The Abdus Salam
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29 September - 10 October, 2008

Dynamics of the Eta model
Part II

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The Eta Model Dynamics, Part II:
Pressure-gradient force, eta coordinate

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Workshop on
"Design and Use of Regional Weather Prediction Models"

The Abdus Salam International Centre for Theoretical Physics (ICTP),
Trieste, Italy

29 September - 7 October 2008

Why eta coordinate (motivation) ?

What is the sigma PGF problem?

In hydrostatic systems:

$$-\nabla_p \phi \rightarrow -\nabla_\sigma \phi - RT \nabla \ln p_S$$

The way we calculate things, in models,

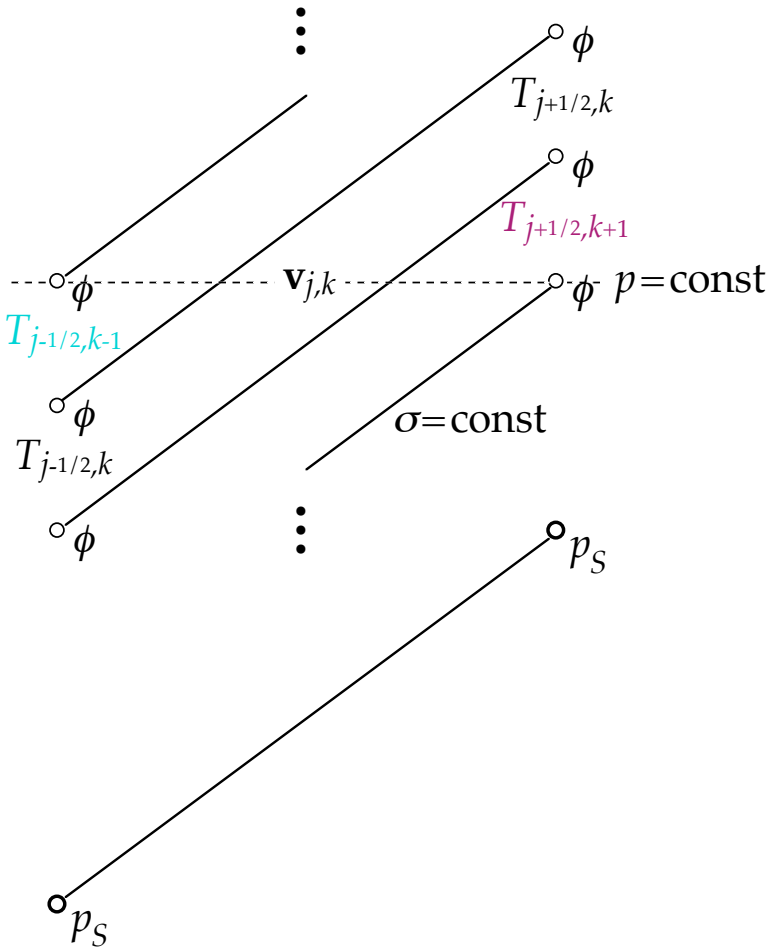
$$\phi = \phi_S - R_d \int_{p_S}^{p} T_v d \ln p$$

Thus: PGF depends only on variables from the ground up to the considered p=const surface !

We could do the same integration from the top; but: we measure the surface pressure, thus, calculation "from the top" not an option !

In nonhydrostatic models: very nearly the same

Example, 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*.

The problem aggravates with resolution ! (If the steepness does)

Mesinger 1982, 1985

TABLE 1.

Errors of the pressure gradient force analogs obtained using the Corby et al. and the Burridge-Haseler schemes, for the "no inversion case" and the "inversion case"; see text for details. Values are given in increments of geopotential ($m^2 s^{-2}$), between two neighboring grid points, along the direction of the increasing terrain elevations. (Note that some of the numbers in the last two lines are slightly different from those published in the referred paper; this is a result of the removal of an error that Mesinger has found in his program for calculation of the Burridge-Haseler scheme values. The numbers published previously actually represented errors of a scheme which, within the geopotential gradient term, used geopotentials of the $\sigma = 0.9$ surface rather than values defined by (4.22).)

	$\Delta\sigma =$	1/5	1/15	1/25	···	$\lim_{\Delta\sigma \to 0}$
Corby et al. scheme "no inversion case"		151.2	−48.7	29.0	···	0
Corby et al. scheme "inversion case"		−159.6	−159.6	−159.6	···	−159.6
Burridge-Haseler scheme "no inversion case"		0	0	0	···	0
Burridge-Haseler scheme "inversion case"		0	−142.1	−153.3	···	−159.6

Thus, as opposed to:

Norman Phillips' (1957) "sigma":

$$\sigma = \frac{p}{p_S} \qquad \text{(Or, later, } \quad \sigma = \frac{p - p_T}{p_S - p_T} \text{)}$$

(Arakawa ?)

Mesinger (1984) "eta":

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

"Step-topography" eta:

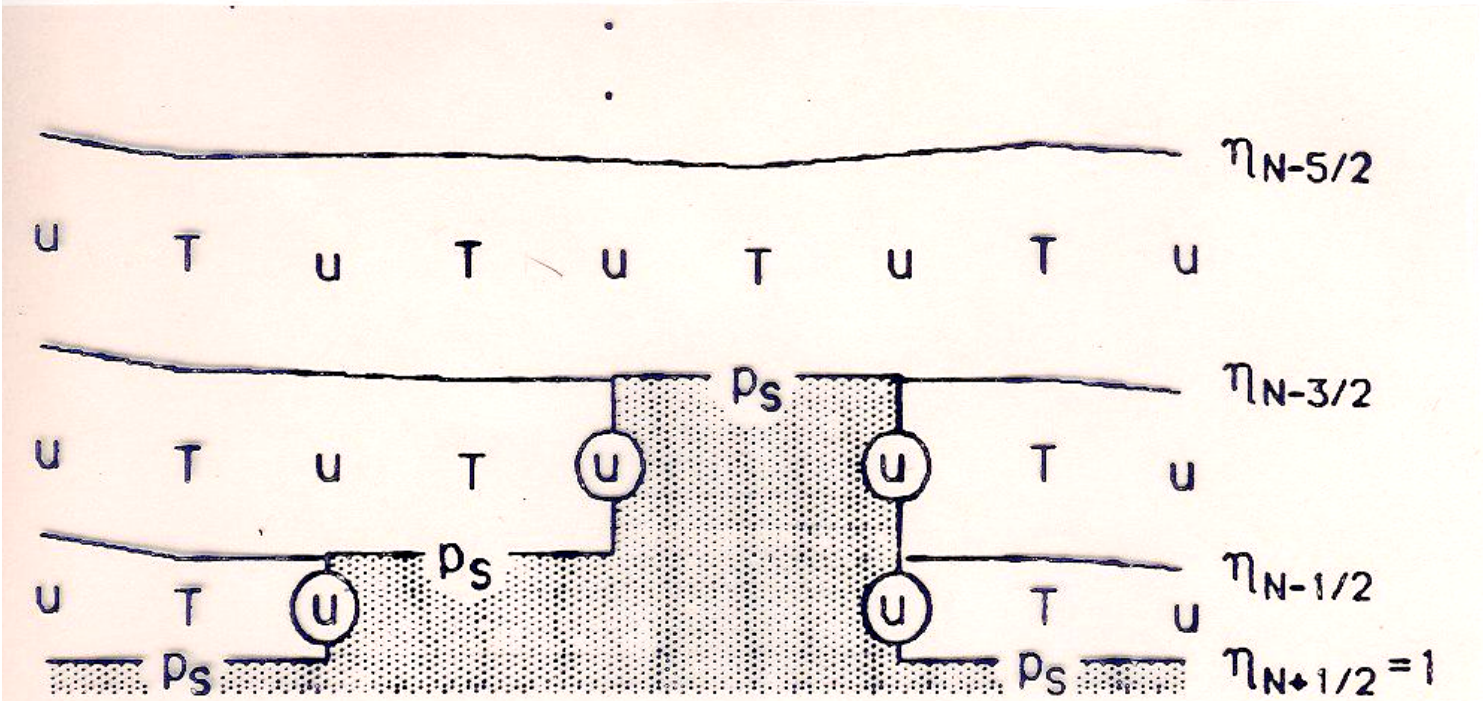


FIG. 1. Schematic representation of a vertical cross section in the eta coordinate using step-like representation of mountains. Symbols u, T and p_s represent the u component of velocity, temperature and surface pressure, respectively. N is the maximum number of the eta layers. The step-mountains are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

In early tests eta/ sigma,

and in those somewhat later in NCEP's full-physics "Eta Model", eta did extremely well:

Sigma

Eta

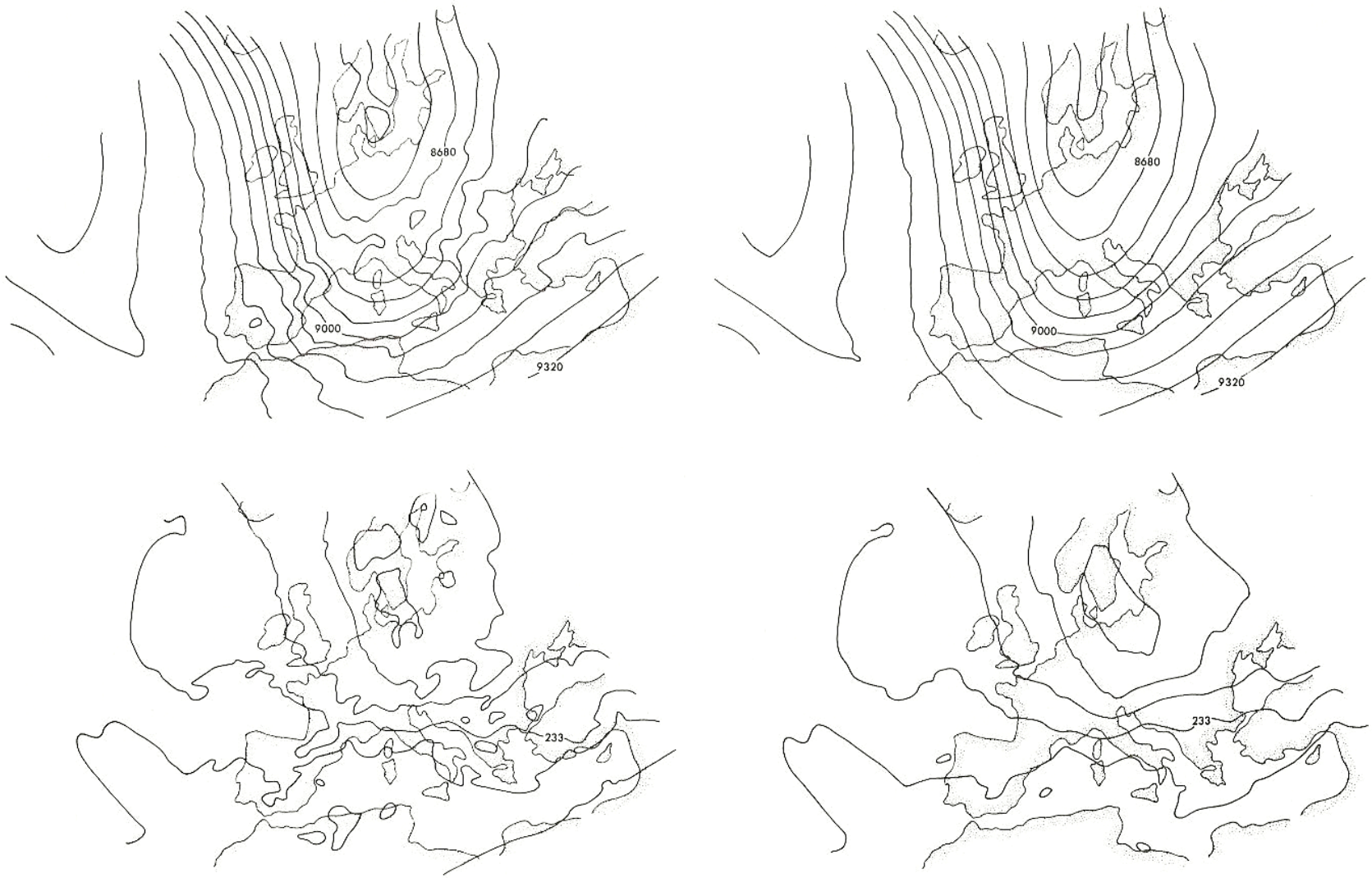


FIG. 6. 300 mb geopotential heights (upper panels) and temperatures (lower panels) obtained in 48 h simulations using the sigma system (left-hand panels) and the eta system (right-hand panels). Contour interval is 80 m for geopotential height and 2.5 K for temperature.

André Robert
Memorial Volume:

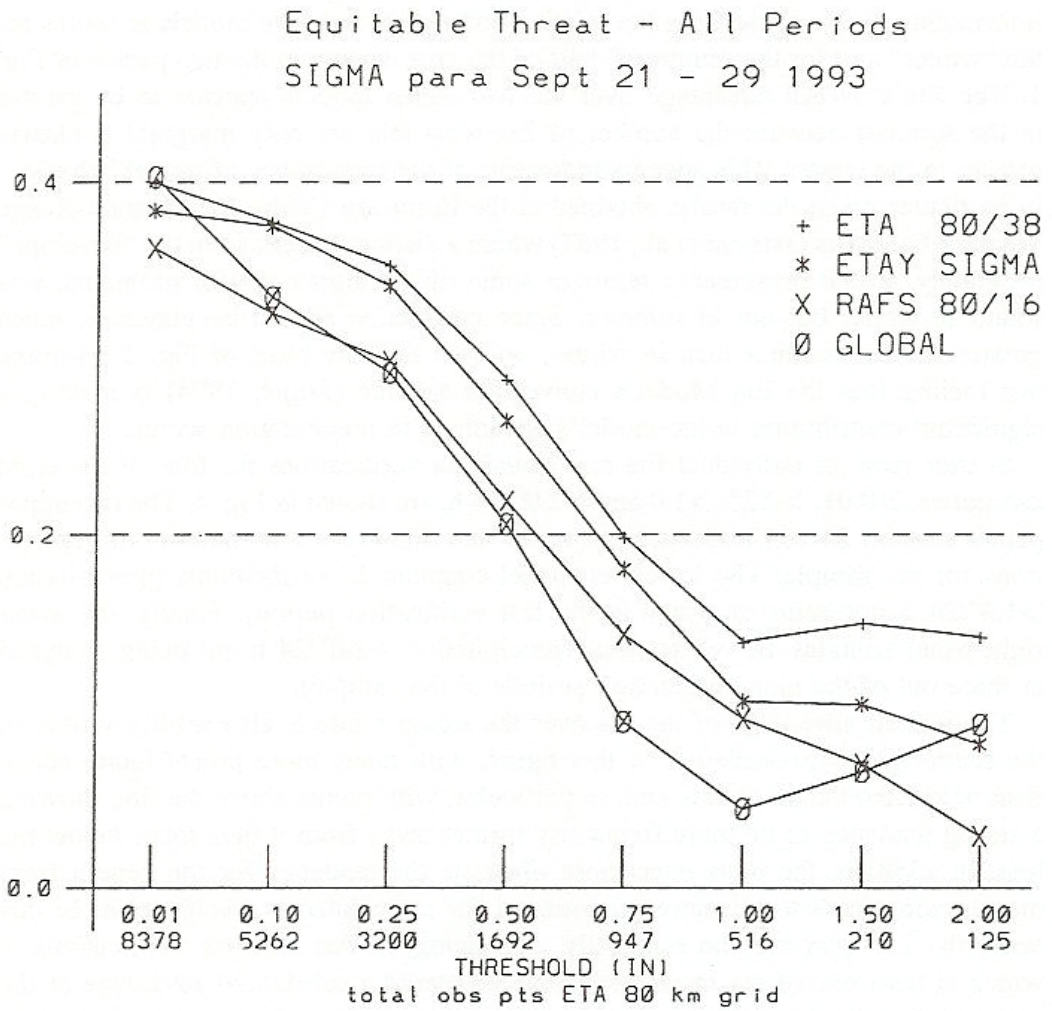
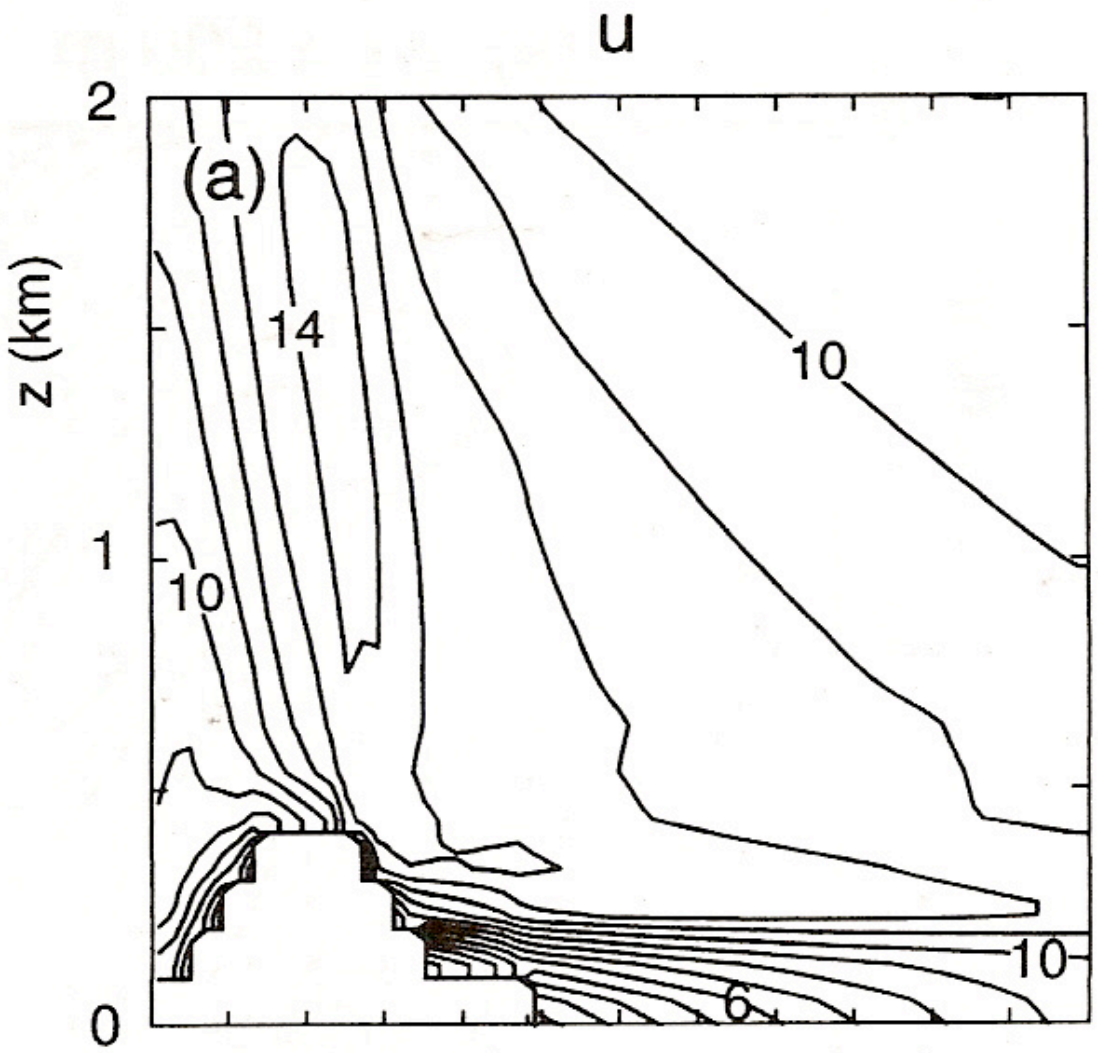


Fig. 3 Equitable precipitation threat scores for two versions of the Eta Model: Eta 80 km/38 layers ("ETA"), and the same version of the Eta Model but run using sigma coordinate ("ETAY"), and for the NGM (RAFS), and the Avn/MRF ("global") Model; for a sample of 16 forecasts verifying 1200 UTC 21 September 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.

Quite a few more !

However,

a 10-km Eta in 1997 did a poor job on a case of the so-called Wasatch downslope windstorm, while a sigma system MM5 did well; also: Gallus, Klemp (MWR, 2000)



Gallus, Klemp
MWR 2000,
Fig. 6 (a),
horizontal
velocity

("Witch of Agnesi" mountain)

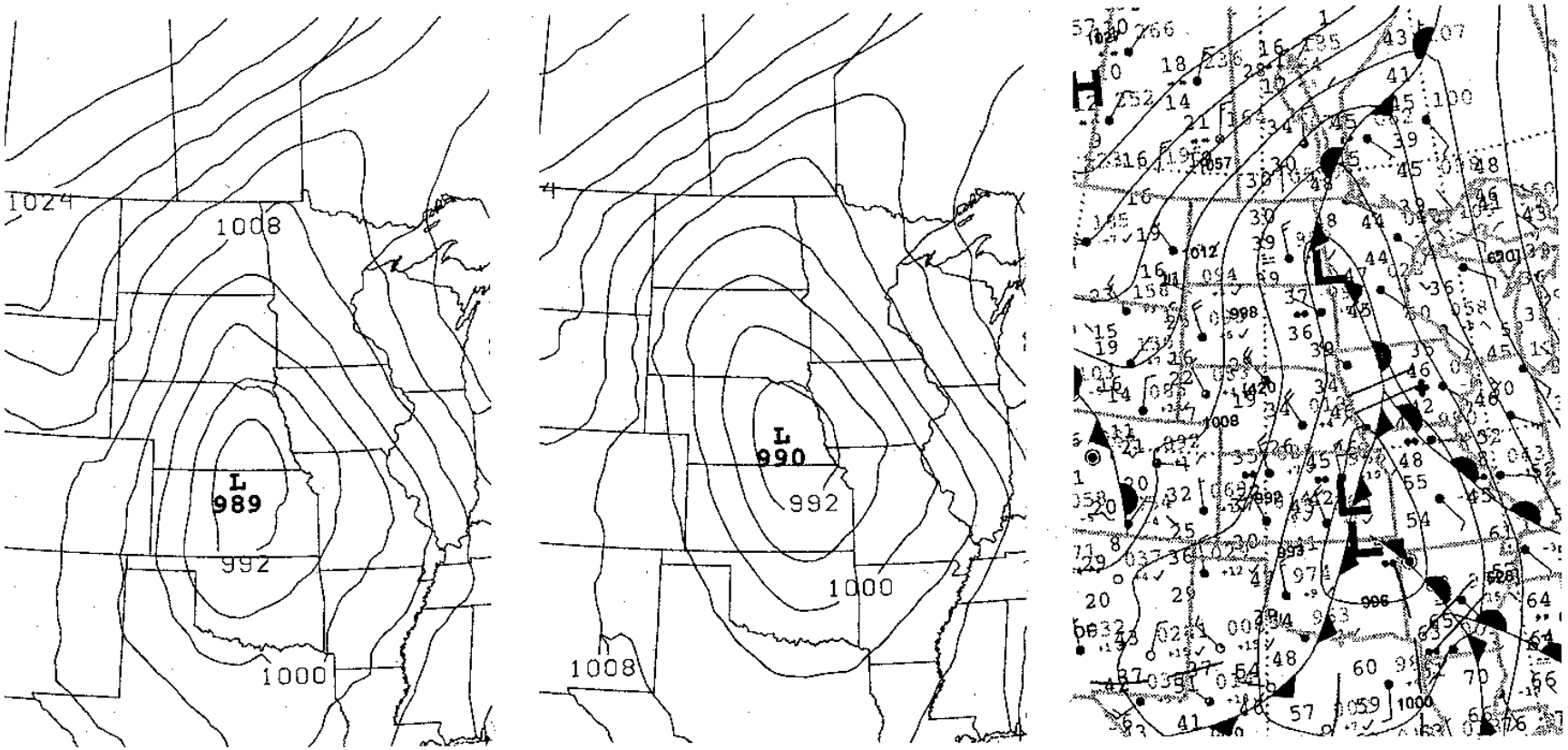
Eta: bad press for quite some time:

"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 ??

One "eta favorable" experiment at the time though, done in 2001:
Eta (left), 22 km, switched to use sigma (center), 48 h position error of a major low increased from 215 to 315 km



~ Just as in earlier experiments at lower resolution

Even so: the downslope windstorm problem;

also:

Claims made (Colle et al. 1999) claiming that sigma system MM5 is better than Eta in placing precip over topography;

Thus, when NCEP's "Nonhydrostatic Mesoscale Model" (NMM) derived from the Eta, was implemented on "hi-res windows" in 2002, switched from eta to sigma

NOAA-wide announcement:

"This choice will avoid the problems encountered at high resolution (10 km or finer) with the step-mountain coordinate with strong downslope winds and will improve placement of precipitation in mountainous terrain".

Thus, when NCEP's "Nonhydrostatic Mesoscale Model" (NMM) derived from the Eta, was implemented on "hi-res windows" in 2002, switched from eta to sigma

NOAA-wide announcement:

"This choice will avoid the problems encountered at high resolution (10 km or finer) with the step-mountain coordinate with strong downslope winds and will improve placement of precipitation in mountainous terrain".

Also: This was just a step toward development of an NCEP version of the "Weather Research and Forecasting" ("WRF") model - and continued precipitation results favoring eta had not enough power to convince management to return to the eta

The downslope windstorm problem:

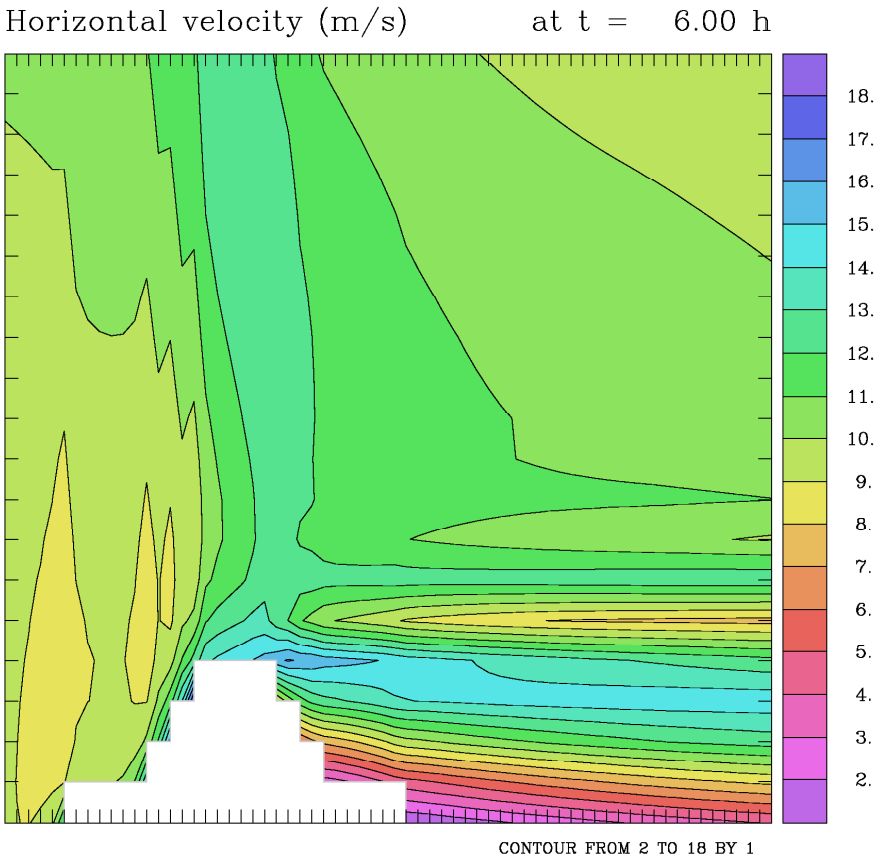
1) What counts is not so much small mountains, but much more large mountains (e.g., Rockies, Andes !!) Many eta/sigma experiments suggest that it is in simulating the impact of large mountains that the benefit from the eta is at its most conspicuous;

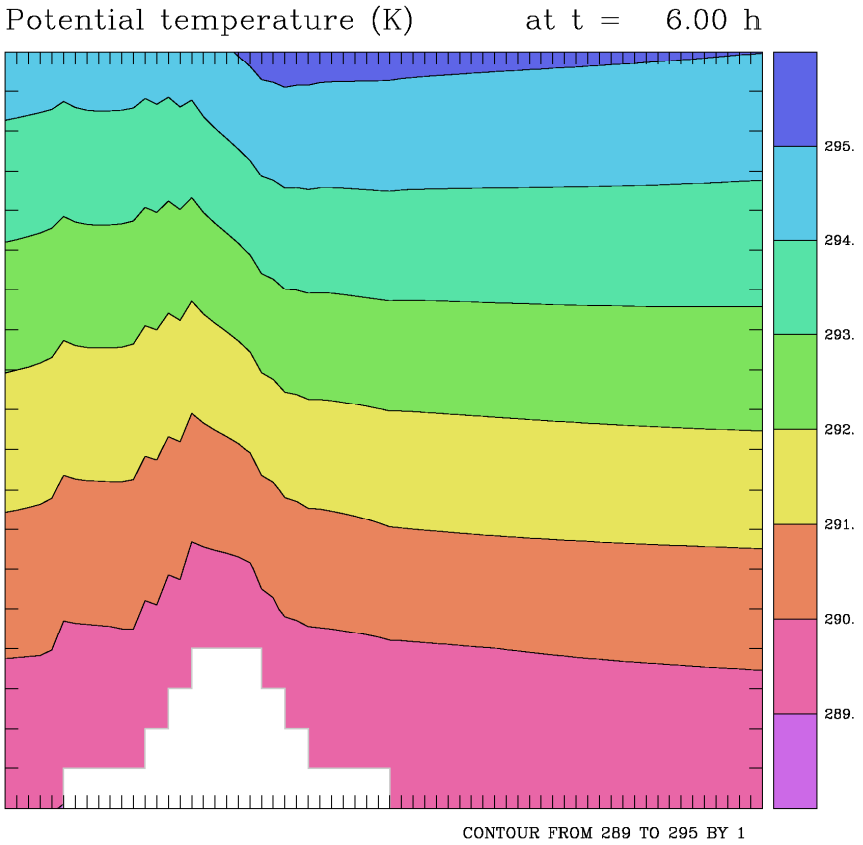
The downslope windstorm problem:

1) What counts is not so much small mountains, but much more large mountains (e.g., Rockies, Andes !!) Many eta/sigma experiments suggest that it is in simulating the impact of large mountains that the benefit from the eta is at its most conspicuous;

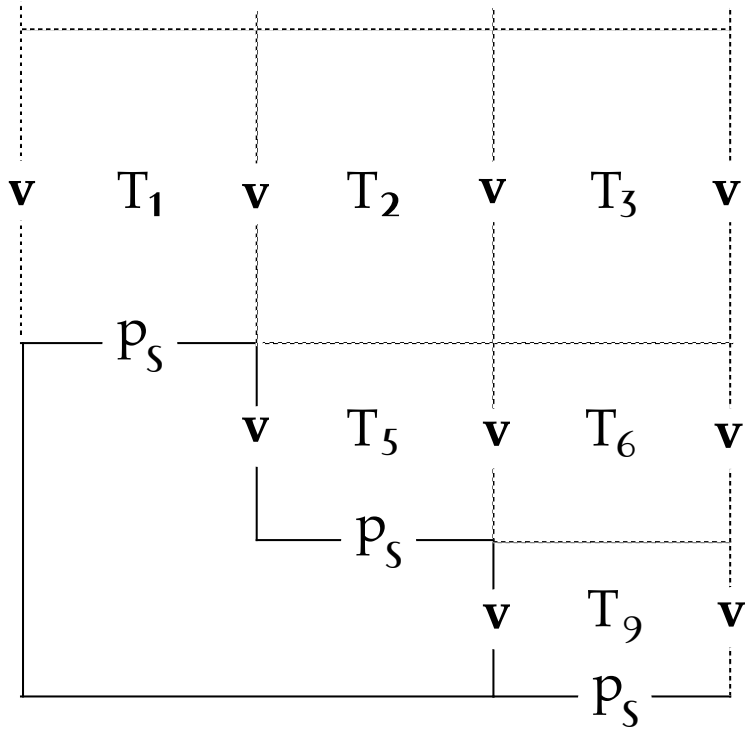
2) The problem of the eta in getting the flow all the way down on the lee side of the mountain can be understood and addressed.

Addressing the downslope windstorm problem:
Flow separation on the lee side (à la Gallus and Klemp 2000):





Suggested explanation



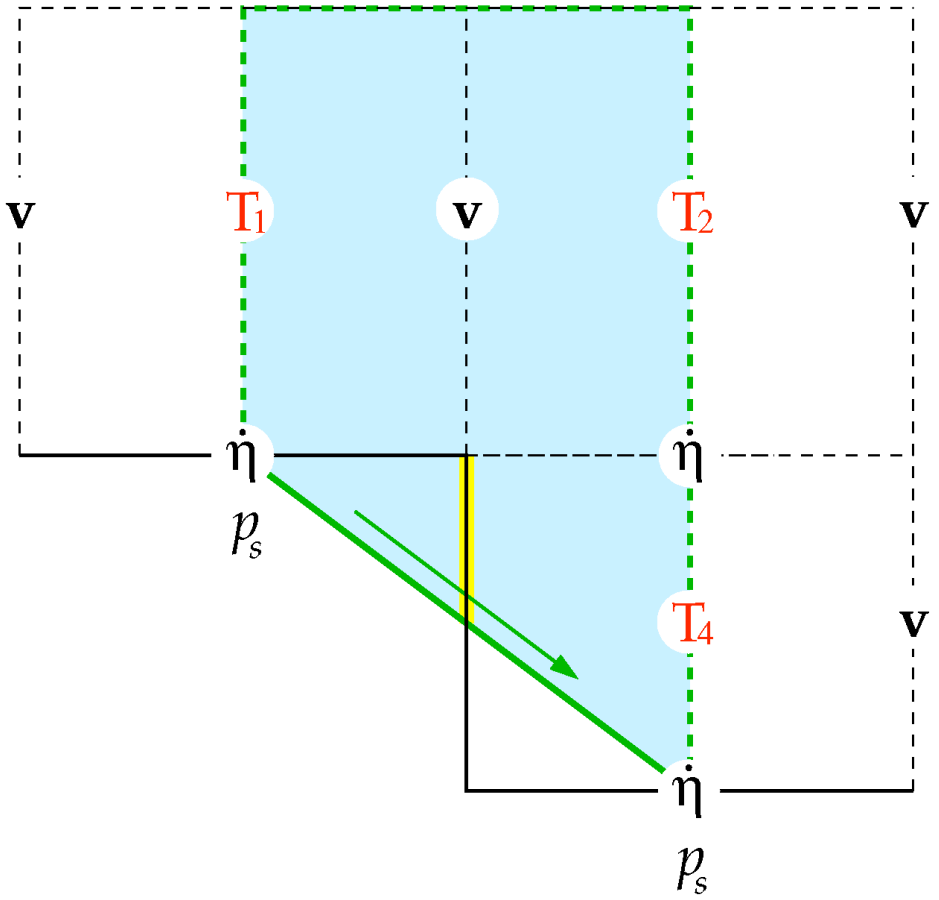
Flow attempting to move from box 1 to 5 is forced to enter box 2 first.

Missing: slantwise flow directly from box 1 into 5 !

As a result: some of the air which should have moved slantwise from box 1 directly into 5 gets deflected horizontally into box 3.

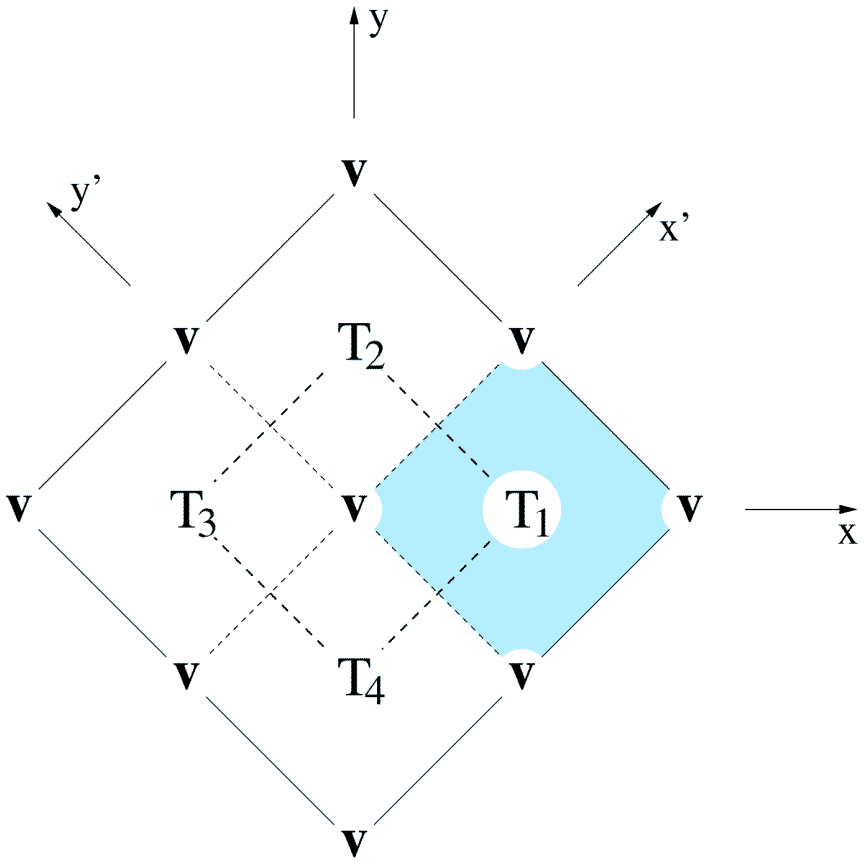
The sloping steps, vertical grid

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



Horizontal treatment, 3D: Identify the highest of four height points neighboring a **v** point

Case #1: Suppose point 1 is the highest:



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

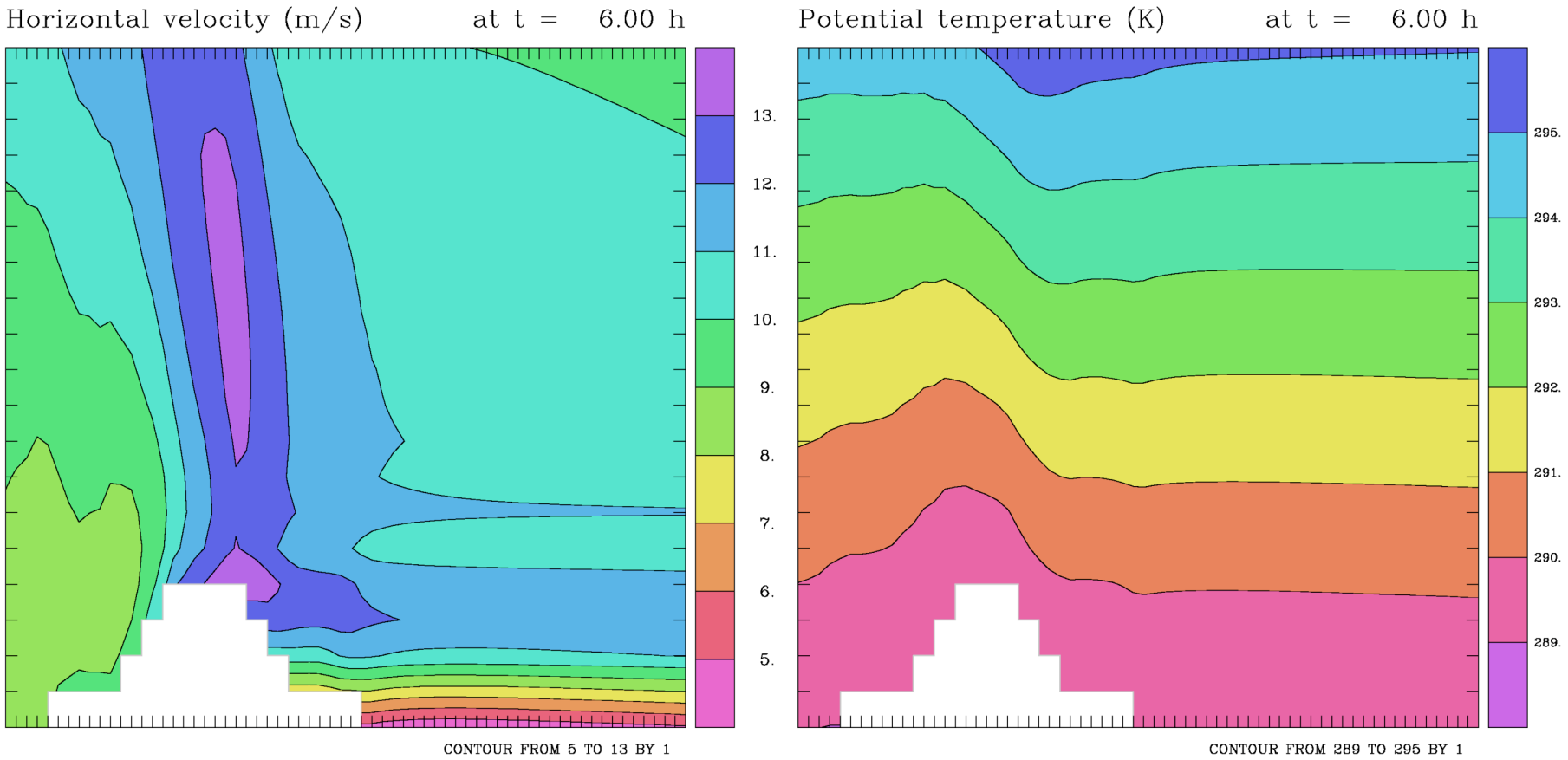
Case #2: topographies of boxes 1 and 2 are the same, and higher than those of 3, and 4; "Slope 2"

Topography descends from the centers of T1 and T2 down by one layer thickness, linearly, to the centers of T3 and T4

Etc.: Slopes 3, 4, …, 8

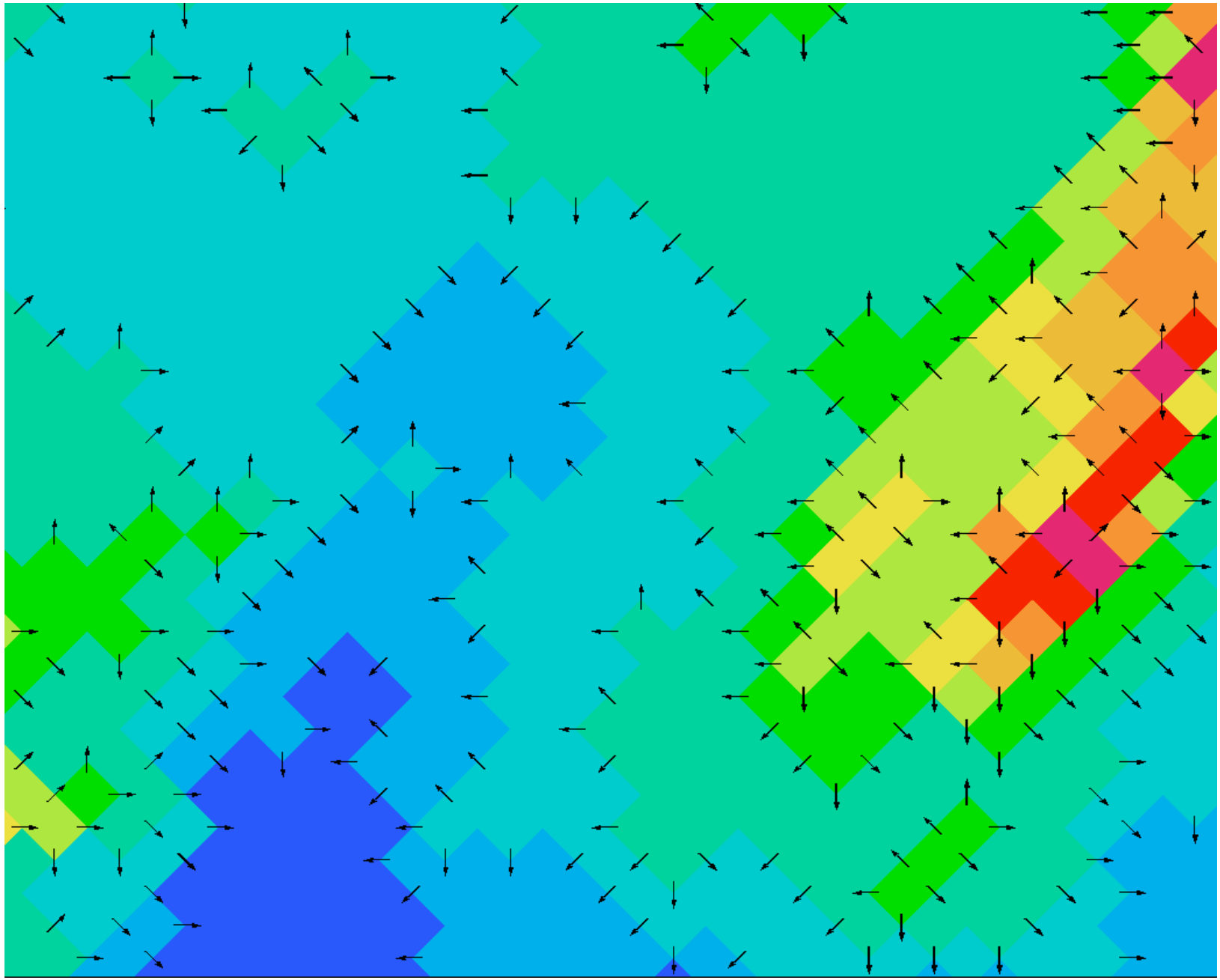
If two opposite, or if three topography boxes are the highest of the four: No slope

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



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

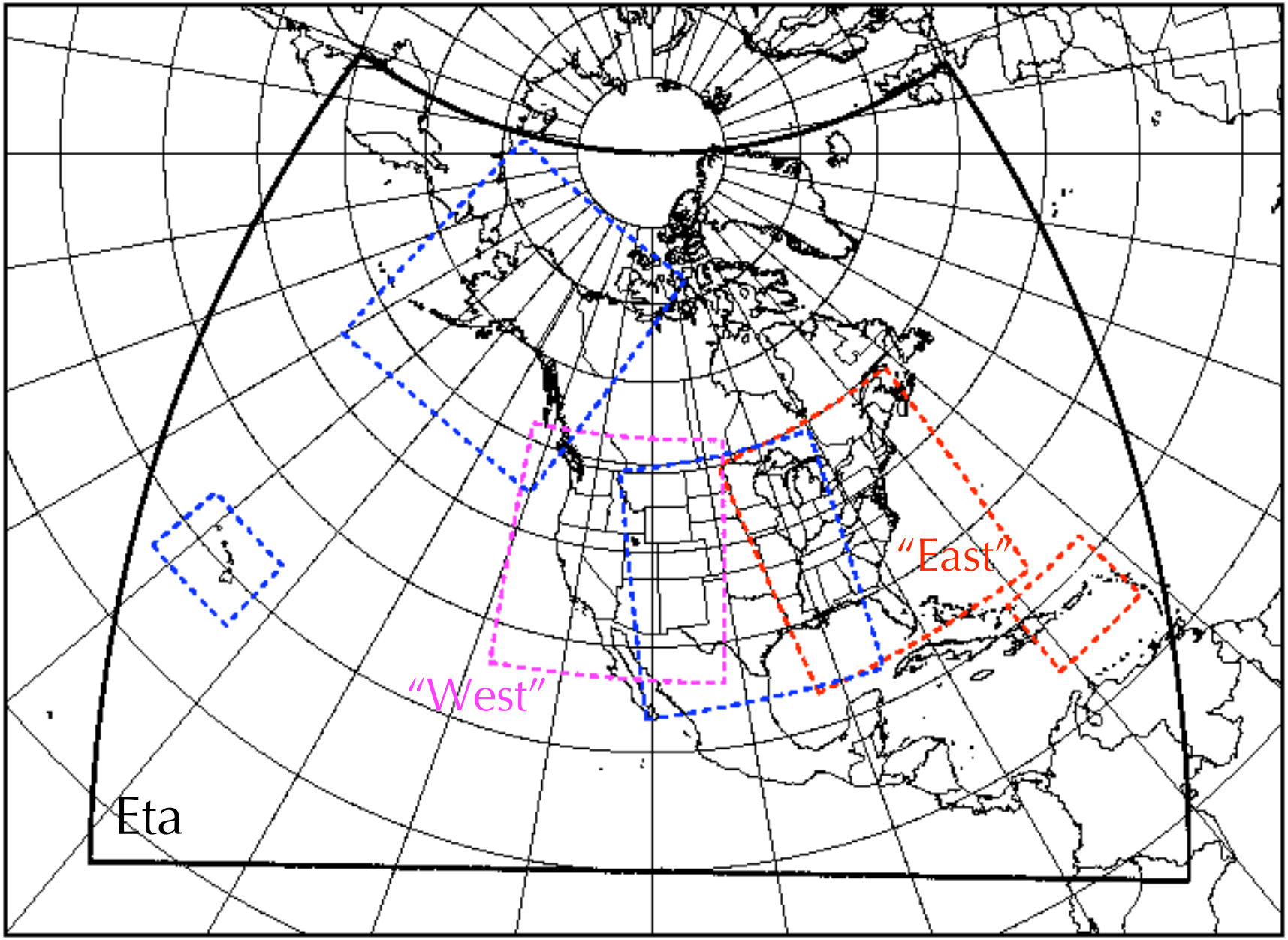
Example of slopes with an actual model topography:



Precipitation: continuously eta-favorable results

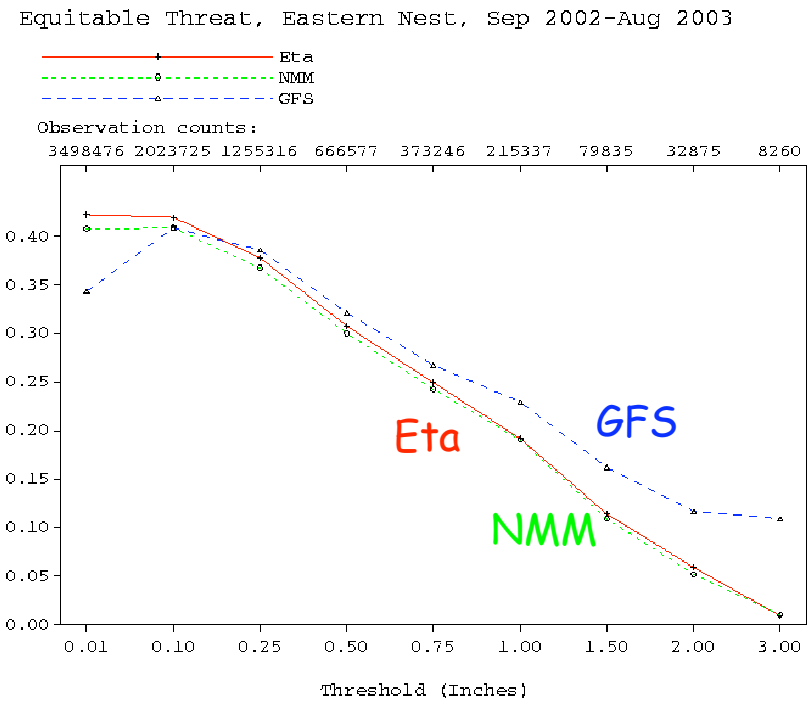
Now three-model precipitation scores were available, on NMM ConUS domains ("East" ,…, "West"), available Sep. 2002 to 2005

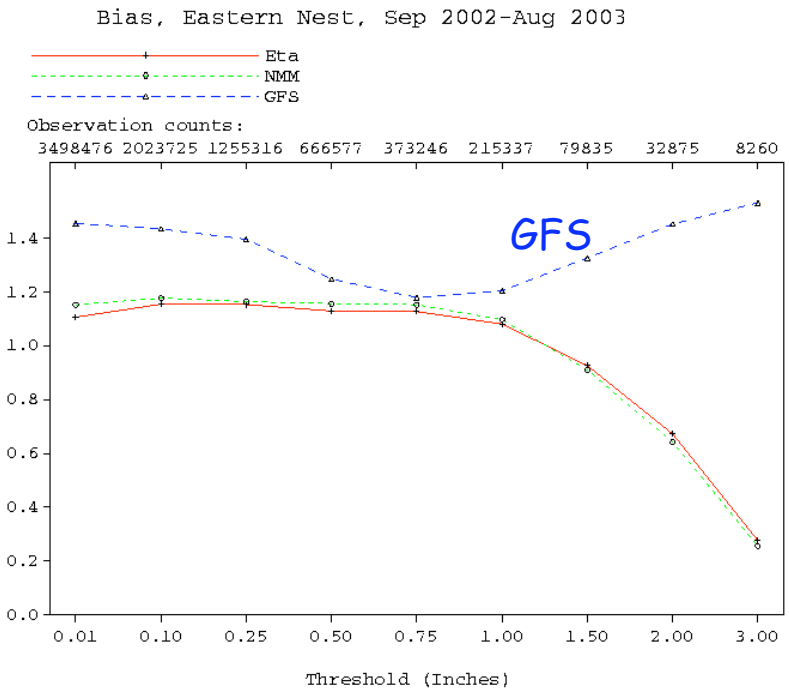
- Operational Eta: 12 km, driven by 6 h old GFS forecasts
  (a considerable handicap compared to GFS of the same initial time);
- NMM: 8 km, sigma, driven by the Eta;
- GFS (Global Forecasting System) as of the end of Oct. 2002 T254 (55 km) resolution, sigma


"East"
"West"
Eta

The first 12 months of three model scores:

East





ETS (Equitable Threat Score)

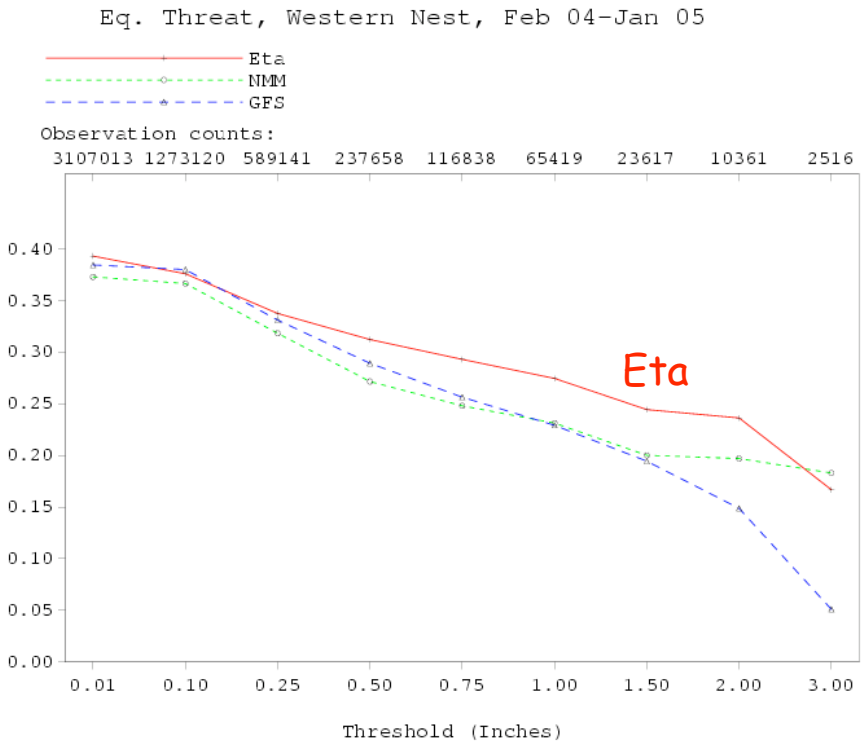
Bias

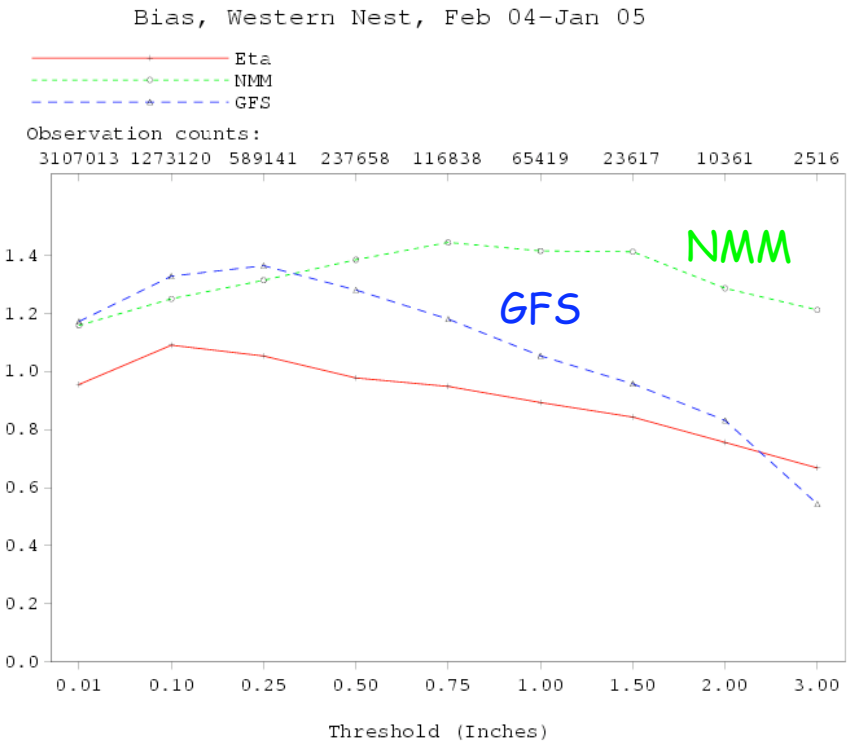
Is the GFS loosing/ winning because of its bias difference?

"The last 12 months": Feb. 2004 - Jan. 2005

(includes high impact California precip,
winter 2004-2005)

The last 12 months, now West



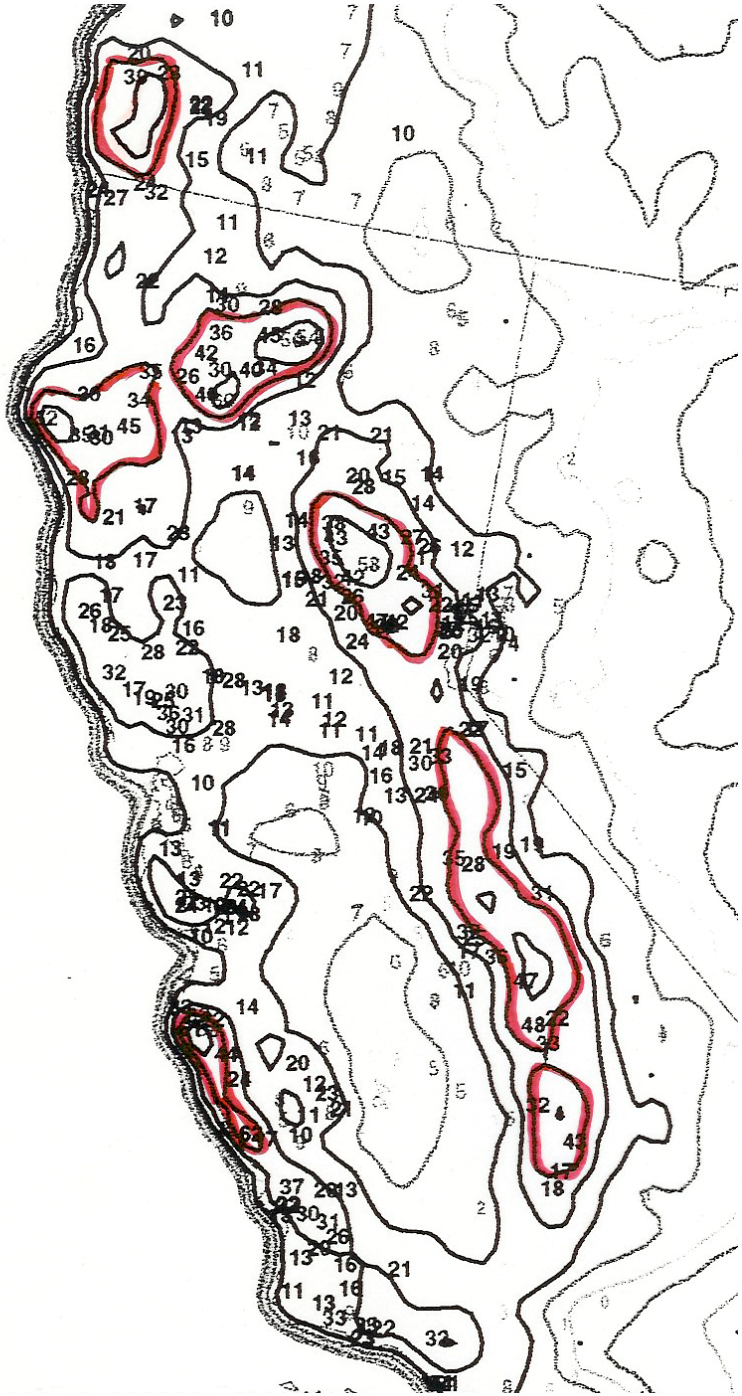


Is the green model loosing to red because of a bias penalty?

An example of precip at one of these events:

(8 Nov. 2002, red contours: 3 in/24 h)

An extraordinary challenge to do well in QPF sense !



What can one do ?

There is a problem with using the ETS:
A model can have a higher ETS because of its erroneously high bias !

The problem addressed first in:

J12.6

17th Prob. Stat. Atmos. Sci.; 20th WAF/16th NWP (Seattle AMS, Jan. '04)

BIAS NORMALIZED PRECIPITATION SCORES

Fedor Mesinger[1] and Keith Brill[2]

[1]NCEP/EMC and UCAR, Camp Springs, MD

[2]NCEP/HPC, Camp Springs, MD

and more recently (also much more successfully!) in

Mesinger, F., 2008: Bias adjusted precipitation threat scores. *Adv. Geosciences*, **16**, 137-143. [Available online at http://www.adv-geosci.net/16/index.html.]

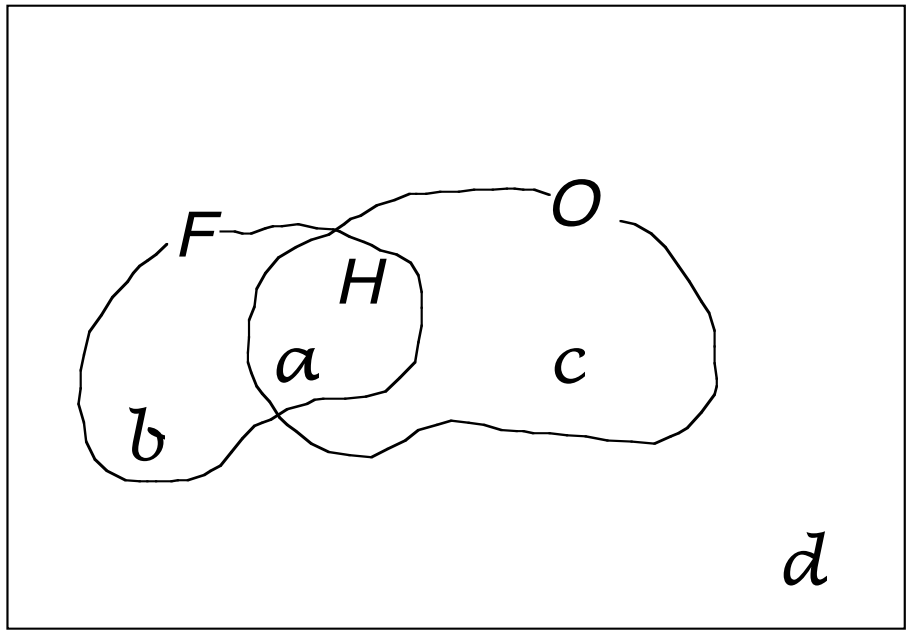
Objective:

obtain ETS adjusted to unit bias,

to show the model's accuracy in placing precipitation

"dHdA" method:

F : forecast,
H : correctly
forecast: "hits"
O : observed



Assume as *F* is increased by *dF*, ratio of the infinitesimal increase in *H*, *dH*, and that in false alarms *dA*=*dF*-*dH*, is proportional to the yet unhit area:

$$\frac{dH}{dA} = b(O - H) \quad b = const$$

(dA=dF-dH)

One obtains

$$H(F) = O - \frac{1}{b}\,\mathrm{lambertw}\left(bO\,e^{b(O-F)}\right)$$

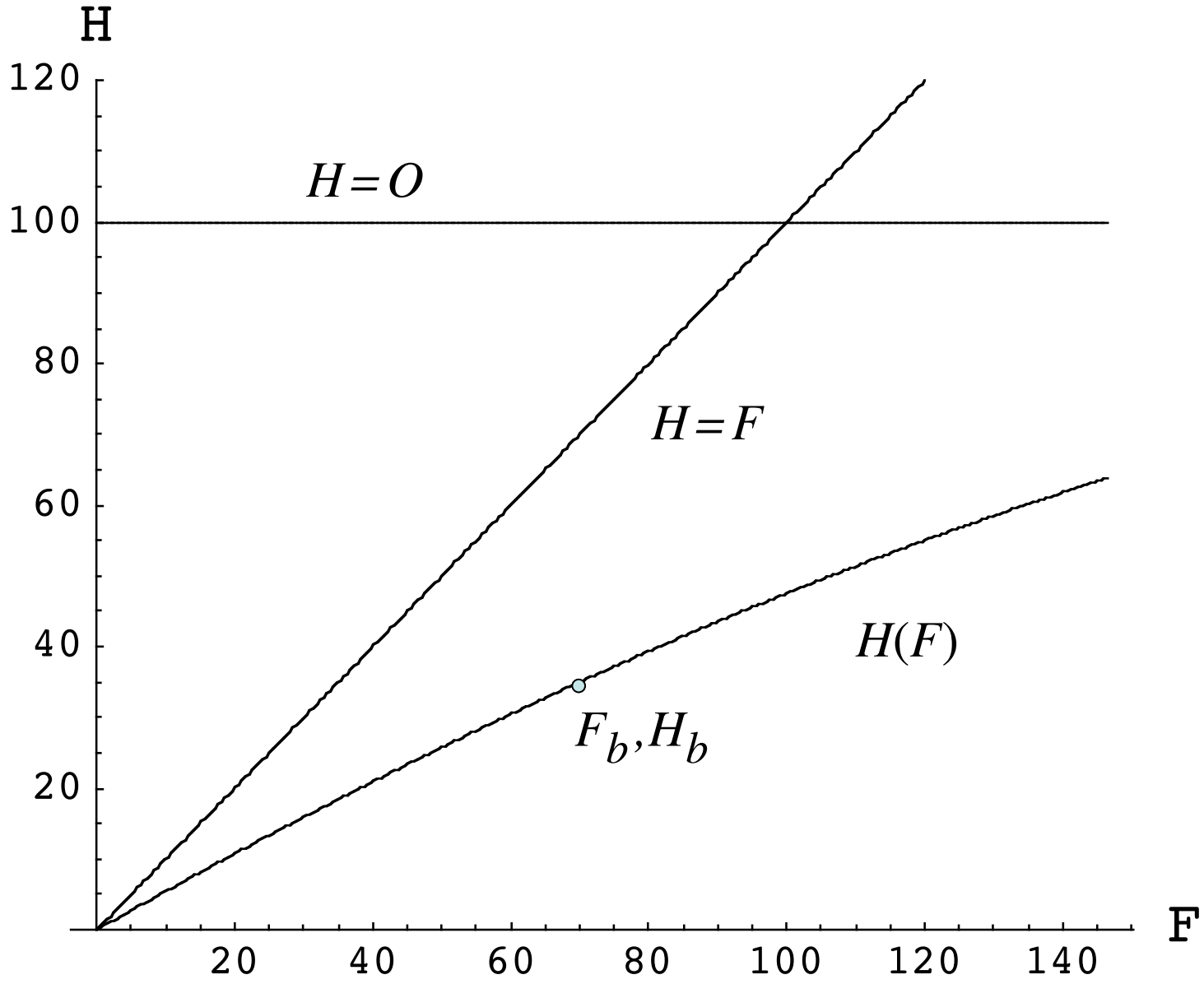
(Lambertw, or ProductLog in *Mathematica*,
is the inverse function of

$$z = we^{w} \;)$$

H (*F*) now satisfies an additional requirement compared to the scheme in Mesinger and Brill:

d*H*/d*F* never > 1

dHdA method

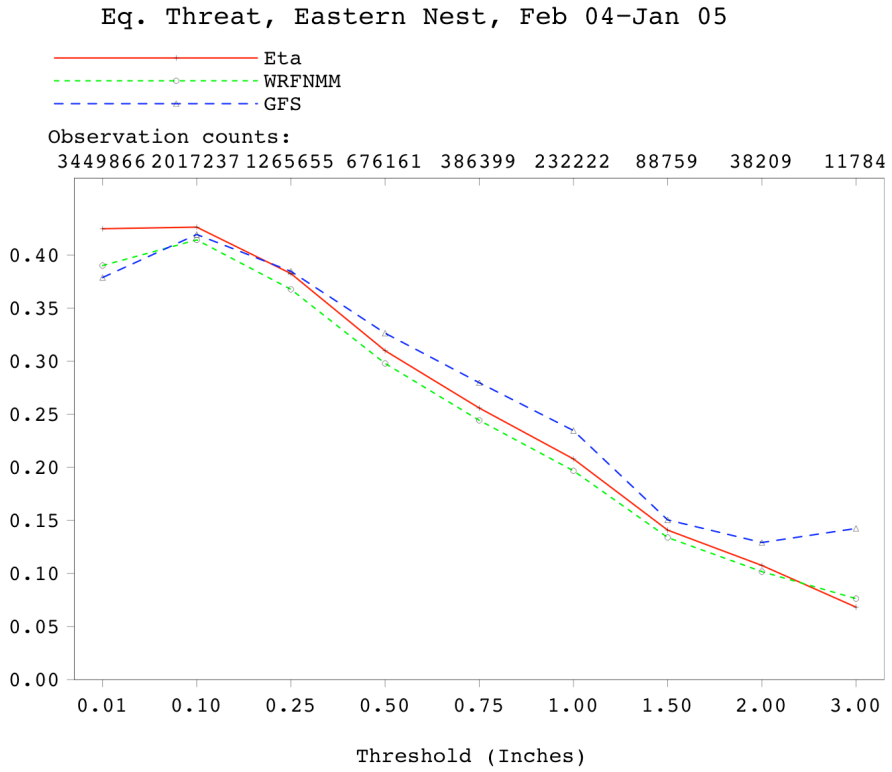


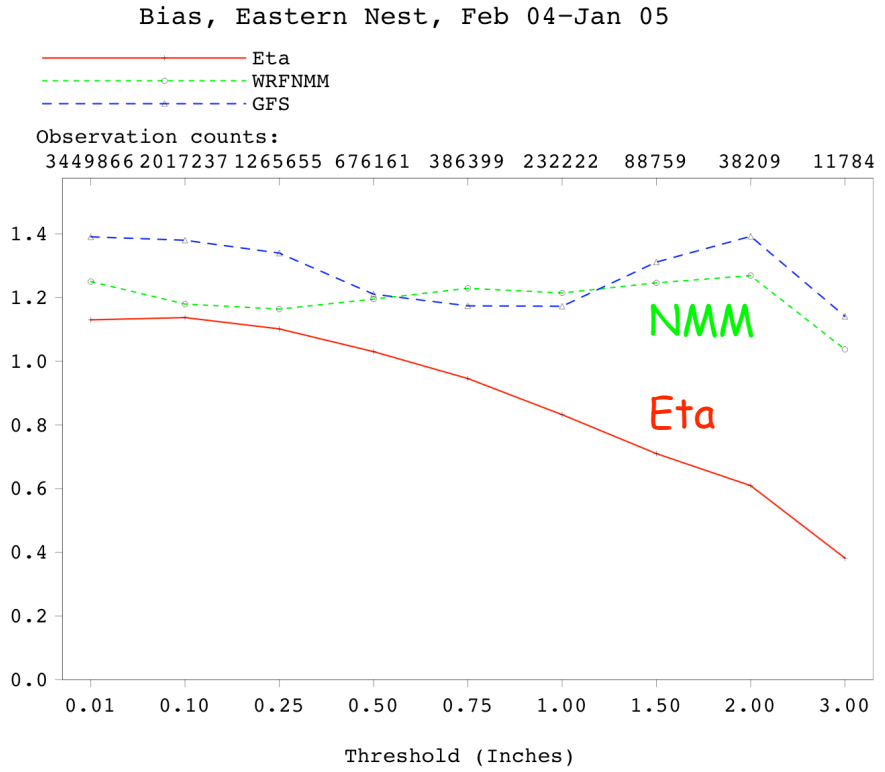
Value of $H(F)$ for $F=O$ is now assumed to be the bias adjusted (bias corrected) value of H, H_a

Using H_a instead of H, and O instead of F, bias adjusted value of ETS is calculated !

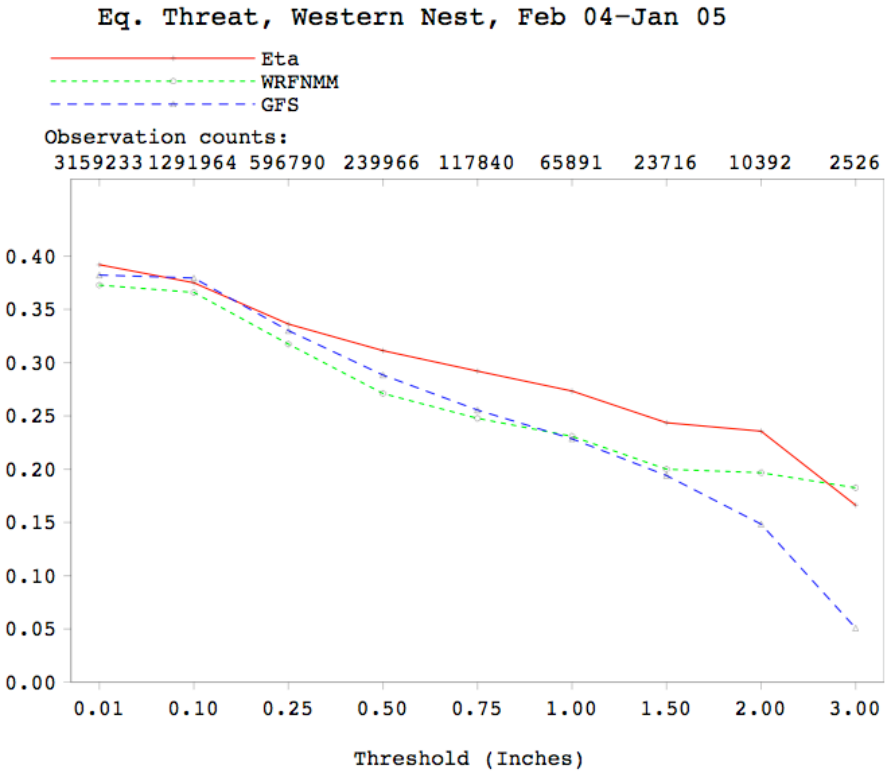
"The last 12 months"

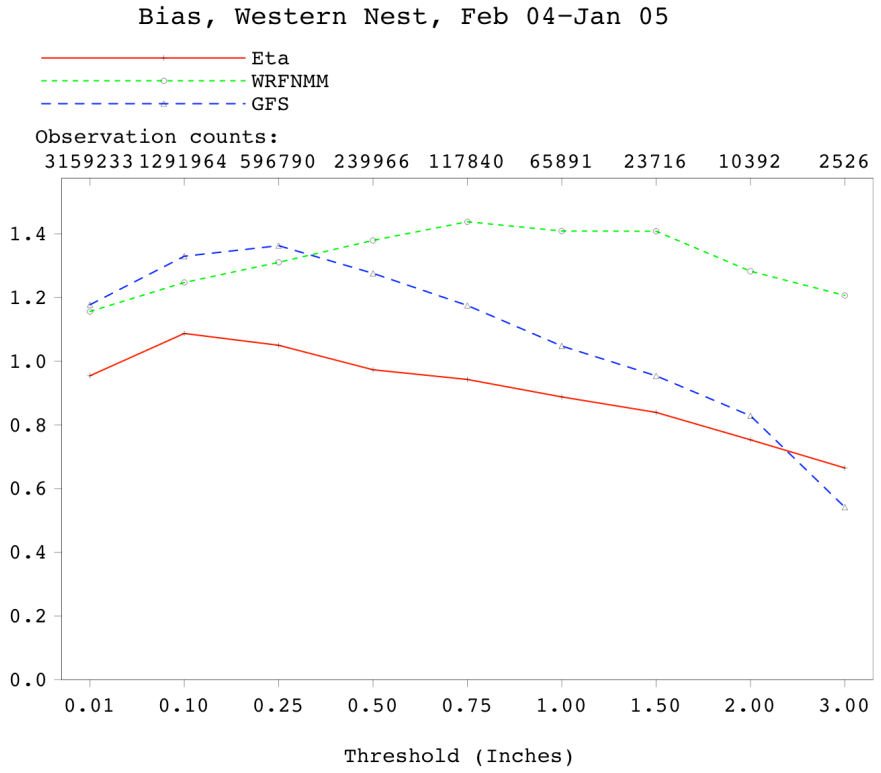
ETS, bias, East



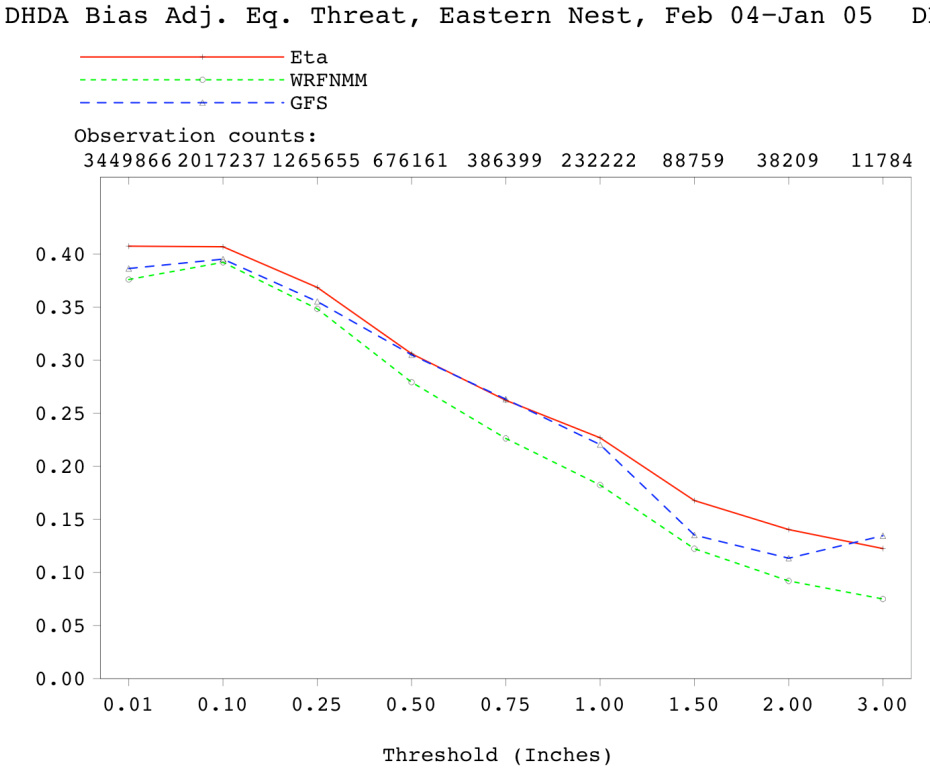


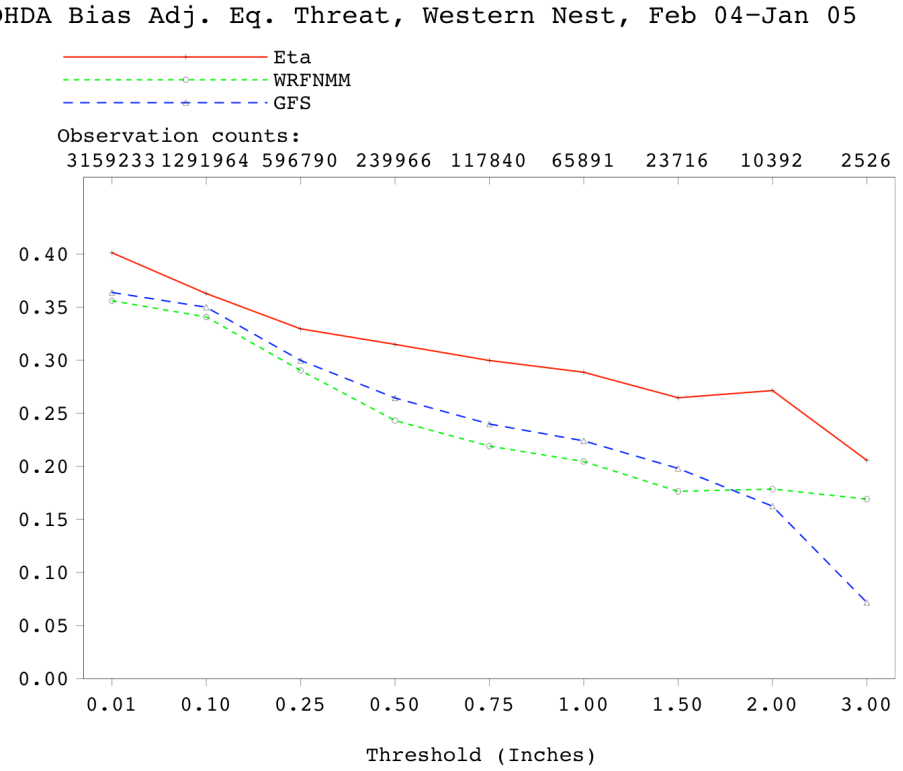
ETS, bias, West





ETS corrected for bias, East, West





"WRF model" vs Eta:

Even so:

NCEP committed (in fact, was told) to implement "a WRF model"

("WRF": Weather Research and Forecasting)

Thus:

12 km NMM-WRF system implemented in June '06, replacing the operational 12-km Eta system

Two systems:

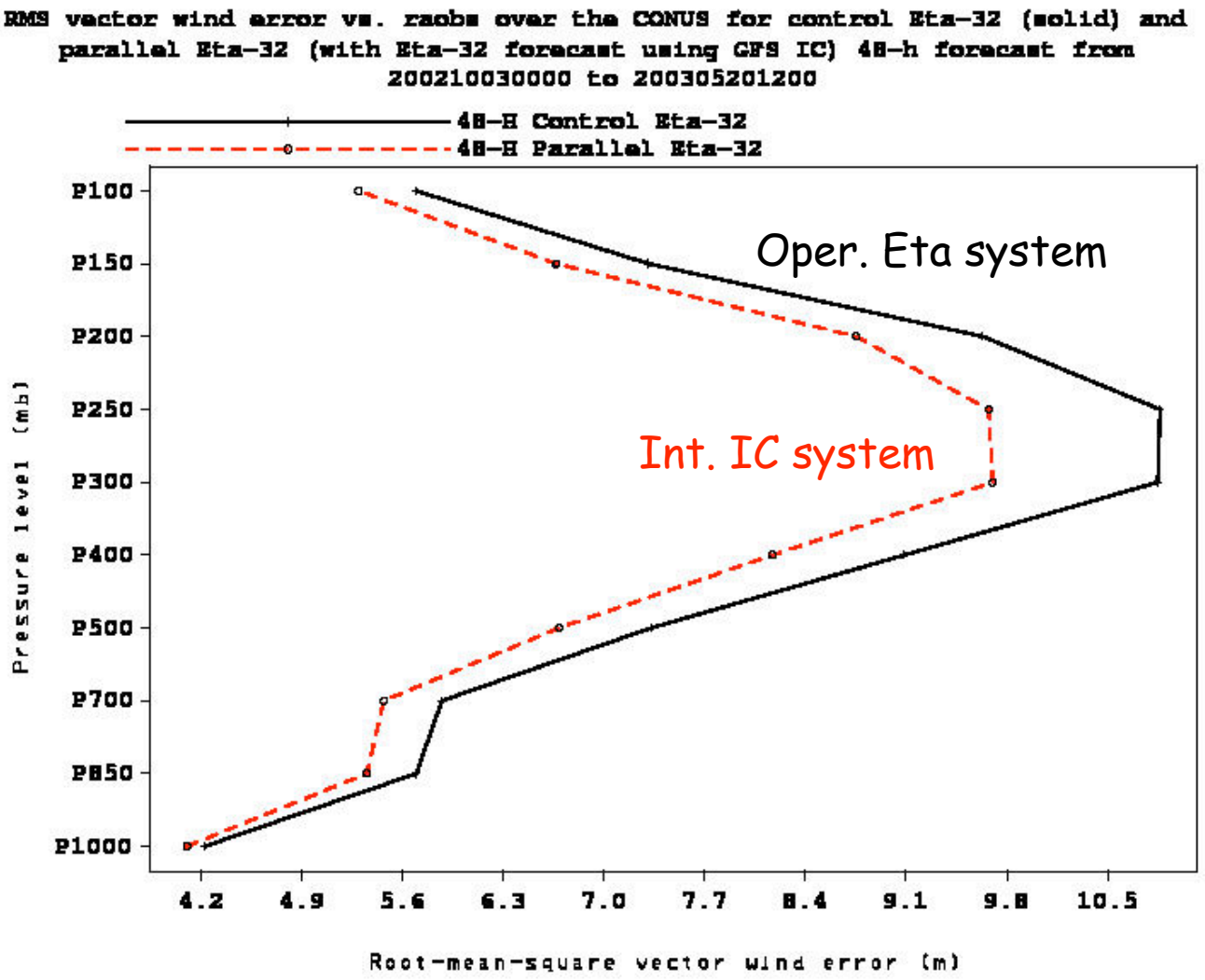
- NMM (NCEP WRF), using a new GSI data assimilation system;
- Operational Eta, using the Eta 3D-Var;

Tested in parallel January-May 2006

Note however the Eta system's problem, its data assimilation system, EDAS, was not performing well:

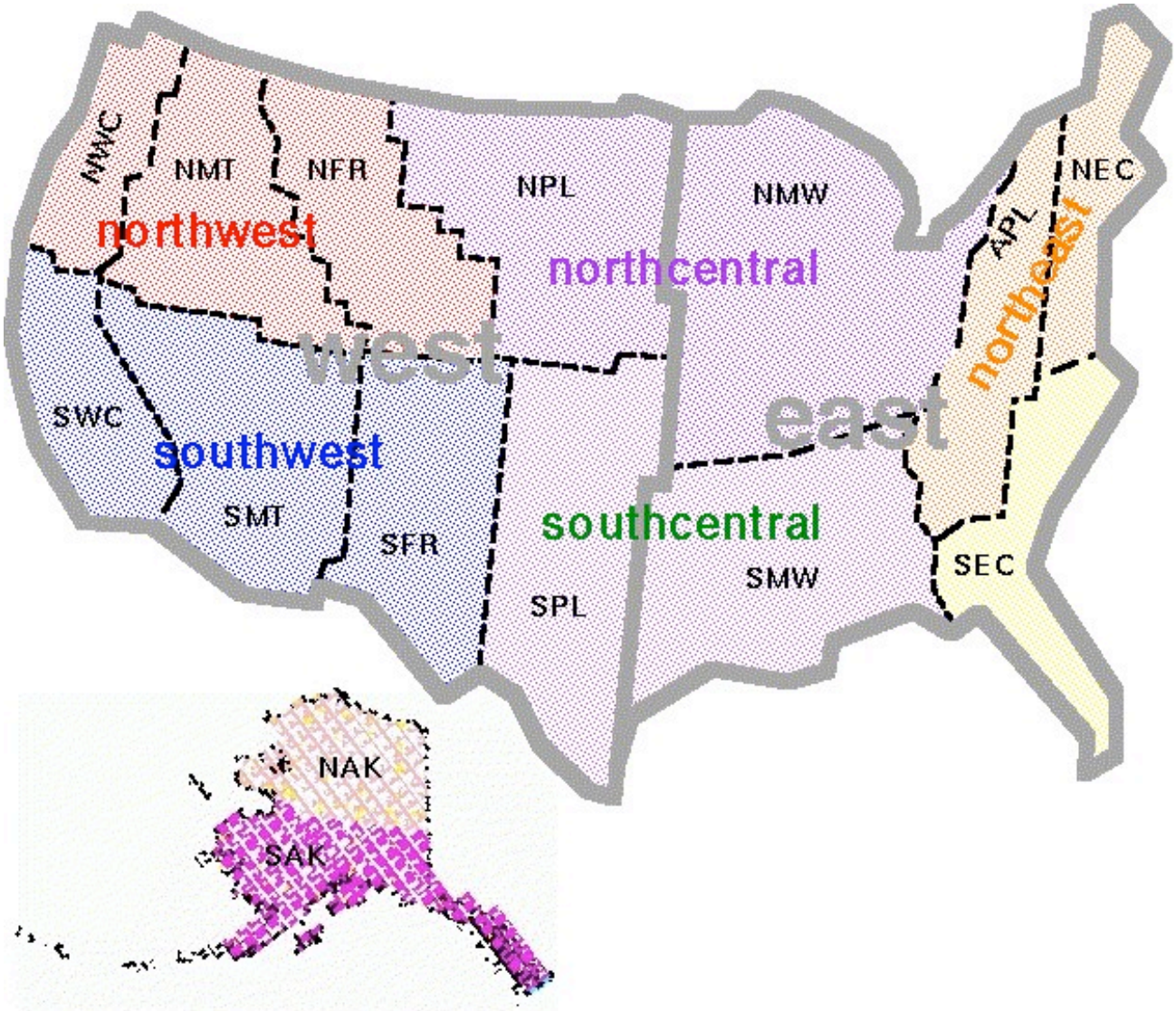
Eta 3D-Var (black) vs Eta GFS interpolated IC (red)

an 8 months parallel, wind rms at 48 h:

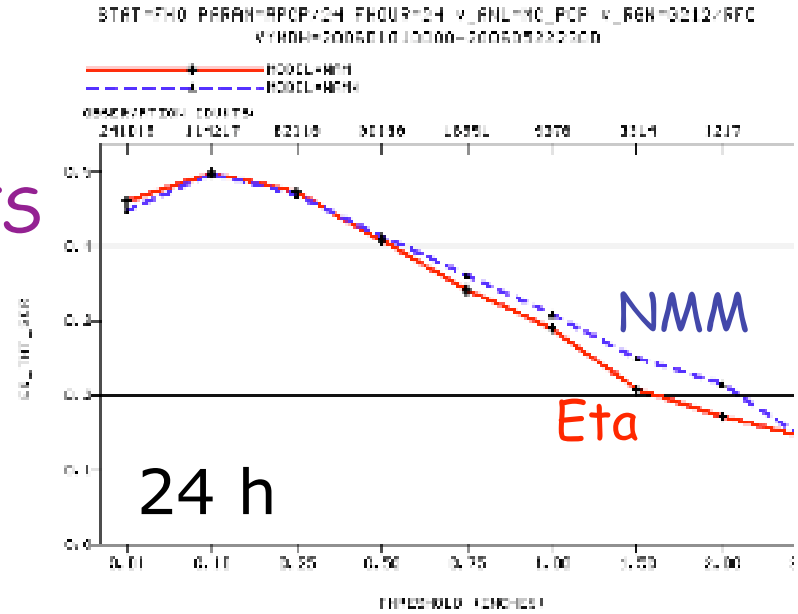


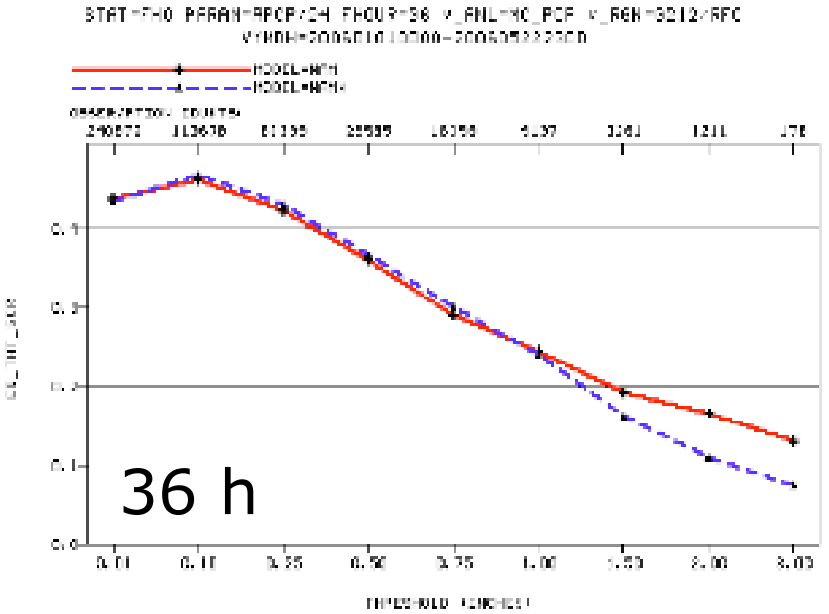
With the Eta data assimilation system abandoned/ replaced by a simple space interpolation off the global system's IC, GFS, everything else being identical, the Eta jet stream level wind error at 48 h is reduced by > 10 percent !!

NMM vs Eta systems, testing Jan-May 2006, precip:

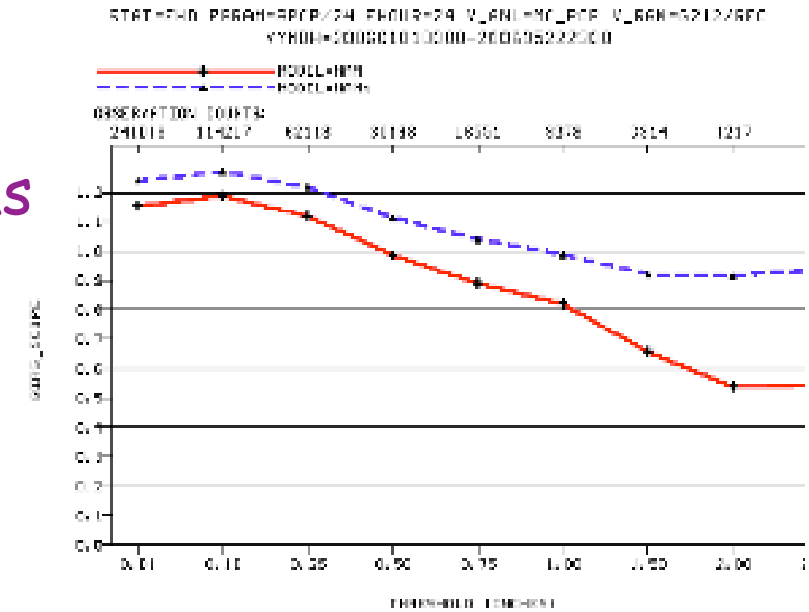


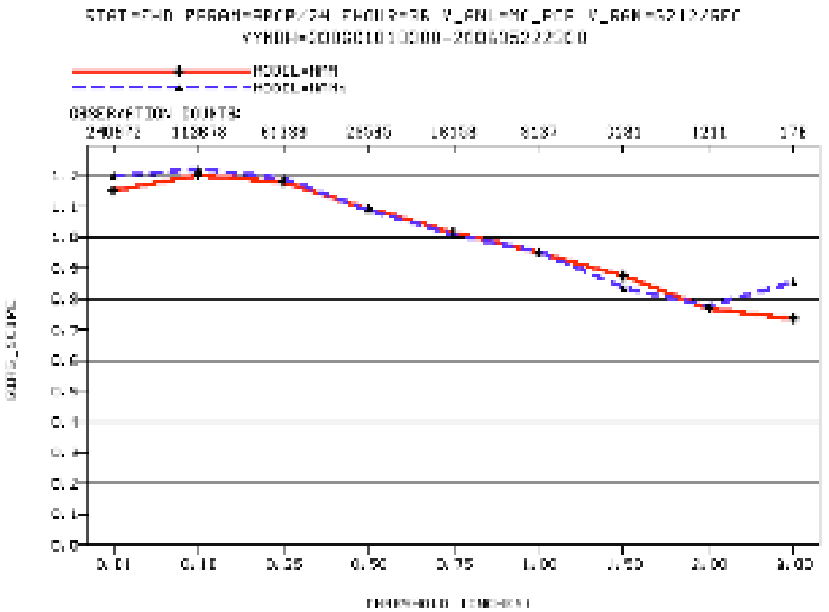
ETS

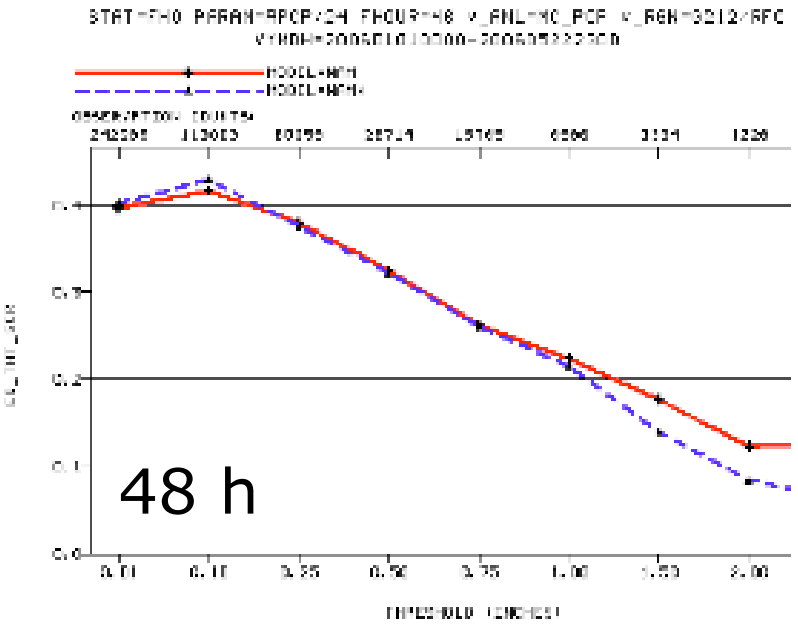


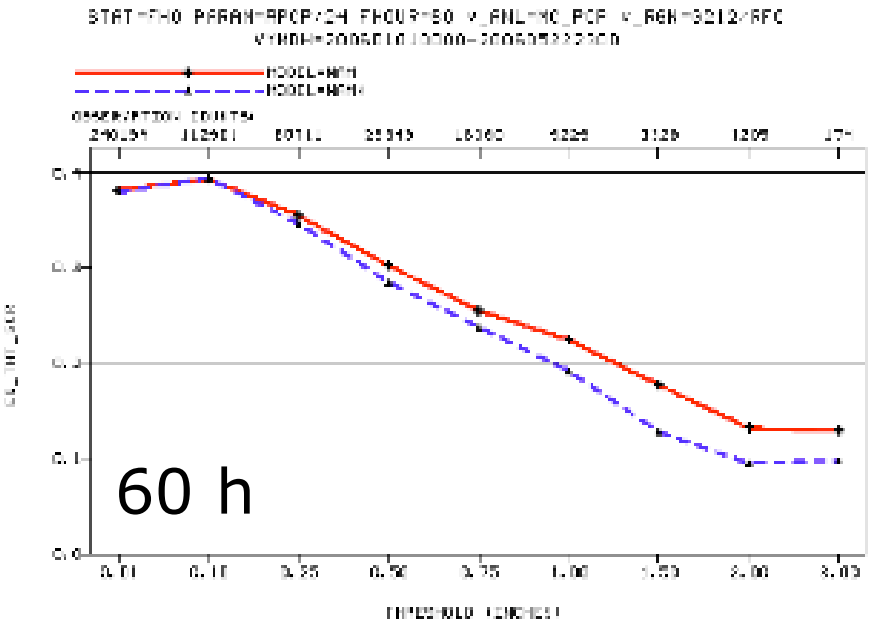


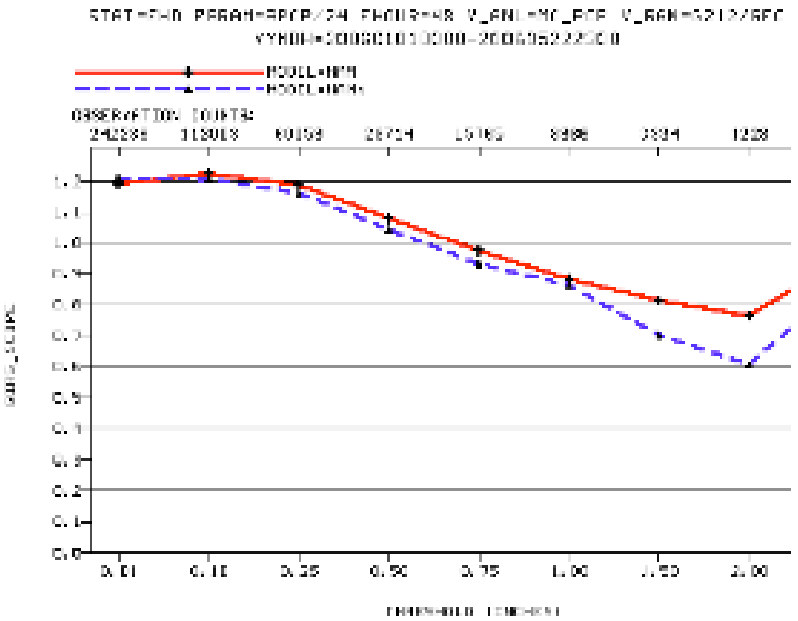
Bias

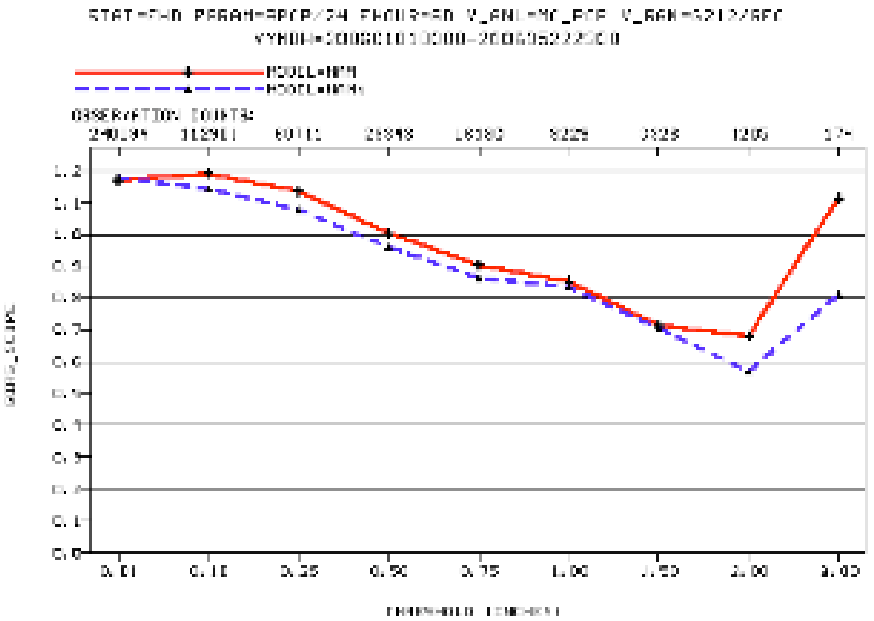


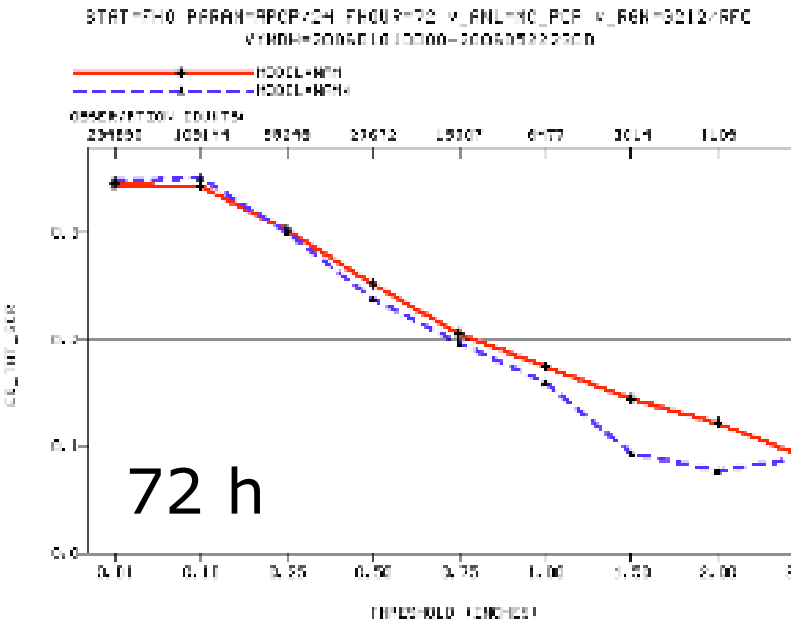


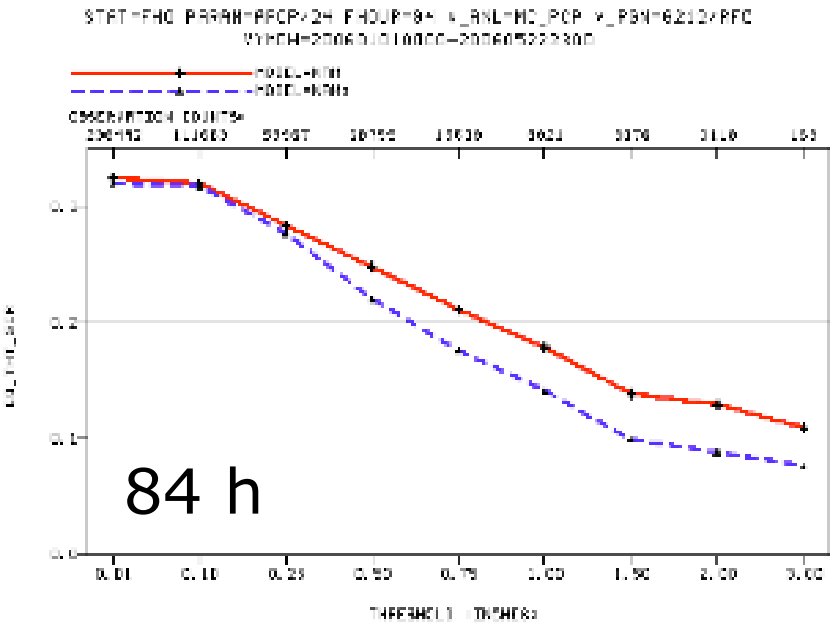

48 h

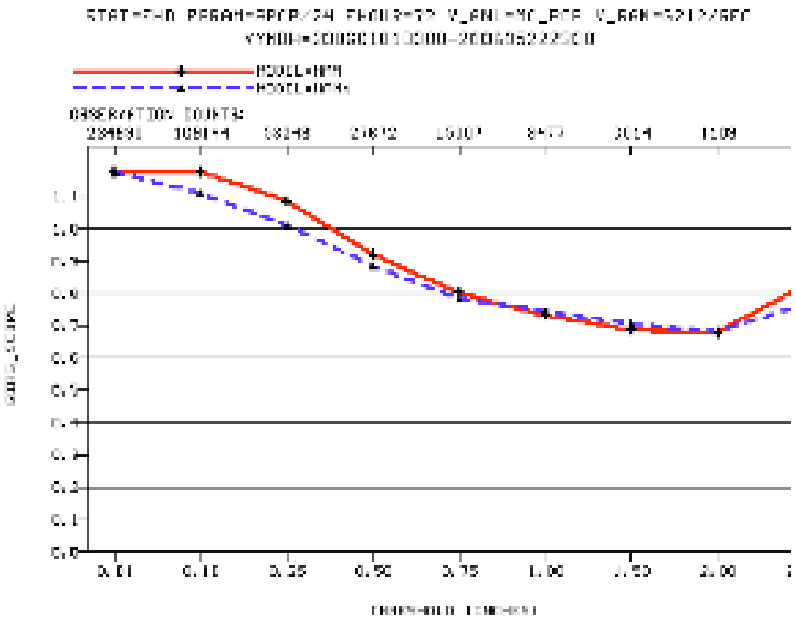

60 h

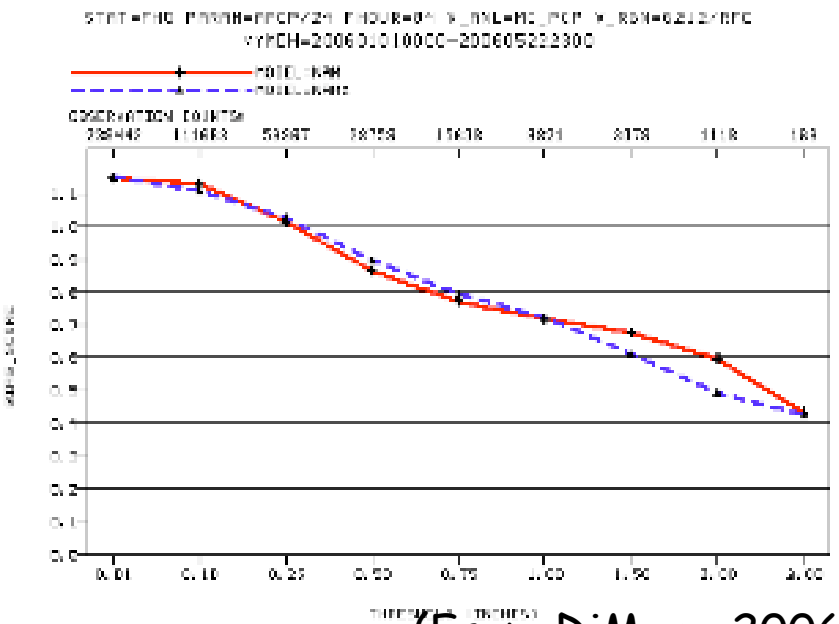








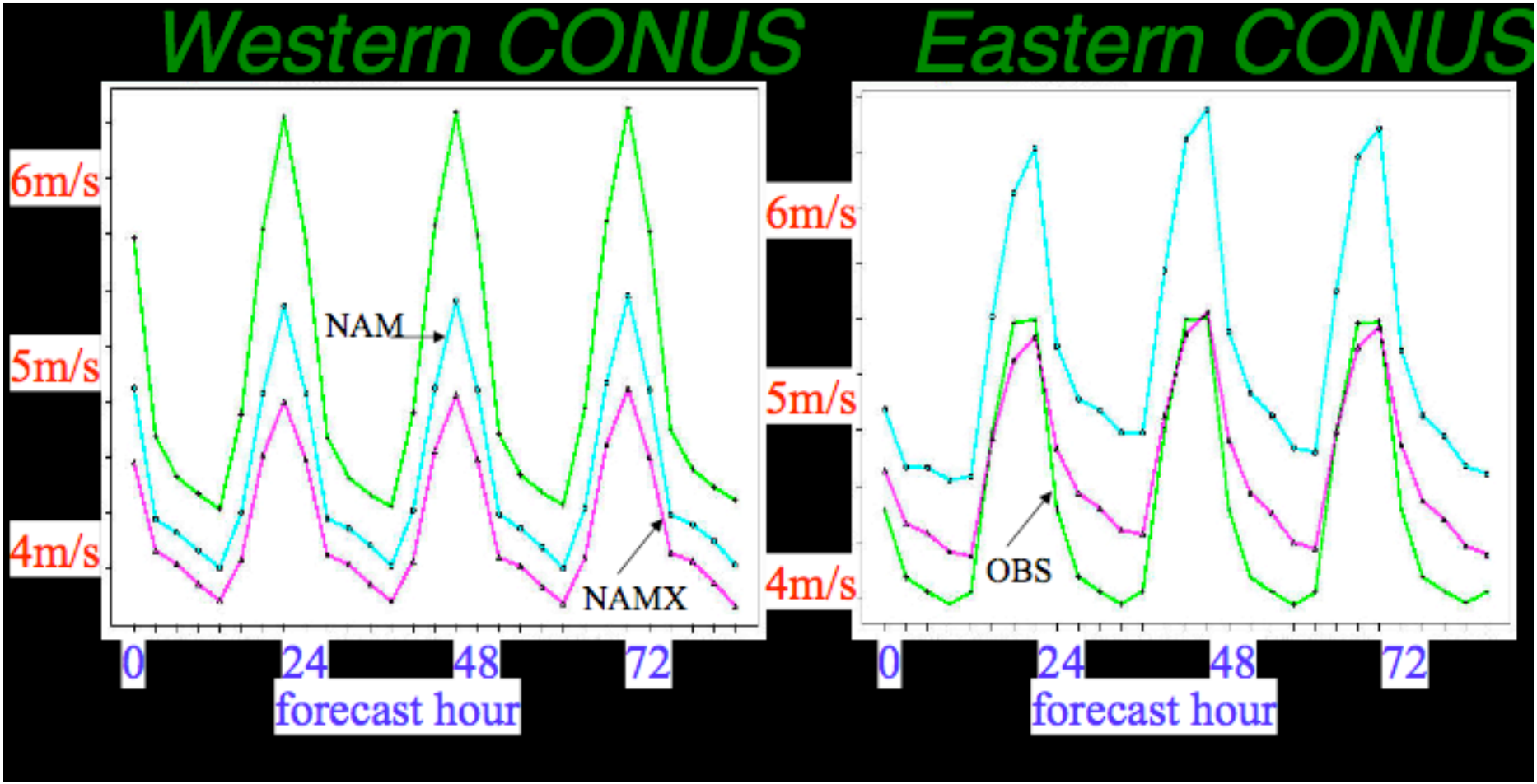




(From DiMego 2006)

2 m wind:

("NAM": Eta/EDAS; "NAMX": NMM/GSI)



(From DiMego 2006)

The only other numerical results posted (?):
rms fits to raobs

fits to winds, 12 h: NMM/GSI very slightly better;
84 h: Eta/EDAS a tiny bit better

Thus, NCEP Eta vs NMM operational systems:

Competitive;

in spite of most likely significant advantage
of the NMM's data assimilation system

Note, however: this refers to "standard" Eta
(as used at ICTP 2002, WorkEta I)

Various Eta refinements since:

ICTP 2005/ CPTEC etaweb, this workshop's code;

Other places?

"Families" form around models

Present community of people/ groups running operationally the Eta, or using it for research

INPE/CPTEC (Brazil), NCMRWF (India), SENAMHI (Peru), Argentina, Hydromet. Service of Serbia, Greece, Belgium, more weather services/ numerous additional centers in Latin America;, several groups doing dust transport forecasts (Israel, Spain, ..), a number of private companies…

Many university groups in various countries (~25 ?)

Workshops (Serbia, ICTP, CPTEC); ICTP 2008

Other model "families":

RAMS, MM5, NCAR WRF, . . .

Among models using or having an option to use quasi-horizontal (eta or eta-like) coordinates :

- Univ. of Wisconsin (G. Tripoli);
- RAMS/OLAM (R. Walko);
- DWD Lokal Modell/COSMO (e.g., Steppeler et al. 2006);
- MIT, Marshall et al. (MWR 2004);
- NASA GISS (NY), G. Russell, (MWR 2007)

Apparently increasing as time goes on ?

"The proof of the pudding is in the eating"

E.g., recall the three low centers case !

References (for the missing ones, check the CPTEC etaweb references site, or "A Guide to the Eta model"):

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