Dynamical core design: A neglected thrust toward increasing NWP skill several days ahead

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Questions to address (THORPEX):

- Re model uncertainty,

(”… associated with numerical schemes, and … processes, …”)

can we go beyond the effort to
“Quantify the contributions of ... to forecast errors”

and also try to identify the *causes* of prediction model errors?

Thus, hopefully, *reduce* the uncertainties?

- Can we claim - if so on what basis - that it is possible to still significantly increase NWP skill a few days ahead?

Question #1: Science Plan issue;

Question #2: An encouragement point

Conclusion:

A (very short) Special Advertisement Section

Bullet #1:

To be dealt with looking at some of the Eta Model results - including comparisons with results of other NCEP operational models

Eta features worth pointed out when comparing the Eta with other models:

- Numerous (Arakawa style) conservation properties enforced on grid point *boxes* (as "physics" is done, "physics friendly") as opposed to points:

  - C grid defined enstrophy and energy, on model's E grid (Janjic 1984);
  - exact energy conservation, in space differencing, in transformation between potential and kinetic;
  - . . .

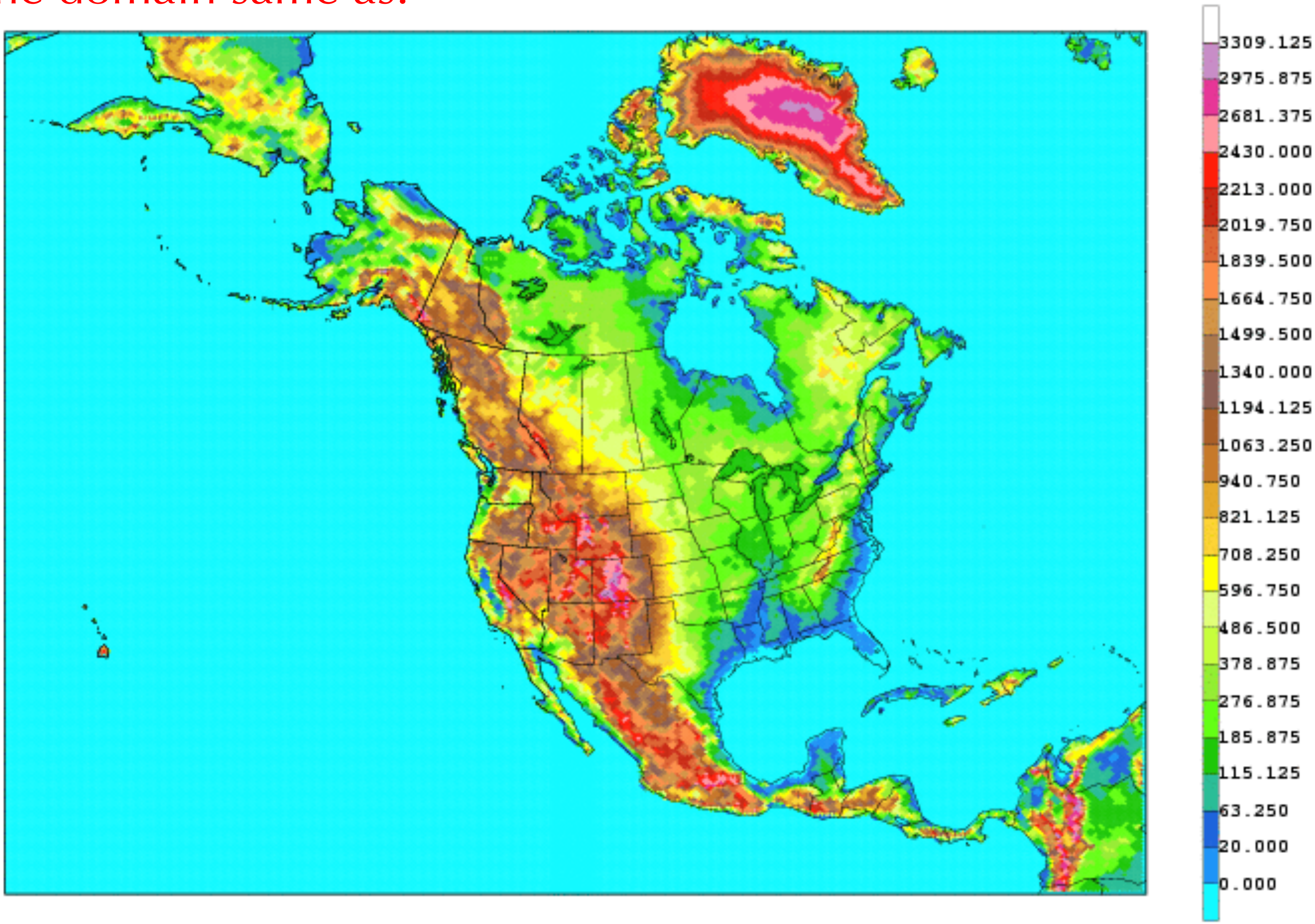
- Efforts to avoid/ minimize computational modes (e.g., its gravity-wave coupling scheme)

- The eta coordinate (quasi-horizontal coordinate surfaces) steep topography results in no PGF problems

The Eta, as operationally run at NCEP:

- 12 km/ 60 layer resolution, 84 hours ahead;
- Lateral boundary condition from the previous, initialized 6 h ago, run of the Global Forecast System (GFS)

The domain same as: **Eta 32 km/45 layer topography** (used for Reg. Reanalysis)



Can one

detect the impact of the advection of the LB error?

Not only is the Eta driven by the GFS forecast of 6 h ago,

(in 6 h, rms errors of 250 mb winds at ~ 48 h forecast time, in cold season, grow by about 10 percent)

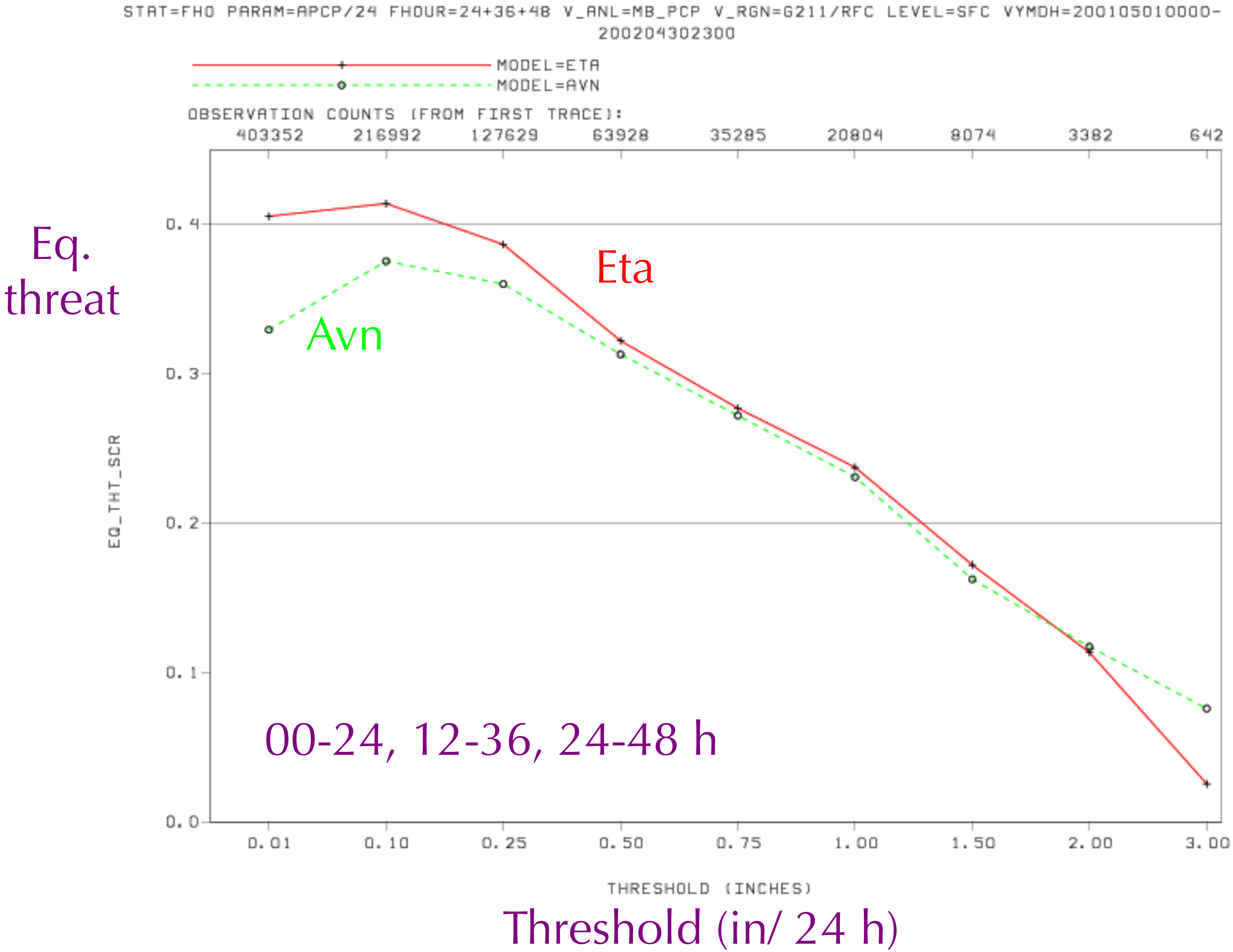
but there is also the mathematical LB error, e.g.,

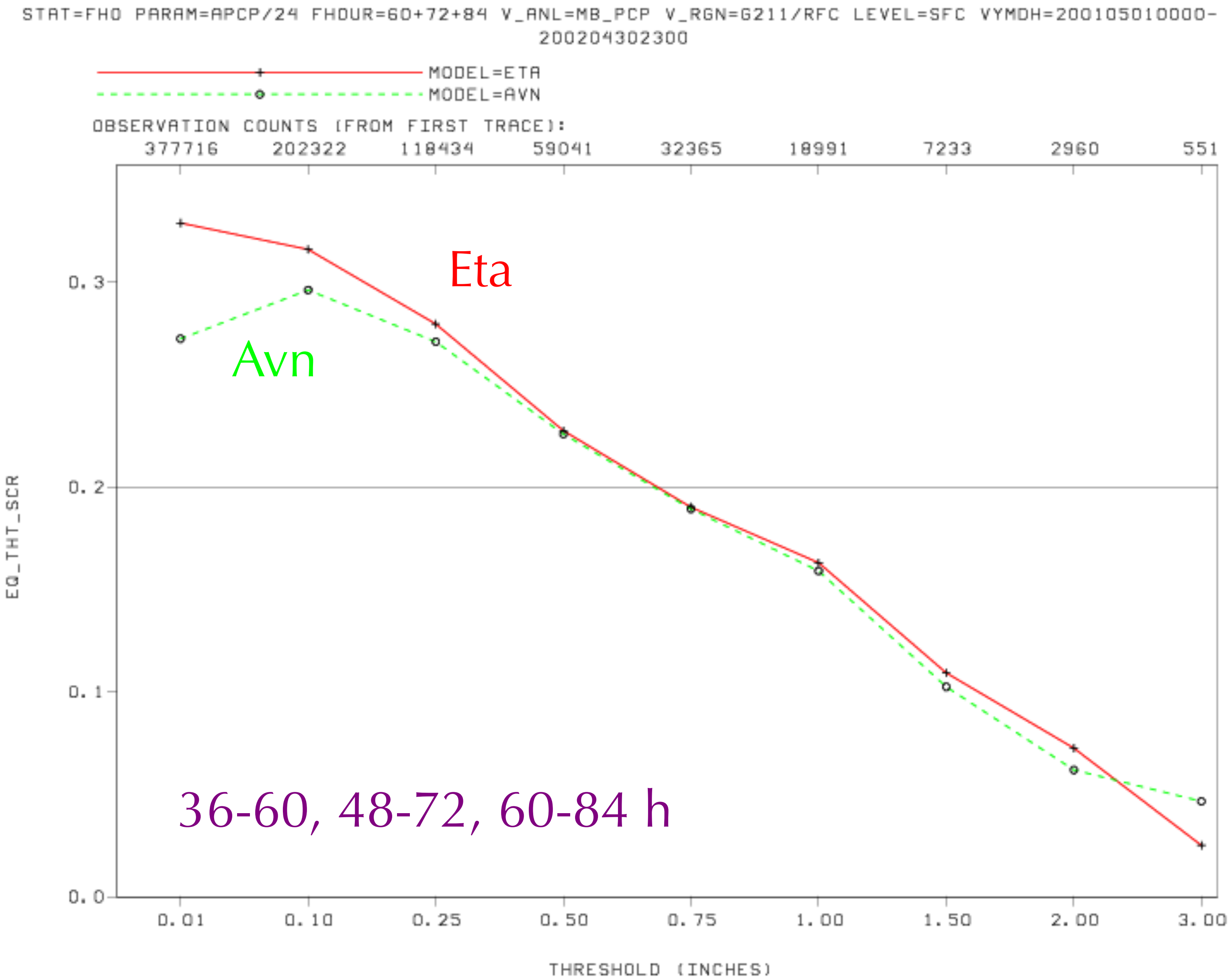
"the contamination at the lateral boundaries … limits the operational usefulness of the LAM *beyond some forecast time range*" (Laprise et al., MWR 2000, emphasis FM)

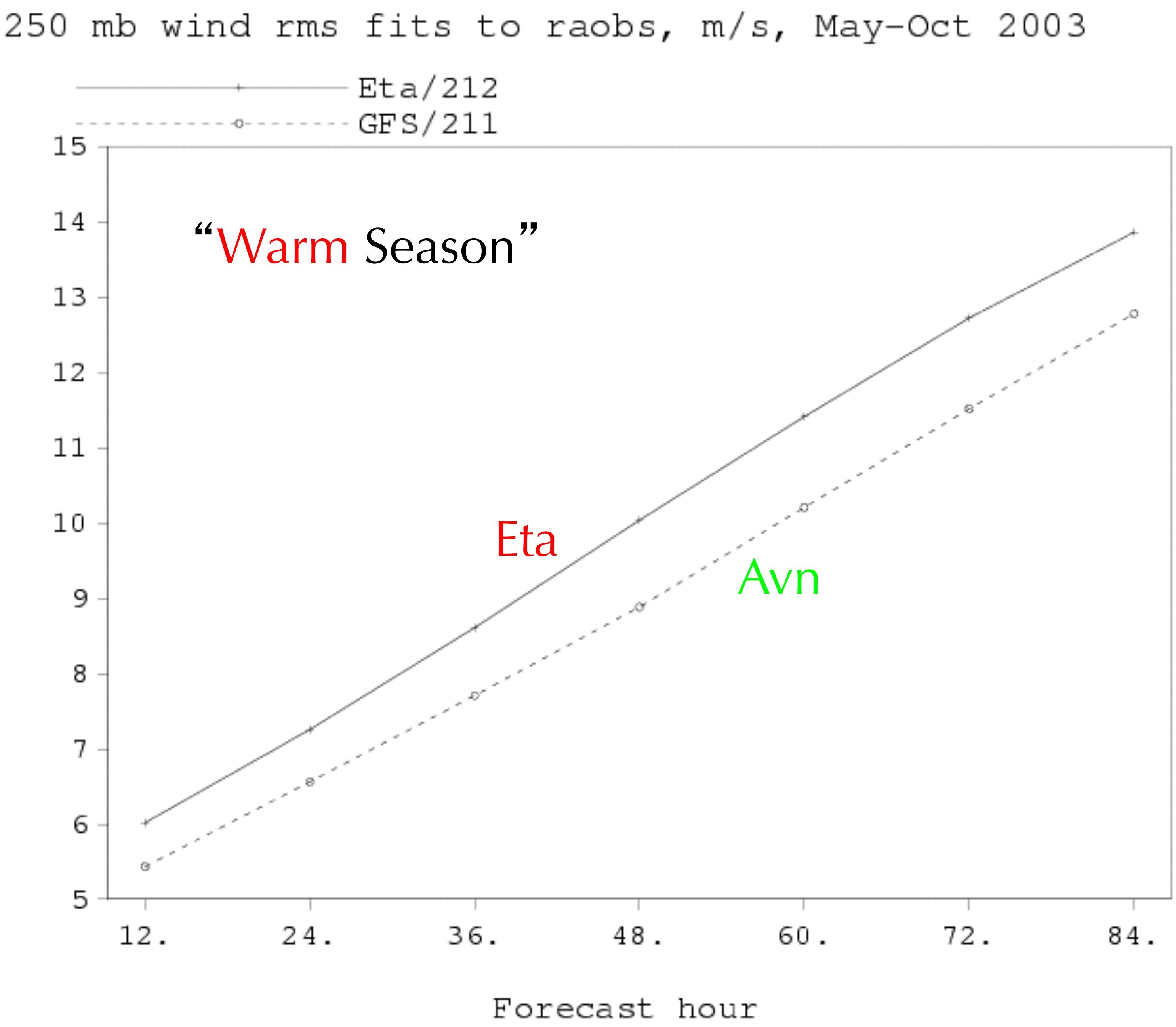
For an answer, I have looked into, Eta vs the Avn/GFS:

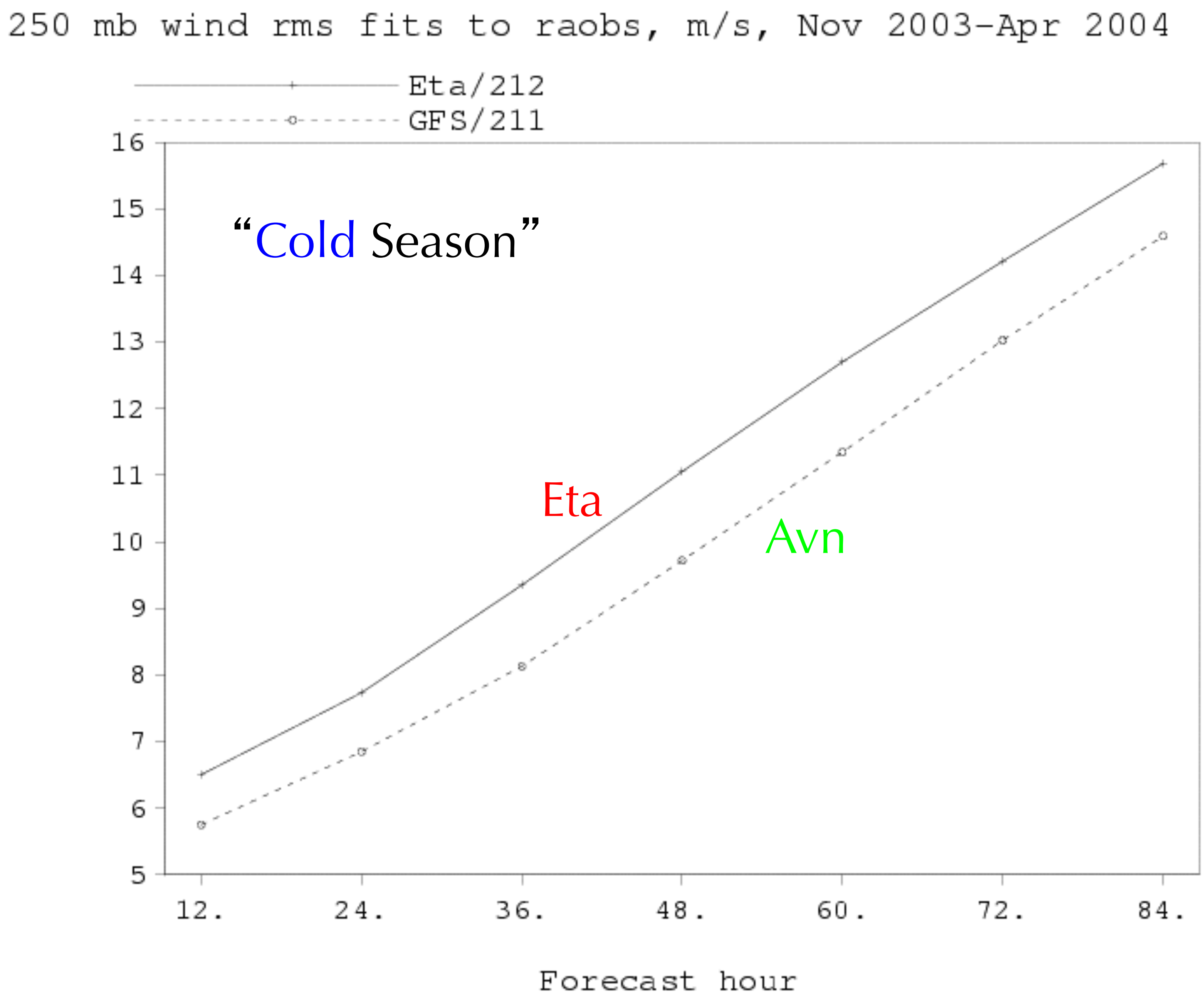
- precip scores, 24 accumulations, 00-48 h vs 36-84 h,
  May 2001-April 2002
  (Eta was extended to 84 h in April 2001)
- rms fist to raobs as a function of time;
- position forecast errors of "major lows" at 60 h:
  Dec. 2000 - Feb. 2001 (Eta run at 22 km/50 lyr)
  Dec. 2001 - Feb. 2002 (Eta run at 12 km/60 lyr,
  Avn T170L42 both winters)

First 12 months of precip scores out to 84 h:




STAT=FHO PARAM=APCP/24 FHOUR=60+72+84 V_ANL=MB_PCP V_RGN=G211/RFC LEVEL=SFC VYMDH=2001050100000-200204302300
MODEL=ETA
MODEL=AVN
OBSERVATION COUNTS (FROM FIRST TRACE):
377716 202322 118434 59041 32365 18991 7233 2960 551
Eta
Avn
EQ_THT_SCR
0.3
0.2
0.1
0.0
36-60, 48-72, 60-84 h
0.01 0.10 0.25 0.50 0.75 1.00 1.50 2.00 3.00
THRESHOLD (INCHES)


250 mb wind rms fits to raobs, m/s, May-Oct 2003
Eta/212
GFS/211
"Warm Season"
Eta
Avn
15
14
13
12
11
10
9
8
7
6
5
12.
24.
36.
48.
60.
72.
84.
Forecast hour



250 mb wind rms fits to raobs, m/s, Nov 2003-Apr 2004
Eta/212
GFS/211
"Cold Season"
Eta
Avn
16
15
14
13
12
11
10
9
8
7
6
5
12.
24.
36.
48.
60.
72.
84.
Forecast hour

(Higher resolution model - the Eta - might be at a disadvantage when it comes to rms errors/ the Eta is output to a 40 km and GFS to an 80 km grid?)

In cold season, 250 mb winds, for a 6 months sample, the Eta is

- ~10-11 h behind the GFS at 60 h;
- ~9 h behind the GFS at 84 h

Advection of the LBC error into the main verification domain, the contiguous United States, should lead to increased error growth rate. Just the opposite happens!

Position forecast errors: winter 2000-2001, rules for the selection of "major lows", 31 cases;

Conf. paper: AMS, Orlando, FL, Jan. 2002:

the Eta was significantly more accurate !

(Lower average and median error, more "wins")

However: attempting to do the same verification for the next winter, I got convinced that the Orlando rules were not as successful as one might wish (included a requirement for a minimum depth, not the best idea); thus:

Revised rules

“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.!

Overall summary:

No sign of the loss in relative skill
of the Eta vs GFS at longer lead times identified;

In relative terms, the Eta is doing best in winter, and,
if anything, it improves with time !

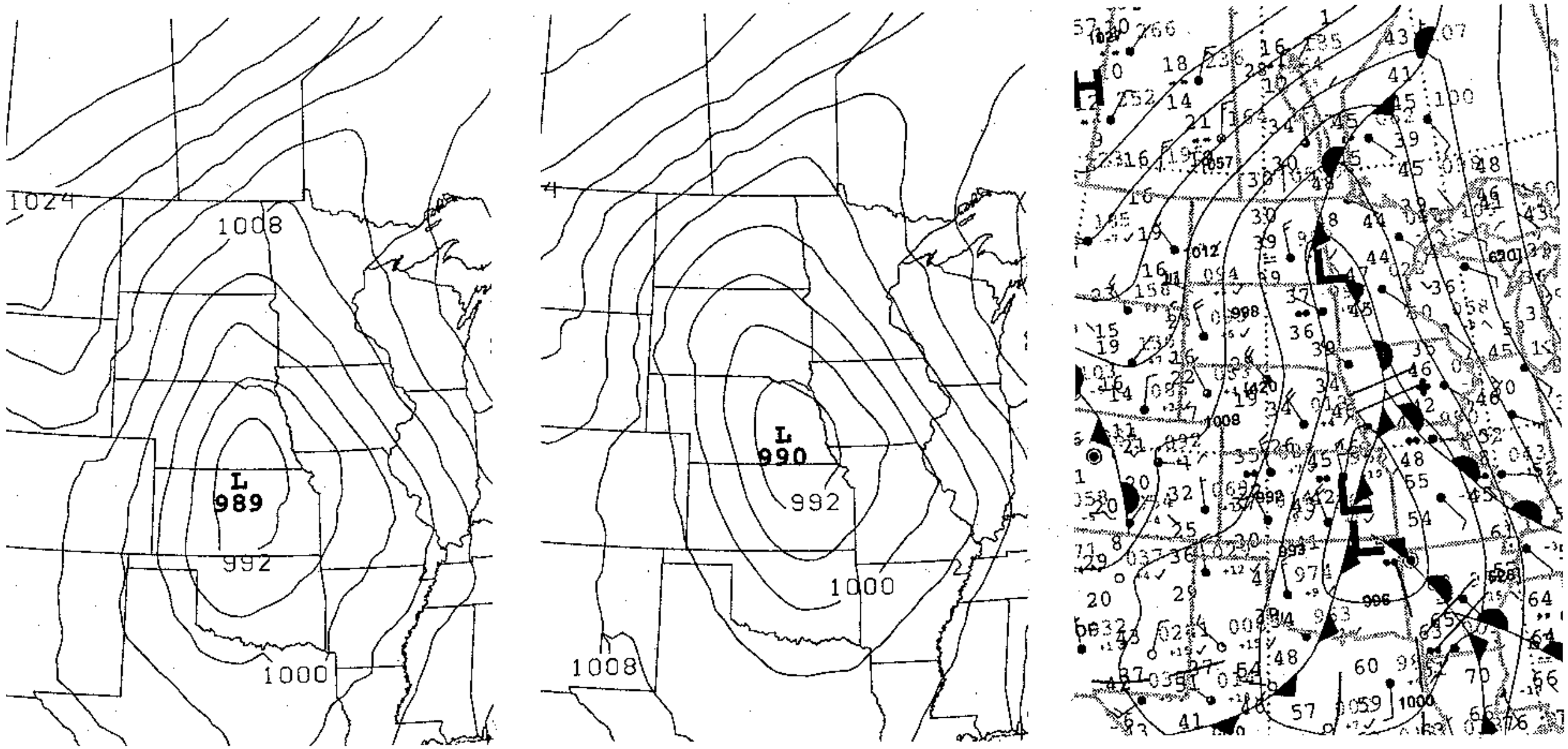
Ingredient(s)/ component(s) must exist in the Eta
that compensate for the inflow of the LB error !

Strong case can be made that the primary candidate for this role is the eta coordinate

Some of the arguments:

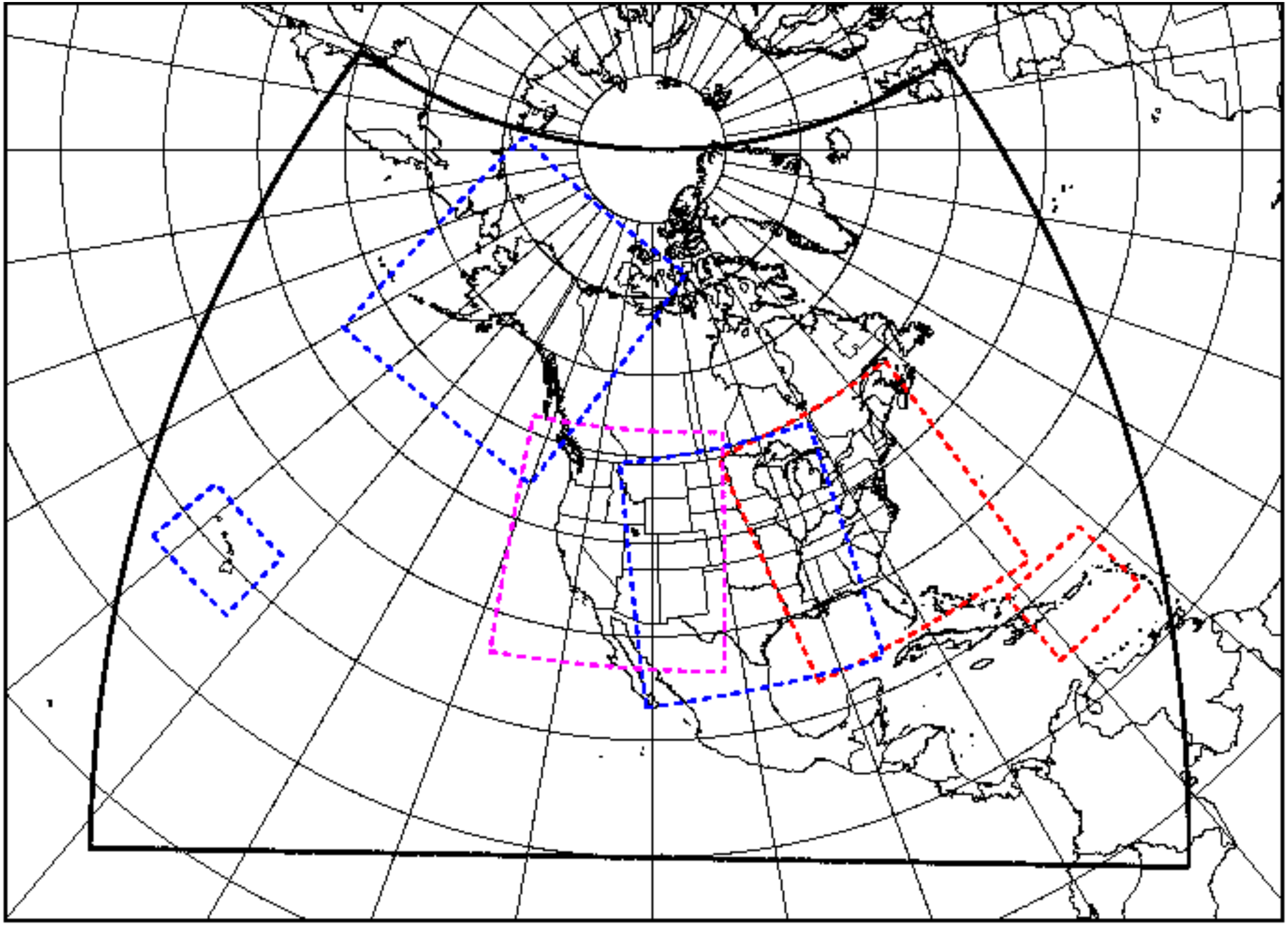
- One eta/ sigma experiment;
- Precip scores for the 1st 12 months of the availability of three model scores on NMM domains (ConUS "East", ..., "West", ...)

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

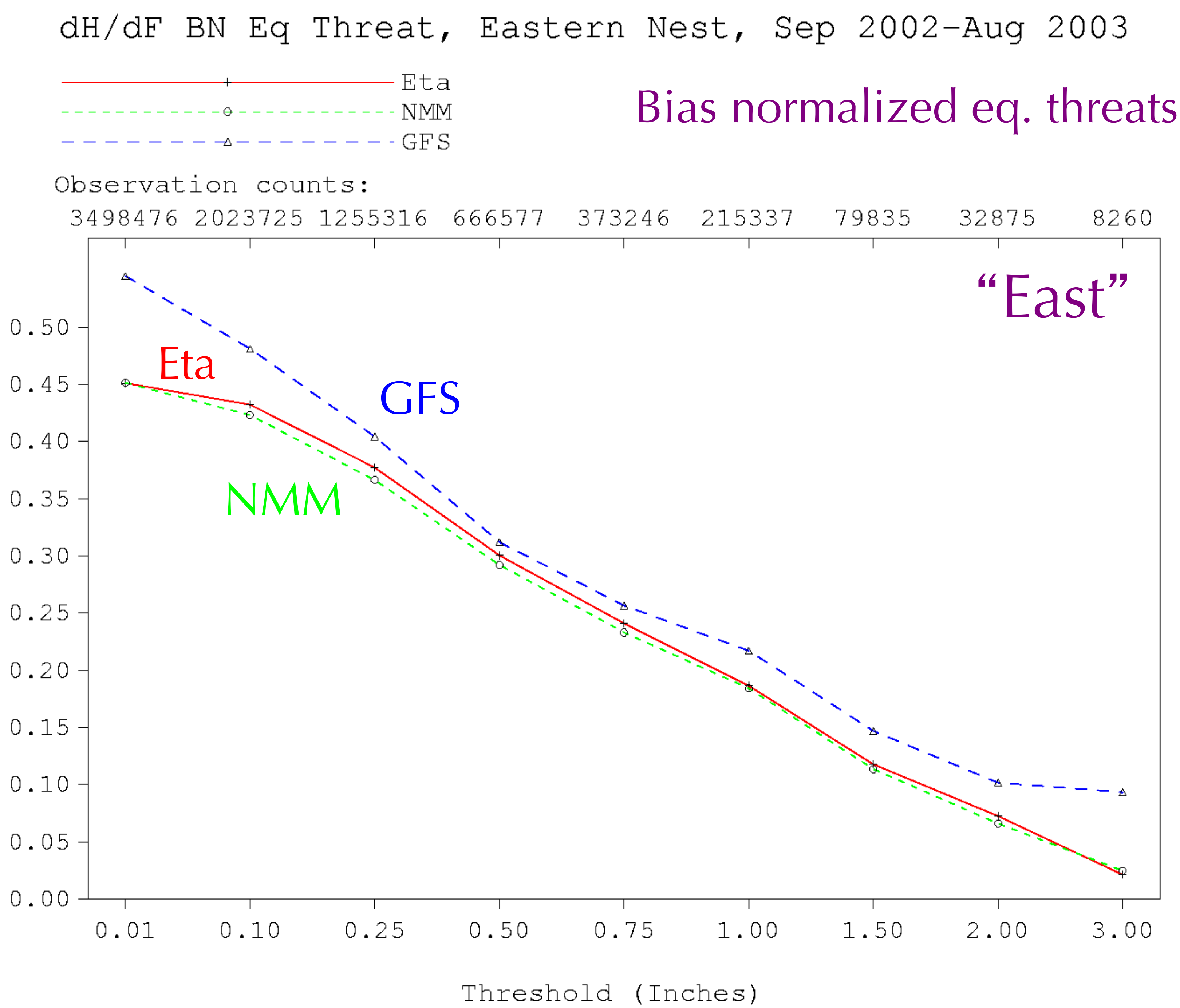


Three-model precipitation scores, on NMM ConUS domains ("East" ,…, "West"), available since Sep. 2002

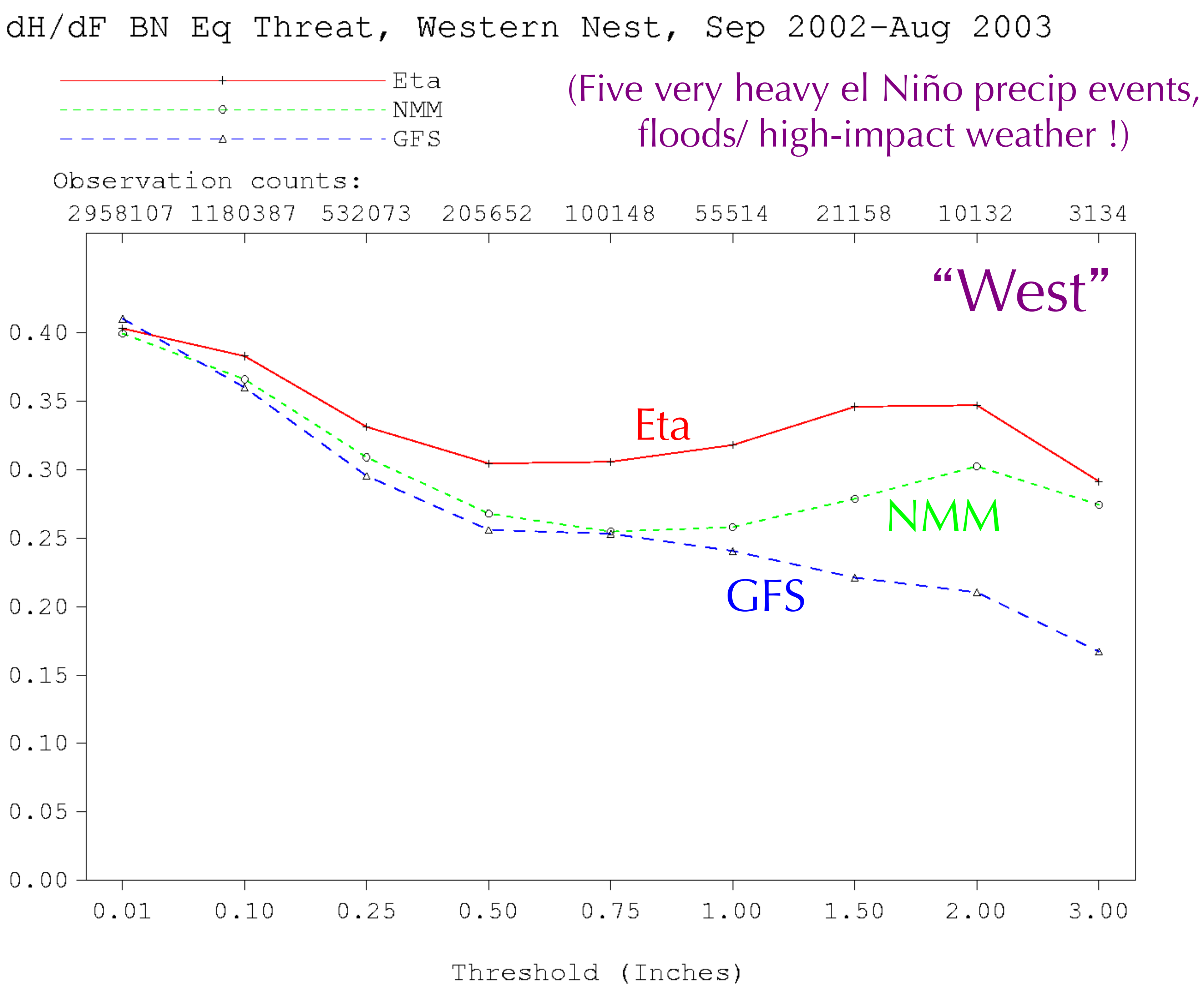
- Operational Eta;
- NMM: “Nonhydrostatic Mesoscale Model” nonhydrostatic, 8 km, most other features same or similar to Eta, but switched back to sigma;
- GFS: T254 (55 km) resolution



Nested Meso-08 Domains



dH/dF BN Eq Threat, Eastern Nest, Sep 2002-Aug 2003
Eta
NMM
GFS
Bias normalized eq. threats
Observation counts:
3498476 2023725 1255316 666577 373246 215337 79835 32875 8260
"East"
Eta
GFS
NMM
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.01 0.10 0.25 0.50 0.75 1.00 1.50 2.00 3.00
Threshold (Inches)


dH/dF BN Eq Threat, Western Nest, Sep 2002-Aug 2003
Eta
NMM
GFS
(Five very heavy el Niño precip events,
floods/ high-impact weather !)
Observation counts:
2958107 1180387 532073 205652 100148 55514 21158 10132 3134
"West"
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Eta
NMM
GFS
0.01 0.10 0.25 0.50 0.75 1.00 1.50 2.00 3.00
Threshold (Inches)

East, no major topography:

GFS best, Eta and the NMM about the same;

West, major and complex topography:

Eta best, overcoming handicaps of

- 6-h lateral boundary error compared to GFS;
- lower resolution compared to NMM

However: what about a lot of bad press the eta had lately:

Poor 10-km Eta performance for a case of Wasatch downslope windstorm, while MM5 did well; Gallus-Klemp (MWR 2000); as a result:

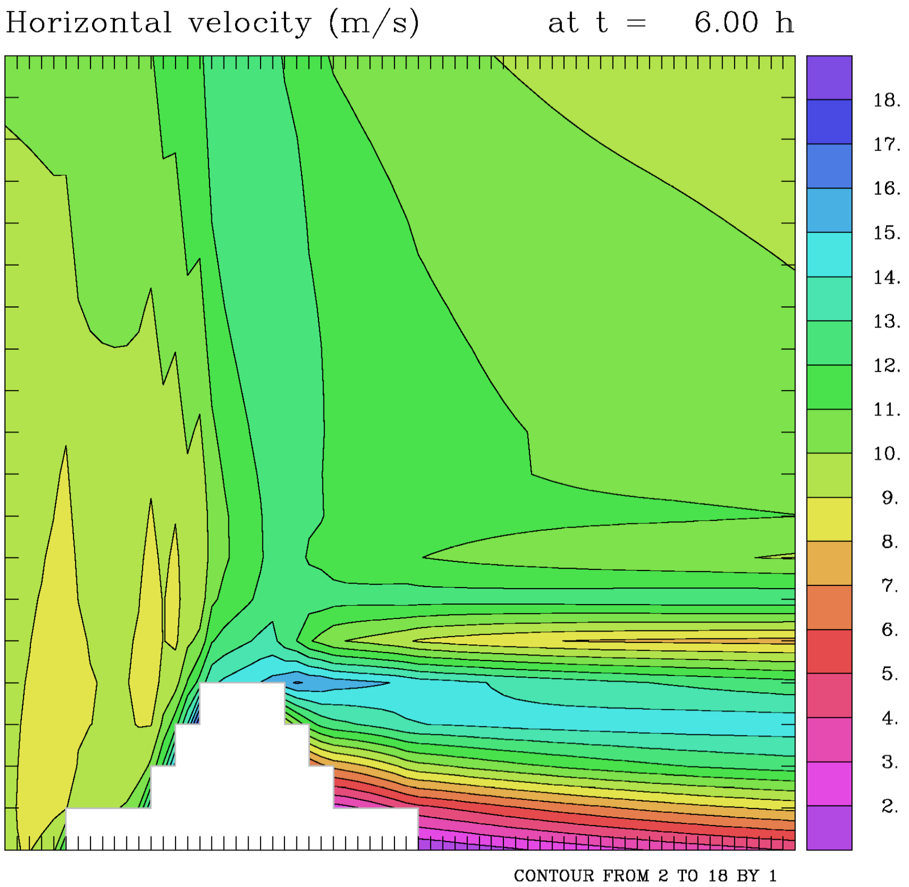
Schär et al., *Mon. Wea. Rev.*, 2002;
Janjic, *Meteor. Atmos. Phys.*, 2003;
Steppeler et al., *Meteor. Atmos. Phys.*, 2003;
Mass et al., *Bull. Amer. Meteor. Soc.*, 2003;
Zängl, *Mon. Wea. Rev.*, 2003;
more?

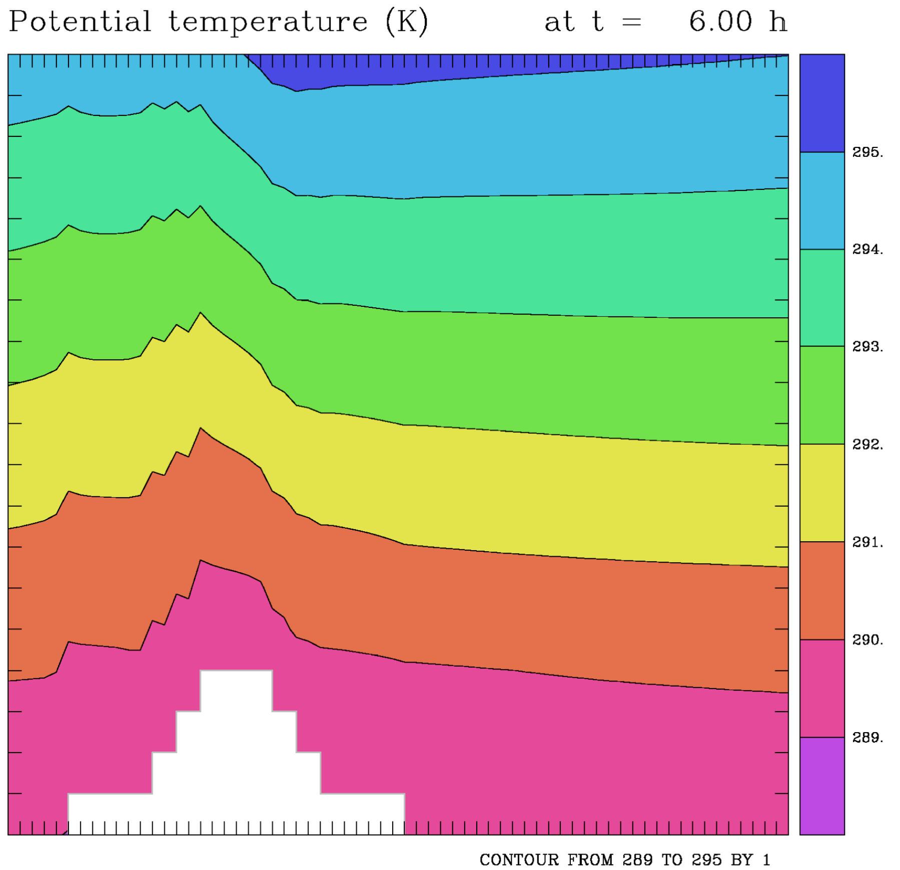
the eta coordinate system is

"ill suited for high resolution prediction models" ?

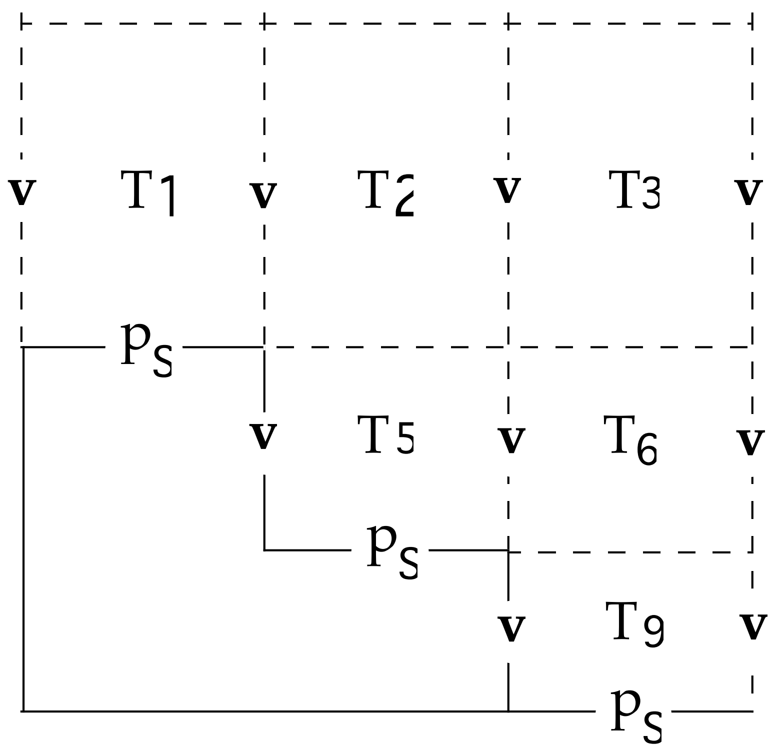
The Eta Problem

Flow separation on the lee side (à la Gallus and Klemp 2000)





Suggested explanation



Flow from left: from the box 1 the flow enters box 2 to the right of it. When conditioned to move downward, it will move downward via the interface between boxes 2 and 5. Some of the air that entered box 2 will continue to move horizontally into box 3.

Missing: the flow directly from box 1 into 5 !

(It would have existed had the discretization accounted for the terrain slope !) As a result: some of the air which should have moved slantwise from box 1 directly into 5 gets deflected horizontally into box 3.

Step-topography discretization (Mesinger 1984):

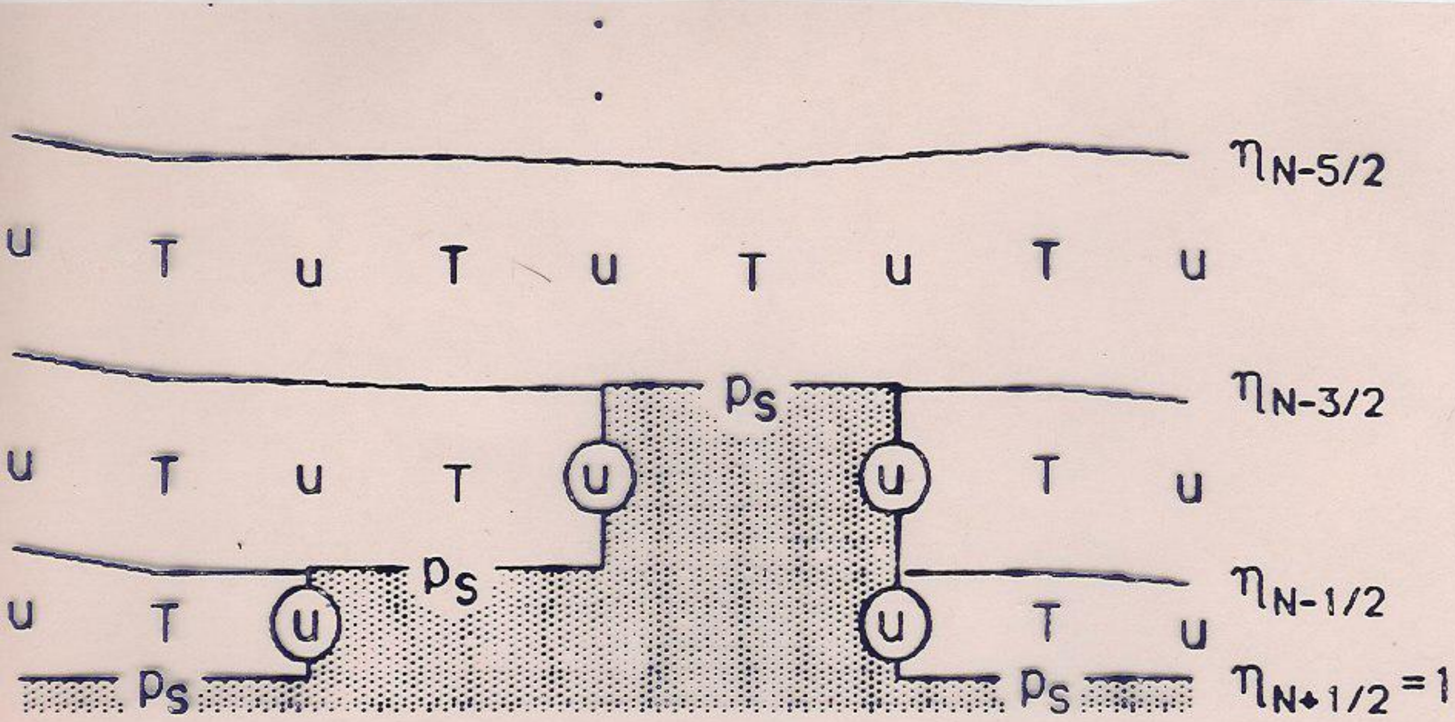


FIG. 1. Schematic representation of a vertical cross section in the eta coordinate using step-like representation of mountains. Symbols u, T and p_s represent the u component of velocity, temperature and surface pressure, respectively. N is the maximum number of the eta layers. The step-mountains are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

Refined (sloping steps) eta discretization

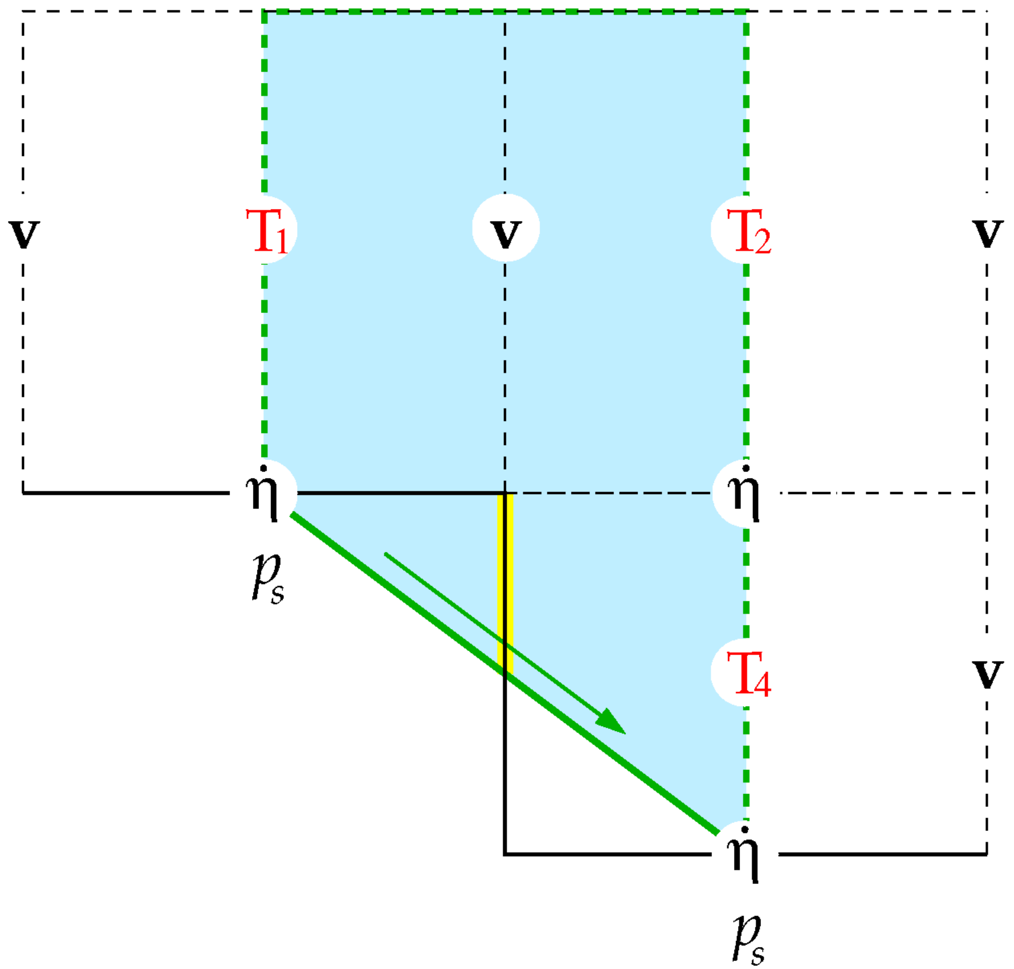
(Fedor Mesinger and Dusan Jovic)

Discretization accounting for slopes

Scheme implemented:
Slopes defined at **v** points, based on four surrounding *h* points.

The sloping steps, vertical grid

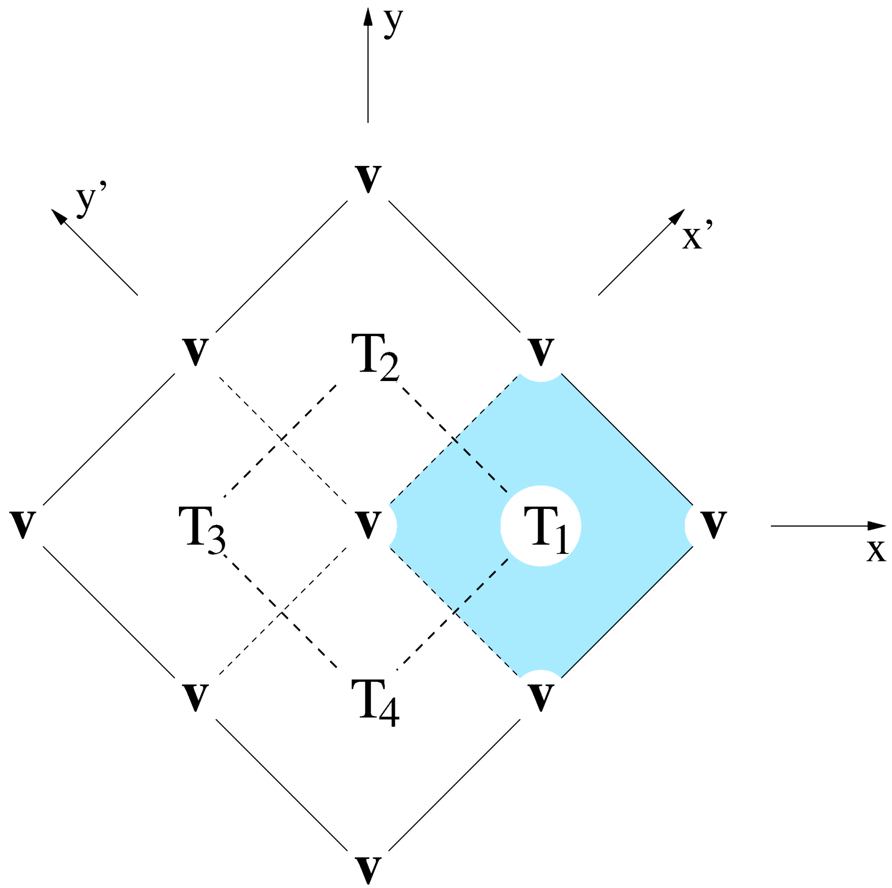
The central **v** box exchanges momentum, on its right side, with **v** boxes of two layers:



Horizontal treatment, 3D: 8 discrete slopes allowed for

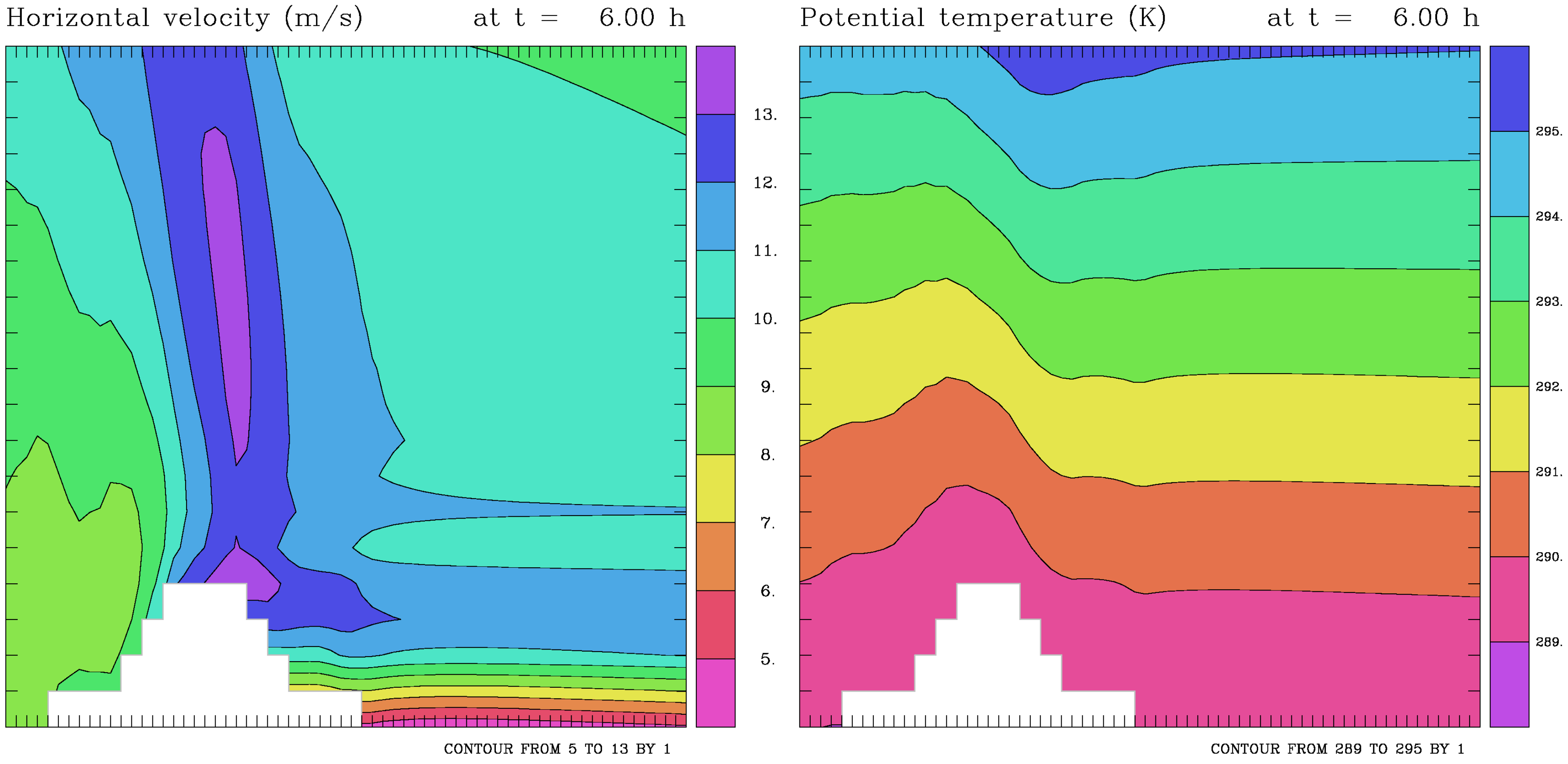
Example #1: topography of box 1 is higher than those of 2, 3, and 4;

"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

Slantwise advection of mass, momentum, and temperature, and "wa":



Velocity at the ground immediately behind the mountain increased from between 1 and 2, to between 4 and 5 m/s. "lee-slope separation" removed. Zig-zag features in isentropes at the upslope side removed.

Thus,

12-km Eta: excellent QPF performance over complex topography ! Better than the sigma system 8-km NMM, and better than the GFS;

The Eta downslope windstorm problem: correctible/ed, while keeping favorable Eta features:

- quasi horizontal coordinates (PGF !);
- approximately finite-volume (because of the quasi-horizontal coordinate and flux-type schemes);
- robustness in the CFL sense

Question #2

Can we claim to be able to still significantly increase the skill of NWP several days ahead?

Yes. How can we tell?

Eta view of things:

- The Eta skill at NCEP – throughout its extended forecast range – is comparable to that of GFS, in spite of its handicaps of

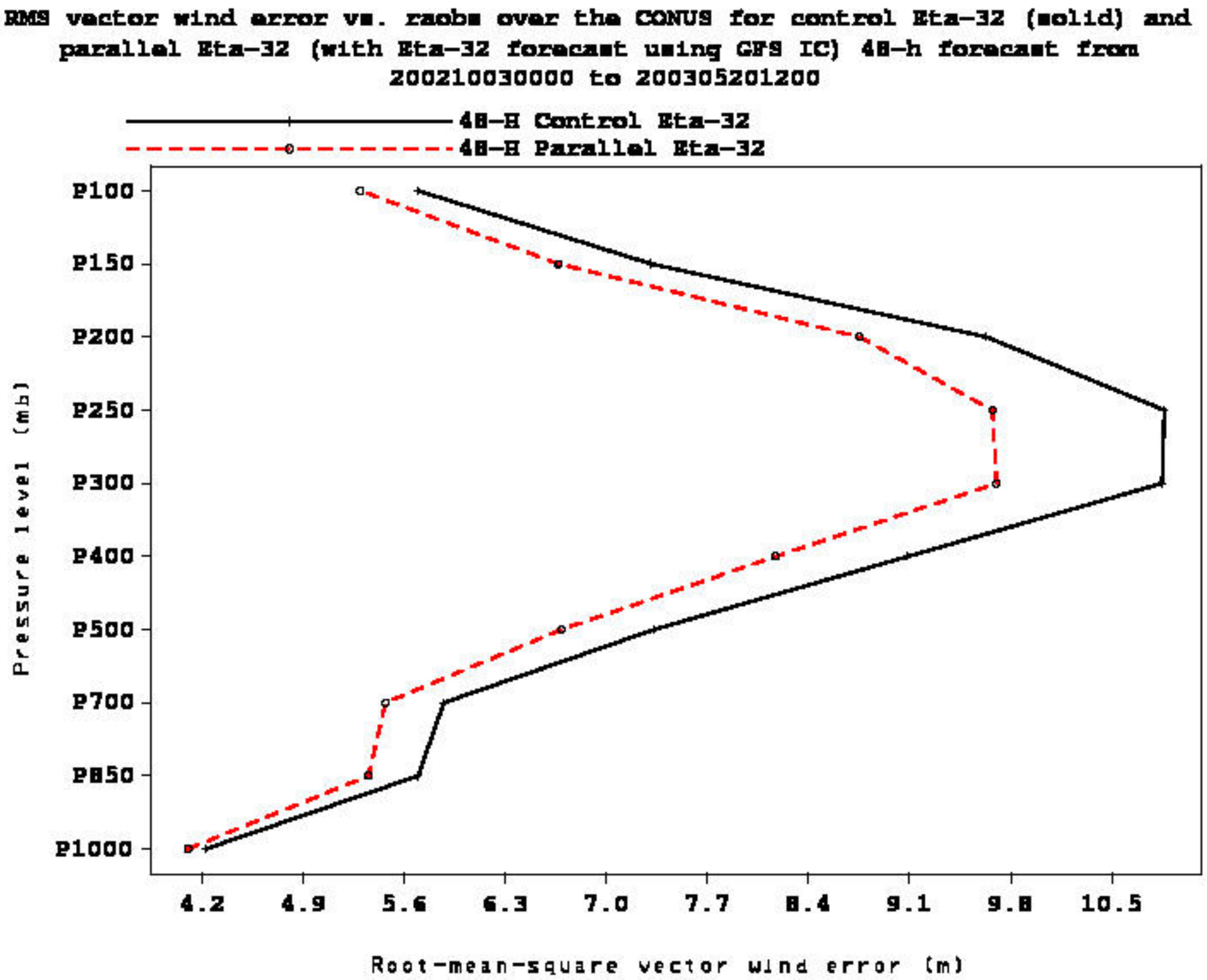
1) absorbing a 6 h error advected at the lateral boundaries;
2) using a considerably less successful data assimilation system

The LB error, 1), is removed by

- having a global Eta-like model, or
- running a global model and the Eta simultaneously

Eta rms wind fits to raobs vs same except in. cnd. interpolated from GFS

Oct. 2002-May 2003, 32-km parallel, 48-h fcsts:



At 250-300 mb, error reduced more than 10%

(A replacement data assimilation system is being developed)

The two operational Eta handicaps:

Each on the order of 10% error at 48 h;
both can be removed/ improved upon !

A Special Advertisement Section

NCEP Regional Reanalysis

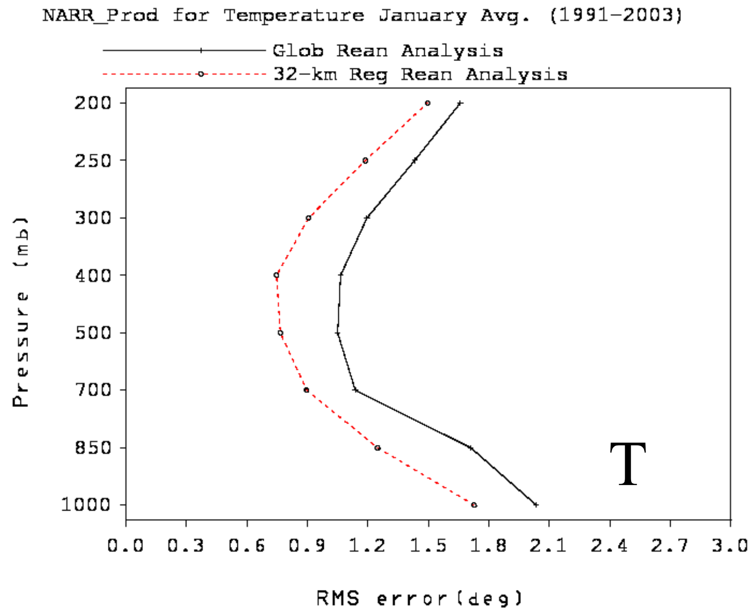
Fedor Mesinger[1], Geoff DiMego[2], Eugenia Kalnay[3], Perry Shafran[4], Wesley Ebisuzaki[5], Dusan Jovic[4], Jack Woollen[4], Kenneth Mitchell[2], Eric Rogers[2], Michael Ek[1], Yun Fan[6], Robert Grumbine[2], Wayne Higgins[5], Hong Li[3], Ying Lin[2], Geoff Manikin[2], David Parrish[2], and Wei Shi[6]

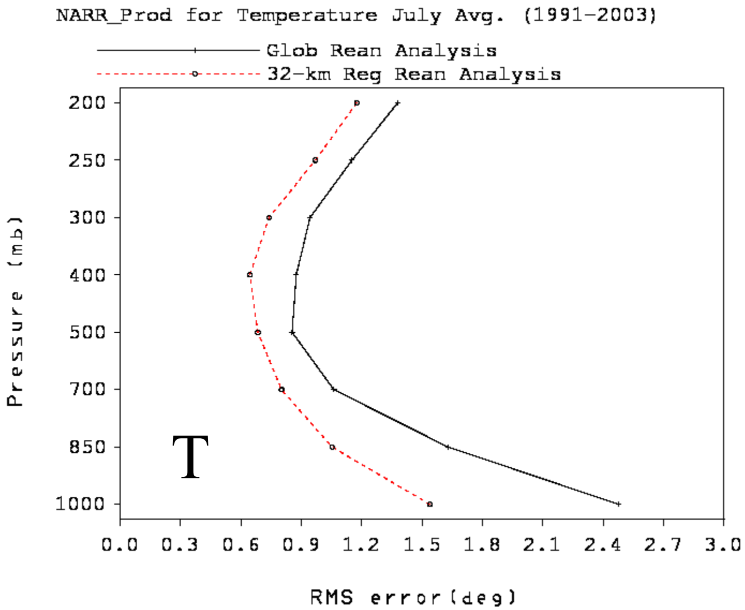
[1]NCEP/EMC and UCAR, [2]NCEP/EMC, [3]Univ. of MD, [4]NCEP/EMC and SAIC/GSO, [5]NCEP/CPC, [6]NCEP/CPC and RSIS

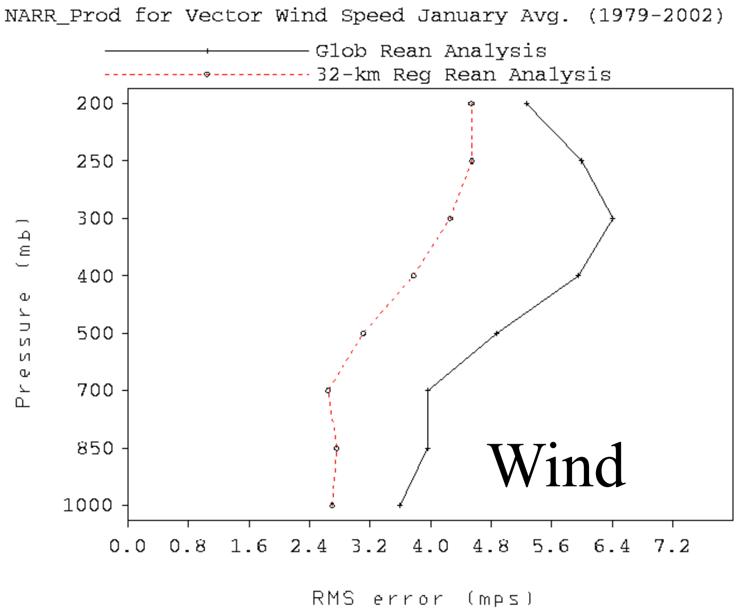
System Design

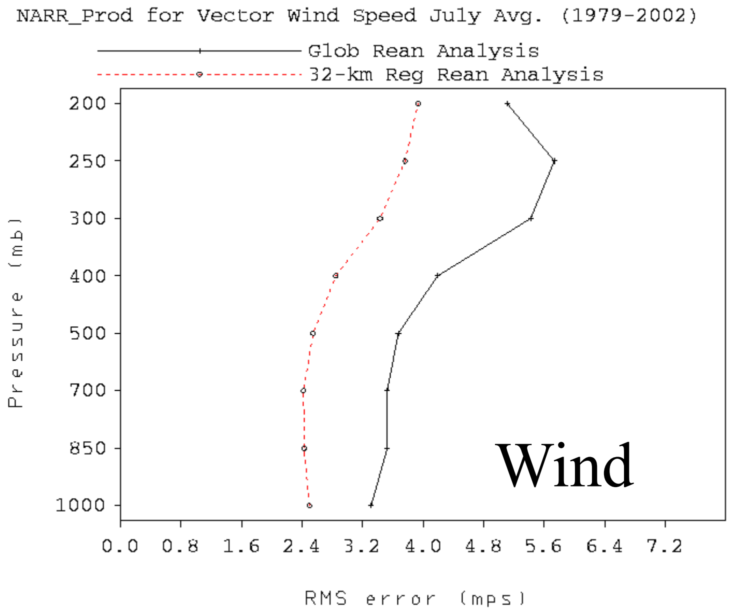
- Fully cycled 3-hr EDAS (3D-Var every 3 h, precip assimilated continuously)
- Lateral boundary conditions supplied by Global Reanalysis 2
- Free forecasts done out to 72 hr every 2.5 days, using GR2 forecast boundary conditions
- Resolution: 32-km, 45 layers
- RR time period: 1979-2003 (continued in near-real time, as in CDAS)

January Avg. Analysis RMS July Avg.









RR free forecasts (re-forecasts),

along with those of the NCEP/NCAR Global Reanalysis free forecasts:

excellent data set for predictability studies !

Abdus Salam ICTP, Miramare, Trieste, Italy
April 11-22, 2005

Workshop + Conference

Regional Weather Predictability and Modelling

WMO sponsorship will be requested

Main message:

Three-model, one-year precip results, “East” vs “West”:
differences strongly suggestive
of arising from features of models’ dynamical cores

Findings of this type
worth looking for and pursuing within THORPEX

Excellent way to improve prediction of high impact weather!

Thank you for the attention !