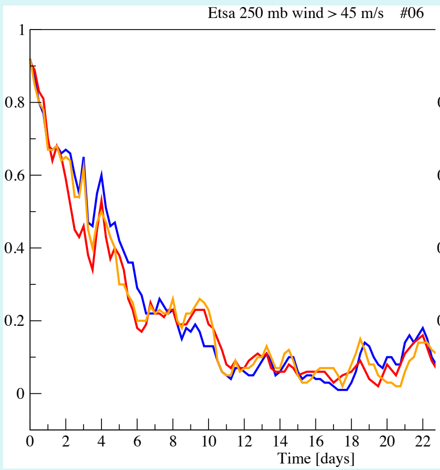


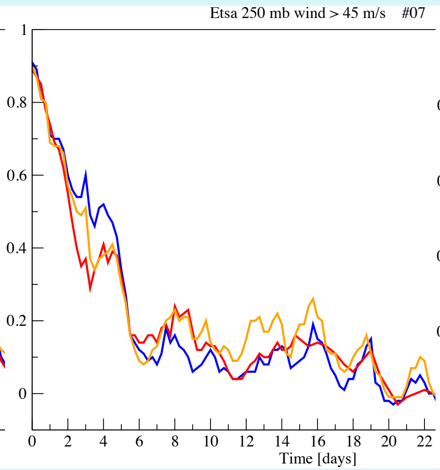


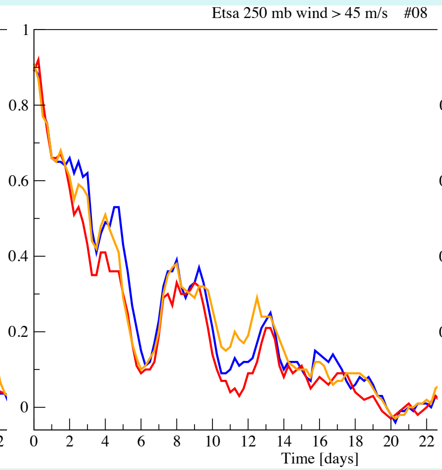


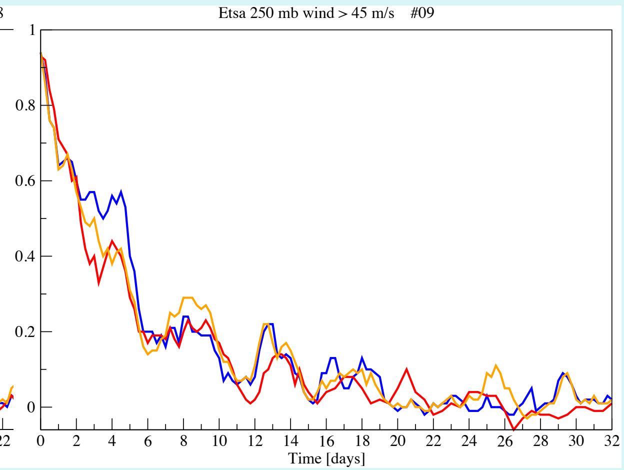


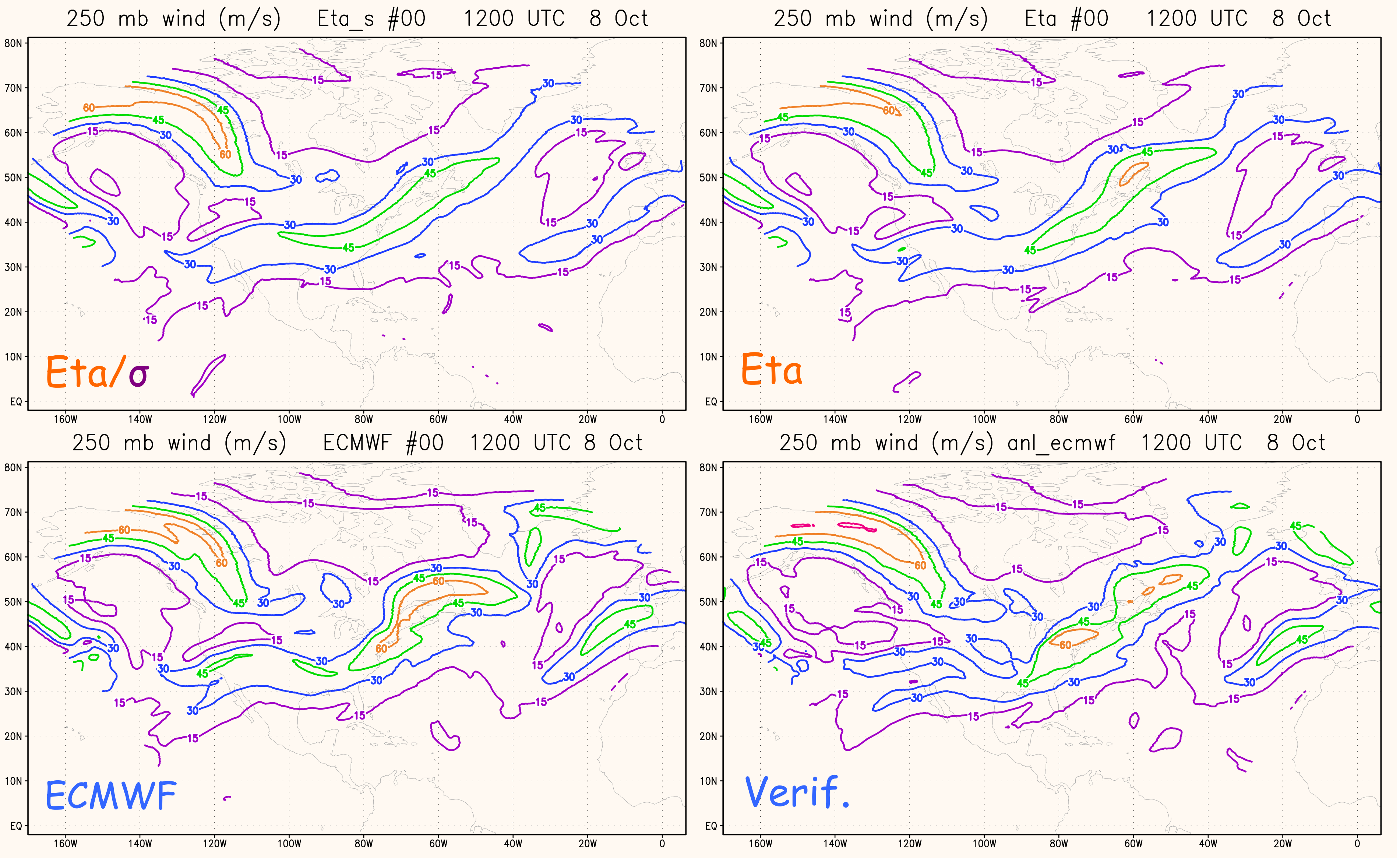




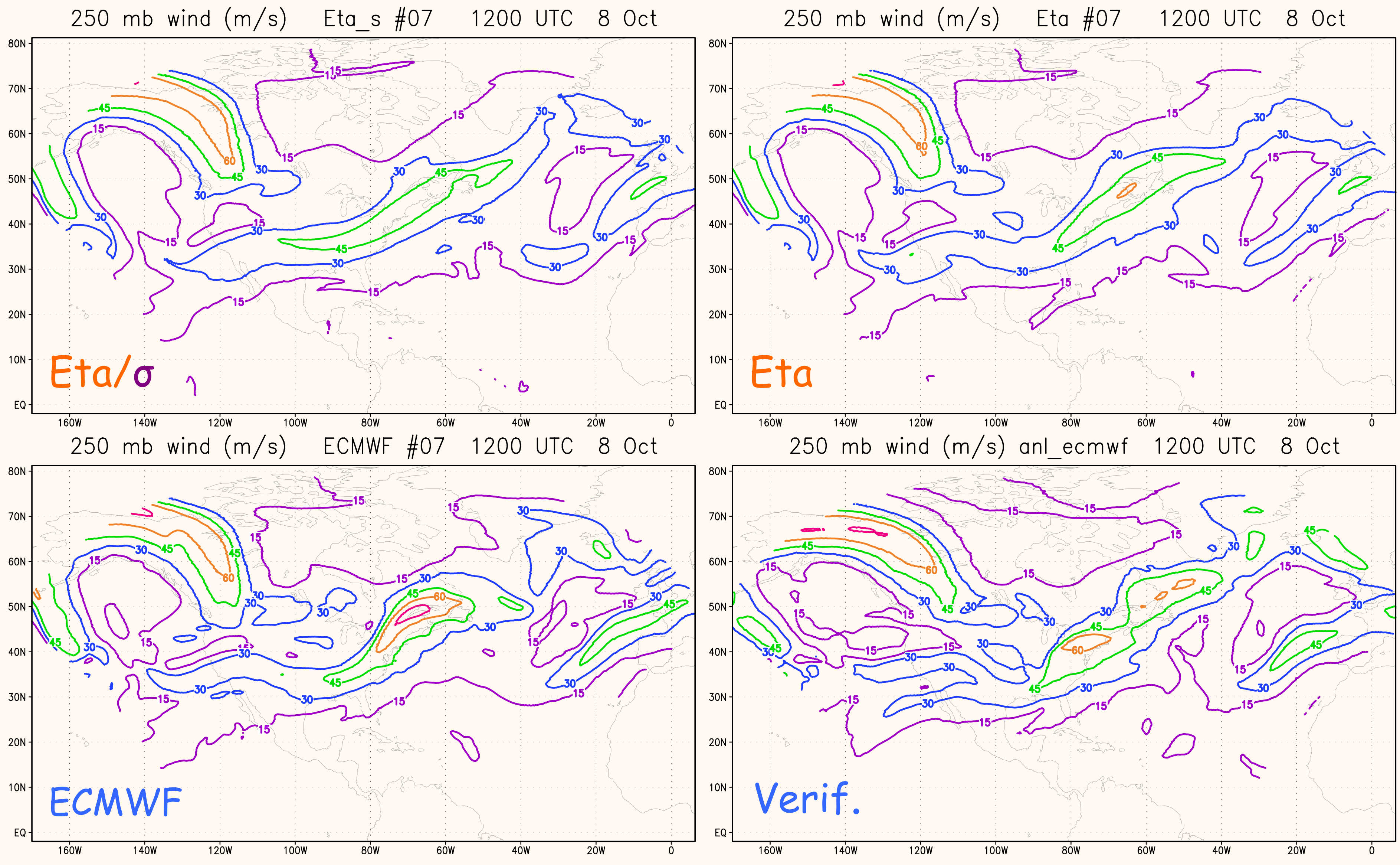








Ensemble members 00 at 4.5 day time: Eta/sigma top left, Eta top right, EC driver bottom left, EC verification analysis bottom right.



Ensemble members 07 at 4.5 day time: Eta/sigma top left, Eta top right, EC driver bottom left, EC verification analysis bottom right.

Take home conclusions #1 (of 2)

Benefit from eta vs sigma, robust evidence for

- More accurate precipitation forecasts;
  (Why? Limited evidence: Flow more around as opposed to too much up and down topography; e.g., McAfee et al. 2011, Chao 2012, …)
- Better placement of lee lows ahead of upper level troughs;

Relevance to eta vs sigma:

- "Sloping steps": an extensively-tested refinement over step topography, removing the Gallus-Klemp problem of flow separation in the lee of a bell-shaped mountain

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Take home conclusions #2

In ensemble experiments, Eta driven by 32-day ECMWF ensemble members

- In spite of absorbing unavoidable LBC errors, Eta did somewhat better than the EC in 250 hPa wind verifications. Why?

- Tests with Eta switched to use sigma, show that the eta coordinate made a significant contribution to the Eta's advantage;

- Advantage was NOT due to using higher resolution;

- The Eta using sigma seems to have done a little better than the driver EC ensemble as well. Why?

  (Maybe: finite-volume vertical advection, MY turbulence, grid-point topography, ...)

- People doing large-scale nudging in RCM work would do well to reconsder reasons as to why do they need to do that, or believe they need to do that.

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Large scale / or “spectral nudging” of RCMs done by many people. E.g.:

QJ 2012:

Spectral nudging in regional climate modelling: how strongly should we nudge?

Hiba Omrani,* Philippe Drobinski and Thomas Dubos
Institut Pierre Simon Laplace/Laboratoire de Météeorologie Dynamique,
Ecole Polytechnique/ENS/UPMC/CNRS,
Palaiseau, France

Many more . . .

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Acknowledgments. It was under the directorship of Eugenia Kalnay of the Development Division of the then National Meteorological Center in the early nineties that critical steps took place enabling the Eta model to achieve its prominence, this having been made possible by Eugenia's respect for results – as opposed to a pre-established plan as to what should happen. Attention to the horizontal diffusion of the Eta was prompted by comments from Sandra Morelli, of the University of Modena, Italy; and experiments that led to the discovery of the problem at 1-km resolution were carried out by Jorge Luis Gomes, and Gustavo Sueiro, of the Center for Weather Prediction and Climate Studies (CPTEC), Cachoeira Paulista-SP, Brazil. Fedor Mesinger's work on the development of the "sloping steps" discretization of the Eta dynamical core has been partially funded by NCEP/EMC via grants to ESSIC, University of Maryland, College Park, MD, awarded by Stephen Lord, then EMC Director. Subsequent work on the Gallus-Klemp problem reported on here was done within a visit of Fedor Mesinger to CPTEC, hosted by Sin Chan Chou, under a grant awarded by the National Council for Scientific and Technological Development (CNPq), Brazil. Our work has been partially supported by the Serbian Academy of Sciences and Arts, via grant F-147, and that of Katarina Veljovic by the Ministry of Science and Technological Development of the Republic of Serbia, under Grant No. 176013.

Some of the references that might have been used:

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