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Fall Colloquium on the Physics of Weather and Climate: Regional Weather Predictability and Modelling

29 September - 10 October, 2008

Limited Area Modeling: some history, what can we do?

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Limited Area Modeling: Some history, what can we do?

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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

Contents:

1. Historical introduction: NWP/ what can be done? LAM/mesoscale modeling - what do we want to do?

2. "Value added"; what is it - how long can it be maintained ("LBC error");

3. An example of a better (value added !) set of forecasts ("The three L centers case")

1. The beginnings of weather prediction, using equations of motion, and as an initial value problem, generally well-known:

Equations of motion well understood already about 1800:

Leonhard Euler: 1707-1783;

Weather prediction via the solution of fundamental atmospheric equations?

Vilhelm Bjerknes (1862-1951)

1904:

If it is true, as every scientist believes, that subsequent atmospheric states develop from the preceding ones according to physical law,

then it is apparent that the necessary and sufficient conditions for the rational solution of forecasting problems are the following:

1. A sufficiently accurate . . . state of the atmosphere at the initial time;

2. . . . the laws according to which one state of the atmosphere develops from another.

At the same time, Max Margules (1856-1920)

(student of L. Boltzmann
and J. Stefan) understood the/ a
difficulty,

Margules (1904):

wind measurements are not
nearly as accurate as needed
to calculate pressure changes
using the continuity equation!

("Can we do it" ?)

(Reference:
Peter Lynch, 2004, 2006)

A little later, during World War One (published 1922)
Lewis Fry Richardson (1883-1953)

went ahead and performed a numerical integration of a full set of governing equations (well, did one 6 h time step)

A most unreasonable result

Yet: a charming and visionary book!

"… errors increase with the number of steps"

(hint of "predictability" !)

Many milestones:

- . . .
- . . .
- First successful NWP effort: Charney, Fjørtoft, von Neumann (1950);
- First operational numerical forecast: 1954;
- . . .

However: How predictable *is* the weather?

Earliest work on atmospheric "predictability": Phil Thompson (1957)

. . . accurate description of the initial state is simply impossible; Consequences?

"… two solutions … initial states that differ …"

"predictability time limit":
a bit more than a week

Breakthrough towards full understanding:
Ed Lorenz (1963)

"chaos theory"

Small scale errors
will grow also !

From:
"The Essence of Chaos"
(Lorenz 1993):

"Chaos"

1. The property that characterizes a **dynamical system** in which most orbits exhibit **sensitive dependence**; full chaos

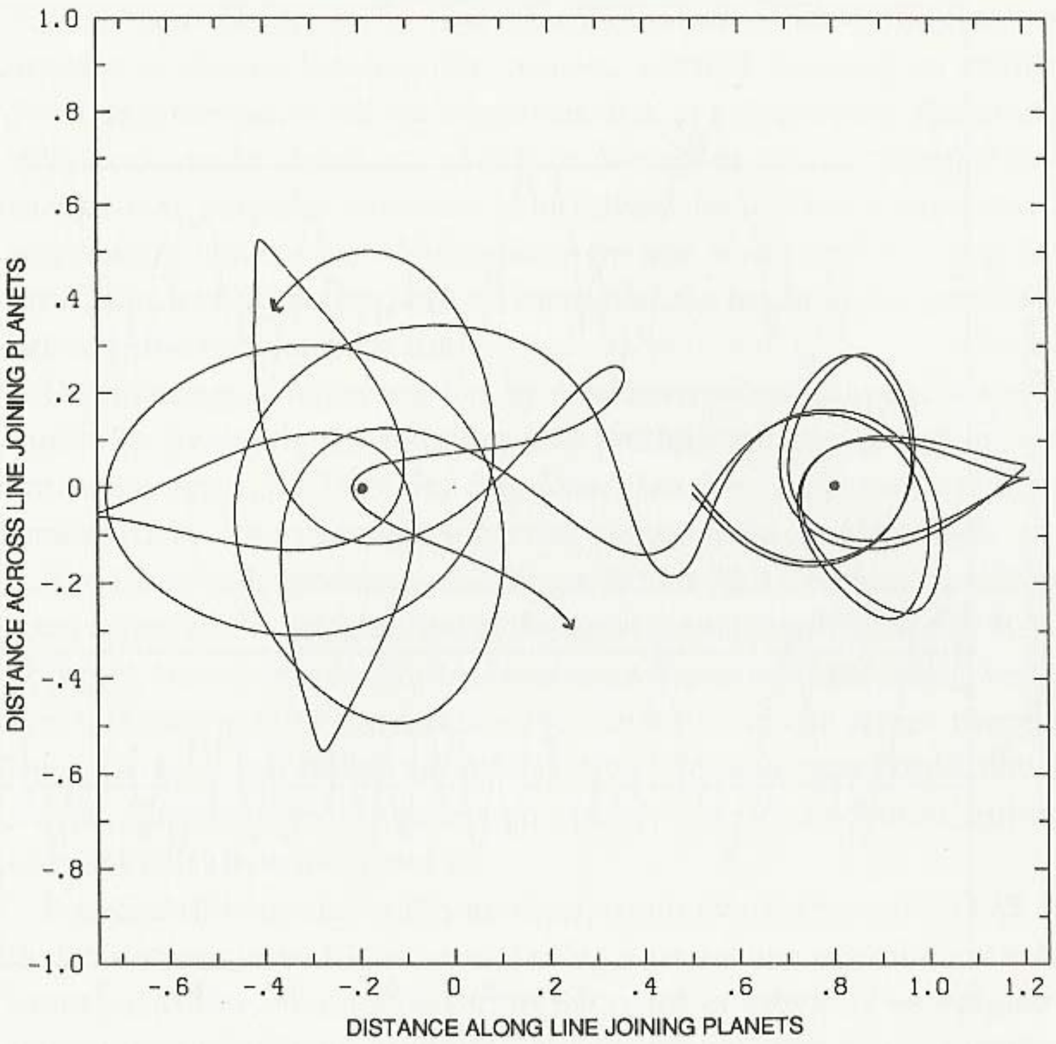


Figure 35. Two possible orbits of a satellite, starting with nearly identical conditions, as given by numerical solutions of Hill's reduced equations, extending for two years. The frame of reference from which the satellite is viewed rotates so as to make the planets, which are located 0.2 units to the left and 0.8 units to the right of the origin, and which are indicated by the dots, appear stationary.

Recently:
Lorenz (1917-2008), March 2006:

Chaos:

When the present determines the future
but the approximate present
does not approximately determine the future

Mesoscale/ limited area modeling:

Purpose: obtain a better result, due to the ability to use higher resolution ("value added")

Some history:

The first operational implementation of a LAM using forecast boundary condition: apparently at SMHI (Bengtsson and Moen 1971)

After some efforts in looking at available records, Bengtsson and Moen became "convinced that [the system] actually was put into operation in 1969" (Bengtsson, personal communication)

(3-level quasi-geostrophic model, used at two resolutions)

Emphasis on actual weather ("mesoscale modeling" ?)

Bushby-Timpson (1967)

"one of the first attempts to predict weather, as distinct from pressure patterns and vertical velocity" (Bushby 1987)

Forecast BC for the "rectangle" version of the UK Met Office model, "Bushby-Timpson 10 level primitive equation model", 1972;

U.S. Nat'l Met. Center (NMC): 1973, "LFM" model;

JMA, Météorologie National, ...

Yugoslavia: January 1978,
manually prepared BCs, off DWD fcst charts
(ancestor of the Eta model !)

What kind of “value added” might we achieve?

Is it just more detail (e.g., topography, land surface, …) ?

Or, ability to simulate additional, more demanding, physical processes ?

More detail / processes requiring smaller scales: “downscaling”

What about “upscaling”?

Two meanings however:

- Improve also largest scales a nested model can accommodate;
- Have nested model impact the “driver model” (so-called “two way nesting”)

But also, other reasons to run a nested (mesoscale) model:

- Have data in your system for various applications;
- Use the model for research/ experiments

LA/ mesoscale modeling:

issues we are talking about ?

One that is unique for LAMs: lateral boundary conditions (LBCs)

However: the objective in mind implies

- use of higher resolution;
- desire to simulate processes we were not able to simulate (or, simulate well) in the "driver" (global ?) model;

What are they? Many

- storms;
- effects of detailed/ steep topography;
- . . .
- . . .

“Value added” and the “LBC error” ?

Running a LAM/ regional model, we must expect to achieve some “value added” over the driver model

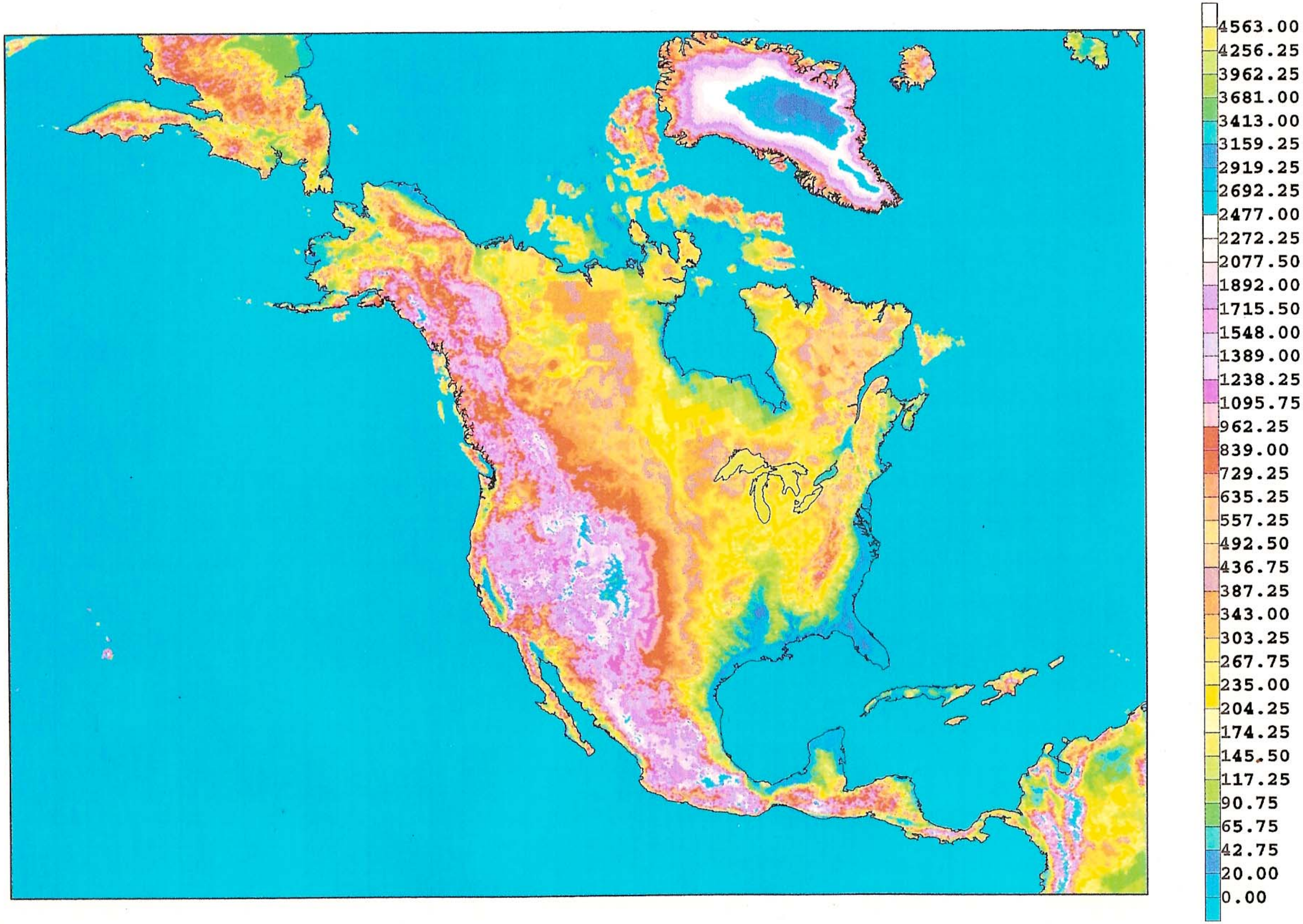
What is it? (Hopefully there is some !)

But there is this “LBC error”, it will be advected into the region of interest ! Will it destroy the value added ?

Example:

Eta model at NCEP

Eta 12 km/60 layer topography



In the NCEP operational setting:

the limited area model/ 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)

This is in addition to 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., 2000)

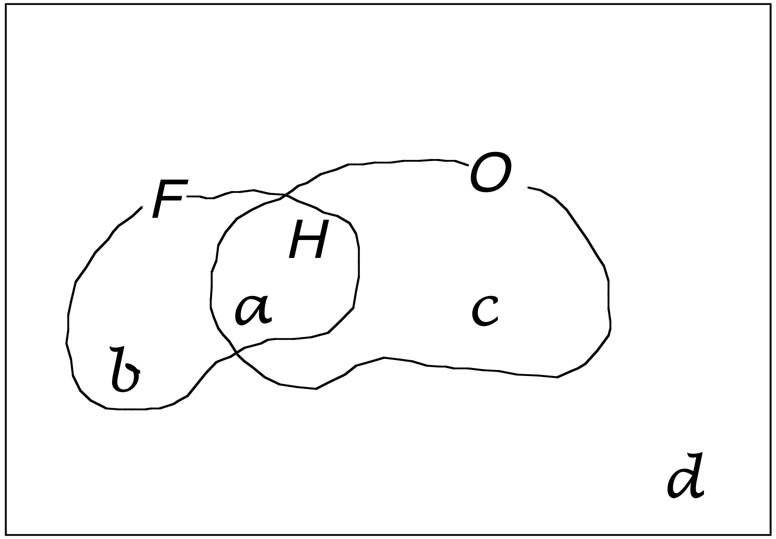
Can one

detect the impact of the advection of the LB error?

For an answer, I have looked into,

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

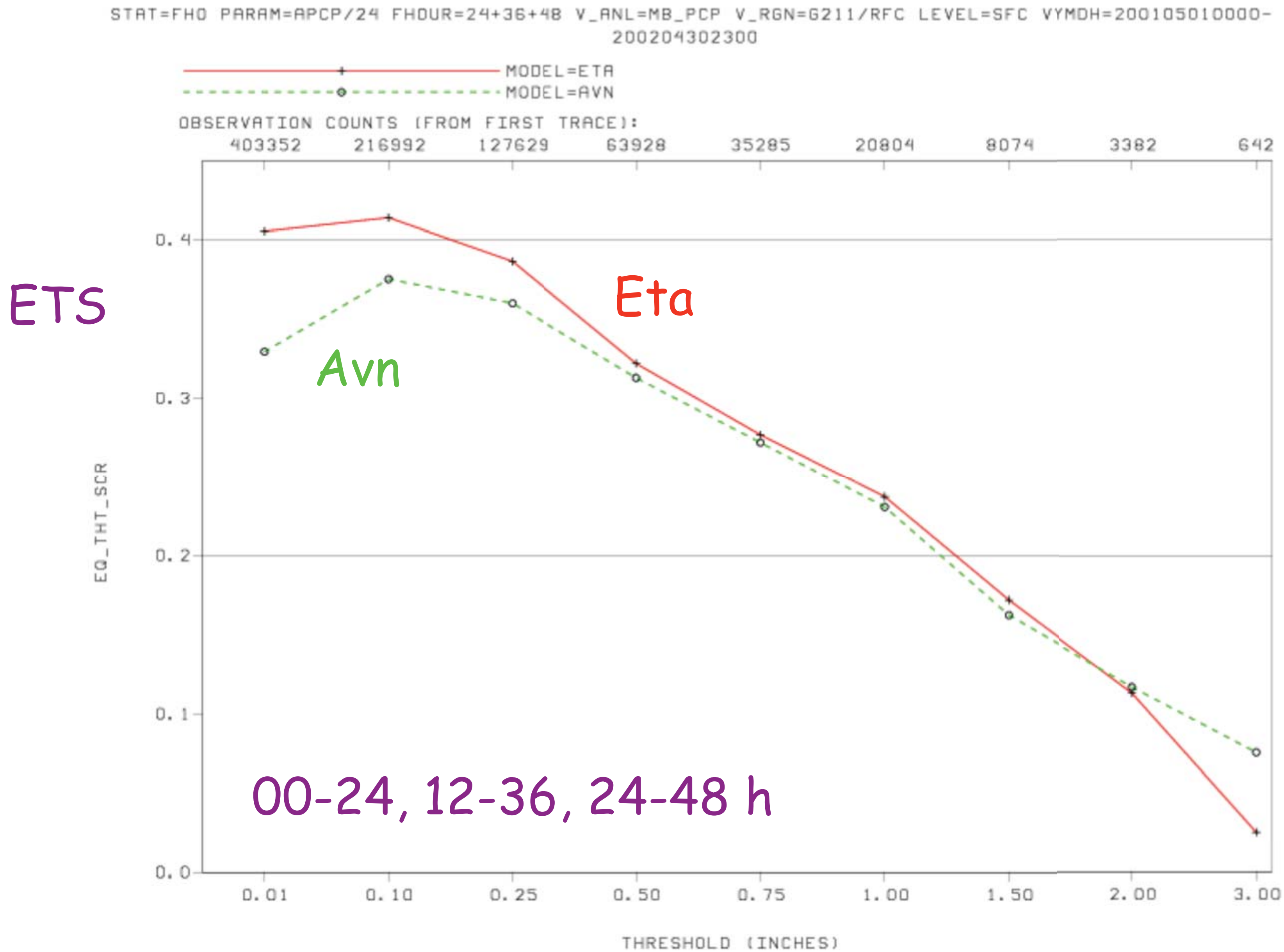
Forecast, Hits, and Observed (*F*, *H*, *O*) area,
or number of model grid boxes:

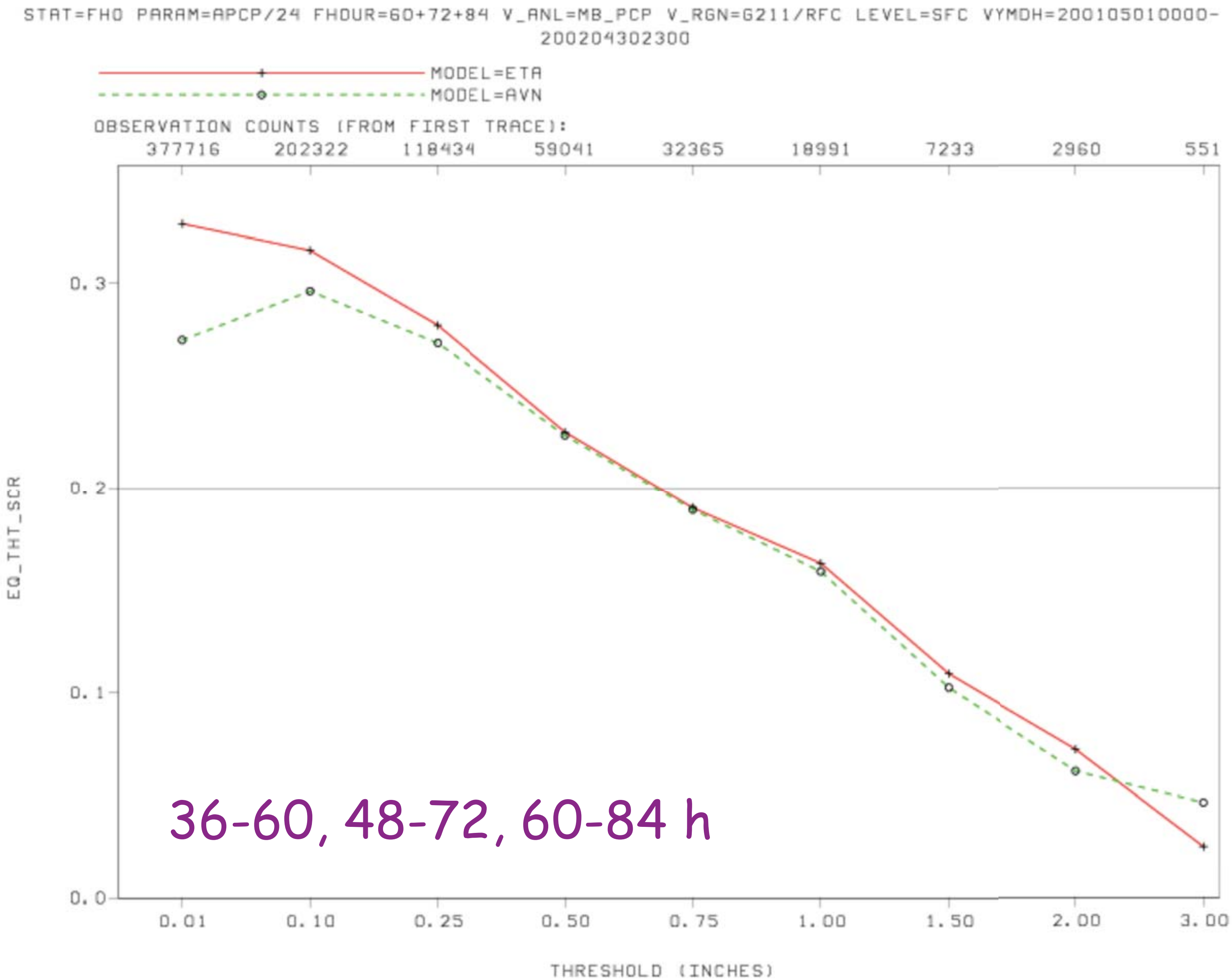


$$ETS = \frac{H - E(H)}{F + O - H - E(H)}$$

"Equitable Threat Score"

12 months of forecasts:

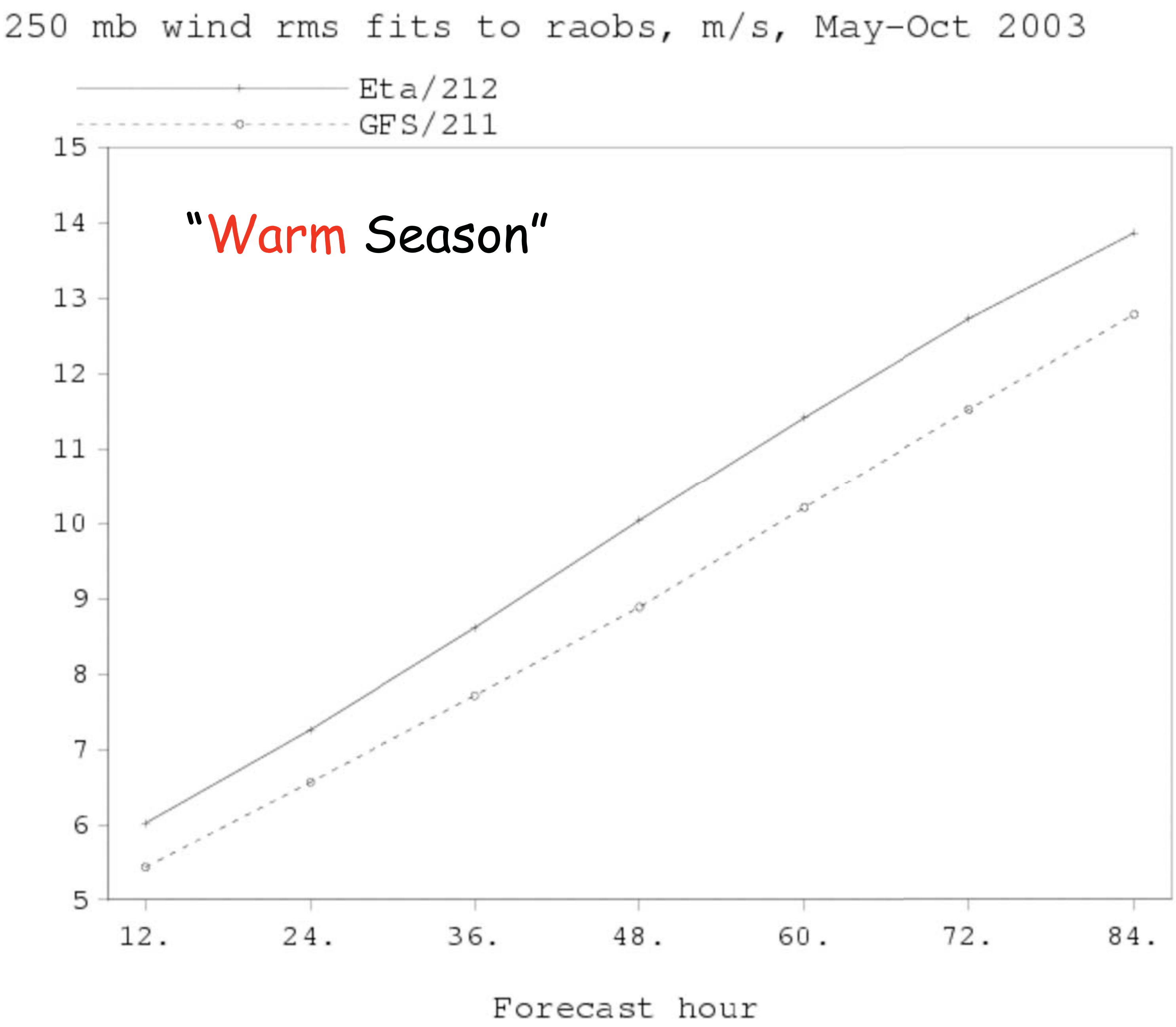




Relative QPF skill, Eta vs GFS, about the same !

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
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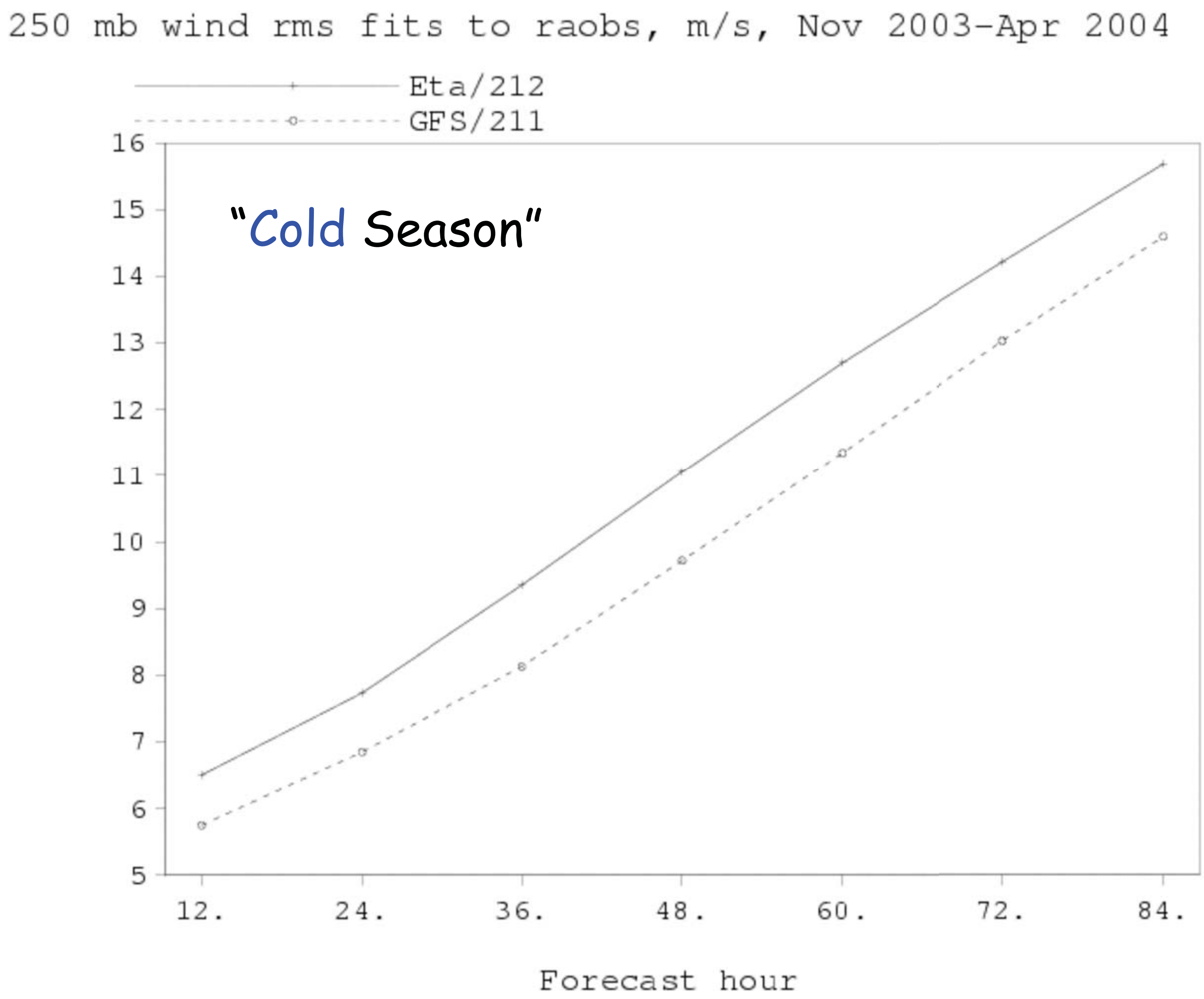
7
6
5
12.
24.
36.
48.
60.
72.
84.
Forecast hour


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

In cold season, 250 mb winds, 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 !

I’ve also looked into

position forecast errors of “major lows”

The idea: a “major low” is one with a center clearly identifiable (like one of a hurricane)

For objectivity: *A code-like definition is needed* !

“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, two winters

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

Example of a section of an HPC analysis:

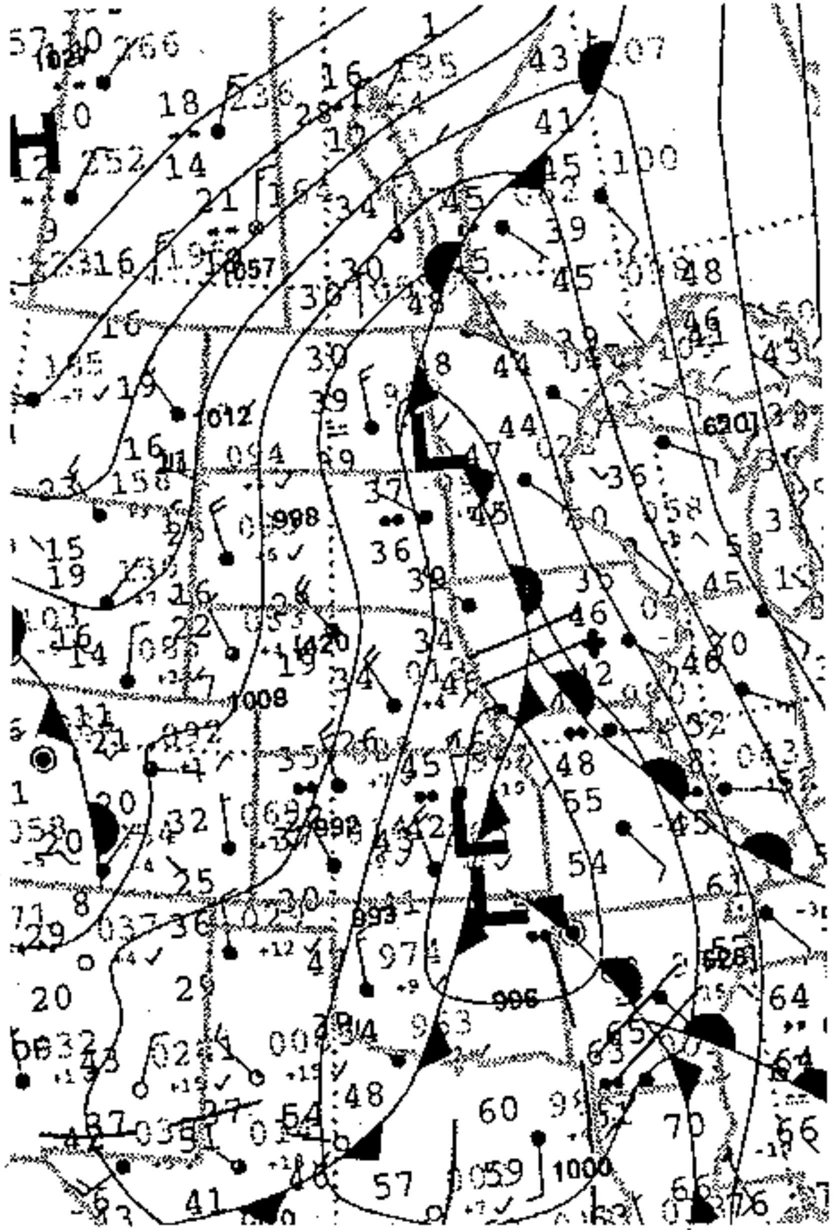


Table 1. Forecast position errors, at 60 h, of "major lows",
east of the Rockies and over land or inland waters, Dec. 2000 - Feb. 2001

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
of the search for signs of the inflow of the LBC error :

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

In relative terms, the Eta, if anything,
improves with time !

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

(This error is not tiny, recall the 6 h error growth)

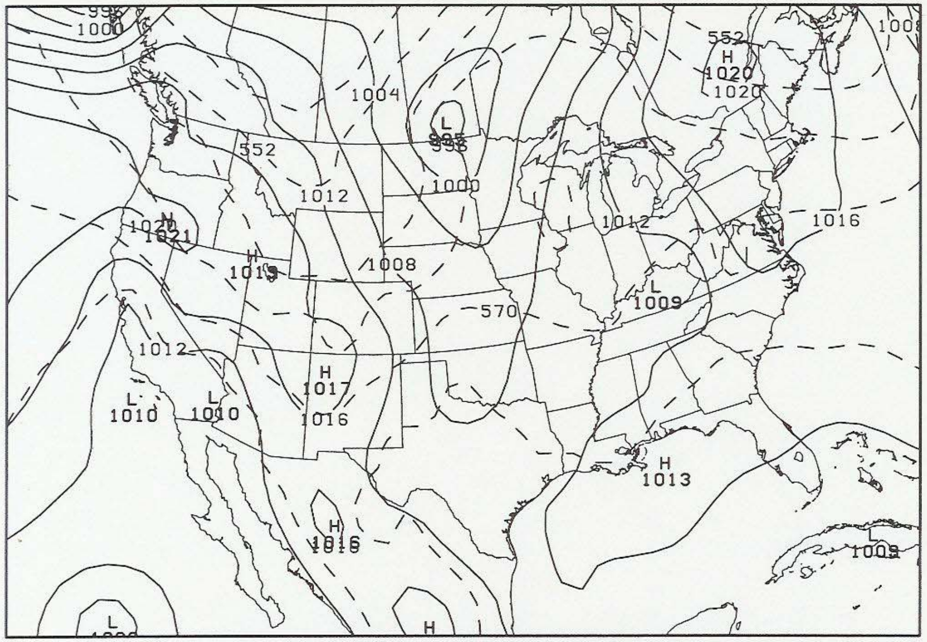
Will get back to the topic in lecture #3 !

3. The three low centers case

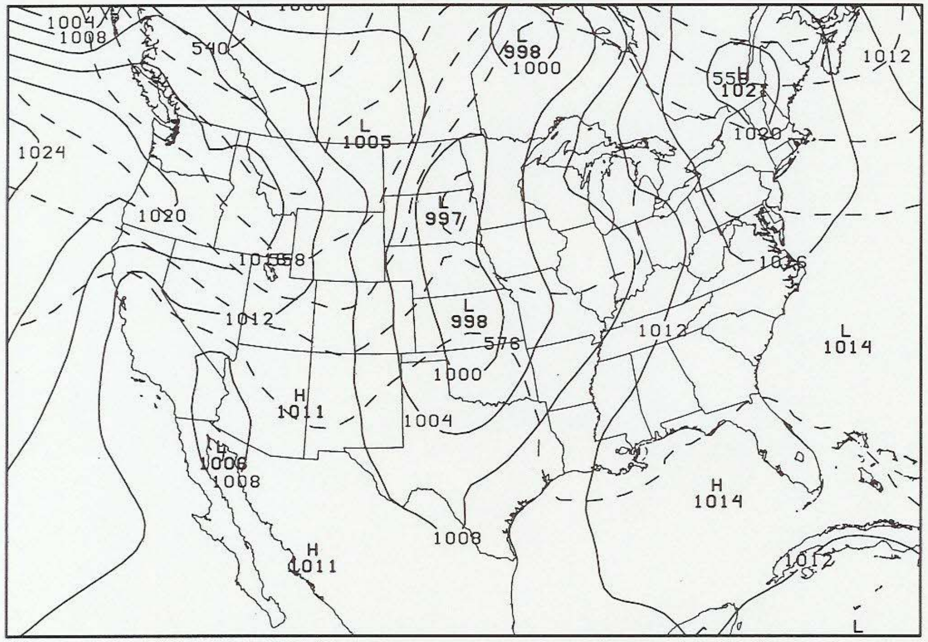
Avn

Eta

60 h fcsts

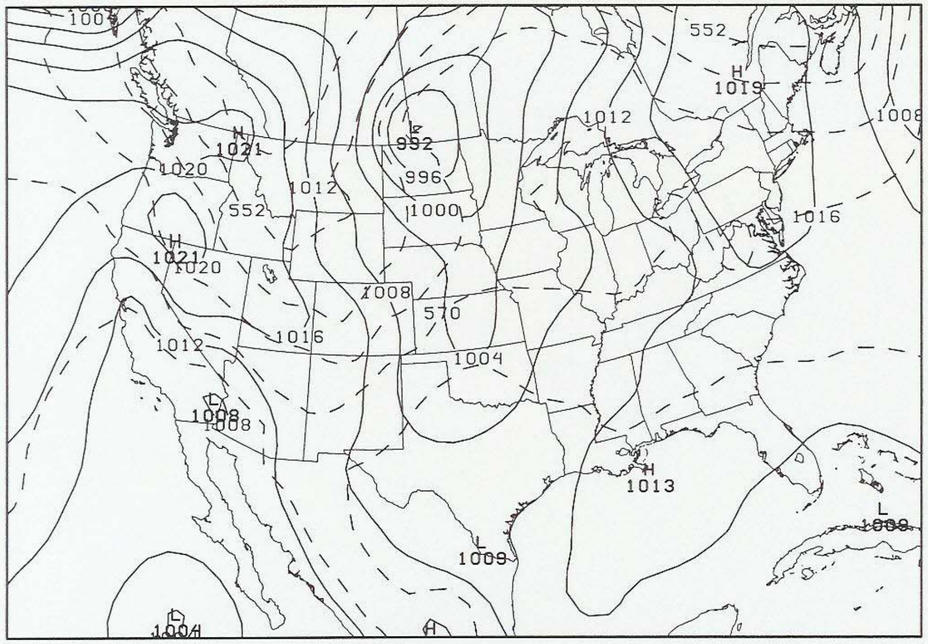


020918/1200V060 SFC MSLP & THCK -- AVN

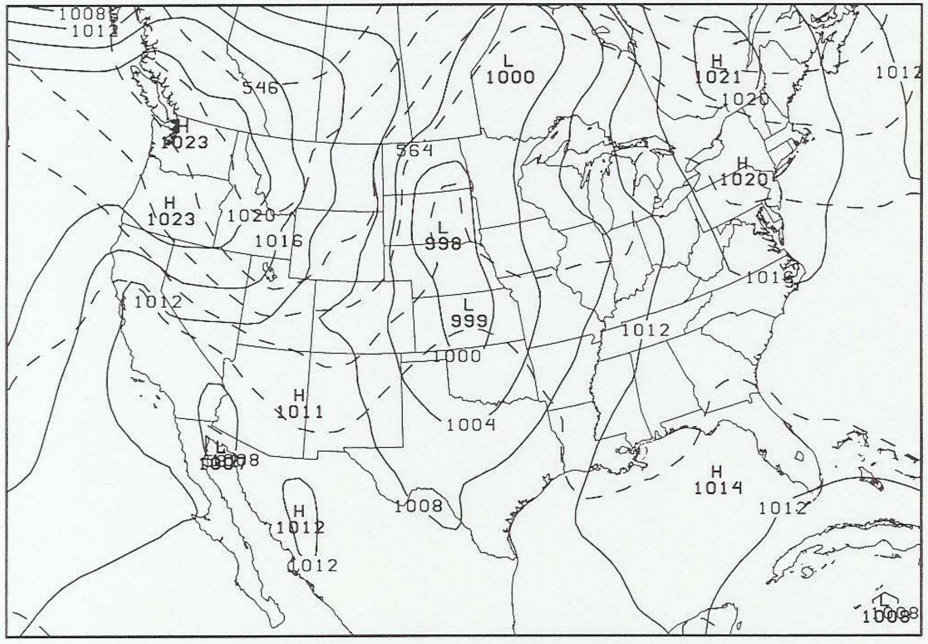


020918/1200V060 SFC MSLP & THCK -- ETA

Avn

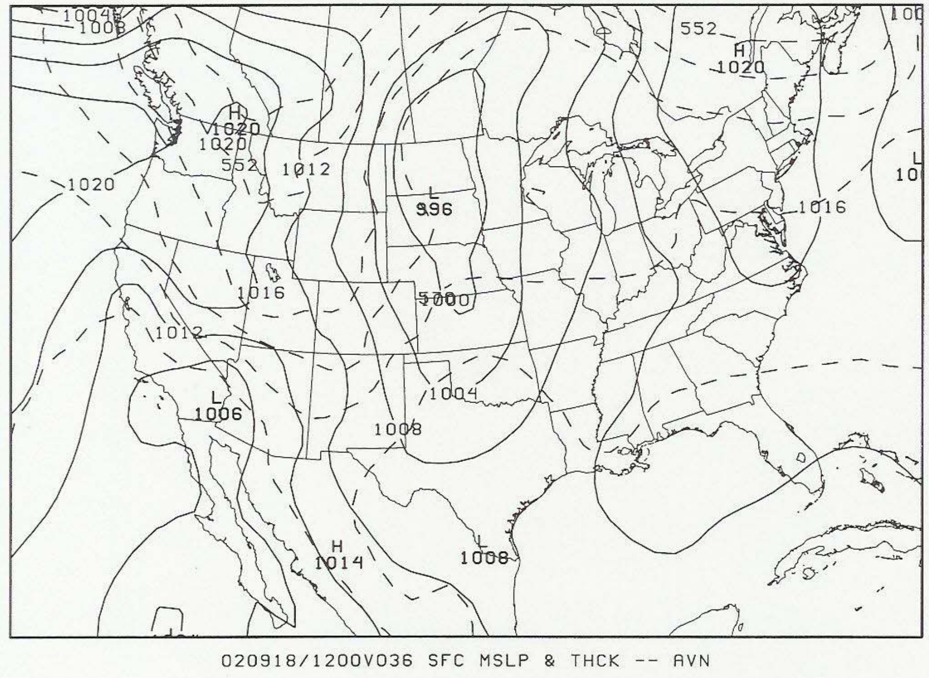


Eta

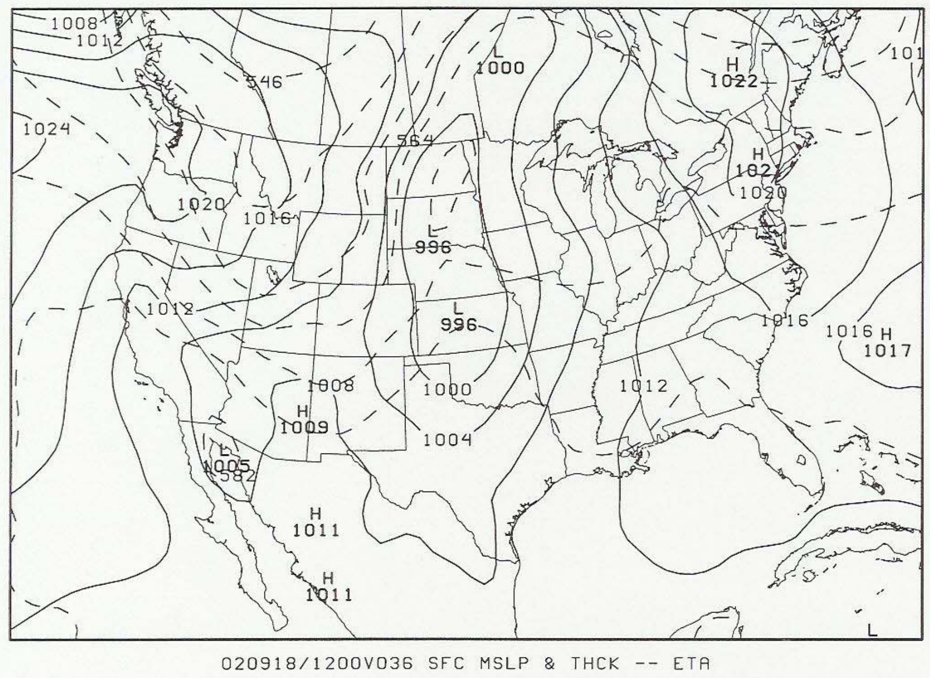


48 h fcsts

Avn

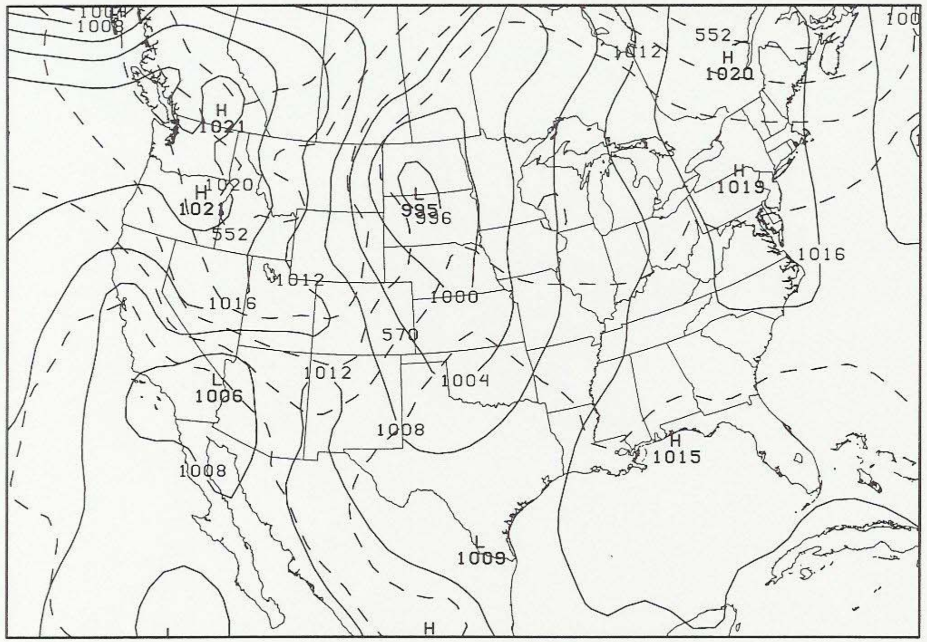


Eta



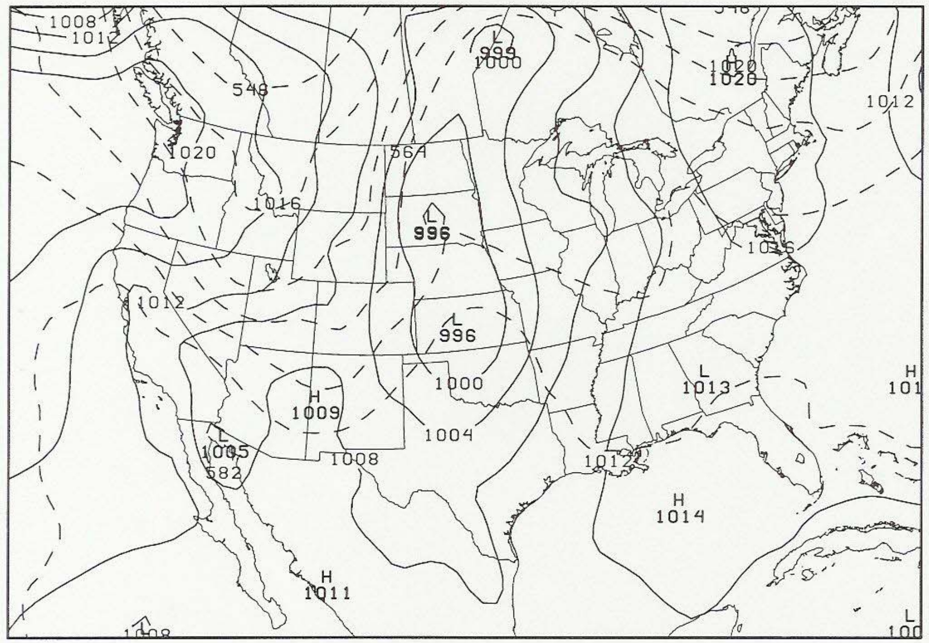
36 h fcsts

Avn



020918/1200V024 SFC MSLP & THCK -- AVN

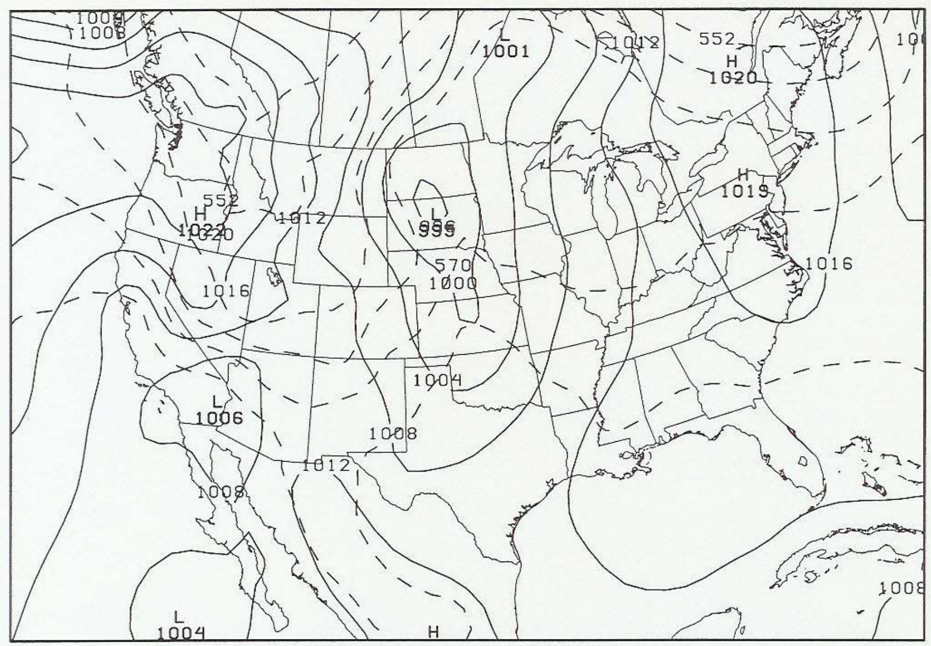
Eta



020918/1200V024 SFC MSLP & THCK -- ETA

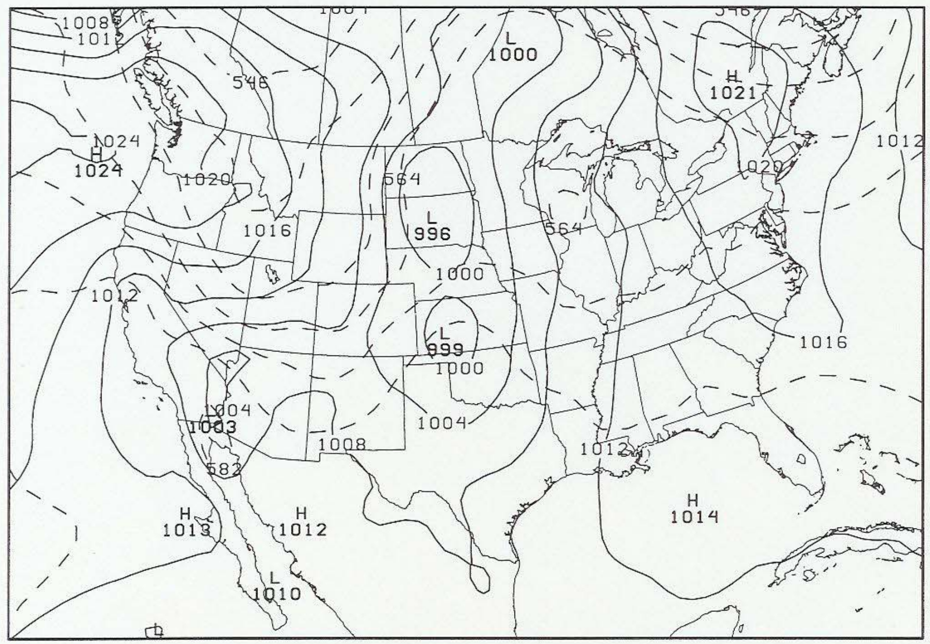
24 h fcsts

Avn



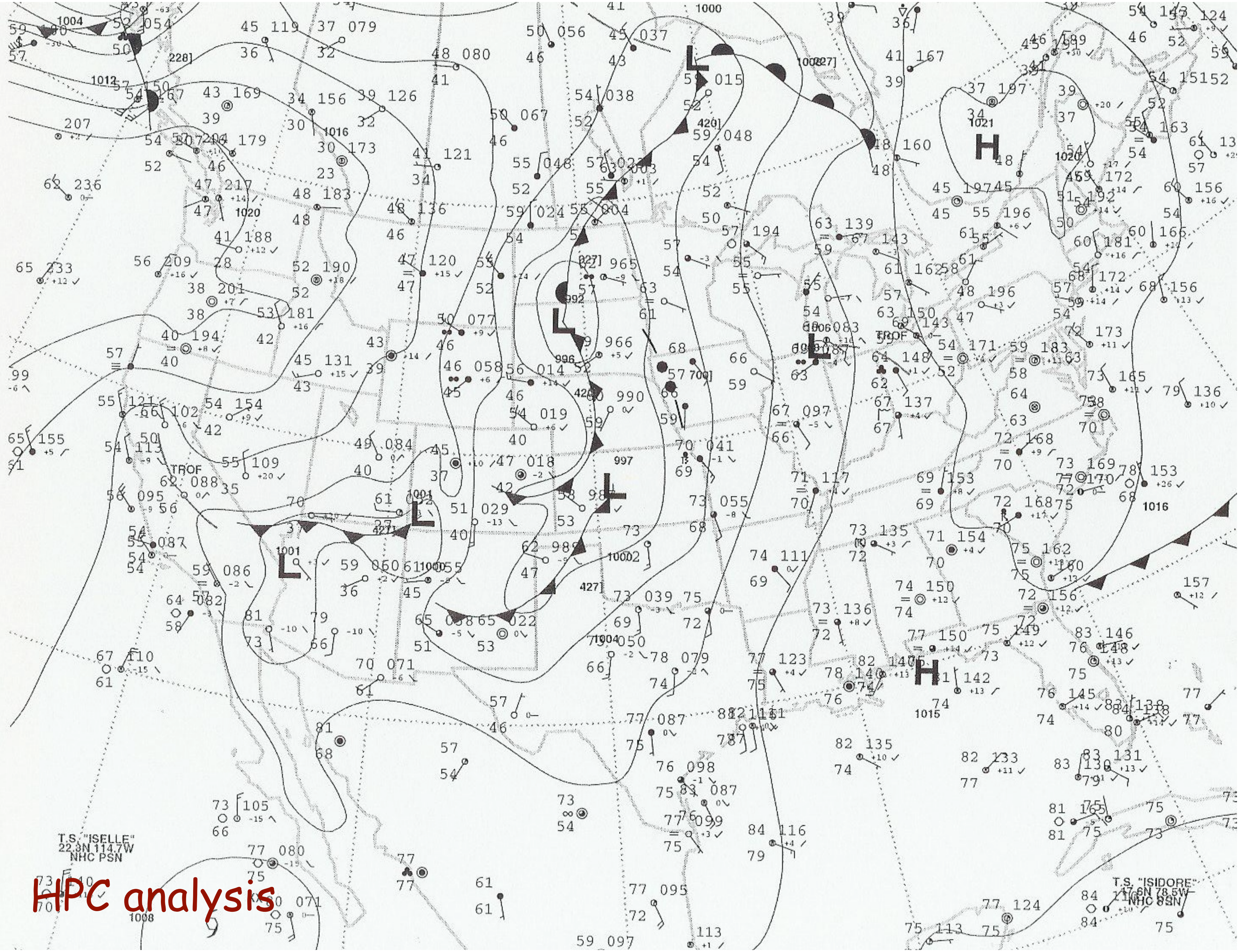
020918/1200V012 SFC MSLP & THCK -- AVN

Eta

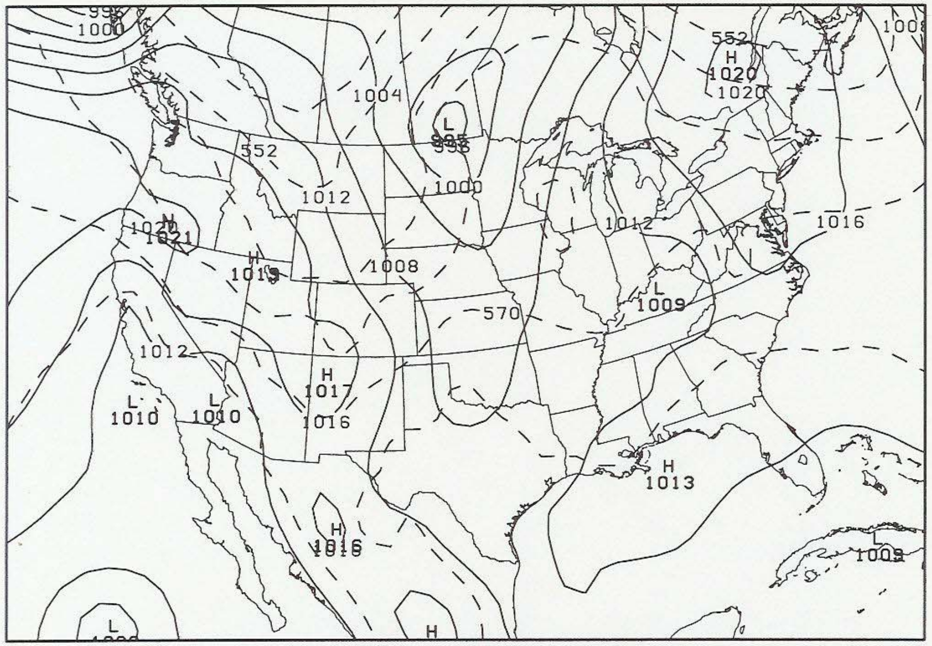


020918/1200V012 SFC MSLP & THCK -- ETA

12 h fcsts

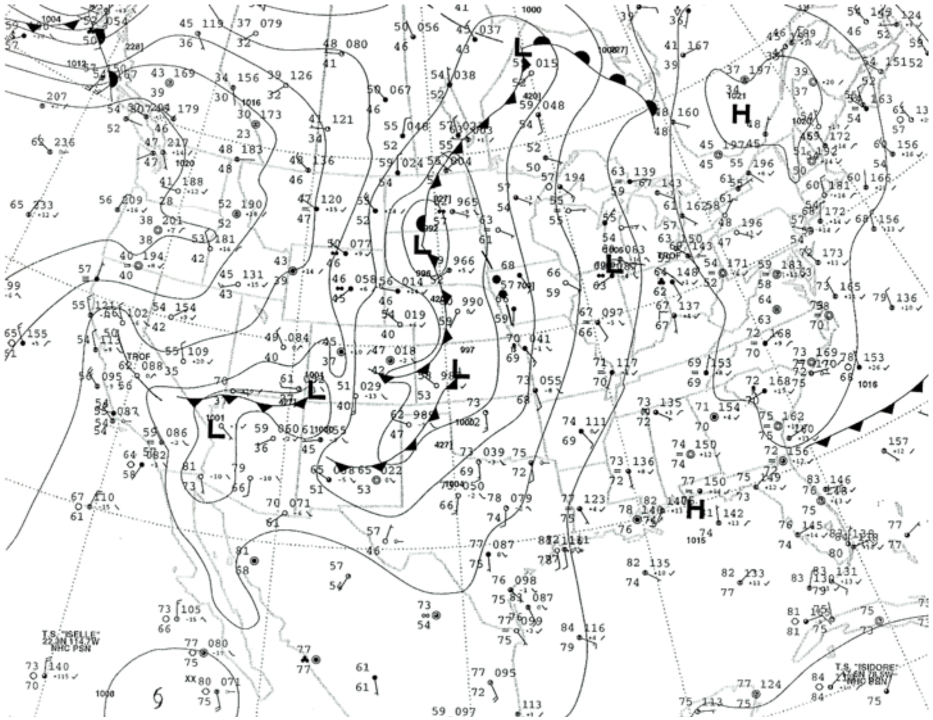


HPC analysis

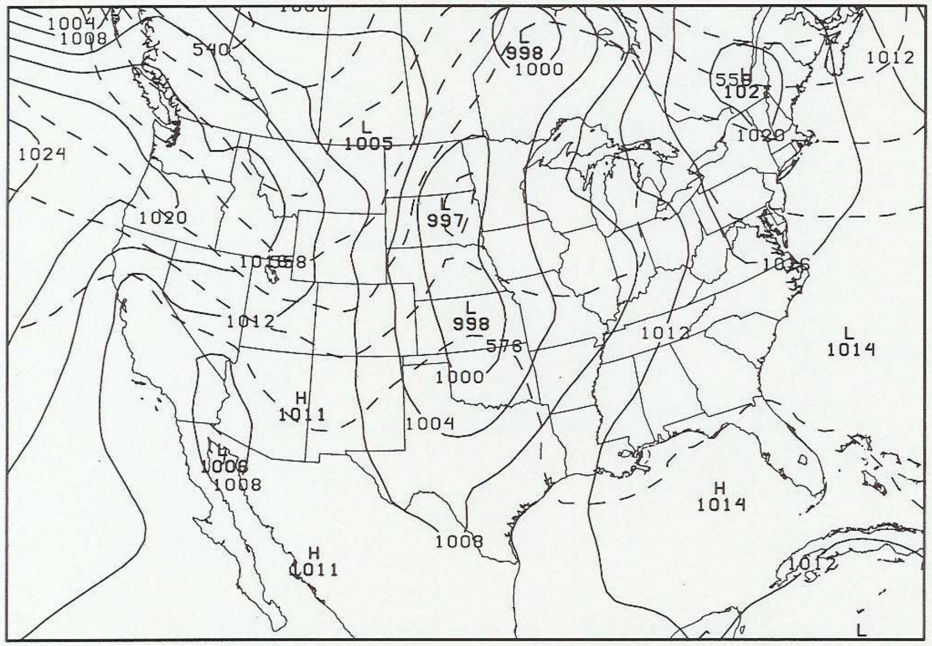


020918/1200V060 SFC MSLP & THCK -- AVN

Avn, 60 h fcst



HPC analysis



020918/1200V060 SFC MSLP & THCK -- ETA

Eta, 60 h fcst

Some of the references made that are not on the "Guide to the Eta model" or CPTEC etaweb references site:

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Laprise, R., M. R. Varma, B. Denis, D. Caya, and I. Zawadzki, 2000: Predictability of a nested limited-area model. *Mon. Wea. Rev.*, **128**, 4149-4154.

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