The Abdus Salam
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Spring Colloquium on
'Regional Weather Predictability and Modeling'
April 11 - 22, 2005

1) Workshop **on Design and Use of Regional Weather Prediction Models,** *April 11 - 19*

2) Conference on **Current Efforts Toward Advancing the Skill of Regional Weather Prediction. Challenges and Outlook,** *April 20 - 22*

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Eta Model at NCEP: Challenges overcome and lessons learned

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Eta Model at NCEP:
Challenges overcome and lessons learned

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Spring Colloquium
"Regional Weather Predictability and Modeling"
Abdus Salam ICTP, Miramare, Trieste, 11-22 April 2005

~ Update of the conference paper:

Mesinger, F., 2004: The Eta Model: Design, history, performance, what lessons have we learned? *Symp. on the 50th Anniversary of Operational Numerical Weather Prediction*, Univ. of Maryland, College Park, MD, 14-17 June 2004, Preprints CD-ROM, available from NCEP, Camp Springs, MD 20746 (lauren.morone@noaa.gov), ppt available at http://wwwt.ncep.noaa.gov/nwp50/Presentations/.

Overall Eta model summary:

Pielke, R. A., Sr., 2002: *Mesoscale Meteorological Modeling*, Second Edition. Academic Press, 676 pp.

Some of the early history:

Design of the Eta ancestor code started in Belgrade,

first code written beginning of 1973

In the same time period, on 7 February 1973, for the first time fcst BCs incorporated in the NMC's first operational PE LAM, the LFM

Aim: use the Arakawa approach

- Maintenance of chosen integral properties;
- Avoidance of computational modes;
- . . .

The very first code: some of each

Some of the features of this very first code that survive in today's Eta

- Choice of the E horizontal grid;
- Lateral BC scheme
  BCs prescribed (or, extrapolated from the inside) along a single outer line of grid points;

Many milestones. A few:

- gravity-wave coupling scheme (Mesinger 1973,1974, …)
- E-grid enstrophy, energy conservation, "ωα", (Janjic 1977)
- Janjic (1984) Arakawa C-grid enstrophy .. conserving scheme;
- eta coordinate (Mesinger 1984);

Eta dynamical core code: Belgrade (Dushka Zupanski), FM at GFDL, -> NMC (1984), ….

Why eta?

I convinced myself (Mesinger 1982) the sigma system problem

- seems to have no acceptable solution;
- should become more serious as we increase resolution;

Quasi-horizontal coordinates are needed !

By the way, can one claim that there is a movement toward quasi horizontal cordinates ?

- LM (DWD) we shall hear about, “shaved cells” (Steppeler);
- RAMS (Colo. State, Duke Univ.) (shaved cells, Walko and Avisar, manuscript available);
- Marshall et al. MWR 2004 (one code ocean atmos. model, eta in the atmosphere)

Back to NMC: more milestones:

- physics package (Janjic, Black; acknowledgements: Betts-Miller, Mellor-Yamada, Harshvardhan);
- testing, removal of physics problems identified;
- analysis system (Rogers, …)
- …

Operational implementation at the then NMC:
12z 8 June 1993, as a replacement of the LFM

(Limited-area fine-mesh model)

Challenges, and an inadvertent experiment:

- Comparisons against the NGM and the RSM;
- The “Early” vs the “Meso” Eta;
- Eta vs the Avn/GFS

- Eta vs the NGM

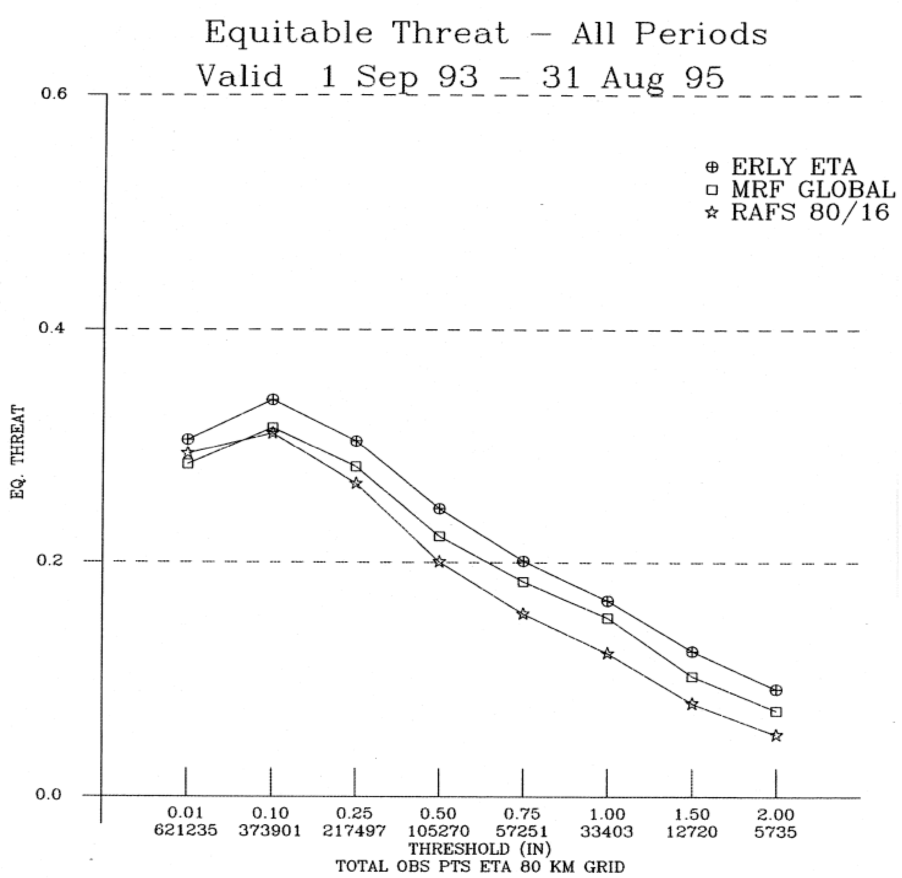
(NGM: “Nested Grid Model”)

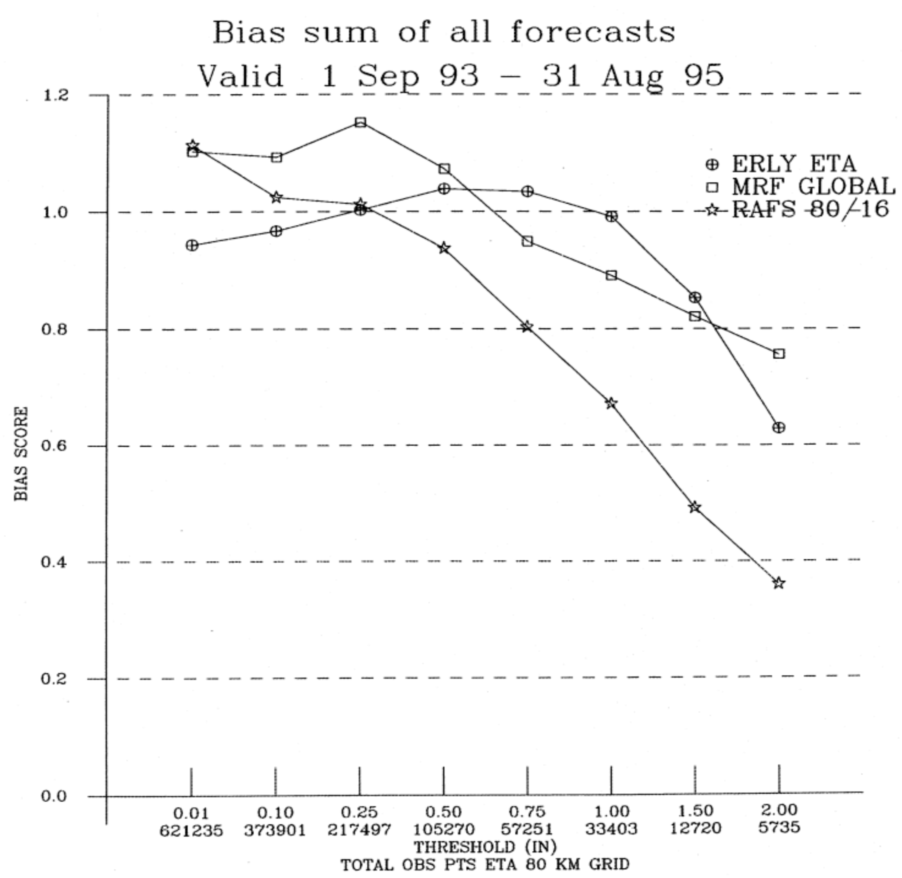
Self-contained grid point model, nested in itself,
operational at the then NMC since mid-eighties

Principal designer: Norm Phillips;
4-th order accuracy since the early nineties

1st 24 months of the Eta, NGM and Avn precip scores:

(Both Eta and NGM ~80 km resolution, physics packages of similar/ not too different complexity) "All Periods": 00-24, 12-36, 24-48 h forecasts





Recall: NGM 4th order formal accuracy, Eta never more than 2nd

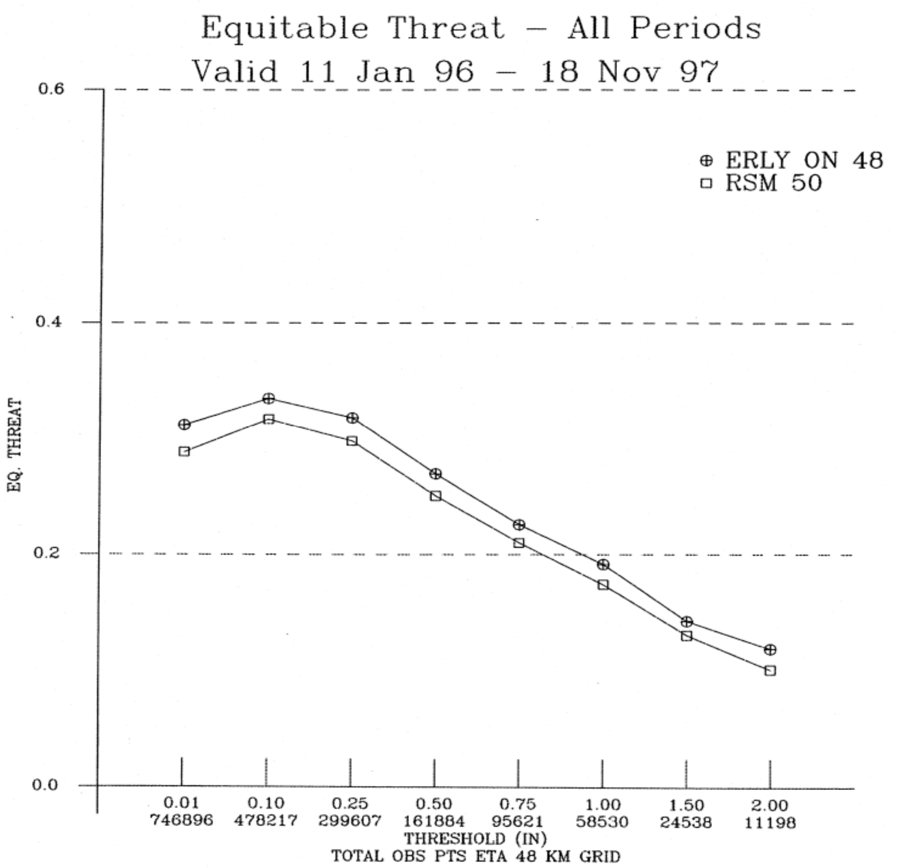
- Eta vs the “Regional spectral model”, RSM

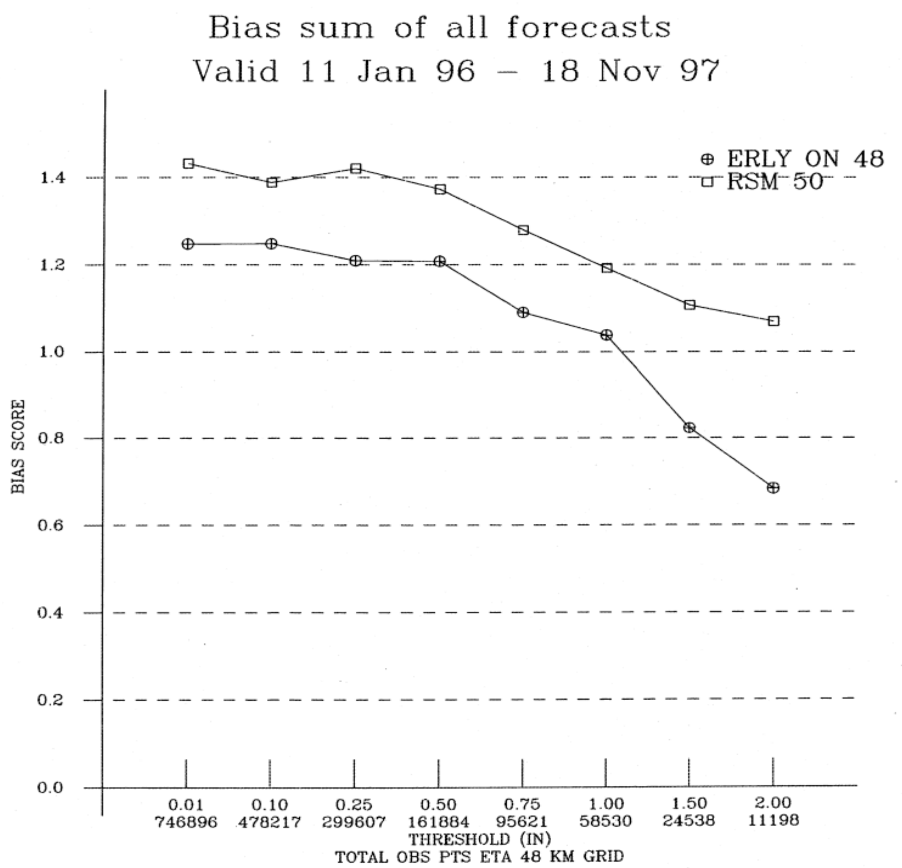
RSM: a perturbation spectral model, “large scales” taken from the “driver” global model (“Avn” or “MRF”), same “physics”

E.g. Juang et al. 1997

Eta vs the RSM:

2 years of scores, 1996-1997, at ~50 km resolution:





Note: Eta is using 12 h "old" Avn LBCs, RSM is using current Avn LBCs

NGM: fourth-order accuracy,

RSM: “infinite” order accuracy/ Taylor-series defined;

both failed to do well in comparisons with the Eta;

there are other “complete model” results pointing to difficulties in benefiting from increased formal accuracy

(Cullen et al. 1997)

Why?

I have repeatedly suggested that “noise” due to physics forcing at individual grid boxes or columns is the likely reason

Taylor series expansion:

assumes smooth differentiable functions,

with values valid at points (not averages of boxes)

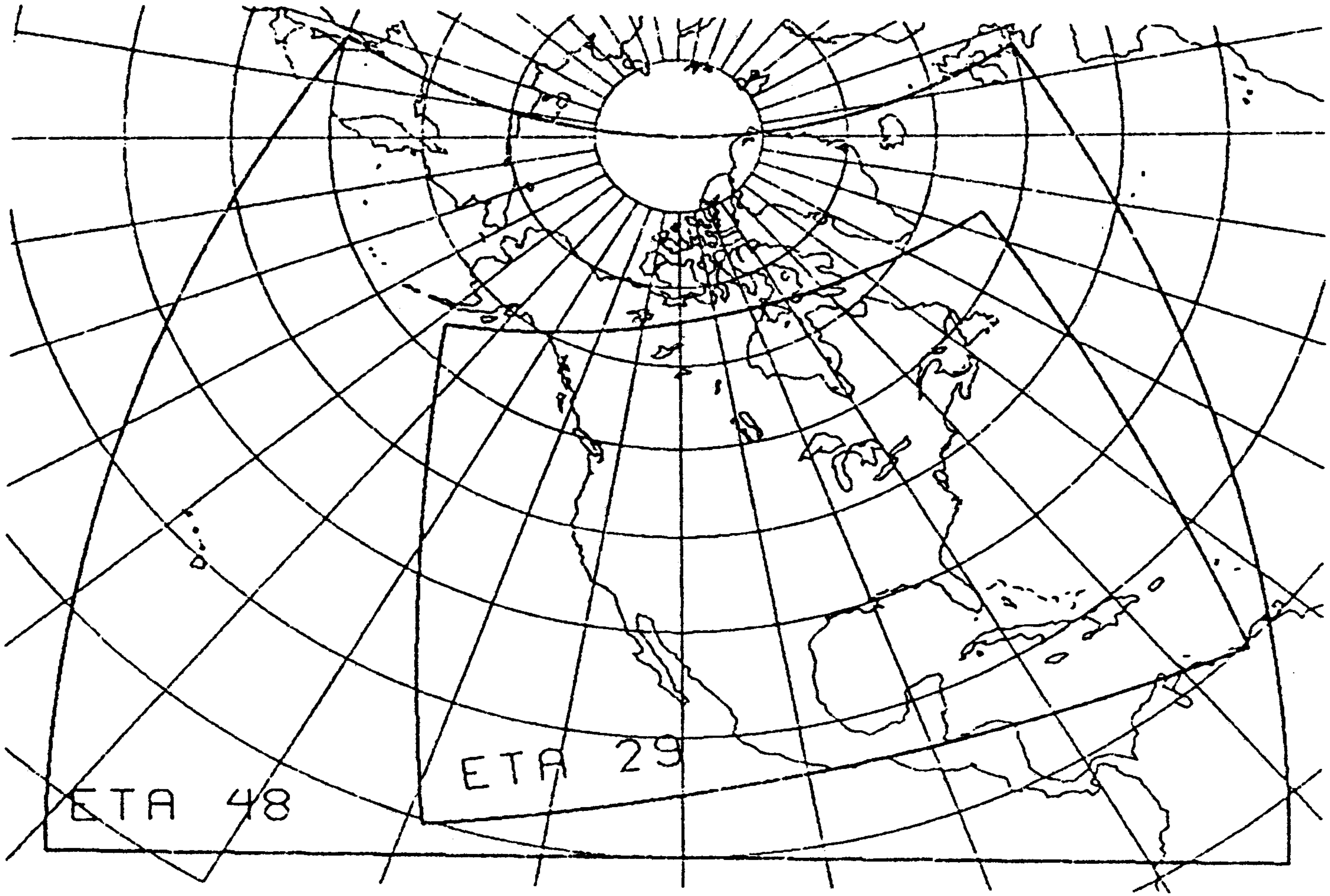
Not consistent with the way we do “physics”

The “Early” vs the “Meso” Eta (the “inadvertent experiment”)

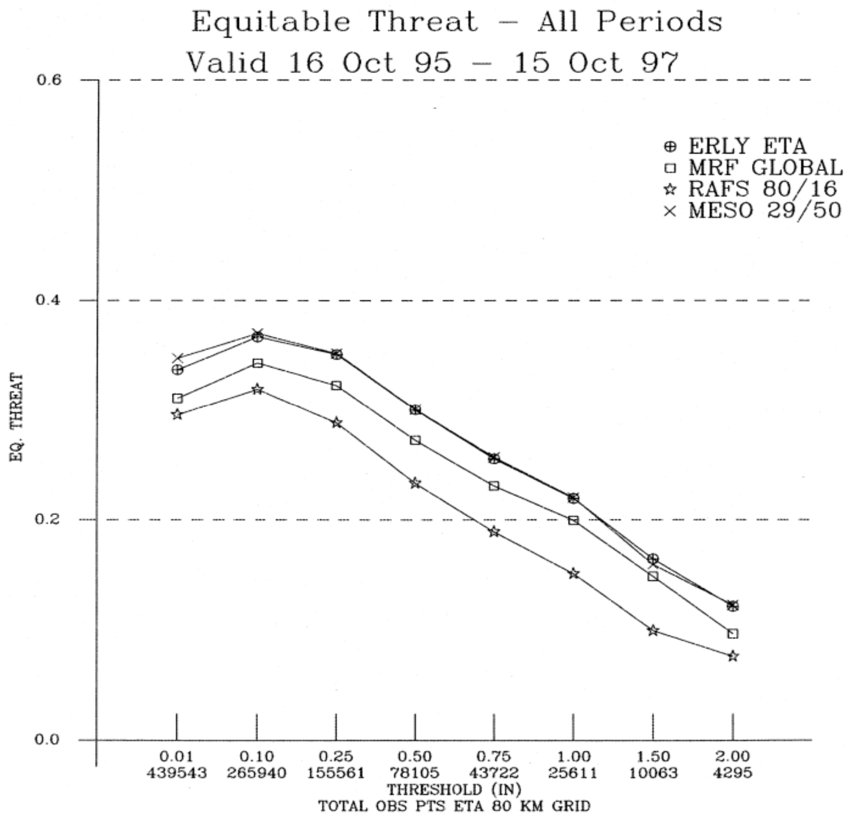
“Early”: 48 km, 12 h old Avn LBCs,

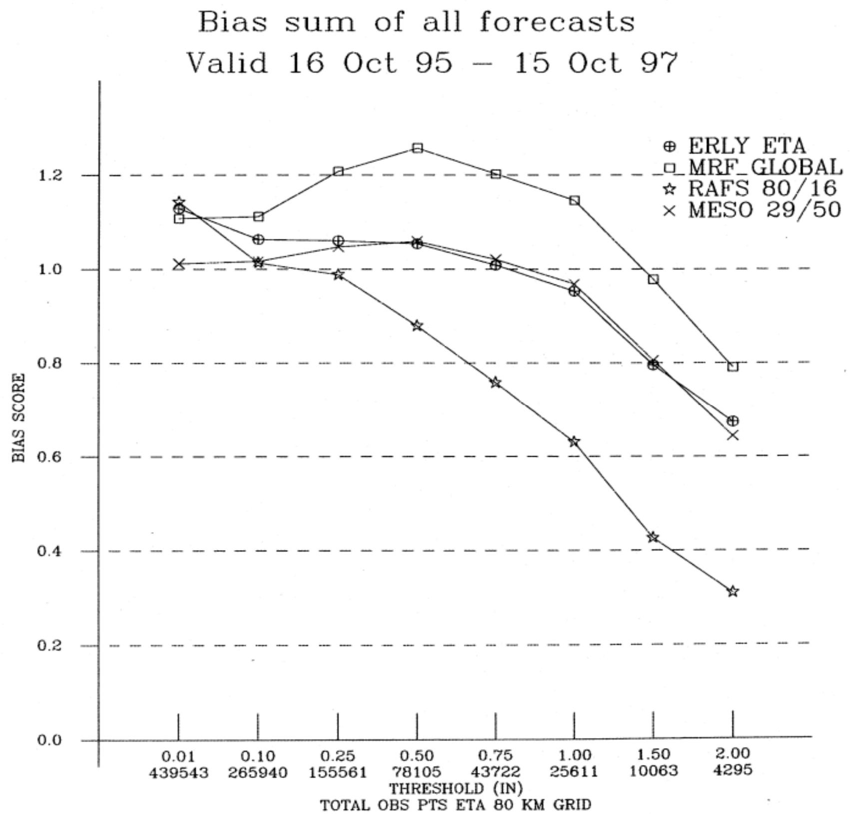
“Meso”: 29 km, current Avn LBCs;

Domains:



2 years of scores:





Scores of the the “Early” and the “Meso” Eta about the same!

The benefit of the large domain compensates the combined benefit of more accurate LBCs and higher resolution !!

Why does the large domain help so much ??

If it indeed does, why are most other groups (e.g., ALADIN, UKMet) using - in comparison - very small domains?

Does large domain help some models but not the others?

Hypotheses: the large domain helps because it allows the nested model (Eta) to improve - compared to the driver global model - on the largest scales the model can accommodate (jet stream !)

This is just the opposite of what is typically expected of nested models ("downscaling")

Can the Eta do this only when there are major mountain ranges upstream of the main verification area (Rockies, Andes) ?

Or, do such mountain ranges only help ?

Eta vs the Avn/GFS

(1) Consider some more

what is "value added" we can expect from a LAM ?

Small scales near topography, higher resolution land types? Of course.

Smaller scales in the initial condition ? Yes in principle, but not easy.

The nested model is able to develop smaller scales !!

(Anthes et al., QJ, 1989)

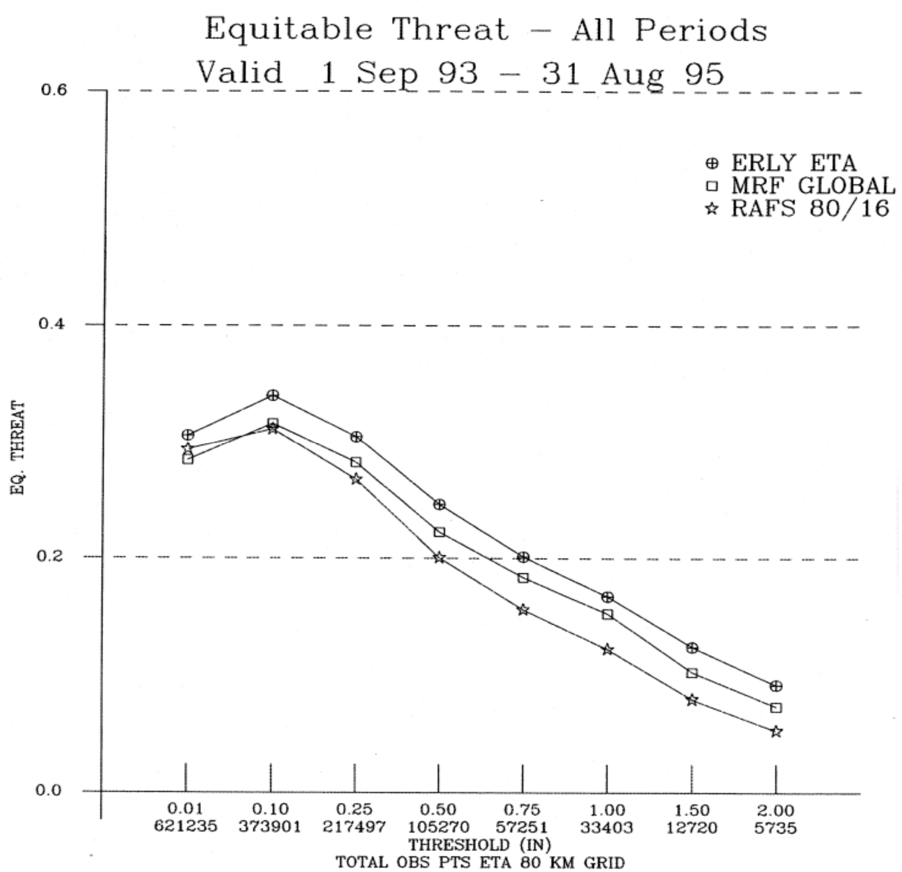
However: (2) there is the mathematical LB error, e.g.,

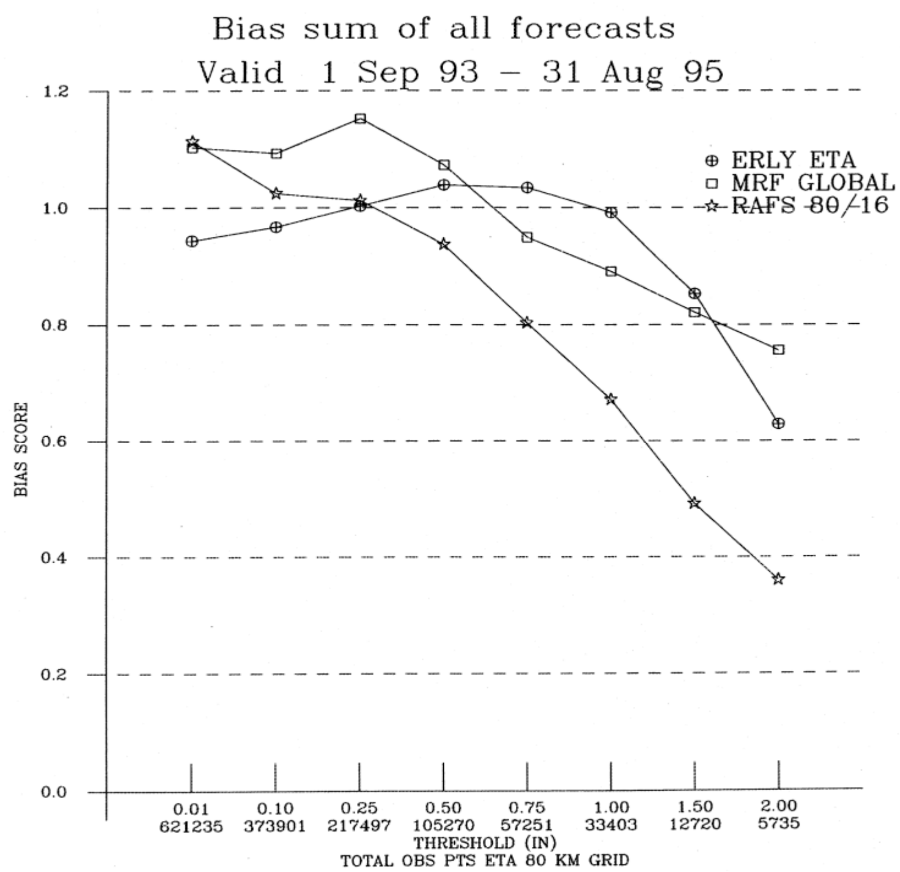
"the contamination at the lateral boundaries … limits the operational usefulness of the LAM *beyond some forecast time range*" (Laprise et al., MWR 2000, emphasis FM)

Eta (at NCEP ~ in the nineties) is using 12 h old LBCs;
can one detect the impact of the advection of the error?

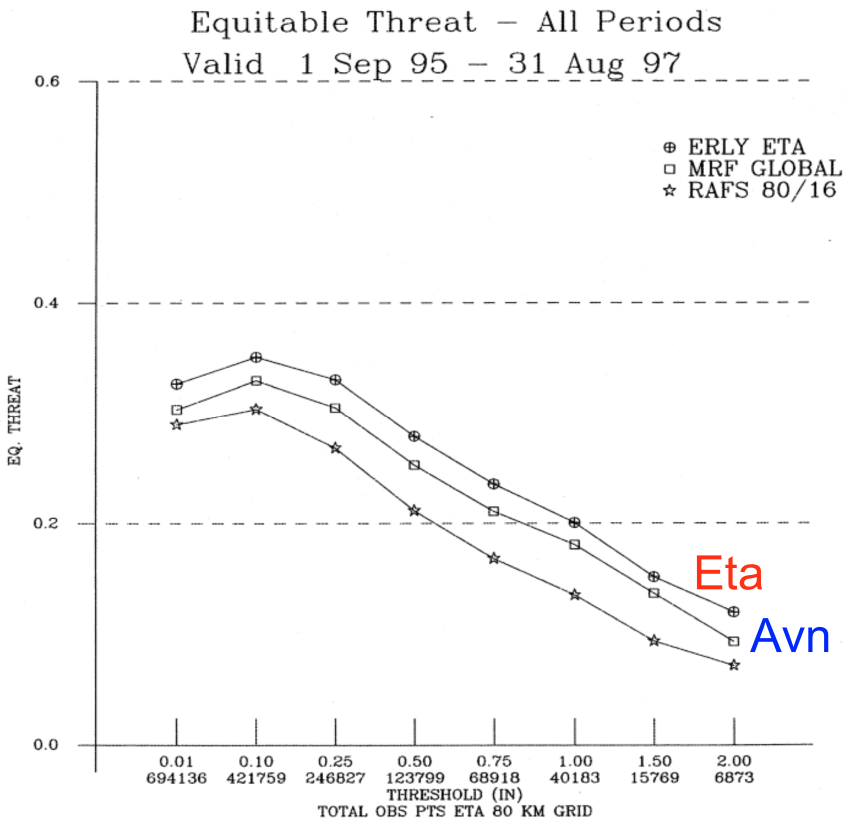
Recall: from Eta vs the NGM (#1,“value added”)

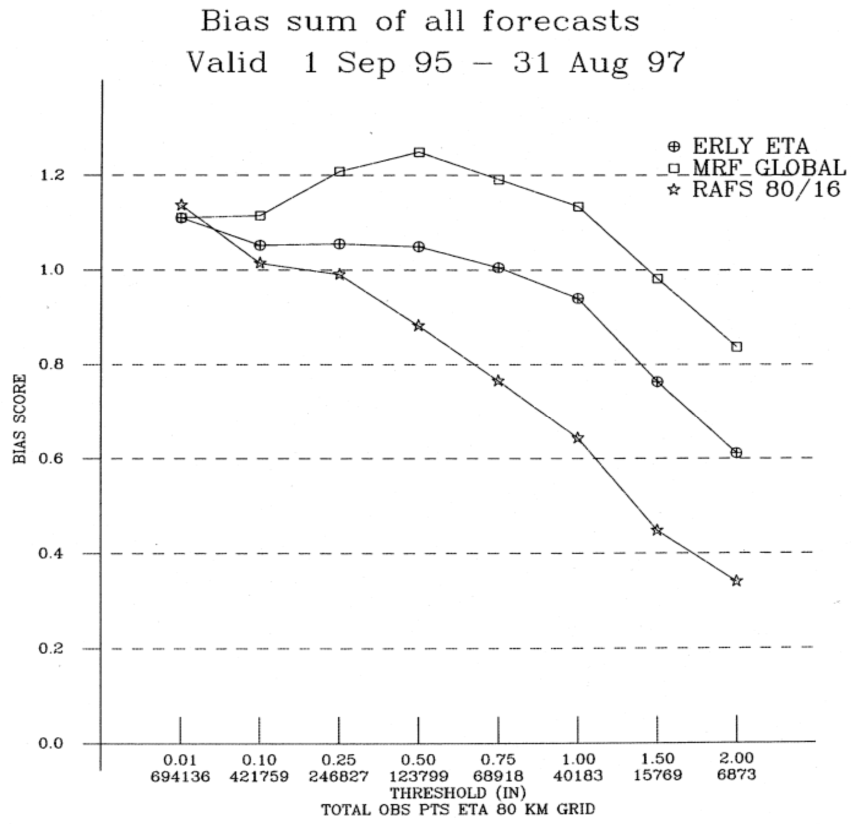
1st 24 months of the Eta, NGM and Avn precip scores:





2nd 24 months of the Eta, NGM and Avn scores:





Eta is using 12 h old LBCs;

(issue #2) can one detect the impact of the advection of the error?

I've looked into 24-48 h scores vs 00-24 h:

no clear differences in the advantage of the Eta, at that time

But what about today?

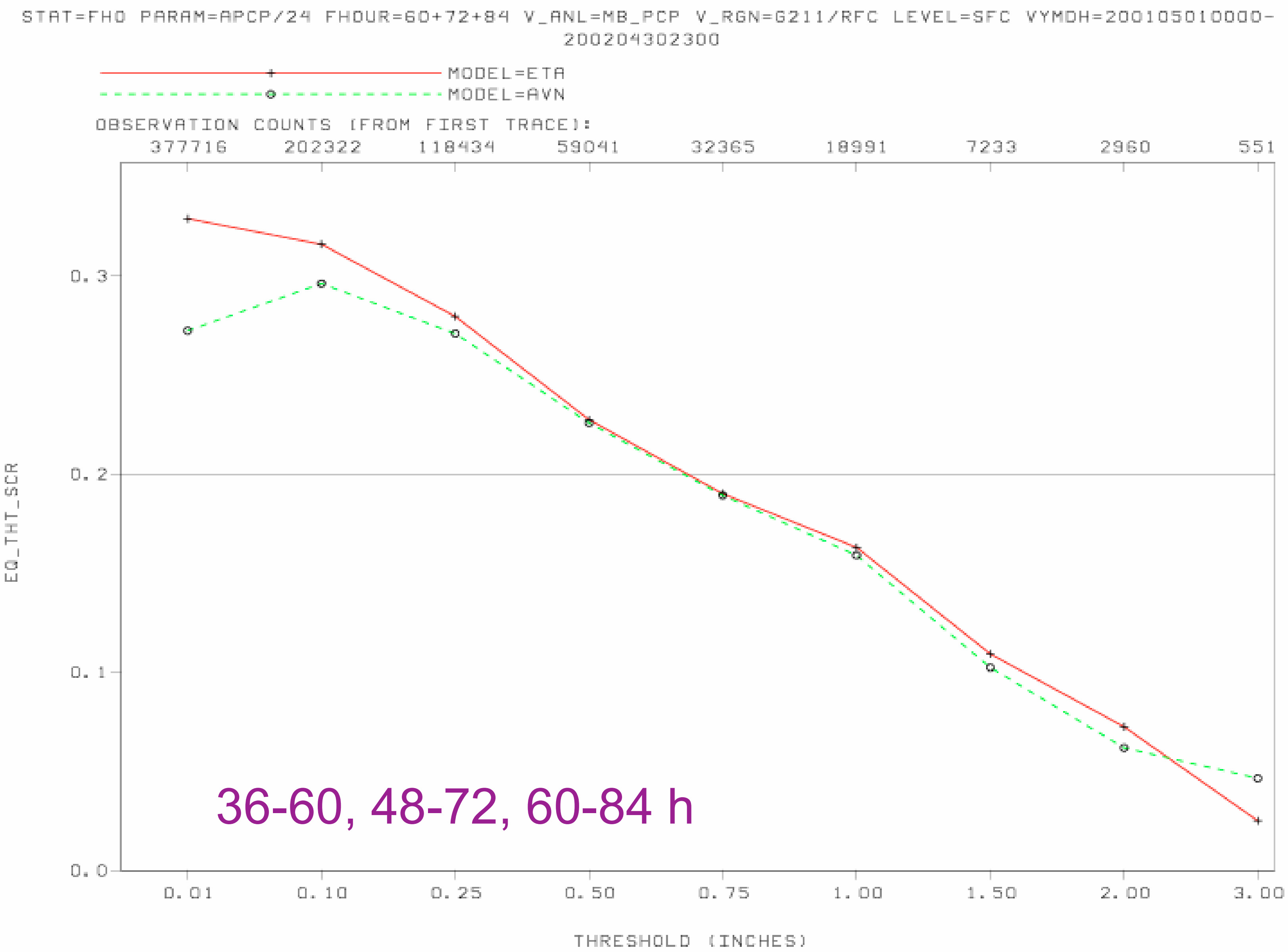
Both models have increased resolution;
Eta has been extended to 84 h as of April 2001;
Can one now
detect the the impact of the advection of the LB error?

Eta is now driven by the GFS forecast of 6 h ago. More accurate than 12, but still a considerable error - as we will see - once the information reaches the main verification area

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

- precip scores, 24 accumulations, 00-48 h vs 36 to 84 h, May 2001-April 2002;
- rms fist to raobs as a function of time;

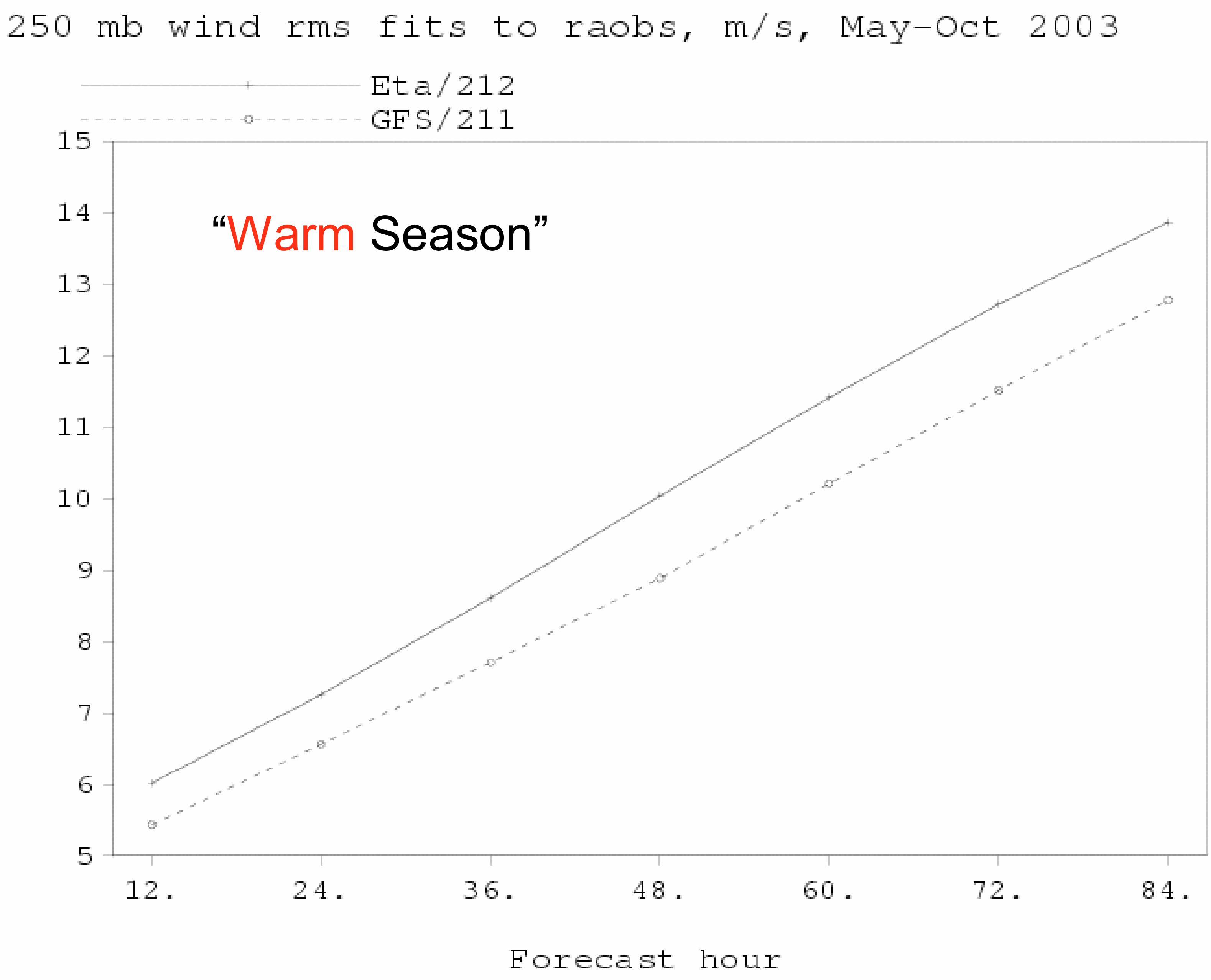

STAT=FHO PARAM=APCP/24 FHOUR=24+36+48 V_ANL=MB_PCP V_RGN=G211/RFC LEVEL=SFC VYMDH=2001050100000-2002043002300
MODEL=ETA
MODEL=AVN
OBSERVATION COUNTS (FROM FIRST TRACE):
403352
216992
127629
63928
35285
20804
8074
3382
642
EQ_THT_SCR
0.4
0.3
0.2
0.1
0.0
Eta
Avn
00-24, 12-36, 24-48 h
0.01
0.10
0.25
0.50
0.75
1.00
1.50
2.00
3.00
THRESHOLD (INCHES)



Relative QPF skill, Eta vs GFS, about the same !

RMS fits to raobs:

upper tropospheric winds presumably ~ the best indicator of the largest scales (jet stream !)


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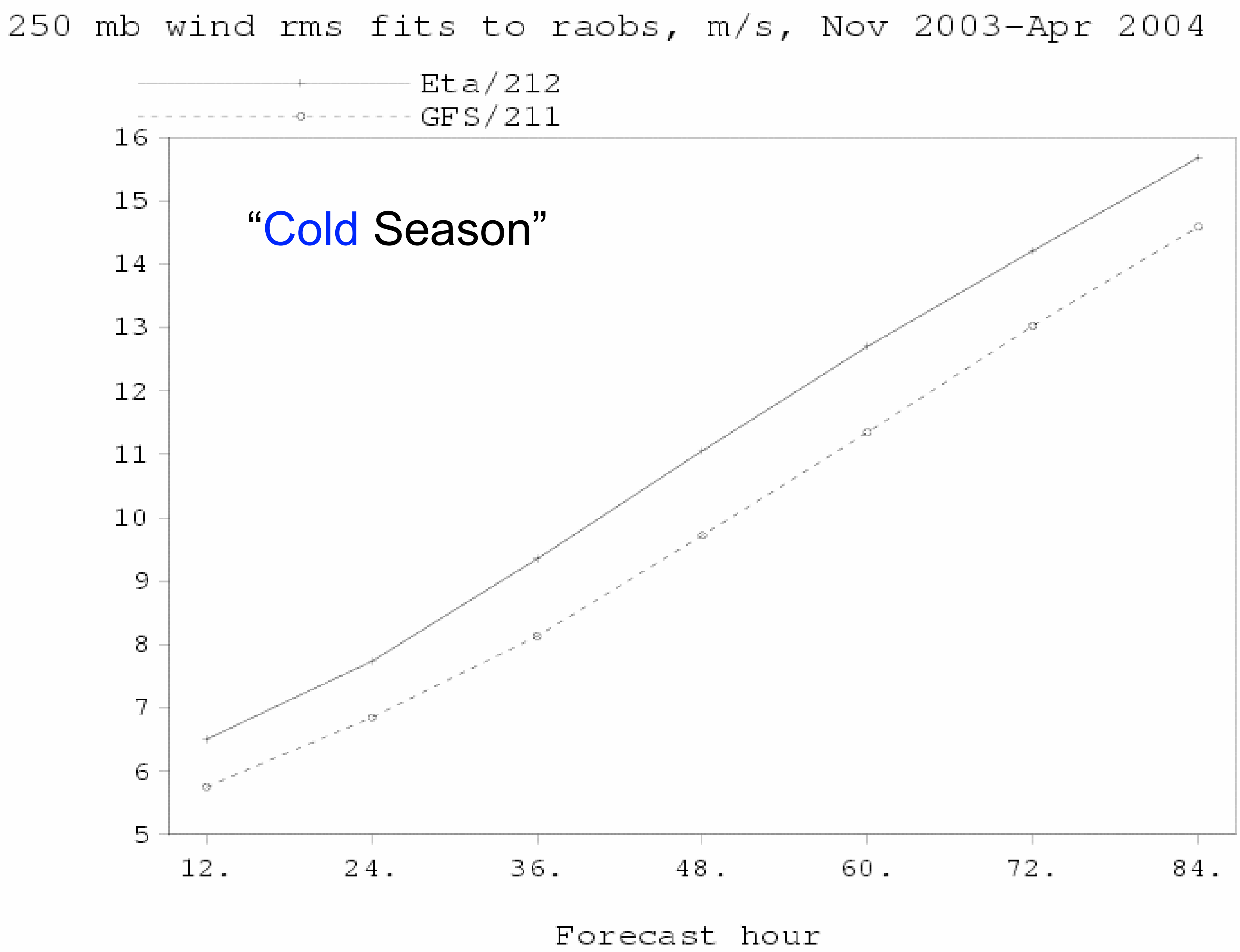
6
5
12.
24.
36.
48.
60.
72.
84.
Forecast hour


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

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

The Eta in relative terms improves a little with time !

But if I am correct re improvement of the largest scales, how could one verify this?

Position forecast errors of "major lows" !?

Winter 2000-2001, rules, 31 cases

(Mesinger et al. 2002, Orlando AMS, for rules and more #s)

the Eta was significantly more accurate !

E.g.: Average errors: Eta 244 km, Avn 324 km
# of wins: Eta 20, Avn 10

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)

The analyses I am talking about:

same as shown in the eta/ sigma experiment of lecture #2:

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

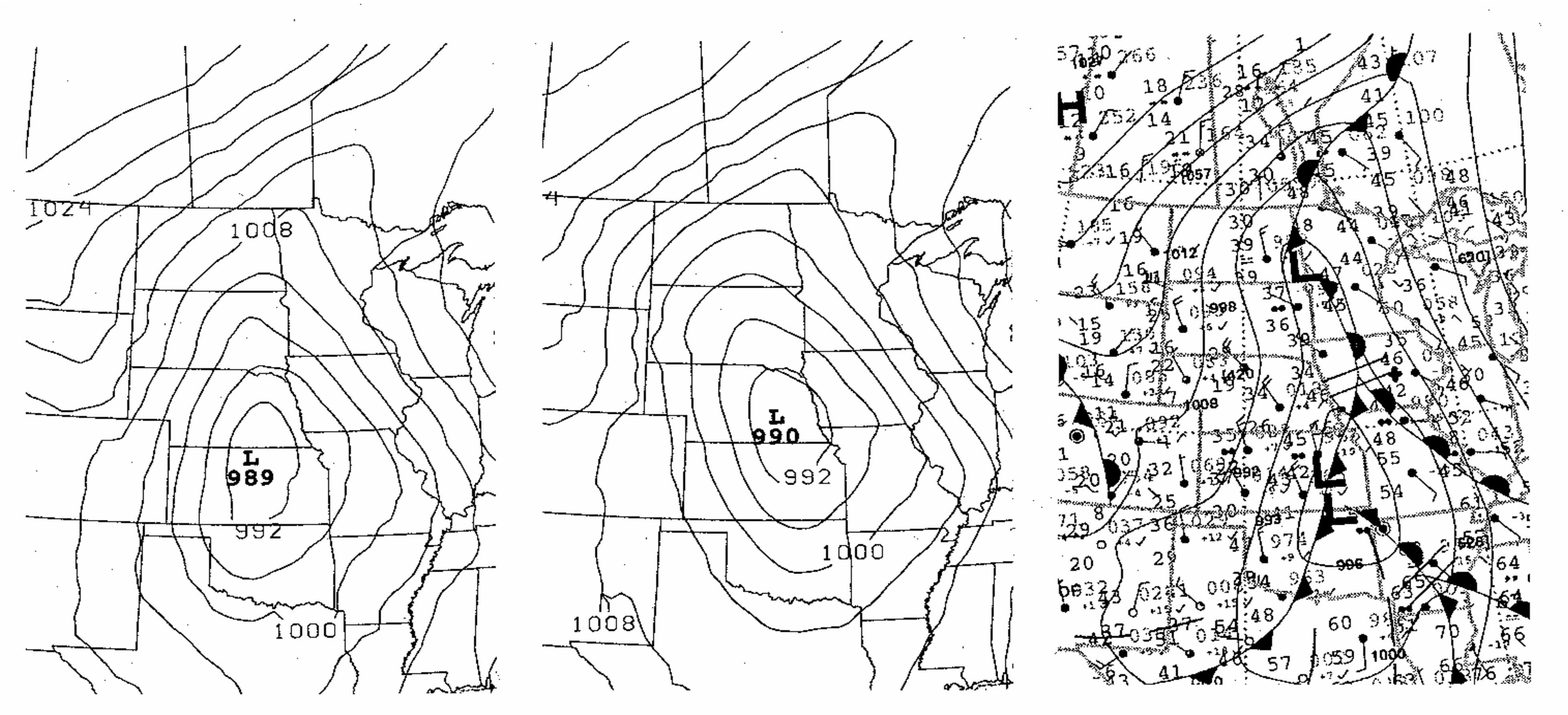


Table 1. Forecast position errors, at 60 h, of "major lows", east of the Rockies and over land or inland waters, Dec. 2000 - Feb. 2001

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.!

An aside:

The Eta advantage the 2nd winter not as conspicuous as the 1st
(Even though the Eta resolution the 2nd winter was higher,
12 compared to 22 km the 1st)

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

- The eta/ sigma experiment of lecture 2;
- Precip scores for the 1st 12 months of the availability of three model scores on NMM domains (ConUS "East", …, "West", …), and for the "last" 12 months shown in lecture 2

Consistent with the Eta doing a little better in winter, as this is the time when the jet stream tends to impinge the Rockies at its southernmost latitudes

The “Workstation Eta” (WS Eta) code:

As maintained by NCEP (Matt Pyle): followed the operational Eta, mostly (with some delay)

However: situation changed with the movement toward the “Weather Research and Forecasting” (WRF) “framework”

“WRF framework”: may not be practical for users outside US

In this situation, WS Eta in one aspect went ahead of the operational Eta: nonhydrostatic option

- Non-hydrostatic option:

Janjic et al. 2001:

$$\left(\frac{\partial w}{\partial t}\right)^{\tau+1/2} \rightarrow \frac{w^{\tau+1} - w^{\tau}}{\Delta t}$$

ICTP 2005 Eta code

Features included that are considered improvements/ refinements compared to NCEP WS Eta:

- Sloping steps eta discretization (lecture #2);
- Changes in the continuity and hydrostatic equations to account for mass removal and addition due to precipitation and evaporation, and the presence of condensates (Mesinger and Lazic, "Blue Book" 2004);
- Changes in the BMJ convection to remove/ ameliorate the problem of undergoing intense convection (reversed DSPs, and no extension of relaxation time);
- Averaging of all four surrounding velocities at h points (including those that are zero at vertical sides) to do turbulence quantities (improves lowest layer winds over topography);

Efforts will be made to support users of the ICTP Eta, probably in cooperation with COLA (Center for Oceans, Land and Atmosphere, Calverton, MD):

- Code upgrades downloadable;
- Manual upgrades, model documentation;
- . . .

(ICTP site, and/or contact

fedor.mesinger@noaa.gov, or fedor@essic.umd.edu, and/or chou@cptec.inpe.br)

Some of the references made

Cullen, M. J. P., T. Davies, M. H. Mawson, J. A. James, and S. C. Coulter, 1997: An overview of numerical methods for the next generation U.K. NWP and climate model. *Numerical Methods in Atmospheric and Oceanic Modelling*, C. Lin, R. Laprise, and H. Ritchie, Eds. The André J. Robert Memorial Volume. Canadian Meteorological and Oceanographic Society/NRC Research Press. 425-444.

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