EMC SACK LUNCH SEMINAR

Fedor Mesinger

ESSIC

Monday March 22, 2010
3pm in Rm 209

An Eta Driven by ECMWF 32-day Ensemble Experiment: What Happens to Large Scales? Do Lateral Boundary Conditions Make a Difference?

Abstract:
Considerable number of authors presented experiments in which degradation of large scales occurred in regional climate integrations when large-scale nudging was not used. There have however been Eta model RCM experiments in which improvement in large scales is hard to dispute. This issue is revisited - by Katarina Veljović, Borivoj Rajković and the presenter - by comparing the large scale skill of the Eta RCM ensemble against that of the ECMWF 32-day ensemble used as its driver. Another issue looked into is that of the lateral boundary condition (LBC) scheme. This is addressed by running the Eta model in two versions differing in the lateral boundary scheme used. One of these is the traditional relaxation scheme and the other is the Eta model scheme in which information is used at the outermost boundary only and not all variables are prescribed at the outflow boundary.

A novelty in these experiments is the verification used. In order to test the large scale skill forecast position accuracy of the strongest winds at the jet stream level is verified. This is done by calculating bias adjusted equitable threat and bias scores for wind speeds greater than a chosen wind speed threshold, with the ECMWF analyses used as truth. 250 hPa is taken as the jet stream level. For greater confidence a traditional RMS difference between the forecast and analyzed winds at this same level is also calculated.

The results show the Eta RCM skill in forecasting large scales with no interior nudging to be just about the same and slightly higher than that of the ECMWF driver ensemble. As to the LBC impact no disadvantage compared to relaxation was seen from using the Eta LBC scheme, in spite of its requiring information from the outermost RCM boundary only.

<http://www.emc.ncep.noaa.gov/seminars>

Update of an earlier conference presentation:

Value added in regional climate modeling:

Should one attempt improving on the large scales?
Lateral boundary condition scheme: Any impact?

Fedor Mesinger [1,2], Katarina Veljović [3], and Borivoj Rajković [3]

1) Serbian Academy of Sciences and Arts, Belgrade
2) Earth System Science Interdisciplinary Center, Un. Maryland, College Park, MD
3) Institute of Meteorology, Faculty of Physics, Un. of Belgrade, Belgrade

fedor.mesinger@noaa.gov

International Conference on

Planetary Boundary Layers and Climate Change

Cape Town, South Africa

26-28 October 2009   A plot added, November 18

Laprise et al. (Met. Atmos. Ph., 2008) tenets:

- Tenet 1: RCMs are capable of generating small scale features absent in the driving fields supplied as lateral boundary conditions (LBC);

- Tenet 2: The small scales that are generated have the appropriate amplitudes and climate statistics;

- Tenet 3: The generated small scales accurately represent those that would be present in the driving data if it were not limited by resolution;

- Tenet 4: In performing dynamical downscaling, RCM generated small scales are uniquely defined for a given set of LBC.

Laprise et al. “Tenet 5”:

- Tenet 5a: The large scales are unaffected within the RCM domain;

- Tenet 5b: The large scales may be improved owing to reduced truncation and explicit treatment of some mesoscale processes with increased resolution within the RCM domain;

- Tenet 5c: The scales larger than or comparable to the RCM domain are degraded because the limited domain is too small to handle these adequately

If you believe in 5c, or if this is "your religion":

"spectral (or, large scale) nudging" inside the domain !

Motivation:

"An fundamental assumption in using RCM states that the large-scale atmospheric circulation in the driving data and in the RCM should remain the same at all time" (Lucas-Picher et al., 2004)

Denis et al. (2002): "the ineffectiveness of the nesting for controlling the large scales over the whole domain"

Thus, "spectral nudging" (Kida et al., 1991, Waldron et al. 1996; von Storch et al. 2000): provide large scale forcing to the model fields throughout the entire model domain

A lot of discussion at:

http://cires.colorado.edu/science/groups/pielke/links/Downscale/

Castro, C. L., R. A. Pielke, Sr., and G. Leoncini: 2005: Dynamical downscaling: Assessment of value retained and added using the Regional Atmospheric Modeling System (RAMS). *J. Geophys. Res.*, 110, D05108, doi: 10.1029/2004JD004721

Castro et al., 4 types of downscaling:

Type 1: NWP (results depends on initial condition);

Type 2: "Perfect" LBCs (=reanalysis) *

Type 3: GCM (=predicted) LBCs, but still specified SSTs inside

Type 4: Fully predicted, both LBCs and inside the RCM domain

* In the paper as published, GCM also included within Type 2

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Castro et al.: Type 2, conclusions:

"Absent interior nudging . . . . failure of the RCM to correctly retain value of the large scale . . ."

". . . underestimation of kinetic energy …" "The results here and past studies suggest the only solution to alleviate this problem is to constrain the RCM with the large-scale model (or reanalysis) values."

The discussion: 35 very small font pages of e-mails …

One e-mail:

Hi Barry

I do not see how a regional model can reproduce realistic long wave patterns, as these are hemispheric features.

Roger

fm:

- We are solving our RCM model equations as an initial-boundary value problem. Doing things inside the domain beyond what RCM equations tell us is in conflict with our basic principles.

  Alternative formulation of the same idea: an air parcel inside the RCM knows about forces acting on it, heating it undergoes, etc. It has no allegiance to a given scale !! (It has no idea what goes on on the opposite side of the globe!)

- If the RCM is not doing well the large scales inside the domain, there must be a reason for it;

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fm, cont'd:

- Type 2 experiments in which reanalysis is declared truth and an RCM's performance is assessed according to how close to the reanalysis it gets are not appropriate to answer this question. The purpose of an RCM is to *improve* upon what we have !

Note that in a "thought experiment" a perfect RCM, one that by definition would behave exactly as the real atmosphere, in a Type 2 experiment would depart from reanalysis more and more as the domain gets bigger! (LBCs are not perfect !!)

- There are results claiming or showing improvements in large scales, and at least one Type 3 - albeit somewhat dated - in which improvement in large scales can hardly be questioned !

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Giorgi et al., Climatic Change, 1998, 40, 457-493;

Mitchell, Fennessy, et al., GEWEX News, 2001, No. 1, 3-6;

Gustafson and Leung, BAMS 2007

Fennessy and Altshuler, 2002:

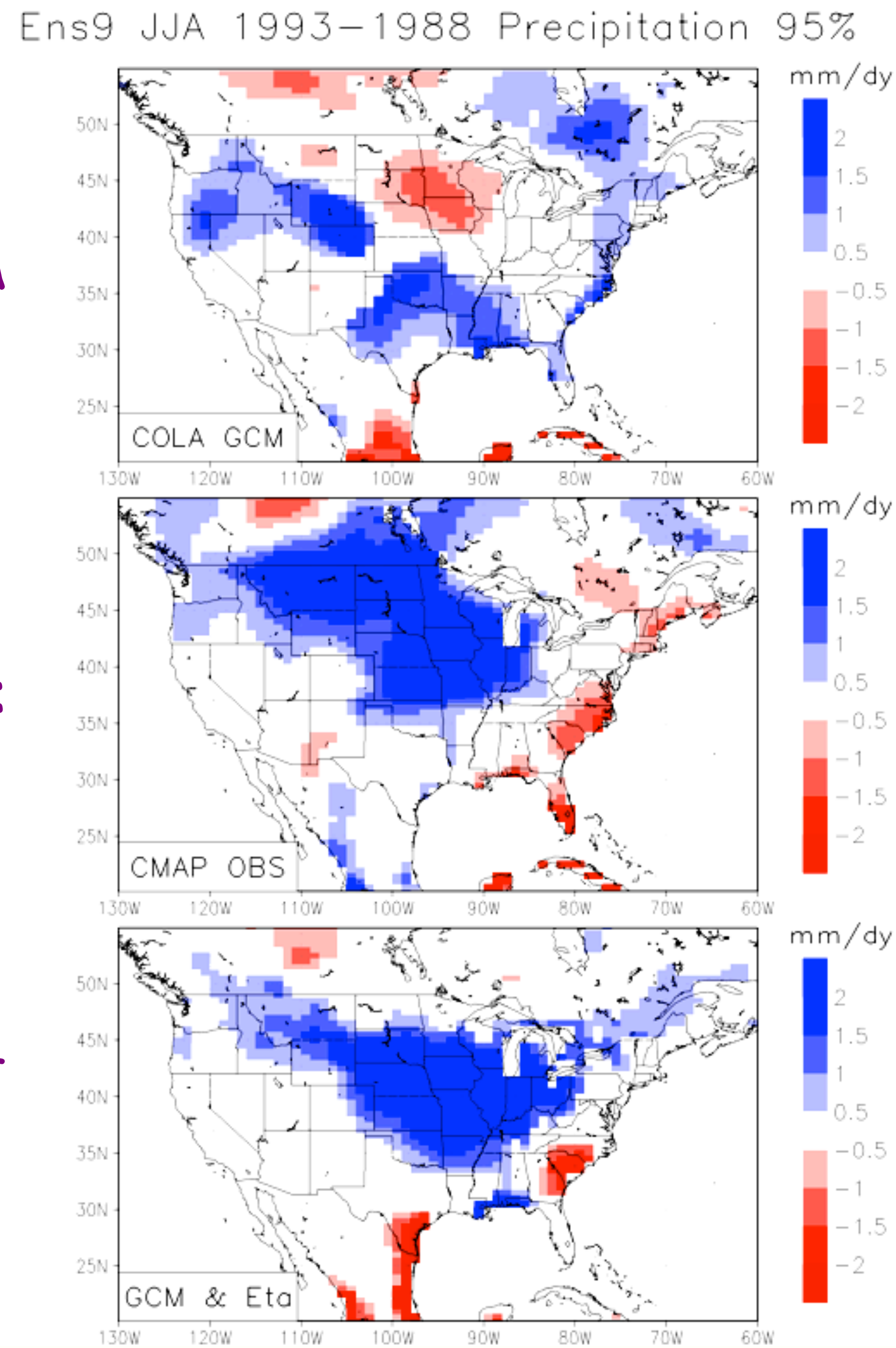
9 ensemble members

precip difference 1993-1988

COLA GCM:

Obs.:

GCM+ Eta:



An earlier 3-member ensemble result published and discussed in

Mitchell, K., M. J. Fennessy, E. Rogers, J. Shukla, T. Black, J. Kinter, F. Mesinger, Z. Janjic, and E. Altshuler, 2001: Simulation of North American summertime climate with the NCEP Eta Model nested in the COLA GCM. *GEWEX News*, **11**, No. 1, 3-6 (Available online at http://www.gewex.org/gewex_nwsltr.html)

The last sentence:

In the end then, a nested continental model whose complex physics package has evolved over 1–2 decades with an emphasis on performance over land may indeed have some advantage over its parent GCM for seasonal-range predictions (1–6 months lead) of continental anomalies during the weak circulation regime of summer.

- Lateral boundary condition scheme(s)

The problem:
Considered already in Charney (1962):

Linearized shallow-water eqs., one space dimension, characteristics;

"at least two conditions have to be specified at inflow points and one condition at outflow".

Charney (1962) (Tokyo NWP Symp.)

tives. We next observe that the specification of u' at a boundary determines $\partial v'/\partial t + U\partial v'/\partial x$ by (2.6) and the specification of q' dertermines v' by elimination of h' and u' from (2.7) with the aid of (2.6) and (2.8). Elimination of u' and h' from equations (2.5)-(2.7) gives

$$\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)\left[\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)^2-gH\frac{\partial^2}{\partial x^2}\right]v' + f^2\frac{\partial v'}{\partial t}=0\,, \tag{2.9}$$

It follows from the theory of characteristics that the domain of dependency of this equation is determined by the coefficients of the highest order terms. Since we are concerned only with the establishment of the boundary conditions, it is sufficient to consider the solution of the equation obtained by omitting the first order time term:

$$v'=\sum_{i=1}^{3} V_i(x-c_i t)\,, \tag{2.10}$$

where the V_i's are arbitrary functions to be determined, and

$$c_1=U\,,\ c_2=U+\sqrt{gH}\,,\ c_3=U-\sqrt{gH}\,. \tag{2.11}$$

The specification of v', $\partial v'/\partial t$ and $\partial^2 v'/\partial t^2$ at $t=0$ determines $\sum^3 V_i$ and linear combinations of the first and second x-derivatives of the V_i and therefore the V_i them-

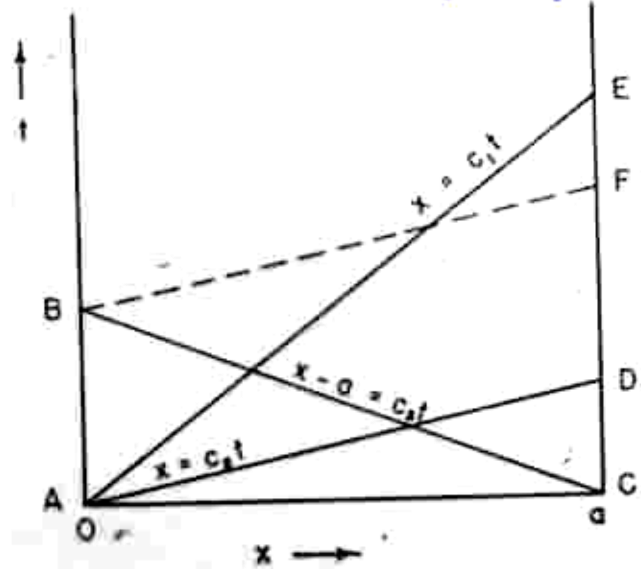


Fig. 1. Domains of dependence of the solutions of the perturbation equation (2.9) in the $x-t$ plane.

tion at $x=a$, determines V_3 along DF. Hence all the V_i's are determined along CF. It is now obvious how by continuation of the above reasoning one may show that the V_i's are determined for all t at the boundaries $x=0$ and $x=a$, and consequently that they are determined for all $0\leq x\leq a$ and $t\geq 0$. Thus the initial and boundary conditions are sufficient to determine the motion. It is also clear that they are necessary in the sense that at least two conditions have to be specified at inflow points and one condition at outflow.

We have tacitly assumed that the Froude

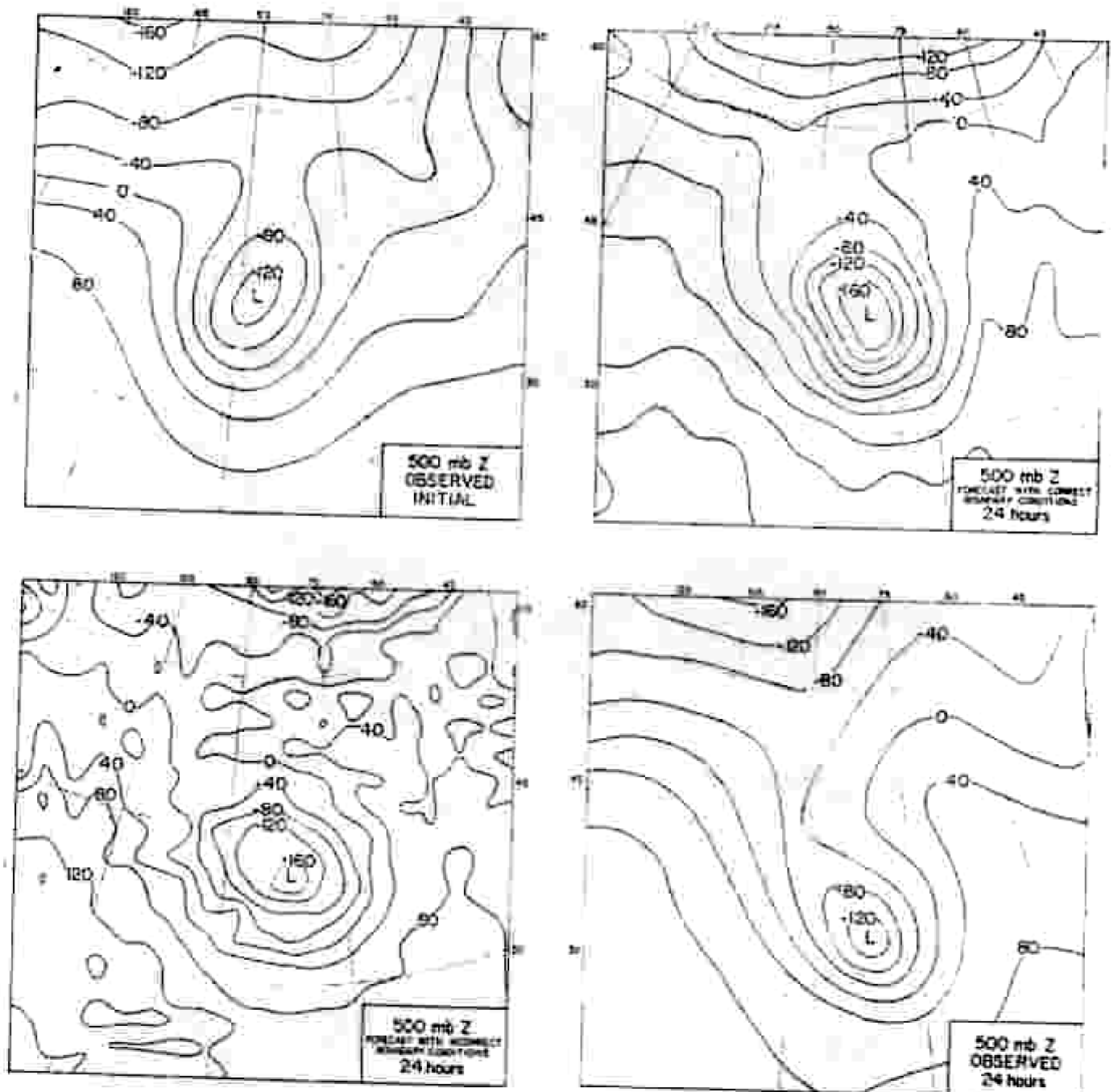


Fig. 2. A comparison of the 24-hour 500 mb predictions made from the primitive equations for a single-layer barotropic atmosphere with both correct and incorrect boundary conditins. The initial time is 24 November, 1950, 1500 G.M.T. The unit of z is 10 feet.

Subsequently:
Sundström (1973)

However:

Davies (1976): "boundary relaxation scheme"

Almost all LA models:

Davies ("relaxation LBCs"):

Outside row: specify all variables

Row 1 grid line inside: specify, e.g.,
$0.875 * Y_{DM} + 0.125 * Y_{LAM}$

Row 2 grid lines inside:
$0.750 * Y_{DM} + 0.250 * Y_{LAM}$

. . .

Lots of statements published claiming that LBCs are highly detrimental to limited area models !!

The Eta LBC scheme:

LBCs needed along
a single outer bndry line
of grid points

(as required by the mathematical nature of the initial-boundary value problem we are solving)

The scheme

- At the inflow boundary points, all variables prescribed;
- At the outflow boundary points, tangential velocity extrapolated from the inside (characteristics!);
- The row of grid points next to the boundary row, "buffer row"; variables four-point averaged (this couples the gravity waves on two C-subgrids of the E-grid)

Thus: No "boundary relaxation" !

Semi-Lagrangian advection the three outermost rows of the integration domain

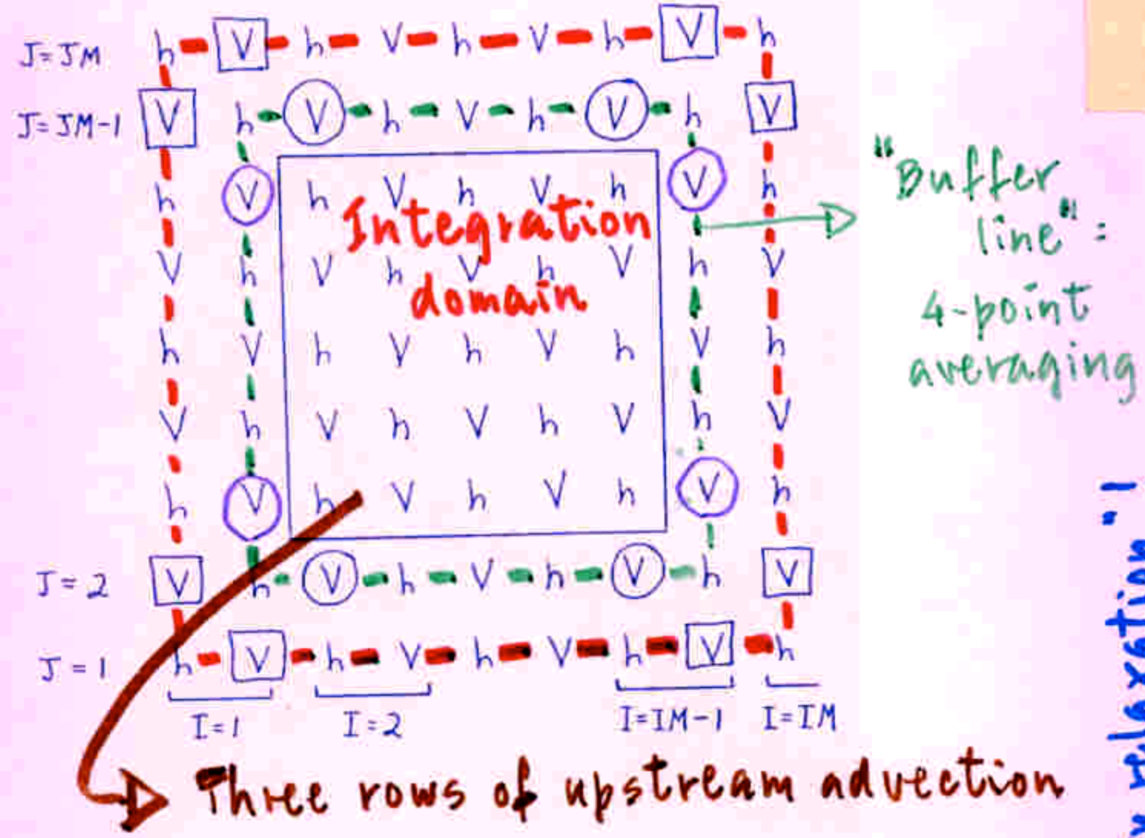


Fig. 7. The eta model's E grid with solid line enclosing the integration domain. Boxed and circled V's are handled differently than others in boundary region, see text.

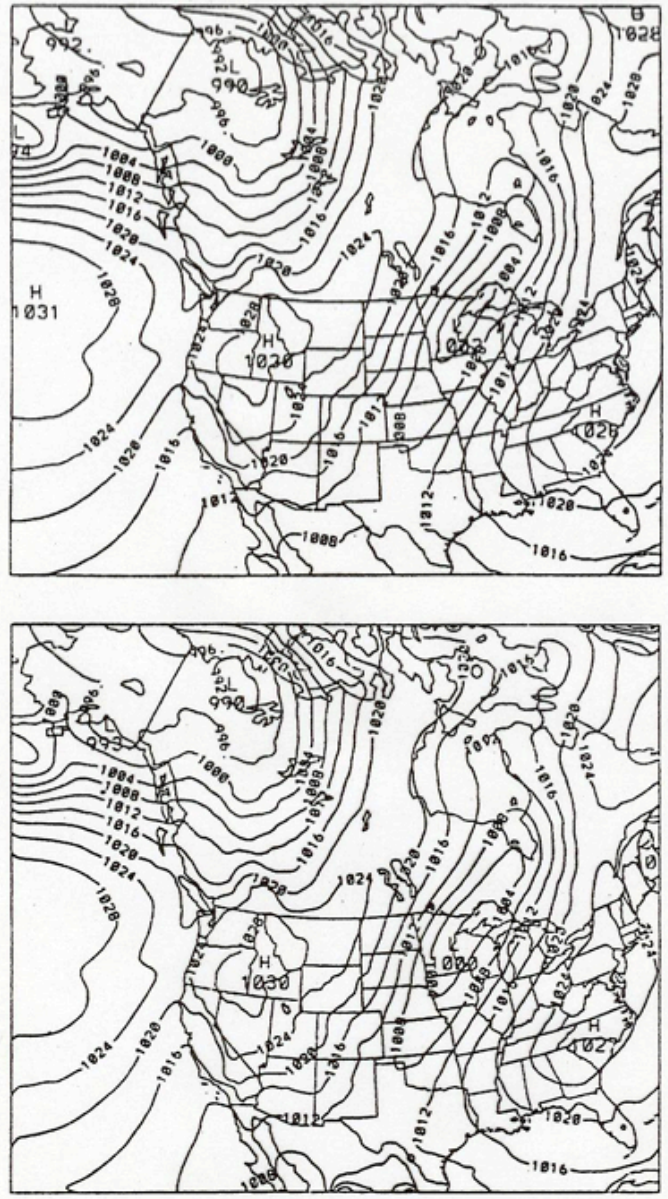
No "boundary relaxation"!

Inflow: u, v, T, p_s prescribed

Outflow: v_{normal}, T, p_s prescribed, $v_{tang.}$ extrapolated

Mesinger 1977

"Control"



"Driven using the "control" for lateral bnd. condition

No space interpolation errors at the lateral boundary

Black at al., RAAOM, 99; 50th Anniv. of NWP, 2001

Figure 4: A section of the then operational 32-km Eta 48-h sea level pressure forecast, valid at 1200 UTC 17 October 1998, top panel; same except for a run over a smaller domain, done using the operational forecast to supply its boundary conditions, bottom panel. Boundaries of the plots shown are the outermost boundaries of the smaller domain, thus, in the bottom panel, all of the forecast domain of the nested run is shown.

"limitation":

Near inflow boundaries, LA model cannot do better - it can only do worse - that its driver model

Thus: have boundaries as far as affordable !

LBC schemes:

"… the dearth of well-posed meteorological models in the literature is striking."

(McDonald, MWR 2003)

Experiments (work in progress, Veljović, Rajković, Mesinger):

Compare the Eta LBC scheme, against Davies':

use GCM (ECMWF) LBCs and drive the Eta using one and the other, look at the difference;

Main objective though:

Can one/ does the Eta RCM "retain value of the large scale"?

(Castro, Pielke and Leoncini, JGR 2005),

or, more ambitiously,

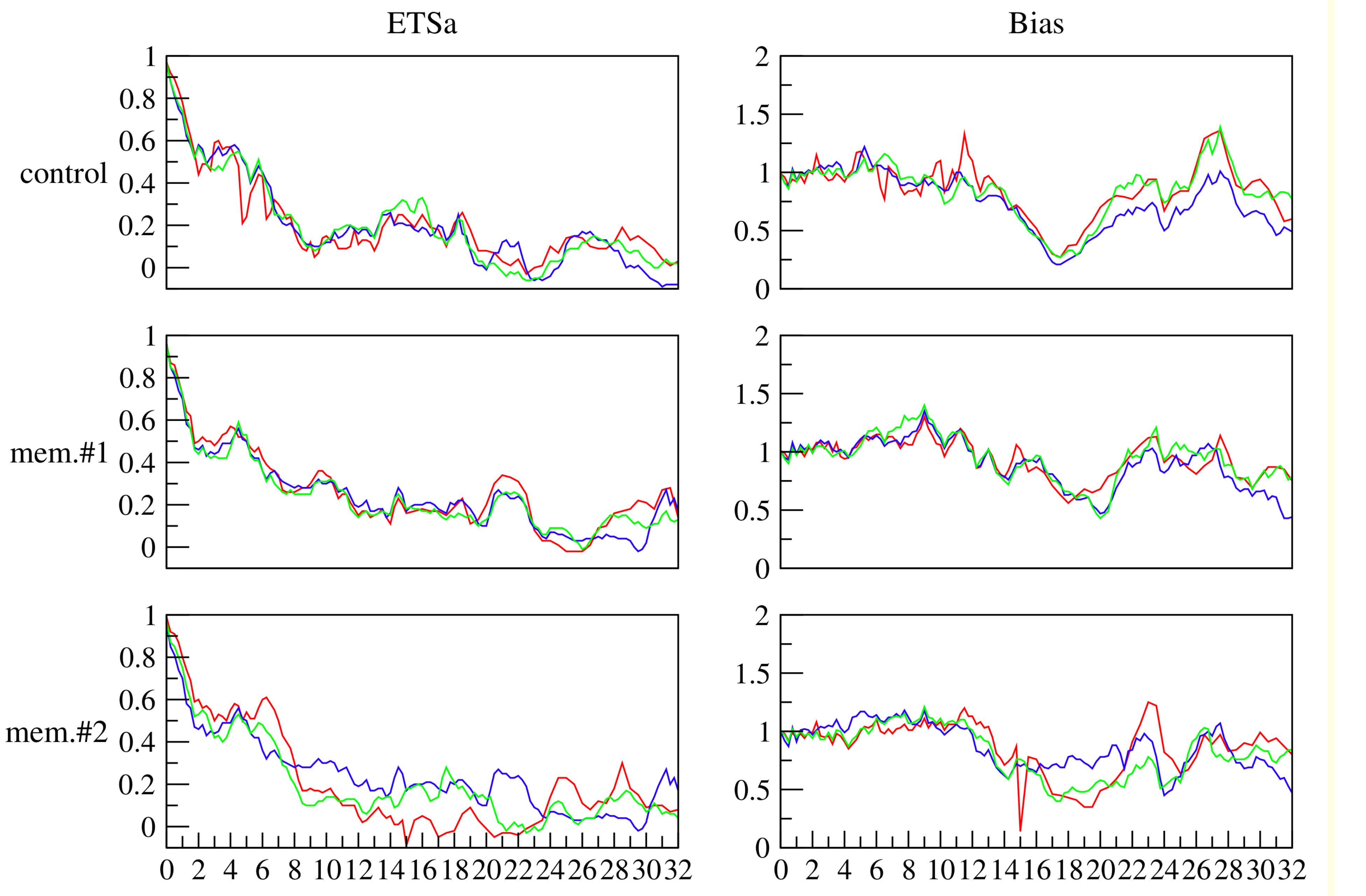
can one improve on the large scale ?

The Eta code used: "Upgraded (community ?)" Eta

Changes compared to the latest NCEP codes:

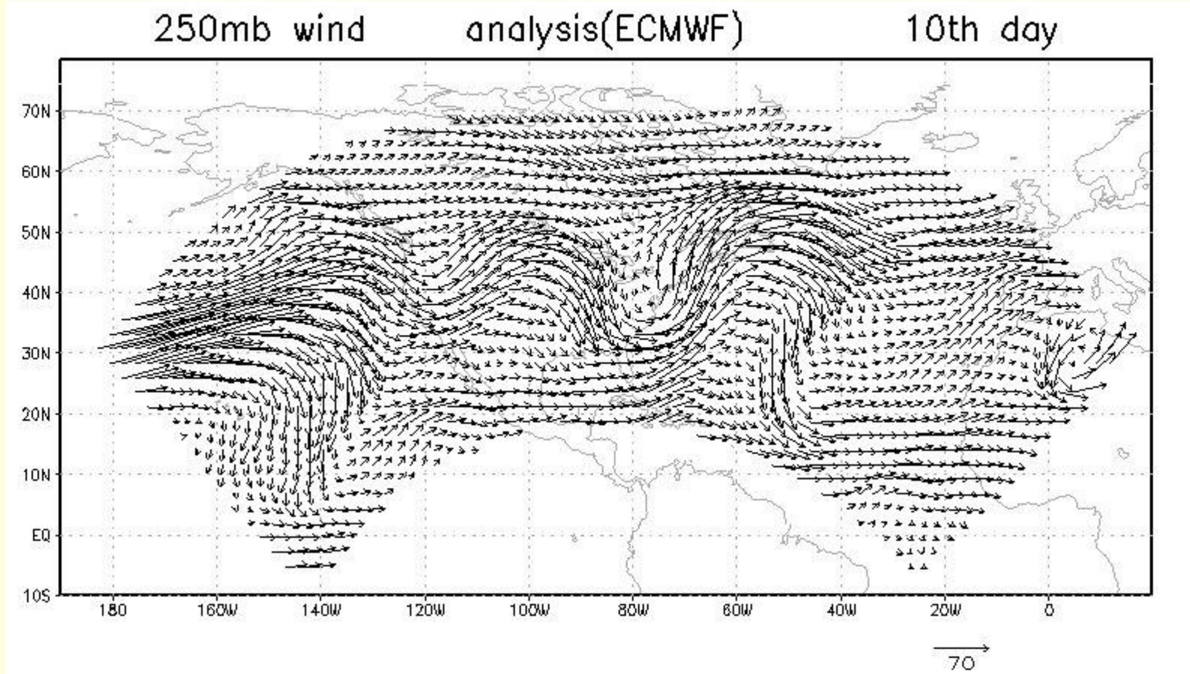
- Sloping steps (simplified shaved cells);
- Piecewise-linear vertical advection of dynamic variables (removes a problem of false advection from below ground with the standard Eta Lorenz-Arakawa finite difference scheme)
- Two problems with the lowest layer winds and steps identified and removed;
- Convection scheme parameters;
- . . .

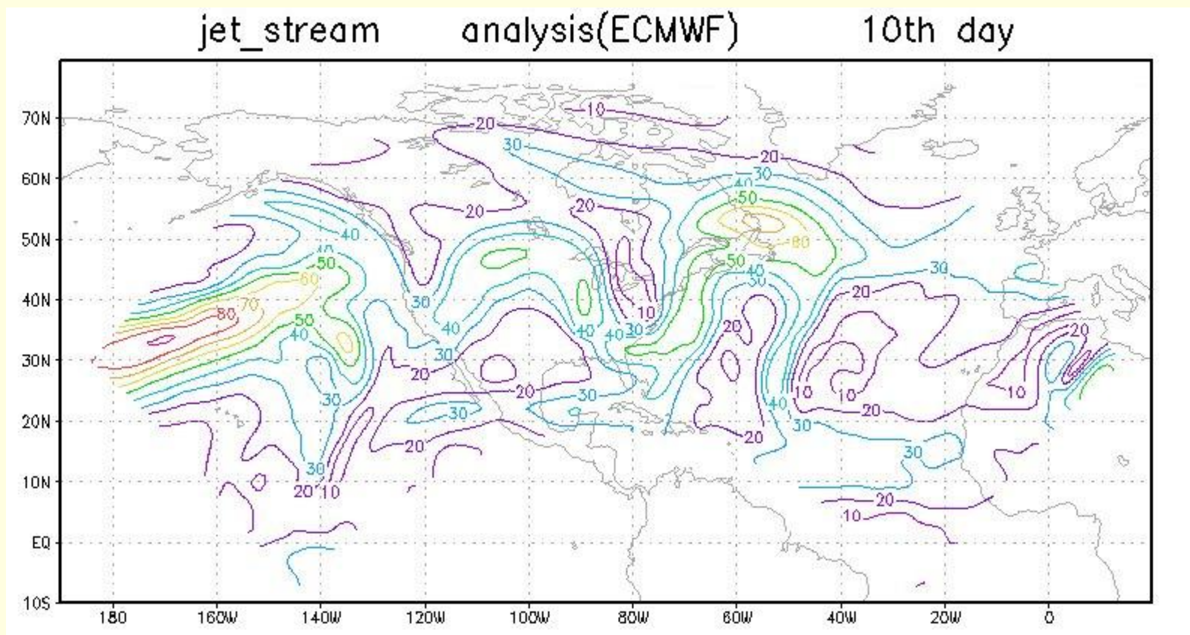
LBC experiments:



How can we identify "the skill in large scales"?

Standard method: "Direct-Cosine Transform" (DCT, Denis et al. 2002)

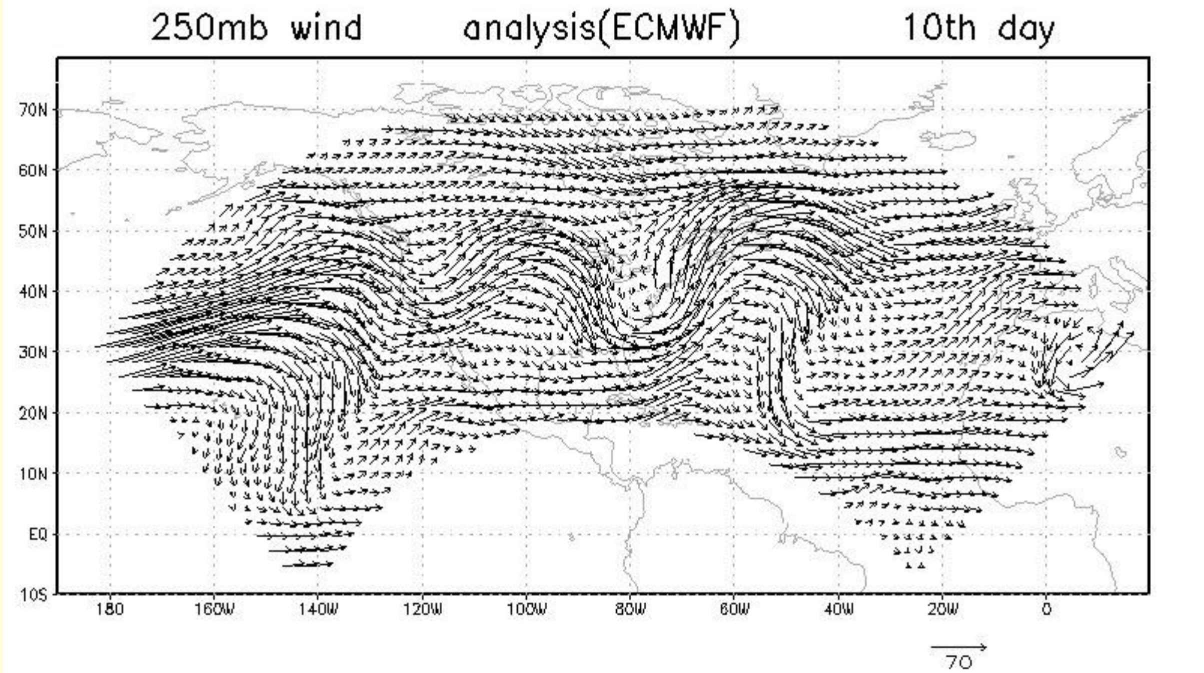


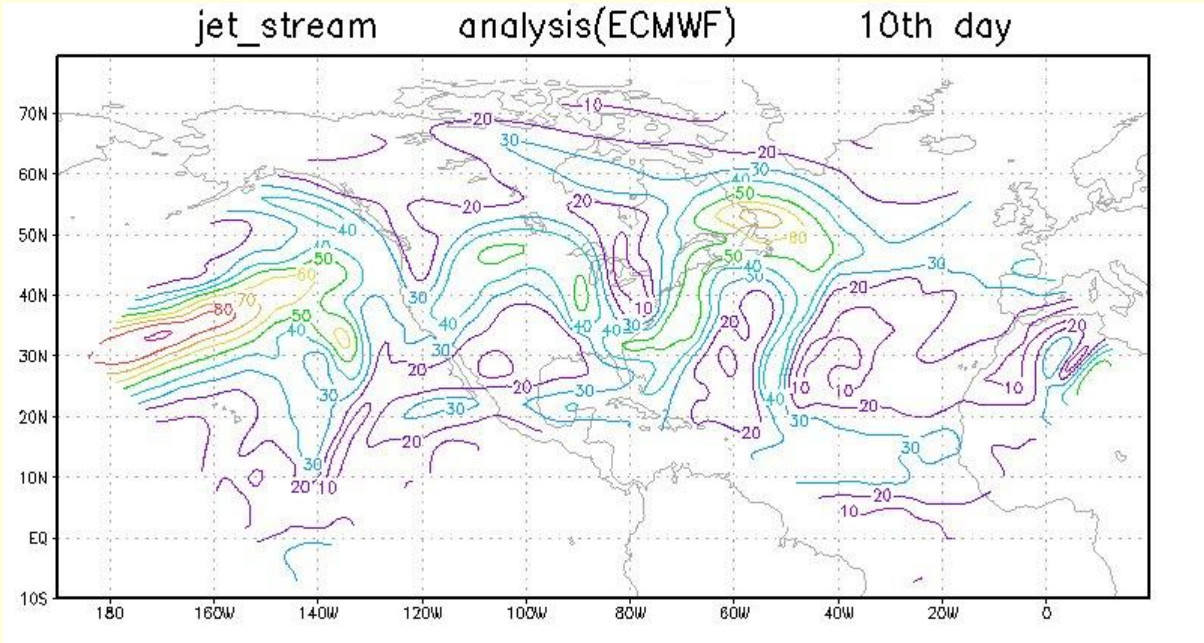


How can we identify "the skill in large scales"?

Standard method: "Direct-Cosine Transform" (DCT, Denis et al. 2002)

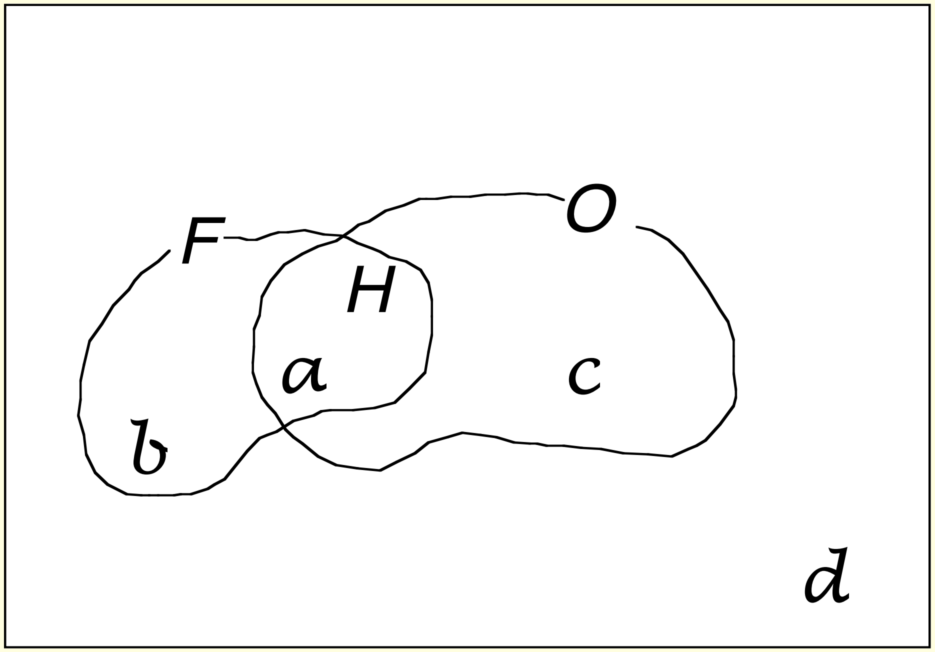
Veljović et al. instead: verification of the placement of the area of wind speeds > a chosen large value (50 m/s, later 45 m/s)





Precipitation verification :

F : forecast,
H : correctly
forecast: “hits”
O : observed



Equitable threat score (ETS):

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

"Bias adjusted ETS":

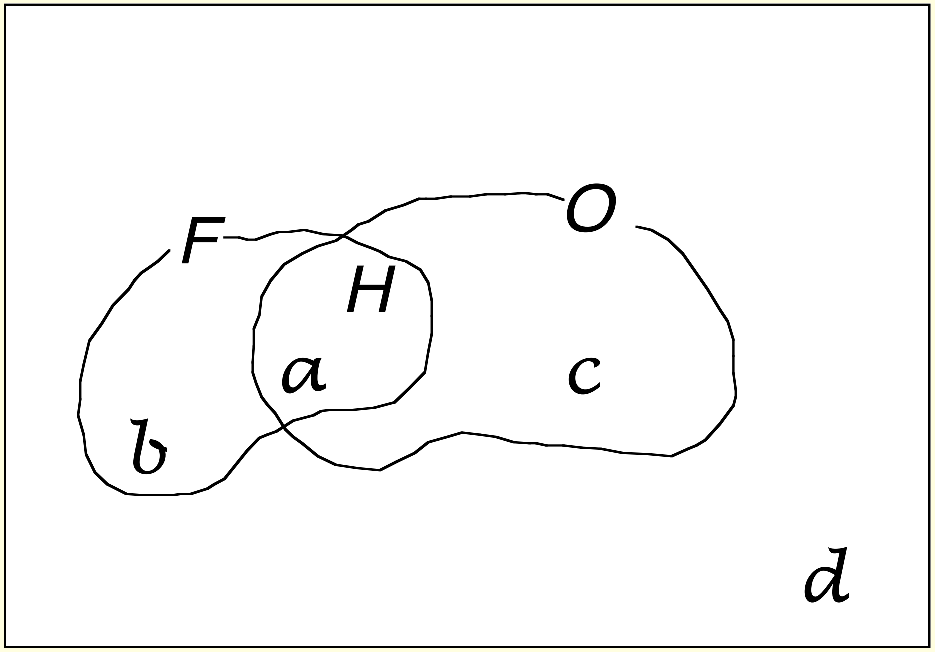
Replace H by H_a:

shows accuracy in *placing* the event

"dHdA method"

(Mesinger 2008):

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



A=*F*-*H* : False alarms;

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

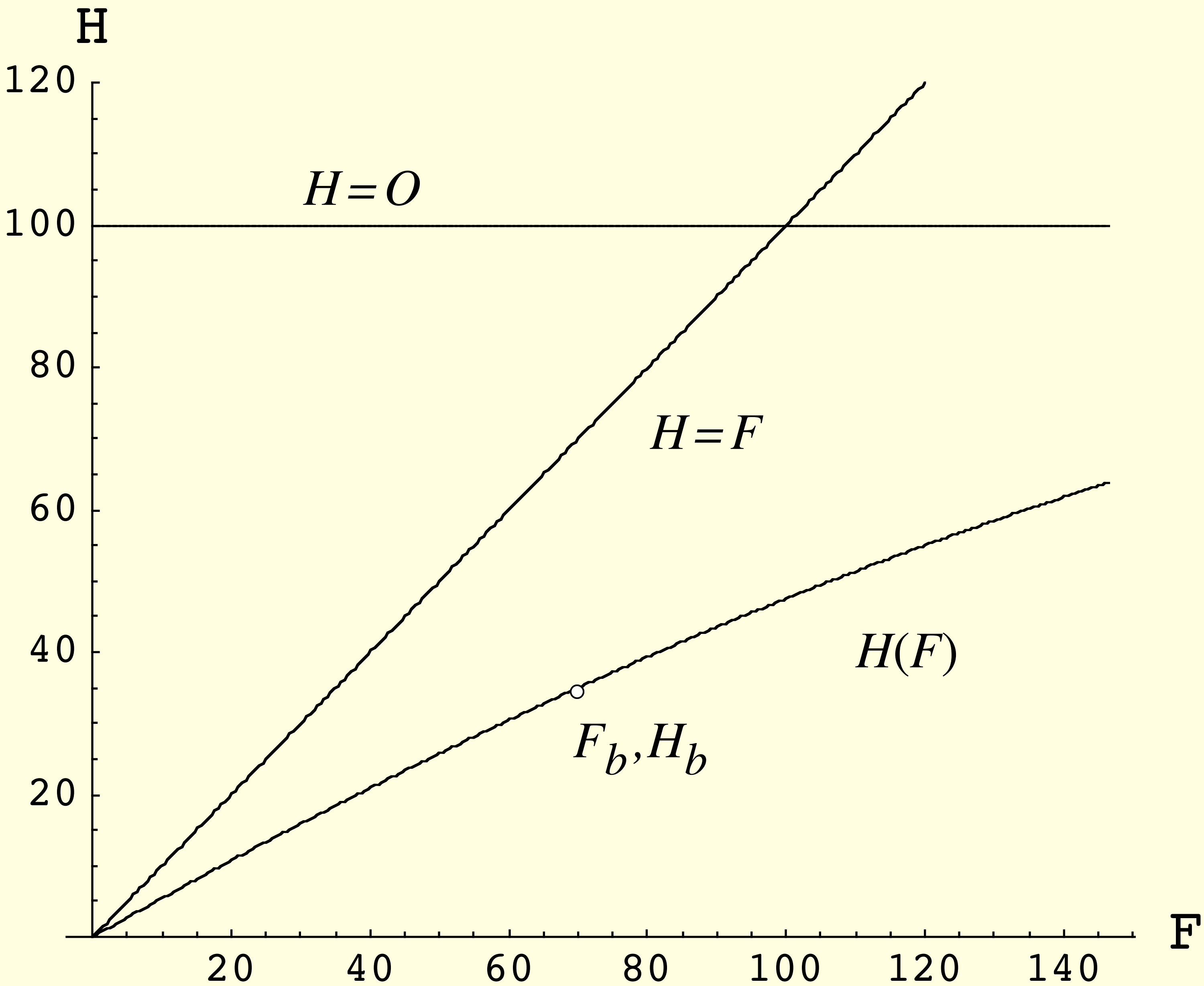
$$H(F) = O - \frac{1}{b}\,\mathrm{lambertw}\left(bO\,e^{b(O-F)}\right)$$

(Lambertw, or ProductLog in *Mathematica*,

is the inverse function of

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

dHdA method



Results

- Experiments in progress, now using the ECMWF 32 day ensemble, initialized 0000 UTC 1 January 2009;

  control T399 (~50 km) / 62 L

Resolution: 31 km/45 layer

Domain size ?

Many people:

things get worse as the domain size gets bigger

Reason: reanalysis used to prescribe the LBCs, and reanalysis used as truth ! (Internal variability !)

Assumption: Improving on large scales is possible. However: One cannot improve on large scales if the domain size is small !

Why is this important?

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things get worse as the domain size gets bigger

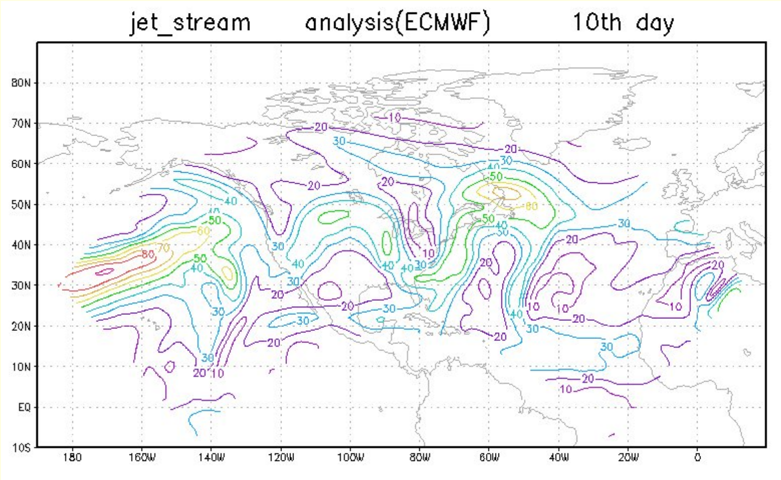
Reason: reanalysis used to prescribe the LBCs, and reanalysis used as truth ! (Internal variability !)

Assumption: Improving on large scales is possible.
However: One cannot improve on large scales if the domain size is small !

Why is this important?

A small gain in large scales is likely to result in large gains in small scales !! :-)

The largest domain of the 10-day experiments (16,400 x 6,000 km):



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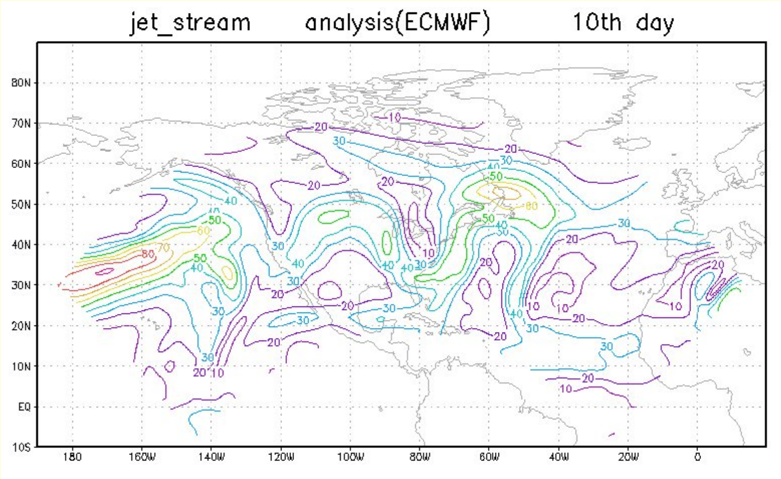
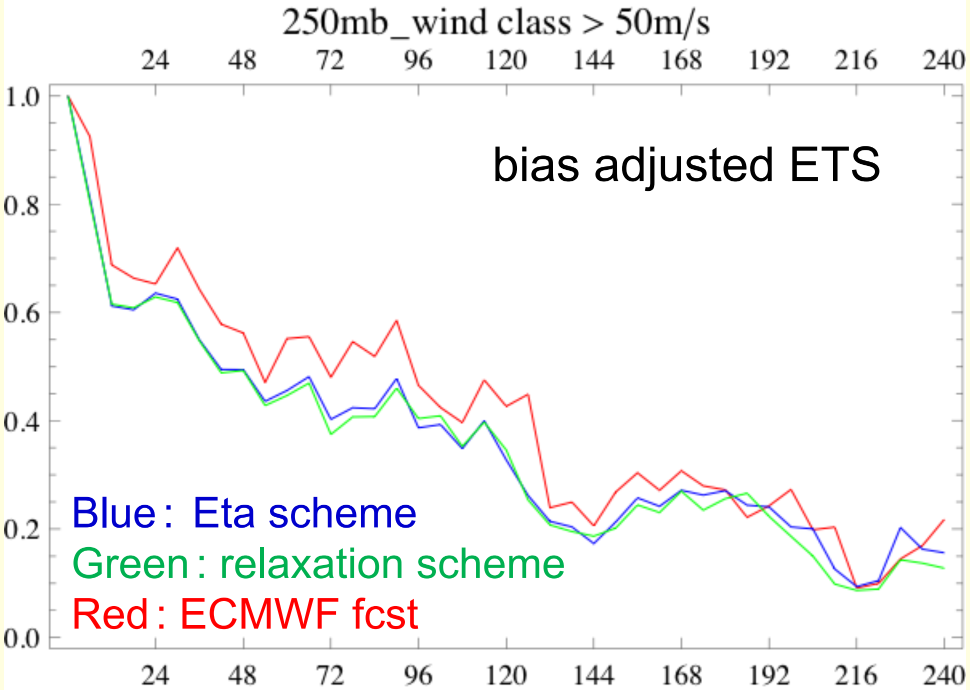
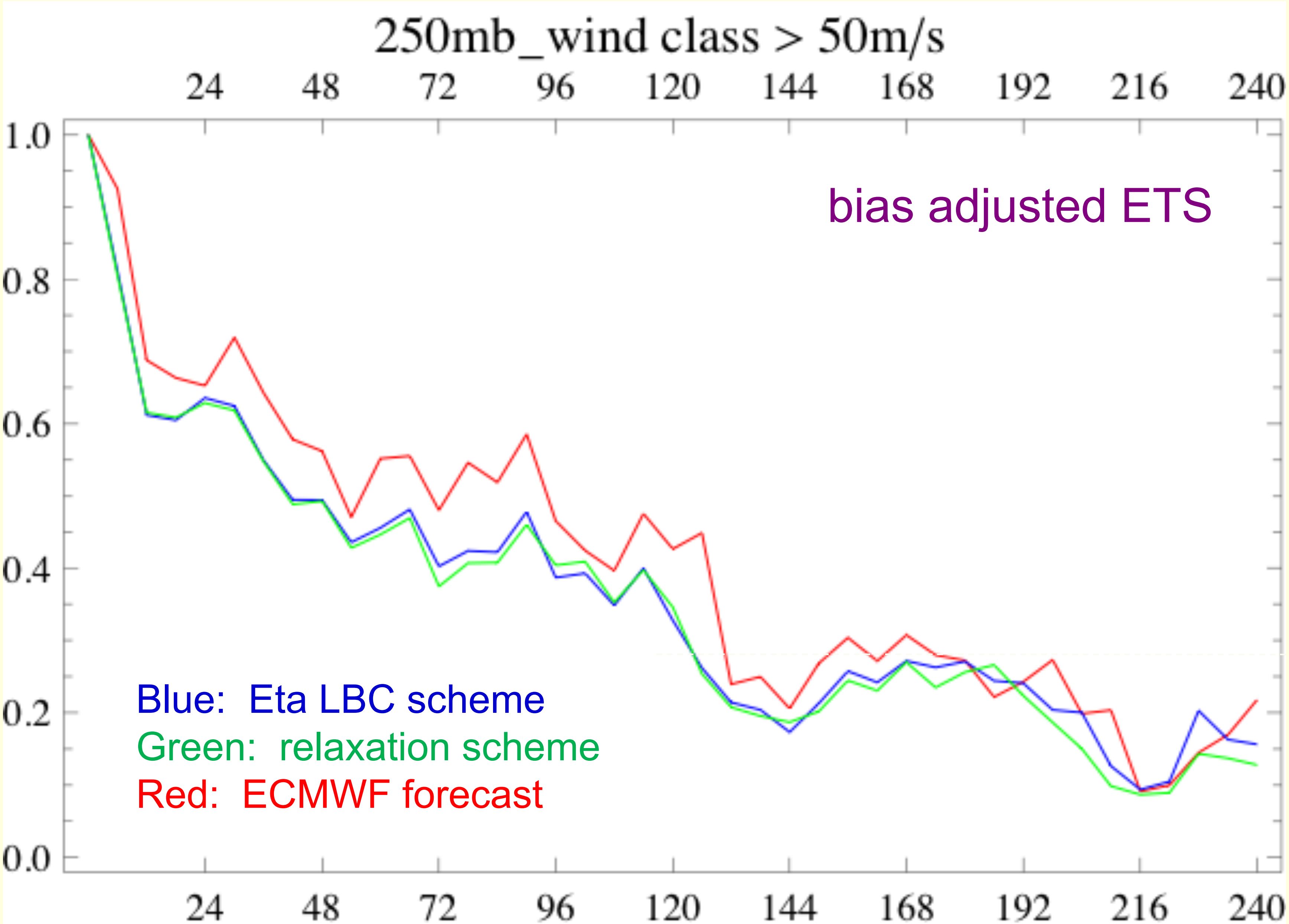
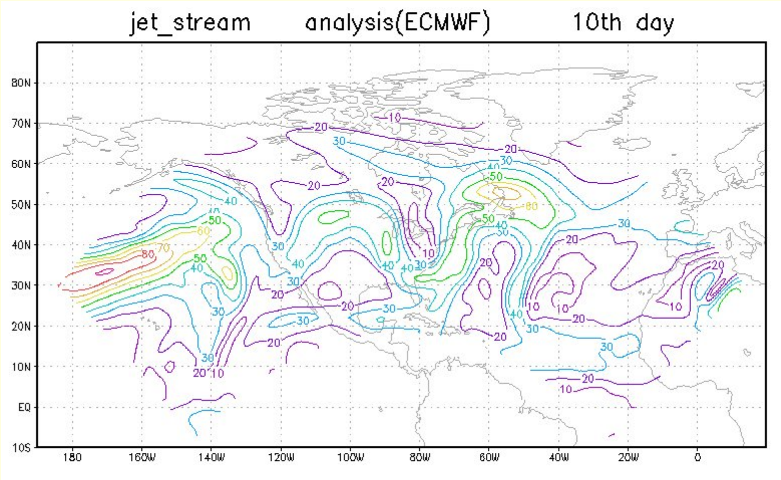
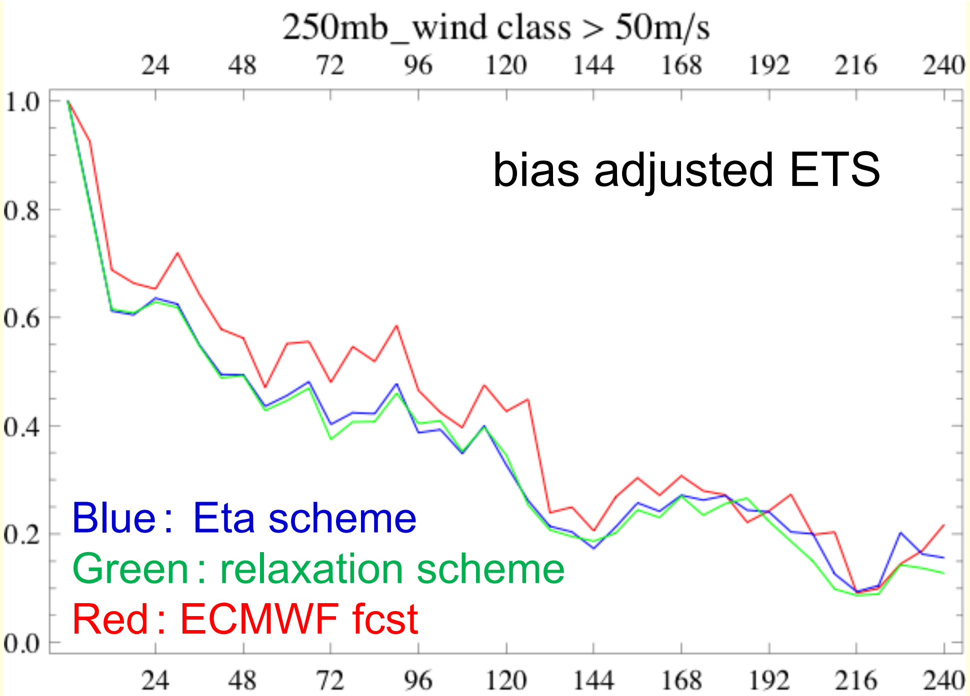





250mb_wind class > 50m/s
24
48
72
96
120
144
168
192
216
240
1.0
0.8
0.6
0.4
0.2
0.0
bias adjusted ETS
Blue: Eta LBC scheme
Green: relaxation scheme
Red: ECMWF forecast

The largest domain of the 10-day experiments (16,400 x 6,000 km):





Two LBC schemes:

Eta scheme vs Davies relaxation scheme

No benefit from relaxation

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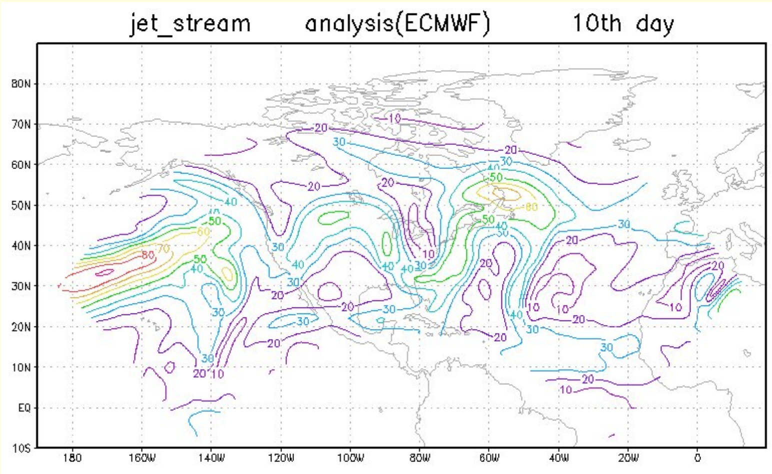

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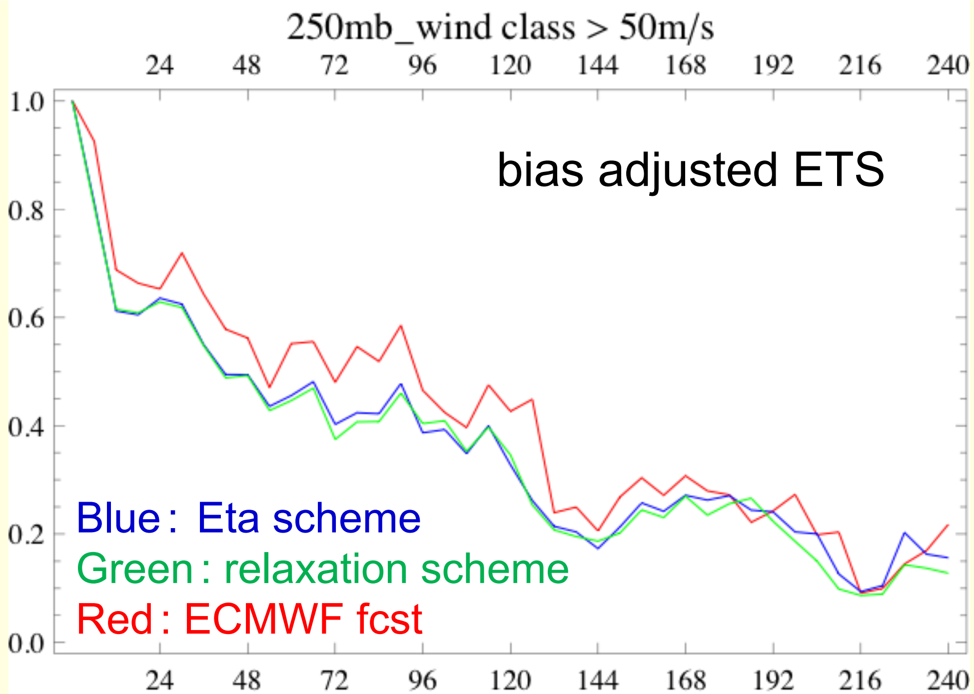

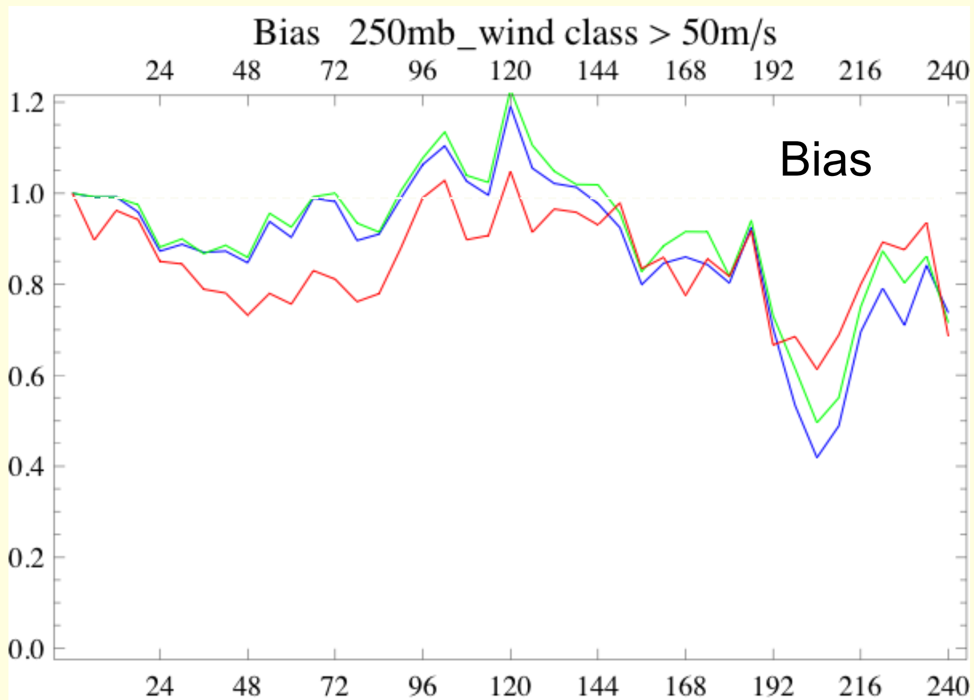

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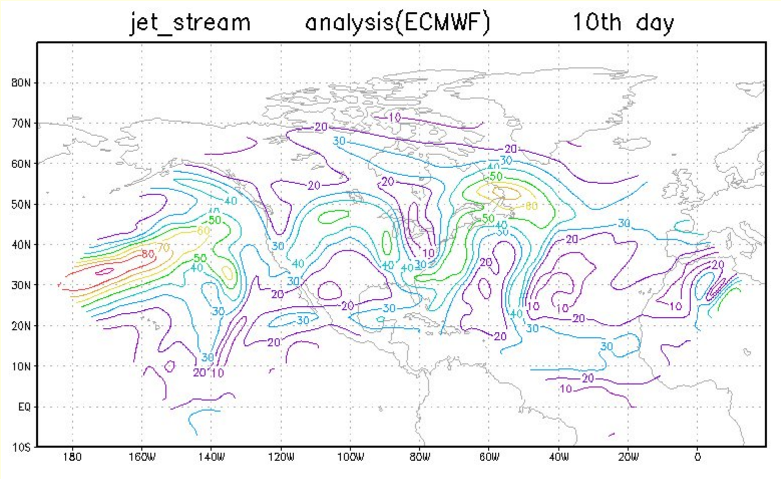


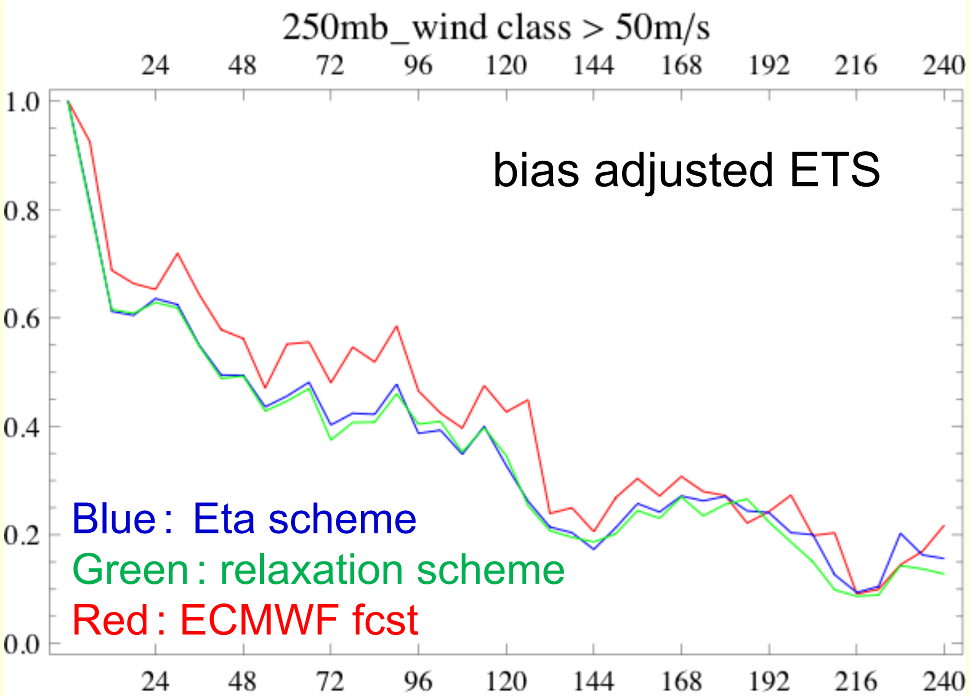
Two LBC schemes:

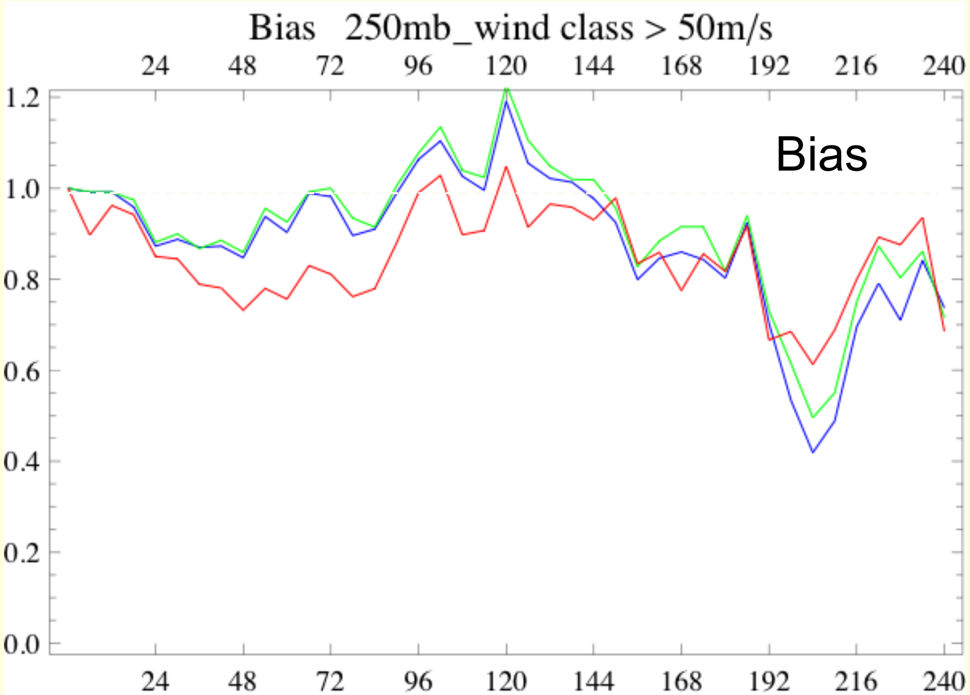
Eta scheme vs Davies relaxation scheme

No benefit from relaxation

Placement and area of wind speeds > 50 m/s at 10 days about the same;

No loss of "value of the large scale"





More recent experiments, in progress:

Driver forecasts:

ECMWF 32-day ensemble forecast members

T399 (~50 km)/62 level out to 15 days, with 6 h output; lower resolution later

Eta RCM: 31 km/45 layer, 12,000 x 7,580 km domain

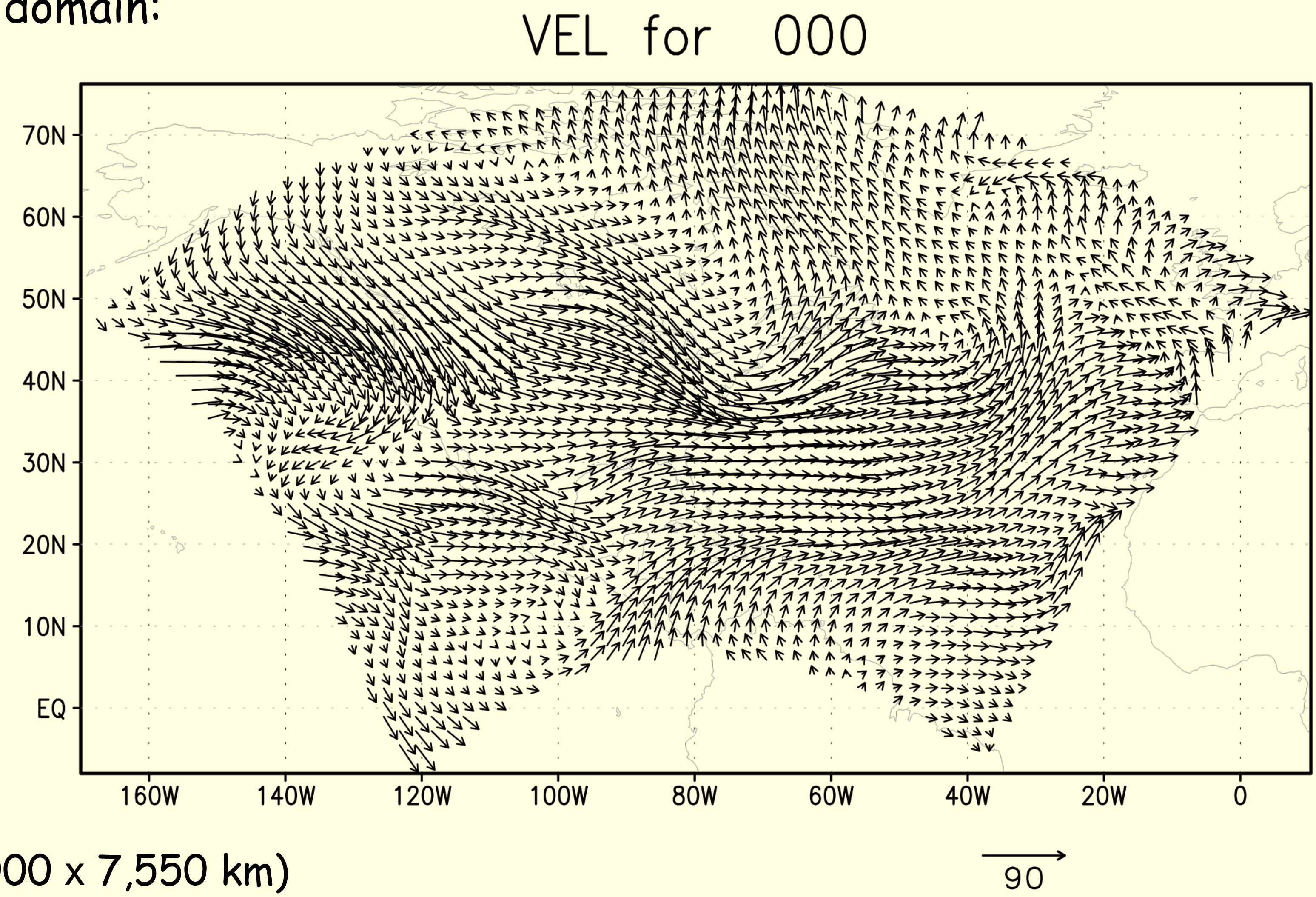
Verification against ECMWF analyses

32 day experiments:

ECMWF 32 day ensemble: ensemble control + 25 ensemble members

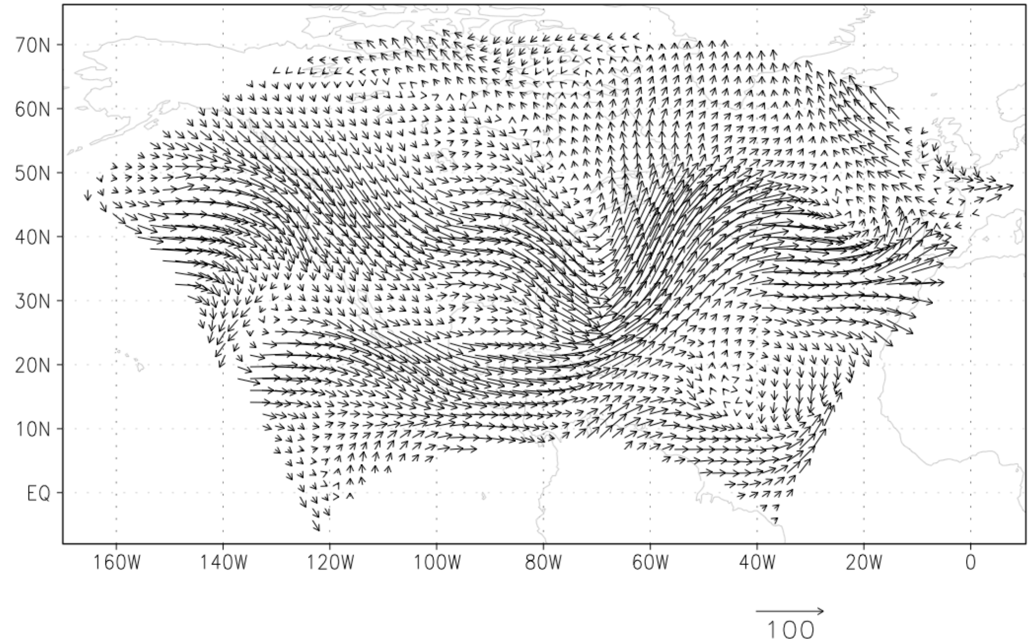
(T399, ~50 km; 62 levels, out to 15 days, reduced resolution later)

The domain:

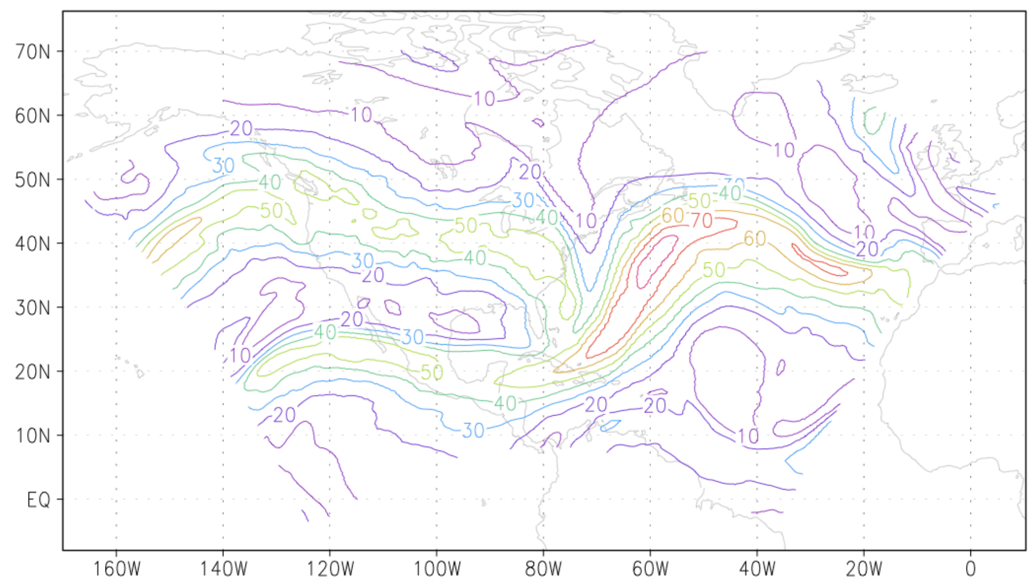


(12,000 x 7,550 km)

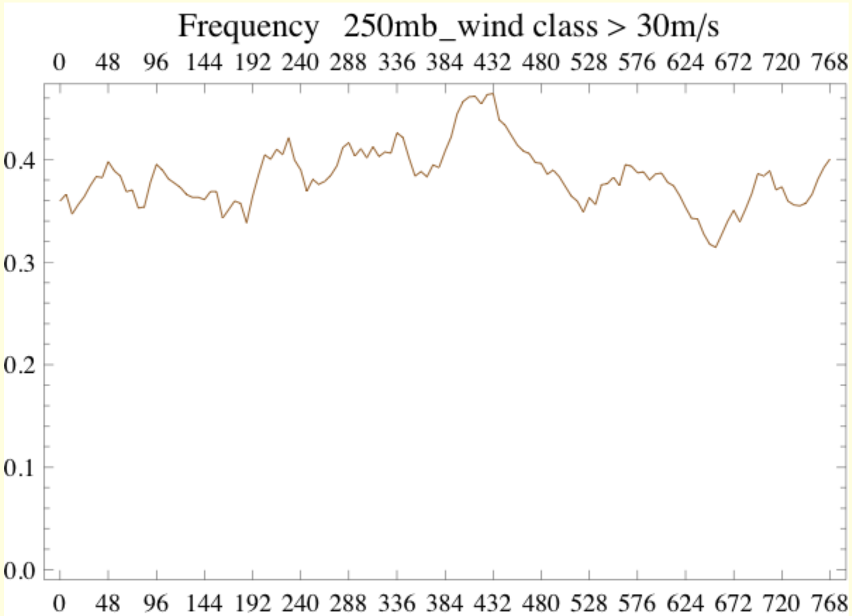
250mb wind analysis(ECMWF) 32nd day

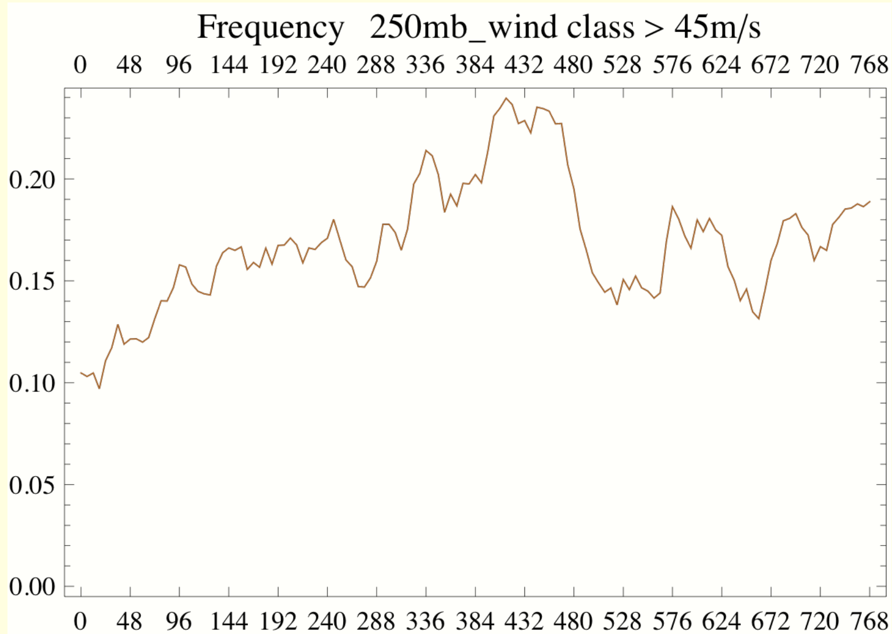


jet_stream analysis(ECMWF) 32nd day



What speeds should we look at ?





> 30 m/s

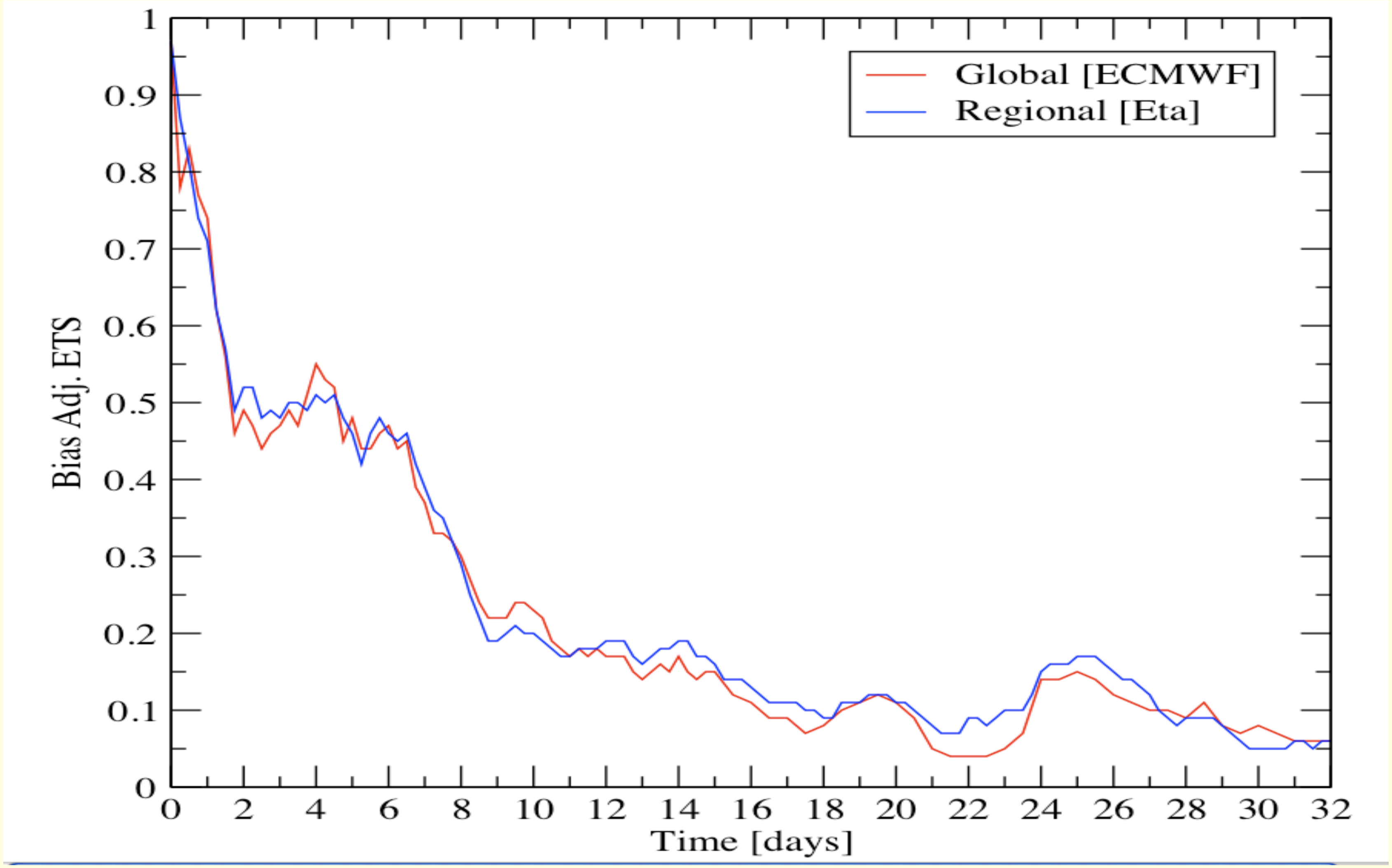
> 45 m/s

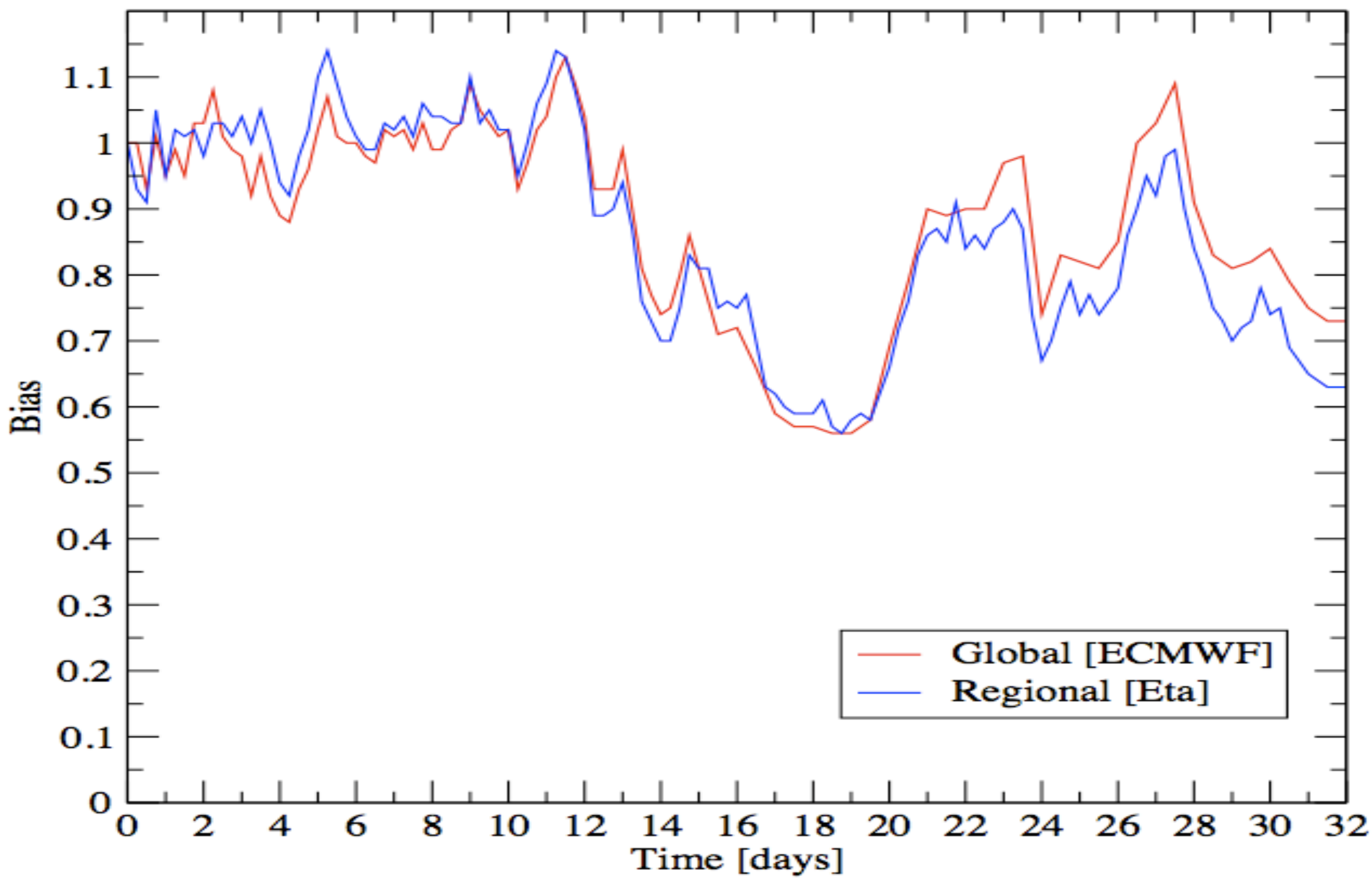
What should one do to assess the skill of an *ensemble* of forecasts ?

Same as what is done with precipitation:

add all of the values of H, F, and O

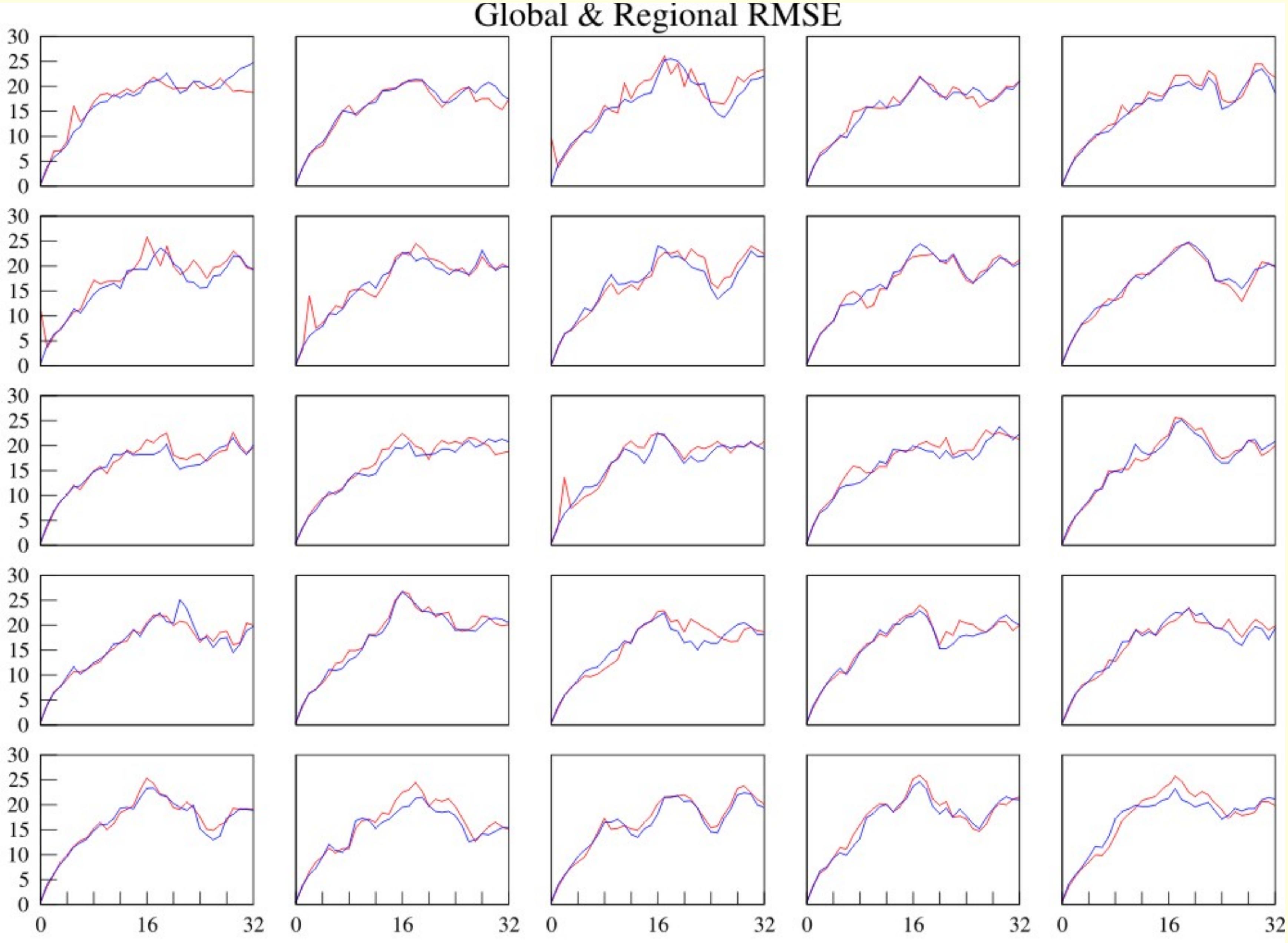
26 (25 members + control) 32-day forecasts:



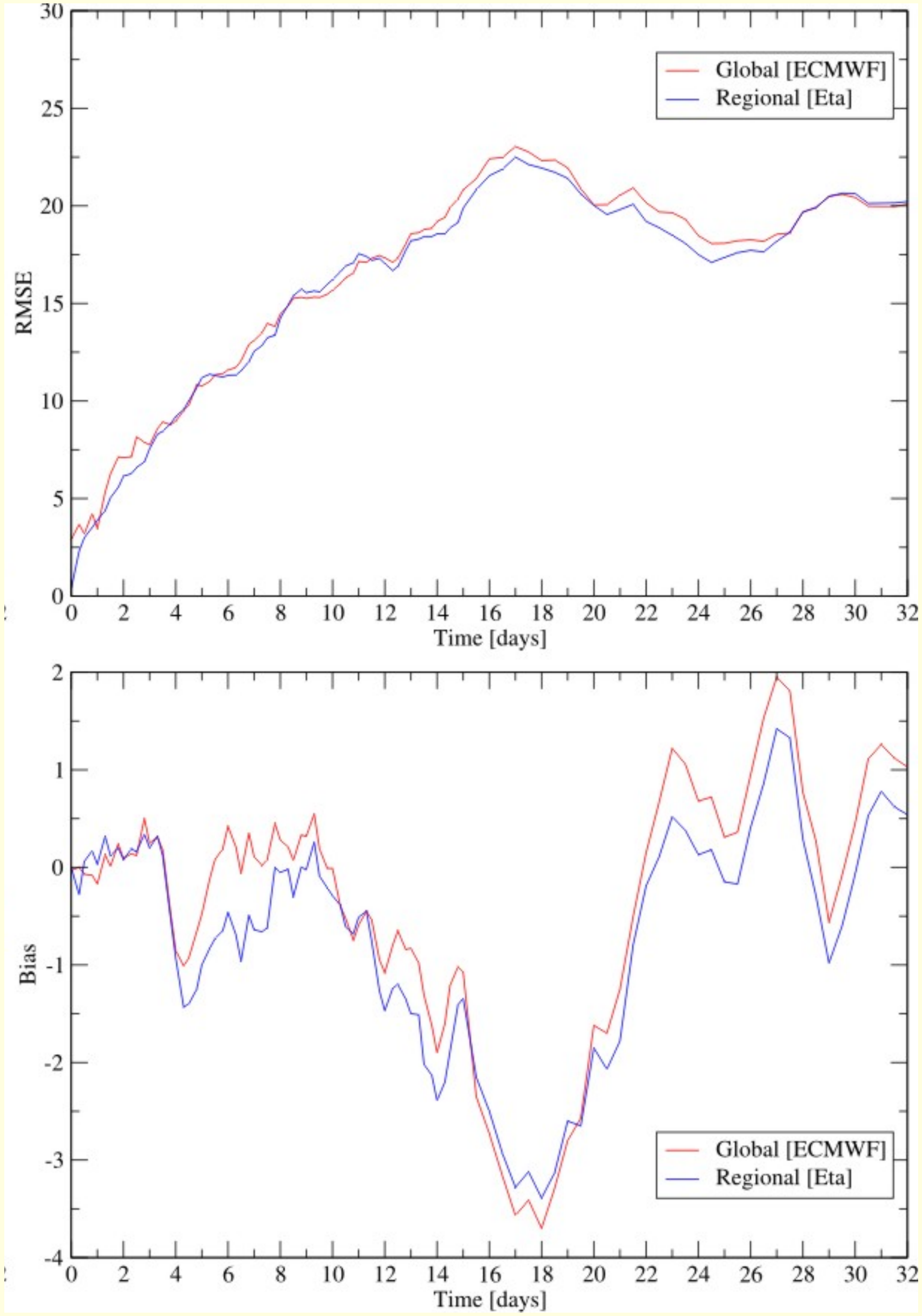


Bias
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Time [days]
Global [ECMWF]
Regional [Eta]

More traditional verification: root mean square 250 mb wind errors:



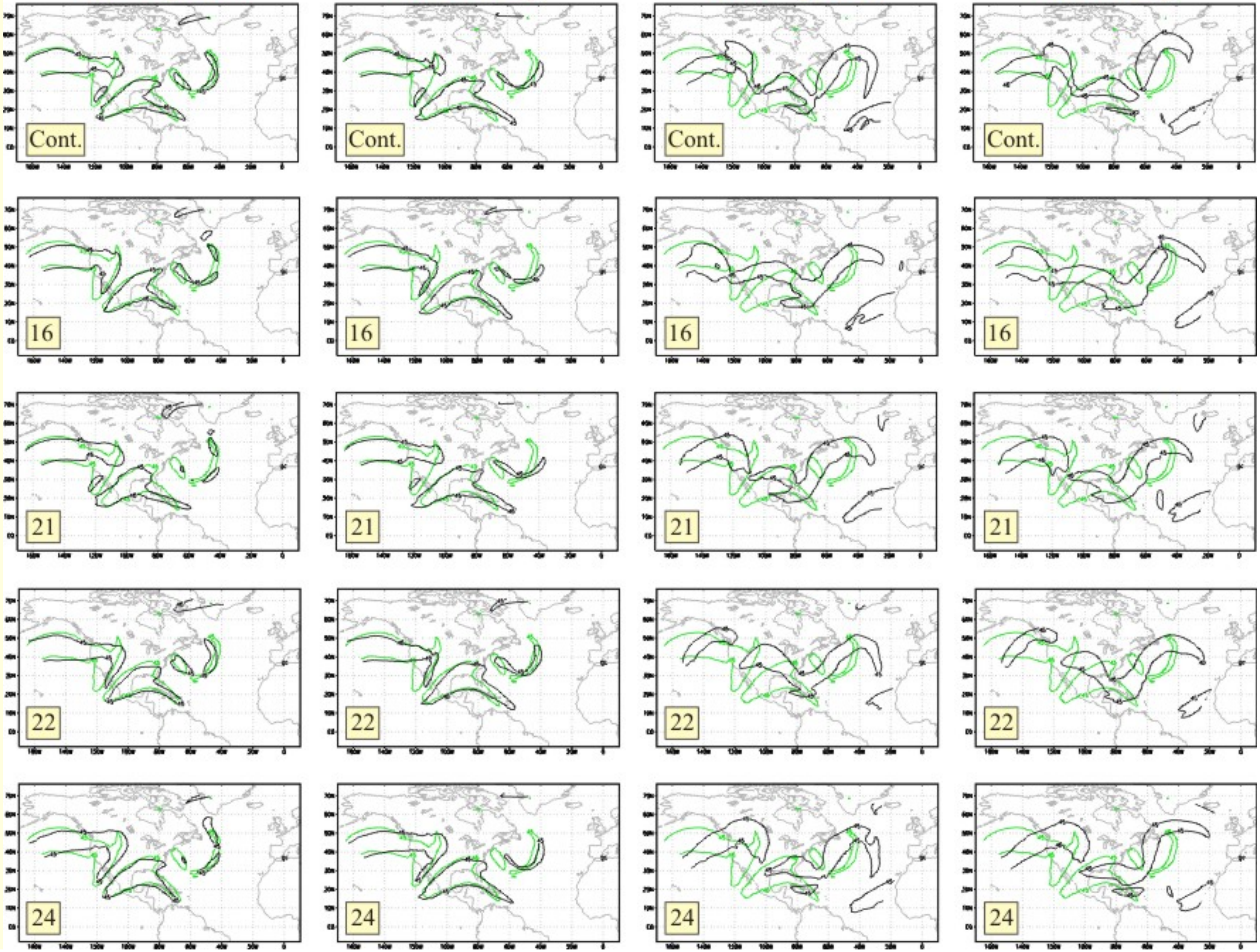
All 26 forecasts:



Green: analyses

Black: forecasts

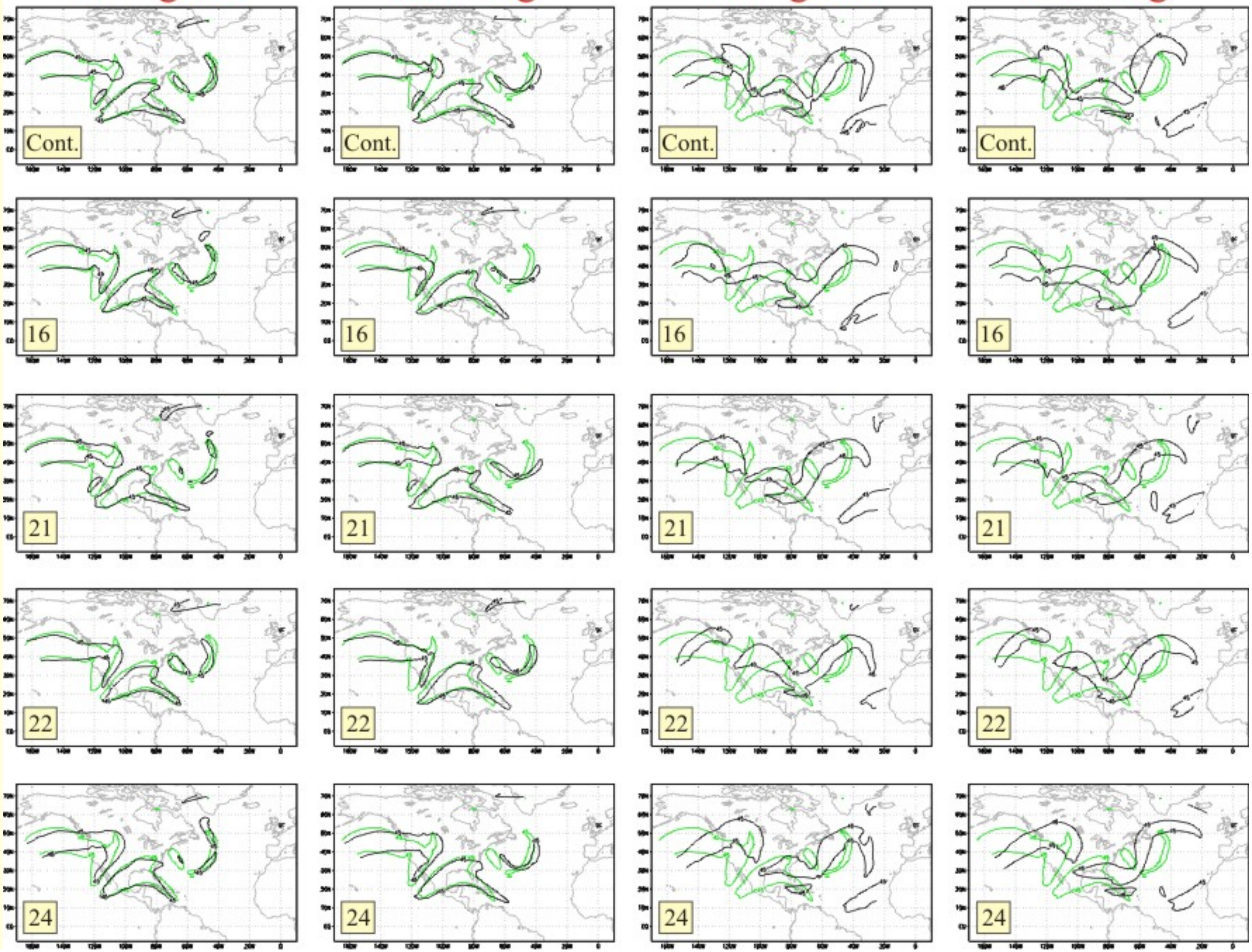
4th an + glob	4th an + reg	8th an + glob	8th an + reg



Green: analyses

Black: forecasts

16th an + glob	16th an + reg	32nd an + glob	32nd an + reg



Thus, take home message:

- No disadvantage from using the Eta LBCs (less resource demanding, less of a constraint) compared to relaxation;

- Running the Eta as an RCM, no significant loss of large-scale kinetic energy with time (?);

- The Eta RCM skill in forecasting large scales (with no interior nudging) just about the same as that of the driver model; frequently even higher !!!!!

- This despite the driver global forecast enjoying a bit of an advantage, since it is done using the same model as that which is a part of the data assimilation system !

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How is that possible ?

What is/are the main advantage/ main advantages of the Eta making this happen?

Some references (most other available in Giorgi 2006, and/or Laprise et al. 2008)

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