Cut-cell Eta: Some history, and lessons from its present skill

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Numerical Weather and Climate Modeling

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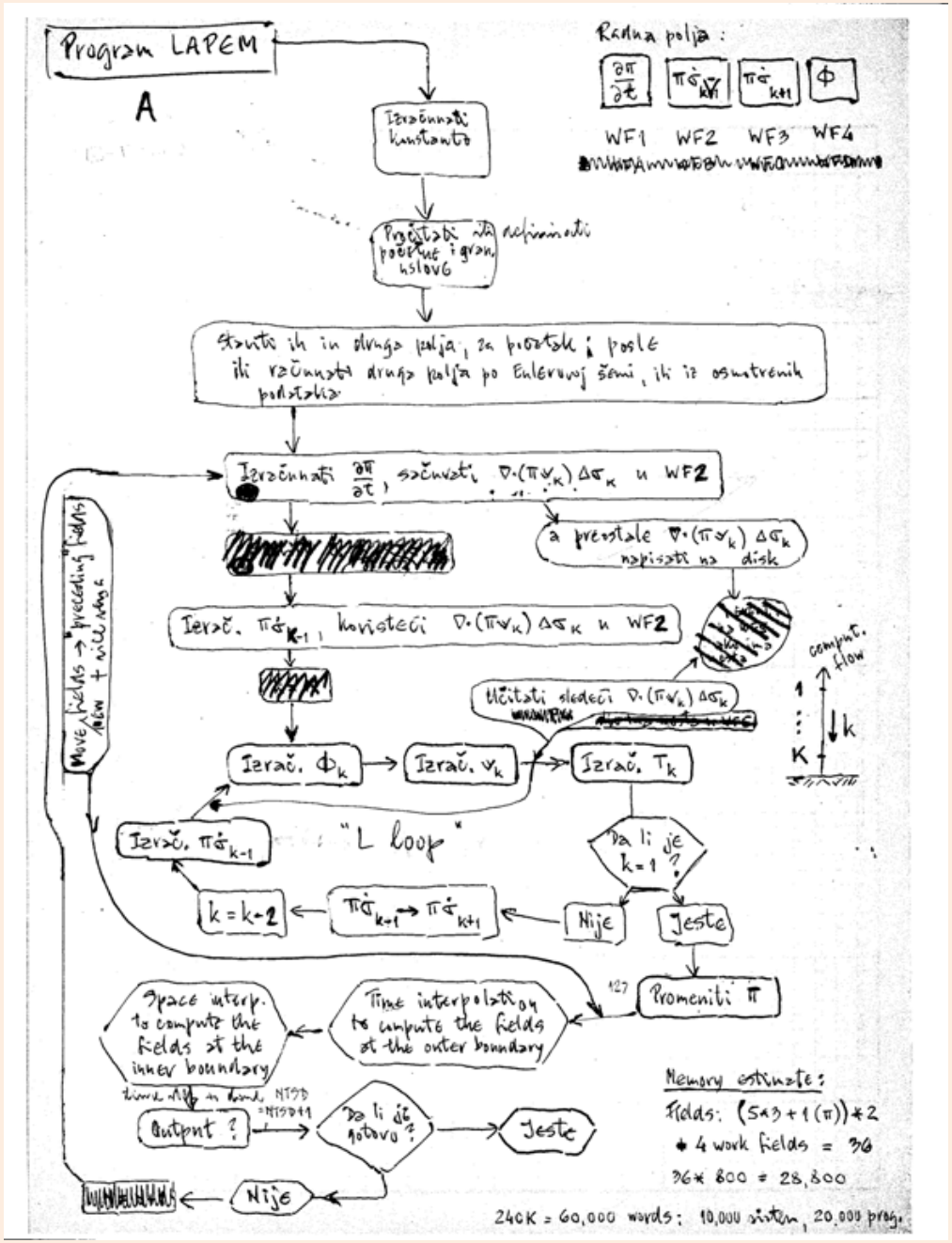
1973:


Program LAPEM
A
Izračunati konstante
Radna polja :
WF1 WF2 WF3 WF4
Pročitati ulazne podatke i granične uslove
računati
Izračunati ∂π/∂t, sačuvati ∇·(πv_k)Δσ_k u WF2
a preostale ∇·(πv_k)Δσ_k napisati na disk
Iterač. πσ̇_{k-1}, koristeći ∇·(πv_k)Δσ_k u WF2
Move fields → preceding "fields" + new values
Učitati sledeći ∇·(πv_k)Δσ_k
compat. flow
1
k
K
Izrač. Φ_k
Izrač. v_k
Izrač. T_k
Izrač. πσ̇_{k-1}
"L loop"
Da li je k=1 ?
k = k-2
πσ̇_{k-1} → πσ̇_{k+1}
Nije
Jeste
Promeniti π
Space interp. to compute the fields at the inner boundary
Time interpolation to compute the fields at the outer boundary
Output ?
Da li je gotovo ?
Jeste
Nije
Memory estimate:
Fields: (5×3+1(π))×2
+ 4 work fields = 36
36×800 = 28,800
240K = 60,000 words; 10,000 system, 20,000 prog.

Skill ?

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

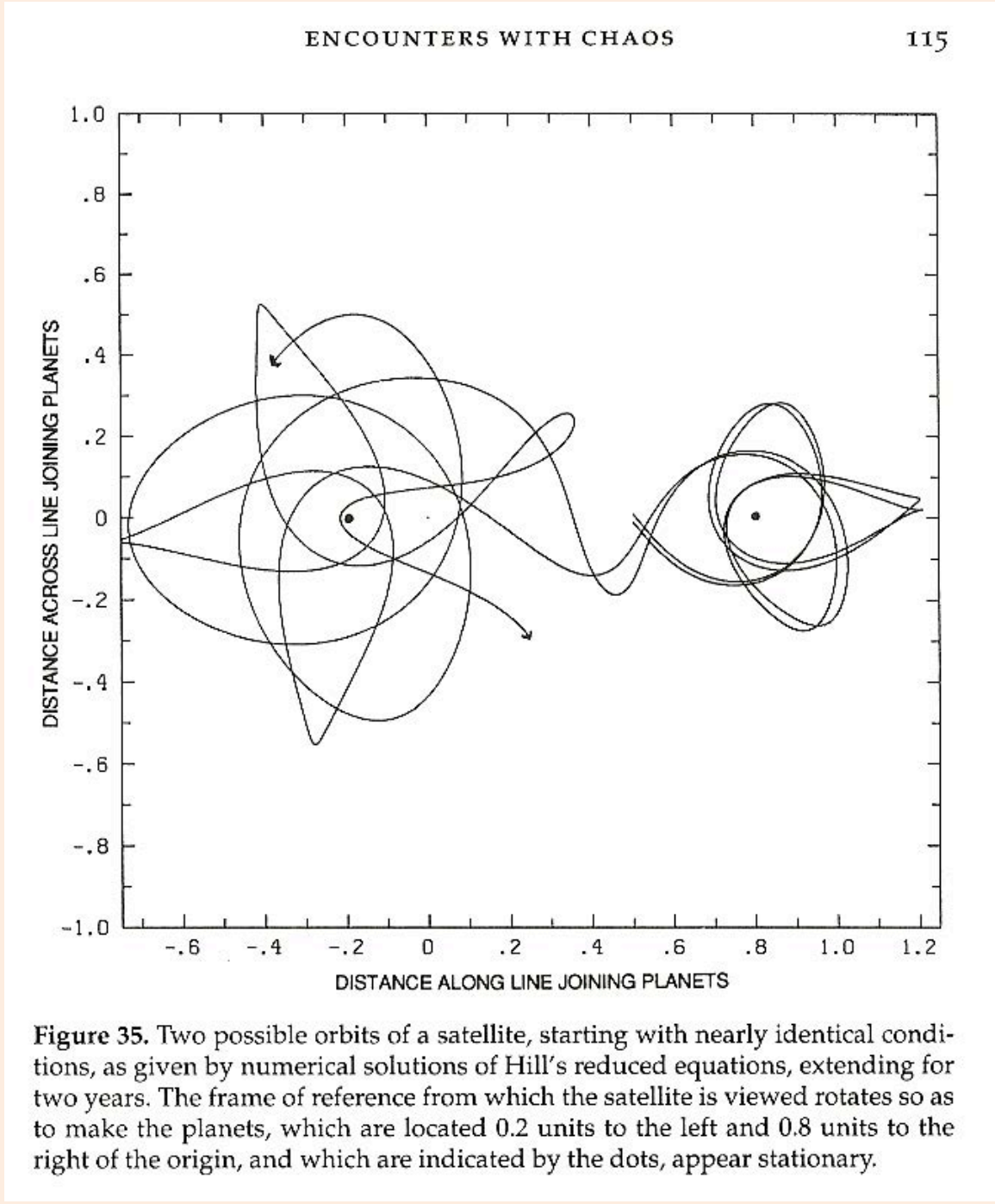


Figure 35. Two possible orbits of a satellite, starting with nearly identical conditions, as given by numerical solutions of Hill's reduced equations, extending for two years. The frame of reference from which the satellite is viewed rotates so as to make the planets, which are located 0.2 units to the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

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

Chaos:

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

Acknowledgement: Posting on Eugenia Kalnay's office door at the Univ. of Maryland

Accuracy of the jet stream position forecast as a dynamical core test: Cut-cell Eta vs. ECMWF 32-day ensemble results

Accuracy ?

of a model, ran using real data IC

Issues:

Atmosphere is chaotic

Results depend on data assimilation system

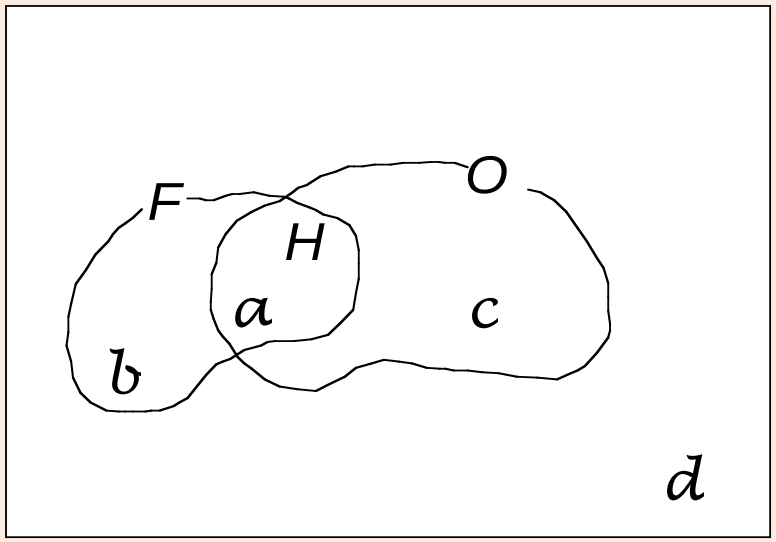
Impacts of both are avoided if we drive our limited area "test model" by ICs and LBCs of an ensemble of a global model

"Although spectral transform methods are being predicted to be phased out, the current spectral model at the European Centre for Medium-Range Weather Forecasts … is the benchmark to beat, and it is not clear that any of the new developments are ready to replace it."

Côté J, Jablonowski C, Bauer P, Wedi N (2015) Numerical methods of the atmosphere and ocean. Seamless prediction of the Earth system: From minutes to months, 101–124. World Meteorological Organization, WMO-No. 1156.

Accuracy of the jet stream position . . . .

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



Many verification scores.

One:

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

"Equitable Threat Score"

or, Gilbert (1884 !) Skill Score

Bias = *F* / *O*

ECMWF once a week runs a 51 member ensemble forecast 32 days ahead

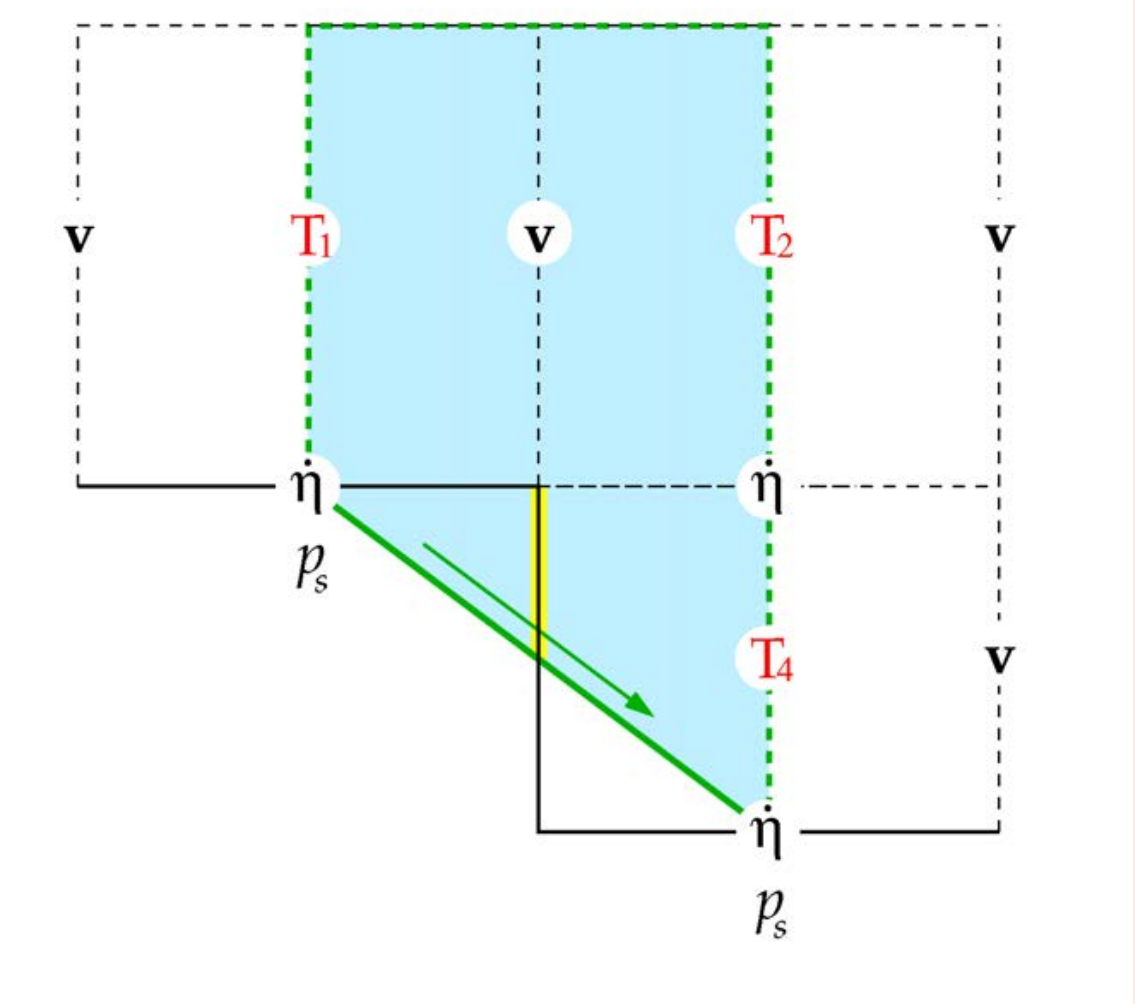
Veljovic K, Rajkovic B, Fennessy MJ, Altshuler EL, Mesinger F (2010) Regional climate modeling: Should one attempt improving on the large scales? Lateral boundary condition scheme: Any impact? Meteorol Zeitschrift, **19**, 237-246, doi:10.1127/0941-2948/2010/0460

Mesinger F, Chou SC, Gomes J, Jovic D, Bastos P, Bustamante JF, Lazic L, Lyra AA, Morelli S, Ristic I, Veljovic K (2012) An upgraded version of the Eta model. Meteorol Atmos Phys **116**, 63–79. doi:10.1007/s00703-012-0182-z

Mesinger, F, Veljovic K (2017) Eta vs. sigma: Review of past results, Gallus-Klemp test, and large-scale wind skill in ensemble experiments. Meteorol Atmos Phys, **129**, 573-593, doi:10.1007/s00703-016-0496-3

To address the Gallus-Klemp (2000) problem: The sloping steps (a simple cut-cell scheme), vertical grid:

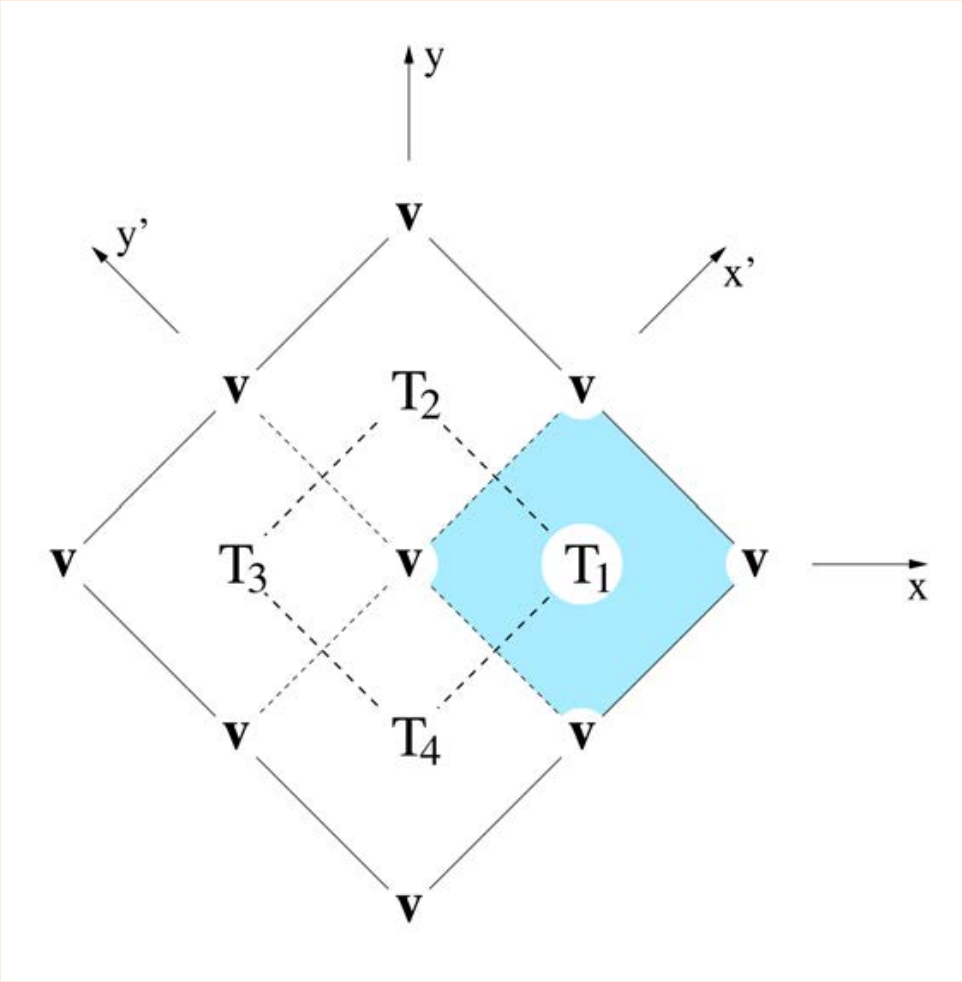
The central **v** box exchanges momentum, on its right side, with **v** boxes of two layers:



Horizontal treatment, 3D

Case #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



Acknowledgements: Dušan Jović, Jorge Gomes

How are grid cell values of topography obtained ?

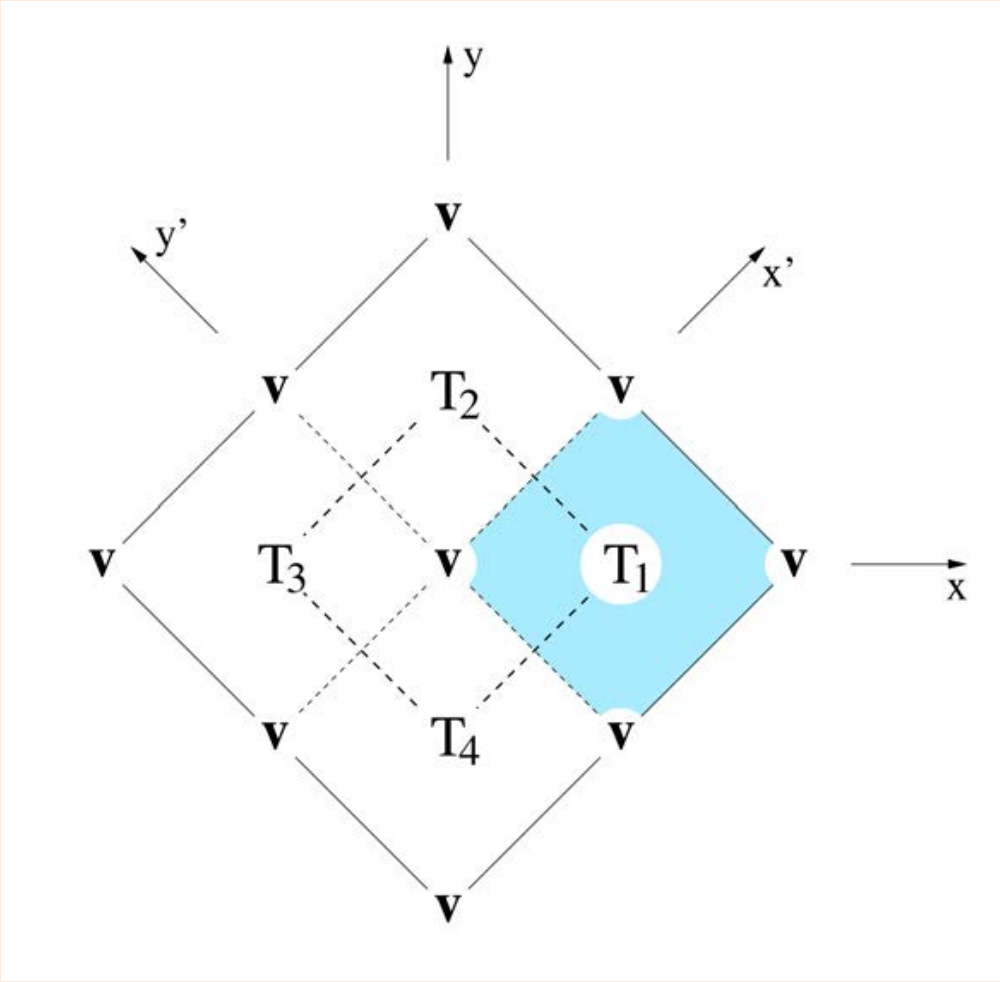
Chop up each cell into n x n sub-cells;

Obtain each sub-cell mean value;

Obtain mean h_m and silhouette cell value, round off to discrete interface value;

Choose one depending on Laplacian h_m

Remove basins with all corner winds blocked;



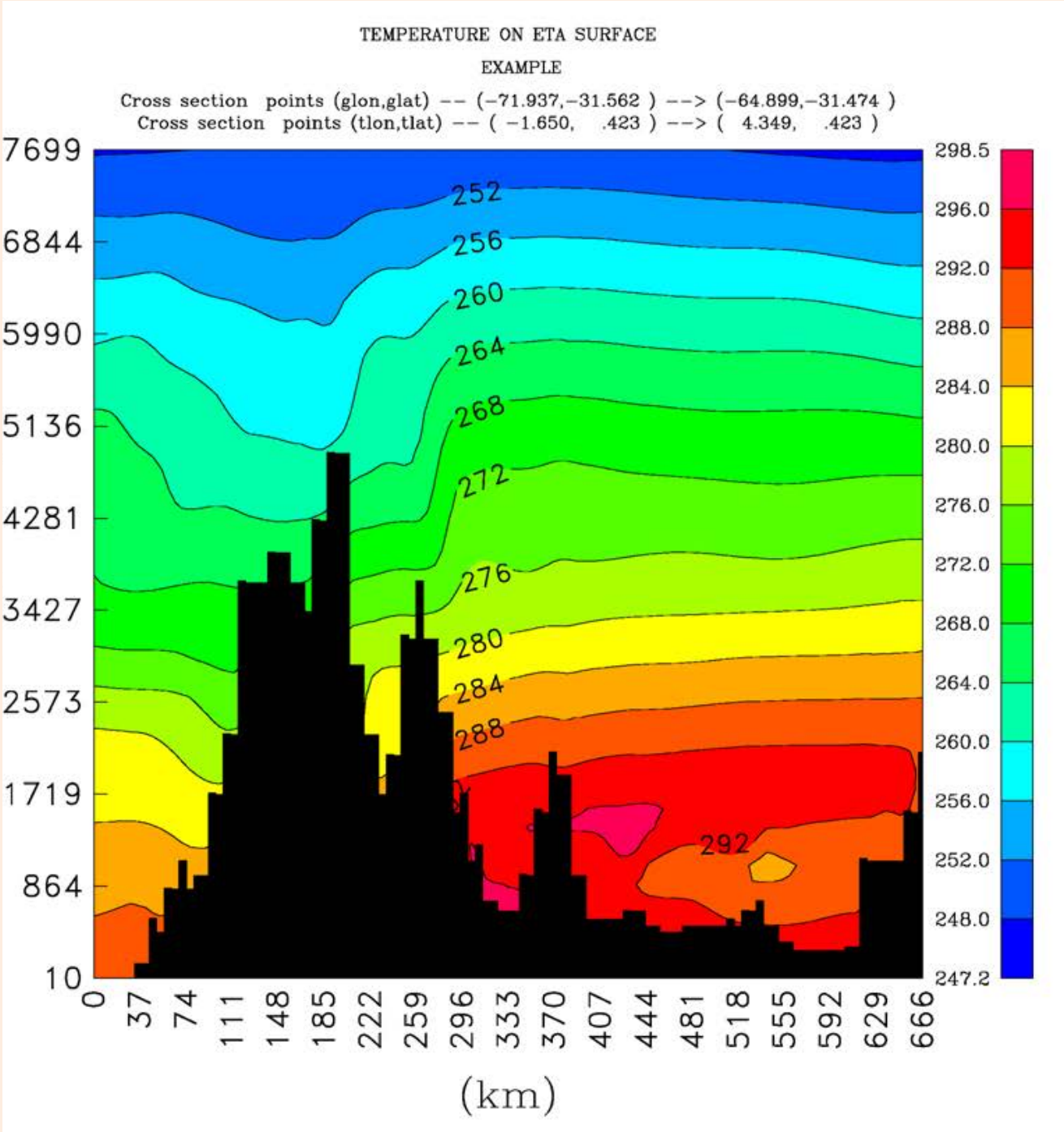
Some more common sense rules (no waterfalls, do not close major ridges by silhouetting), but no smoothing

8 km horizontal resolution,

W/E profile at the latitude of about the highest elevation of the Andes

30 hr forecast:

NCAR graphics, no cell values smoothing

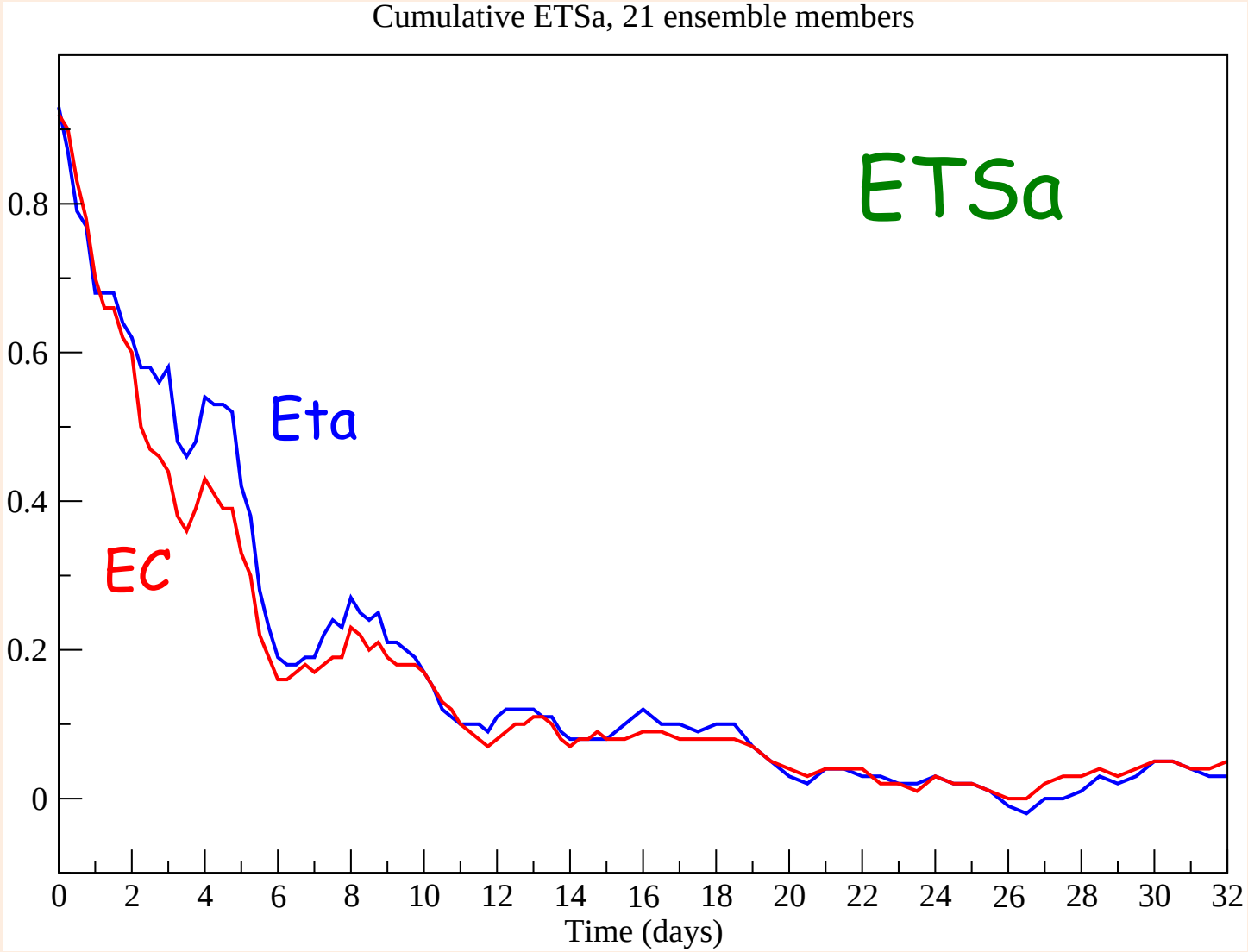


Another cut-cell scheme: Steppeler et al. (2008, 2013):

Steppeler J, Park S-H, Dobler A (2013) Forecasts covering one month using a cut-cell model. Geosci. Model Dev., **6**, 875-882. doi:10.5194/gmd-6-875-2013

Verification results

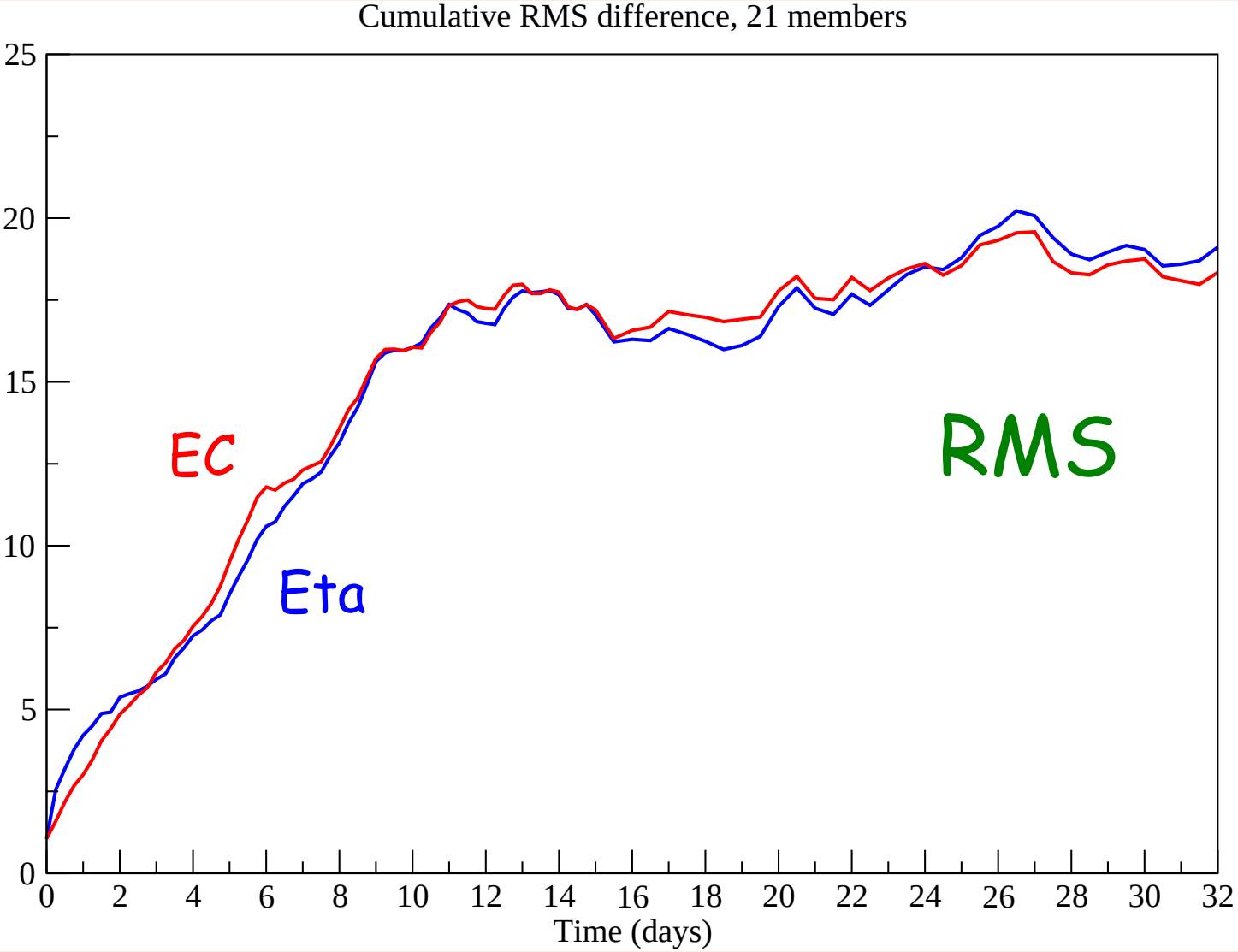
21 ensemble members



Bias adjusted ETS scores of wind speeds > 45 m s^{-1}, at 250 hPa, with respect to ECMWF analyses

ETSa:

More is better !



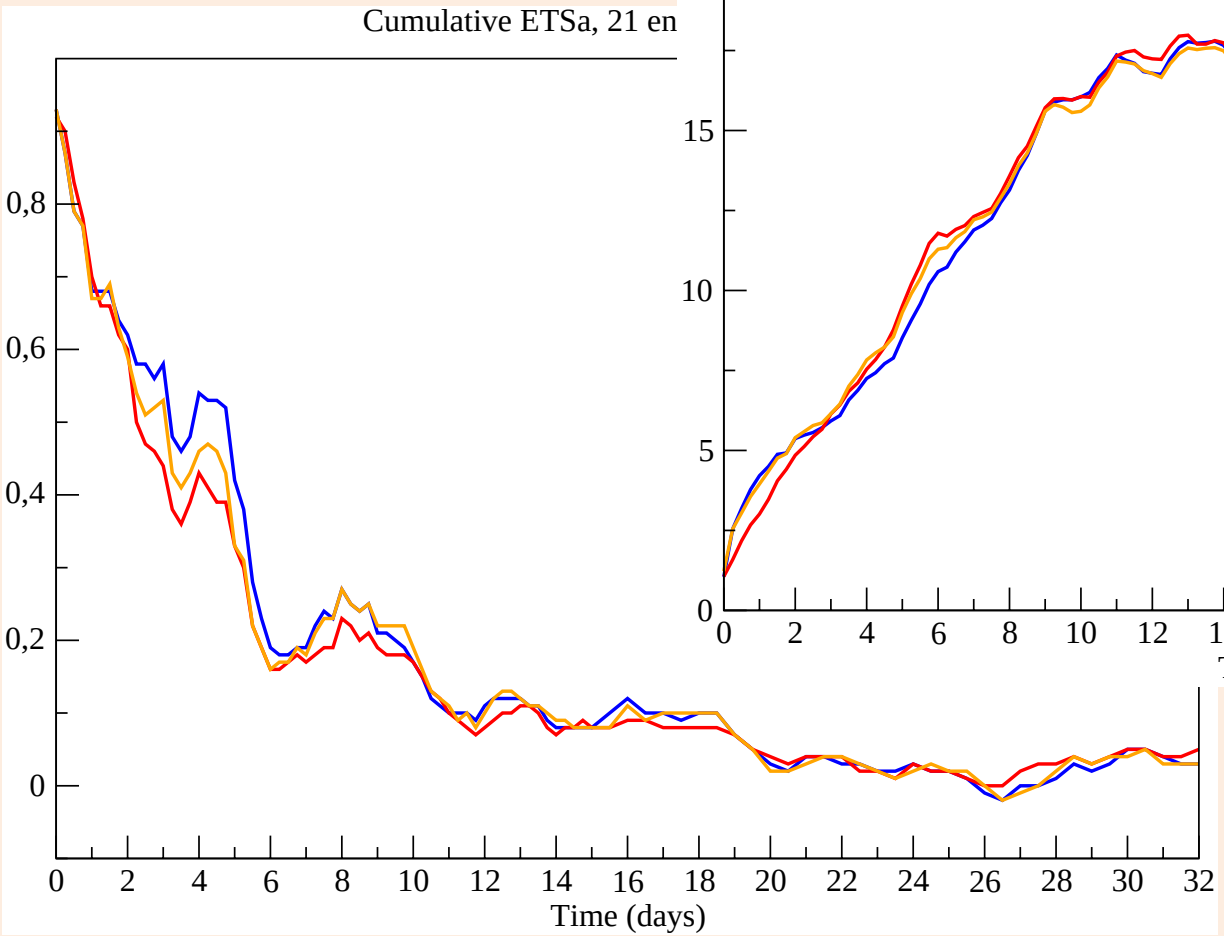
RMS wind difference of 250 hPa winds, with respect to ECMWF analyses

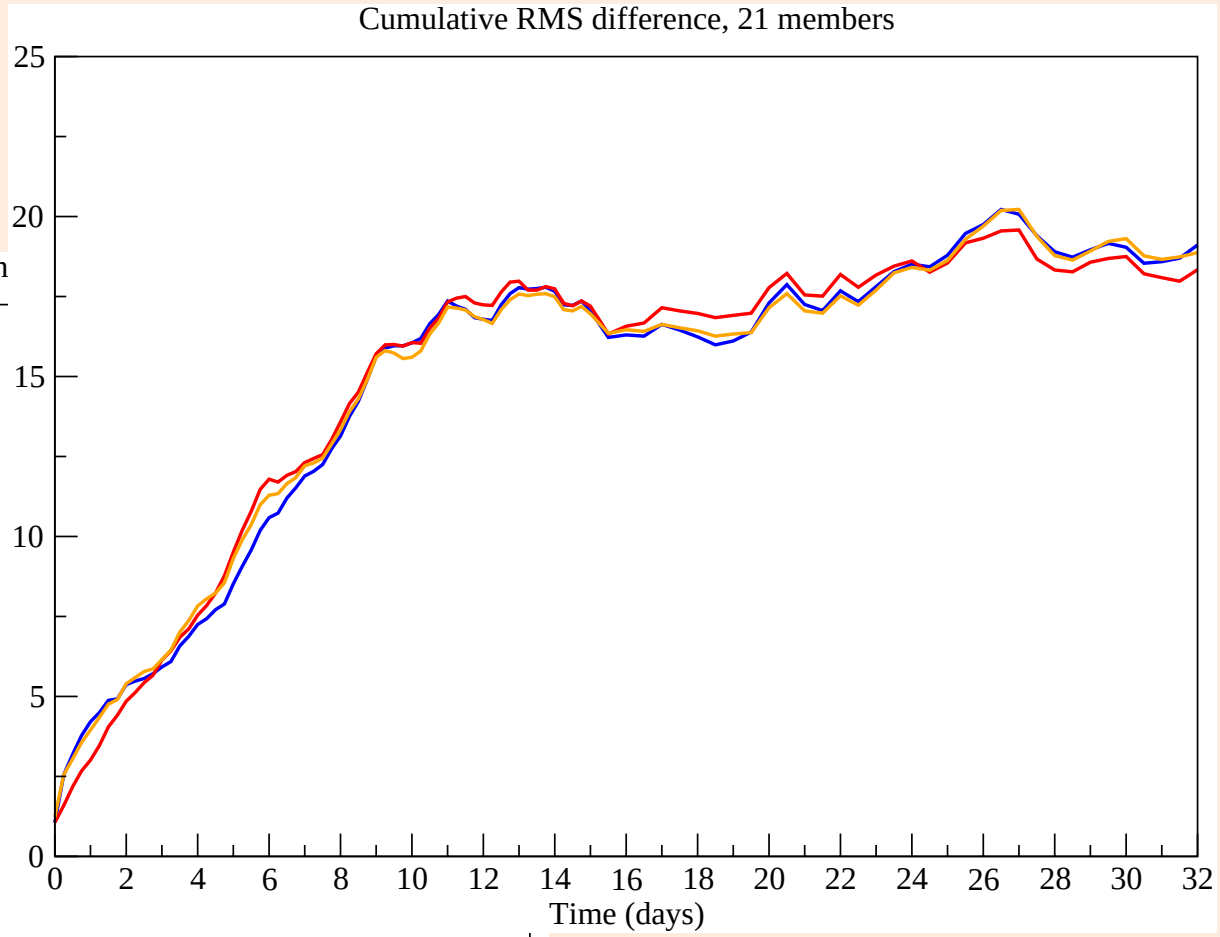
RMS:
Less is better !

What ingredient of the Eta is responsible for the advantage in scores ?

(It is not resolution, the first 10 days resolution of two models was about the same)

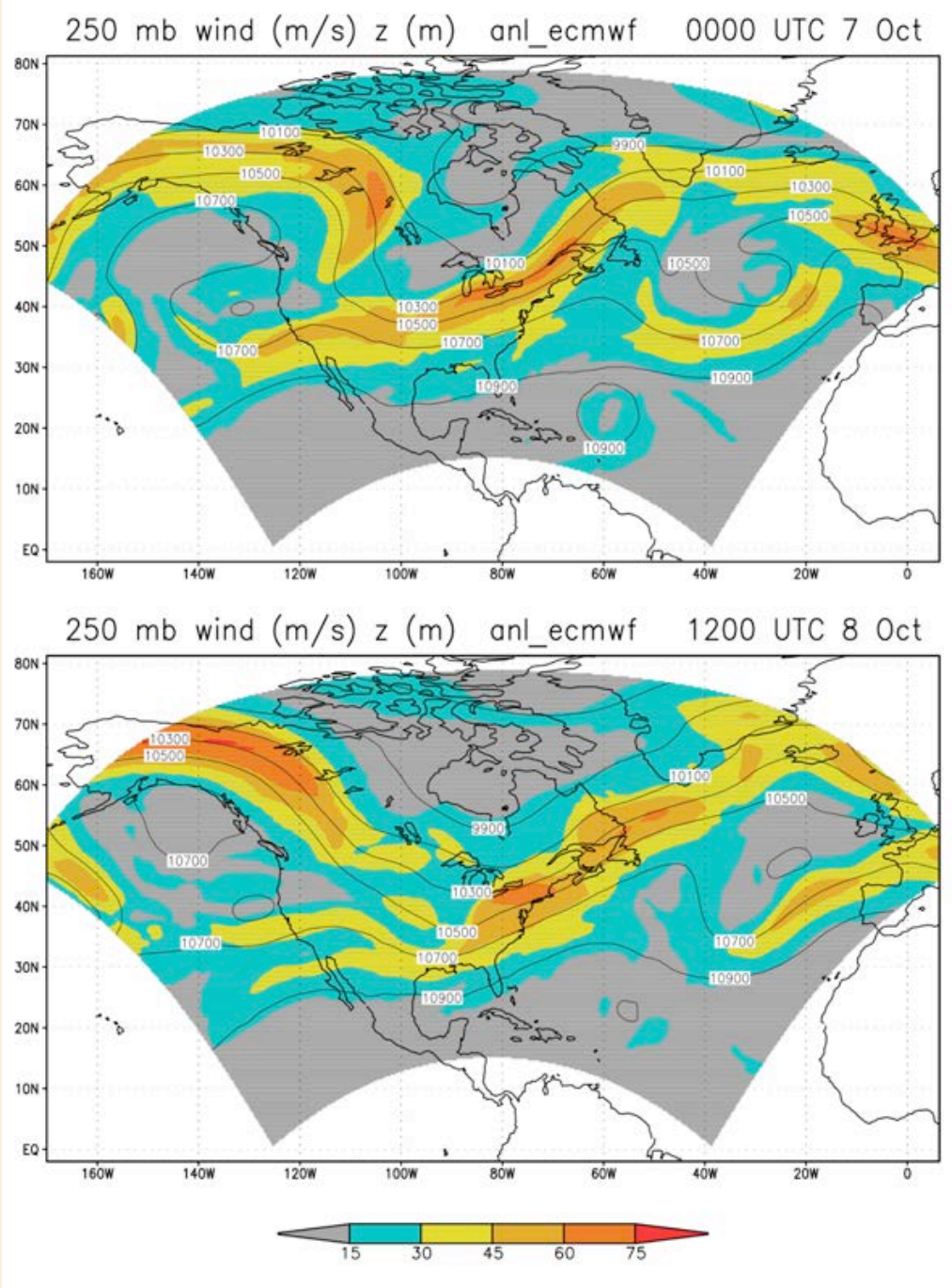
21 members ran using Eta/sigma:



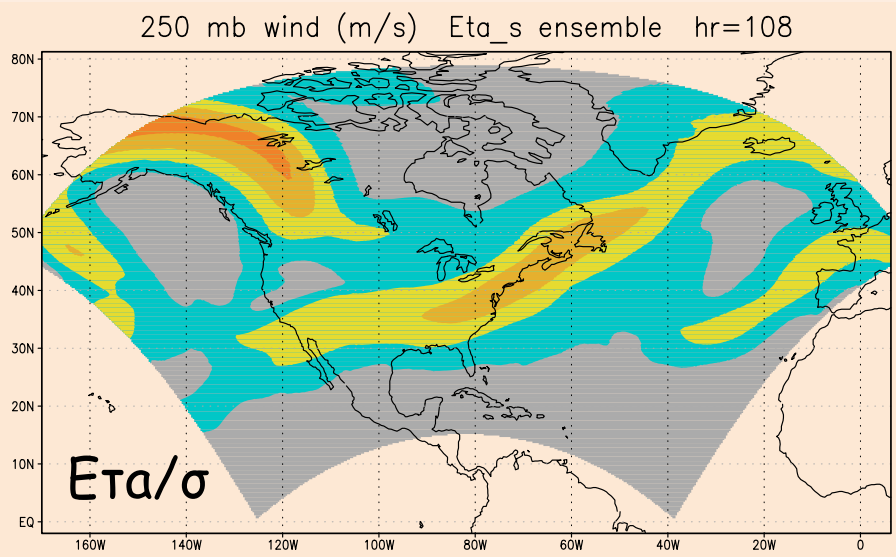


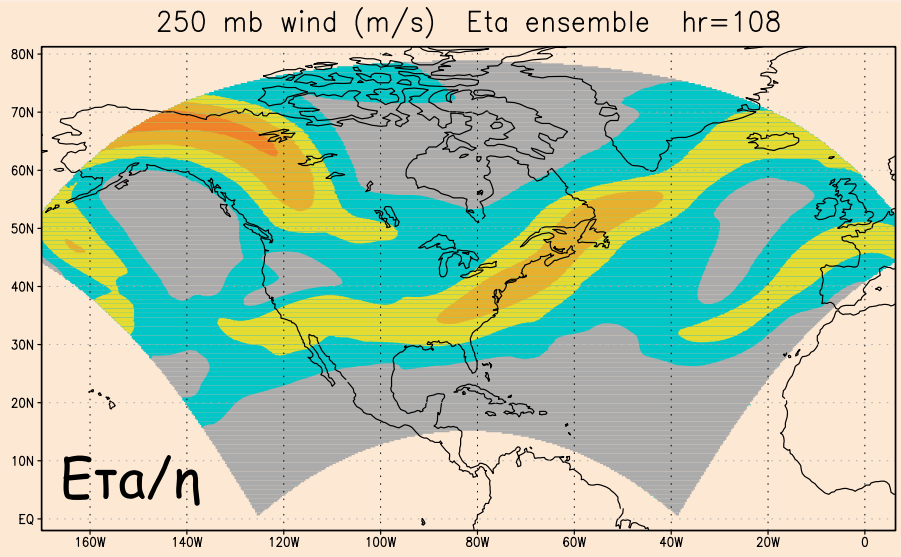
What was going on at about day 2-6 time ?

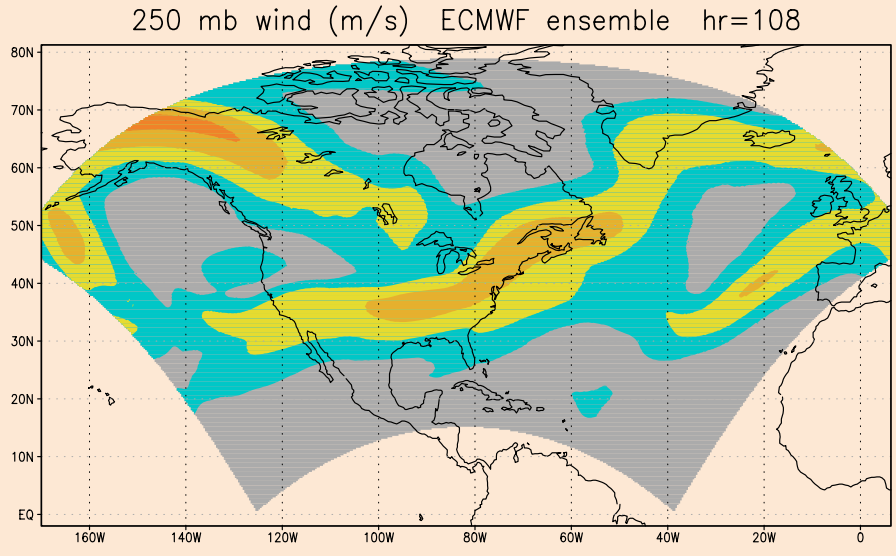
The plot times correspond to day 3.0, and 4.5, respectively, of the plots of the two preceding slides

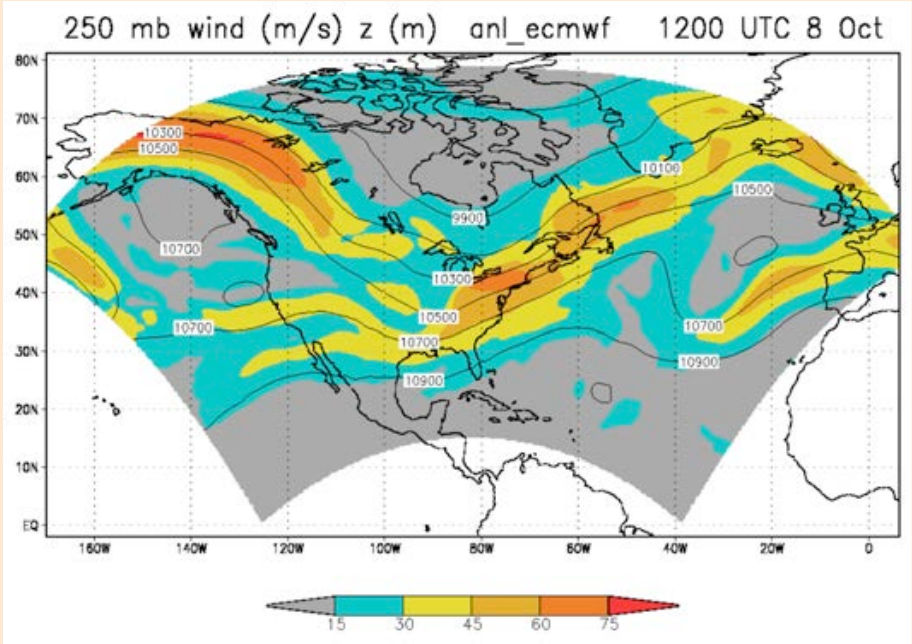


Why was the Eta so much more accurate at this time ?





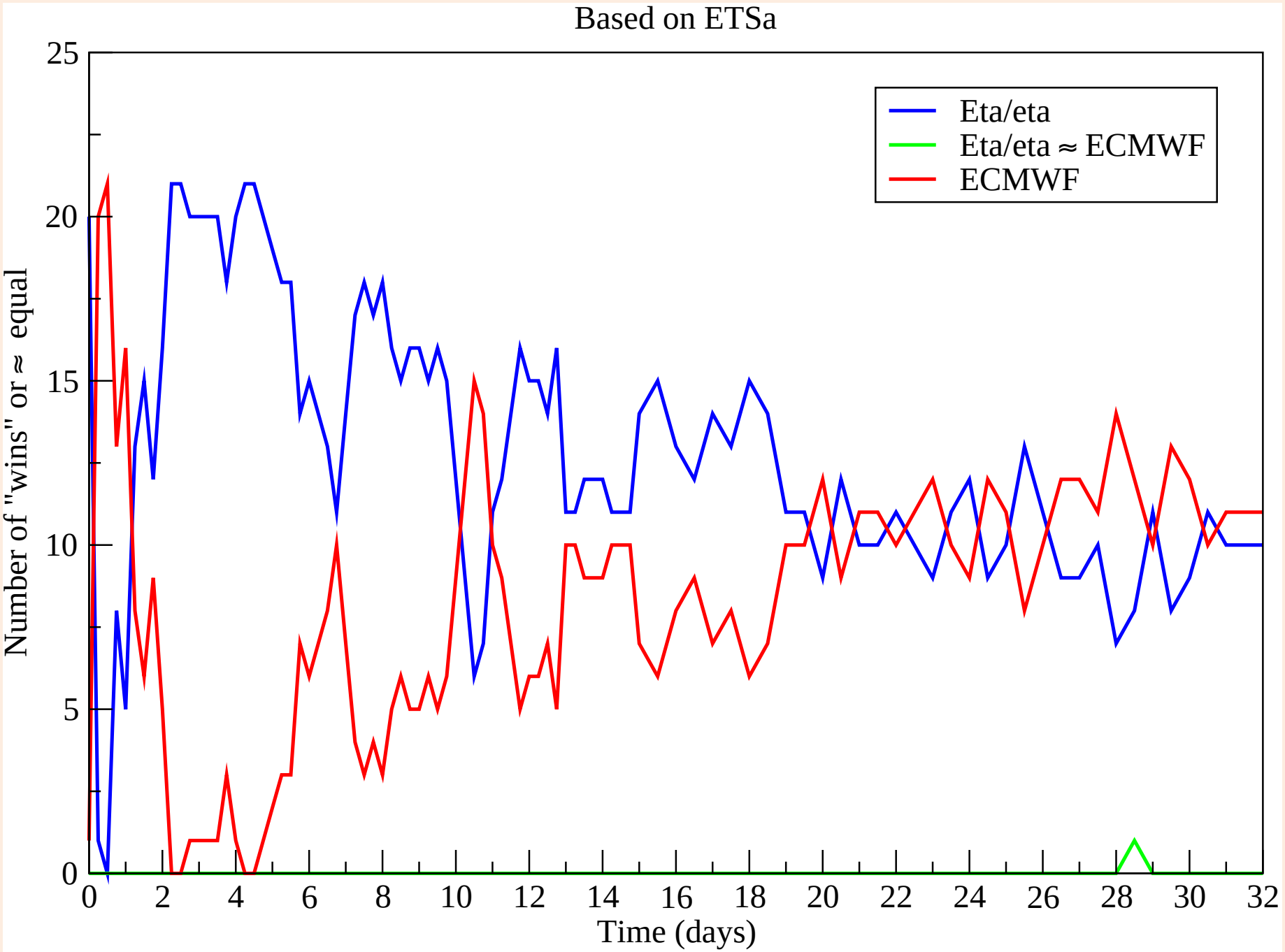




Ensemble average, 21 members, at 4.5 day time: Eta/sigma top left, Eta top right, EC driver bottom left, EC verification analysis bottom right.

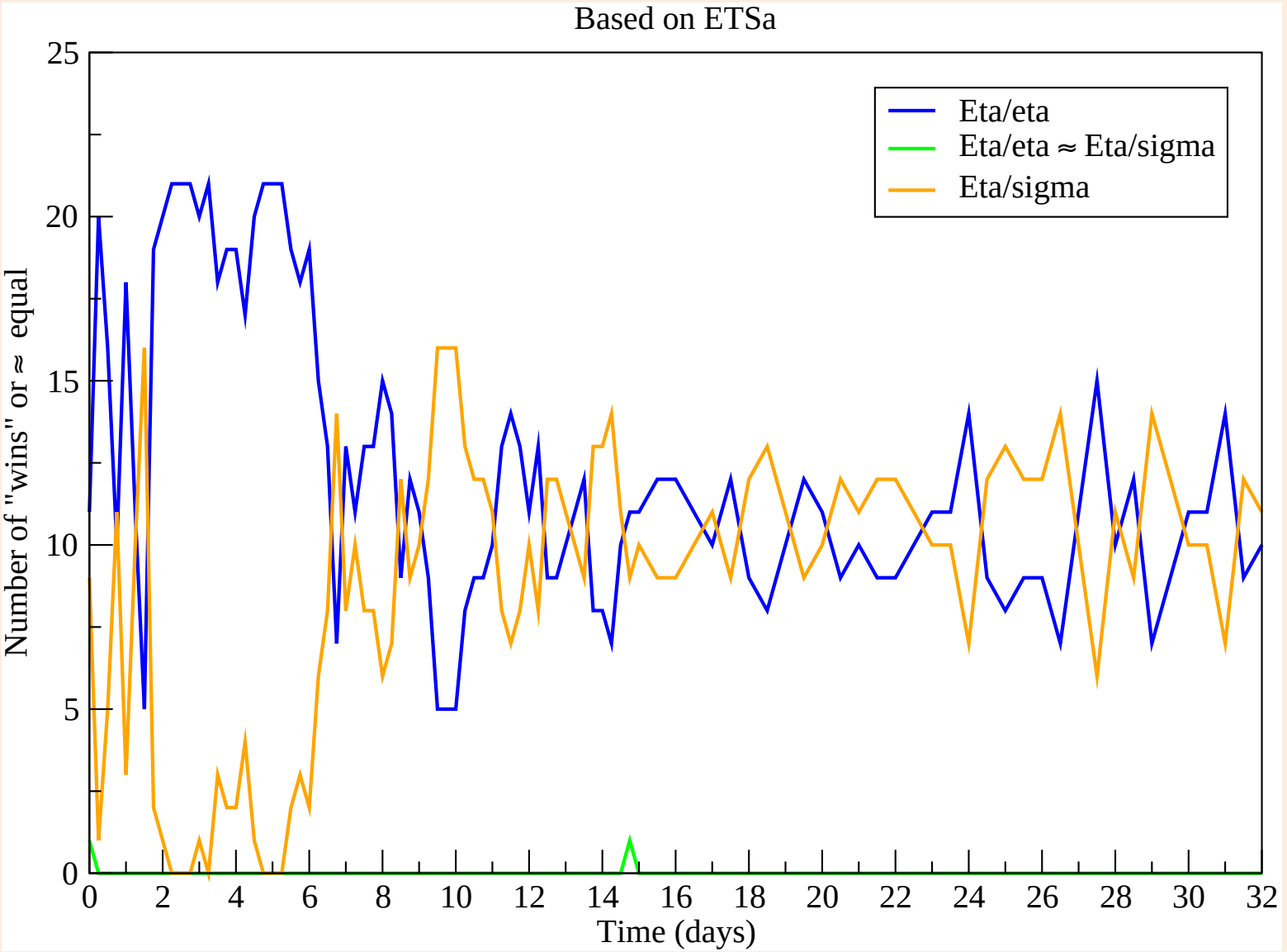
Another way of comparing model skill

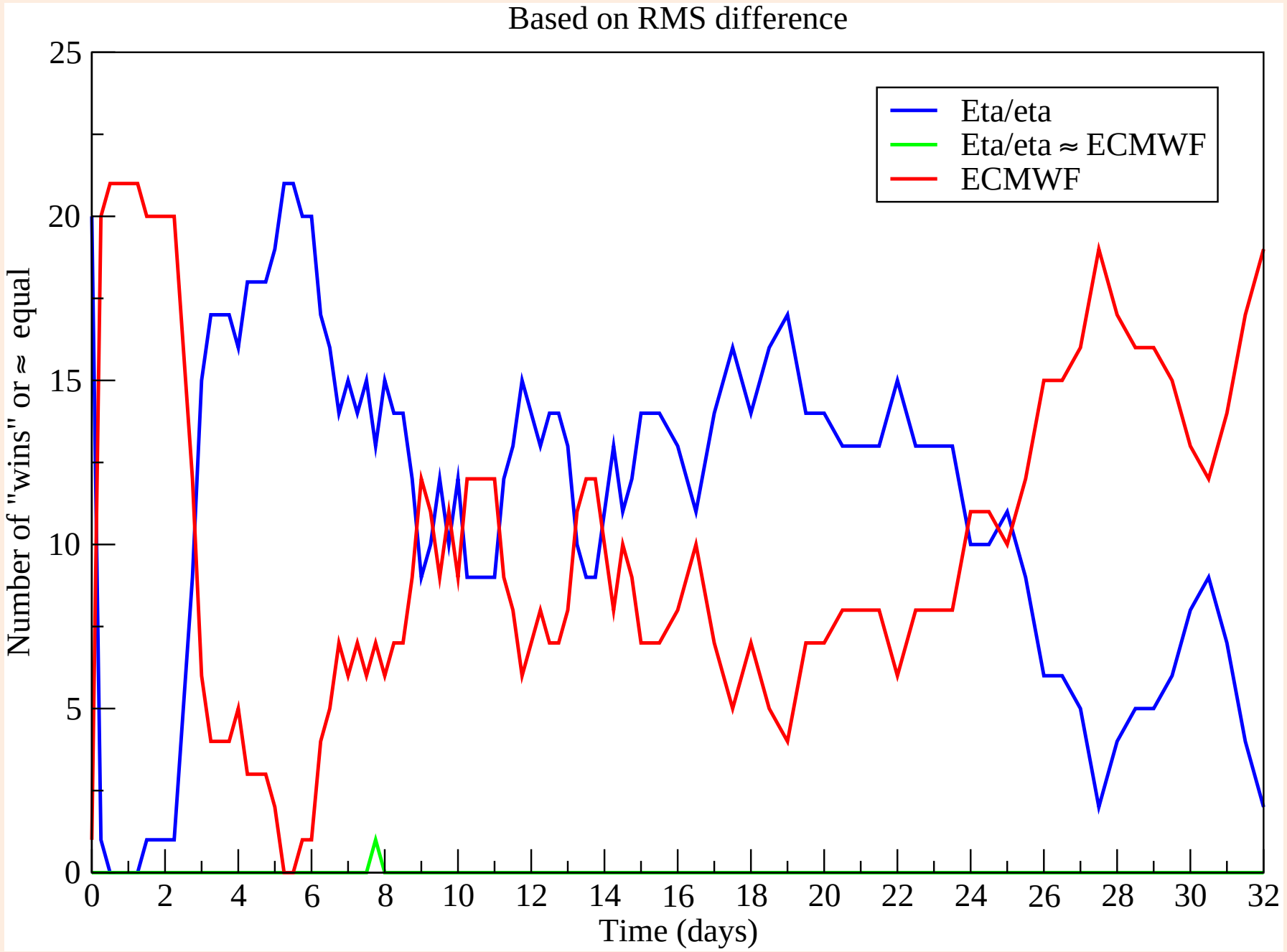
as a function of time: number of "wins"


Based on ETSa
Eta/eta
Eta/eta ≈ ECMWF
ECMWF
Number of "wins" or ≈ equal
Time (days)
0
5
10
15
20
25
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

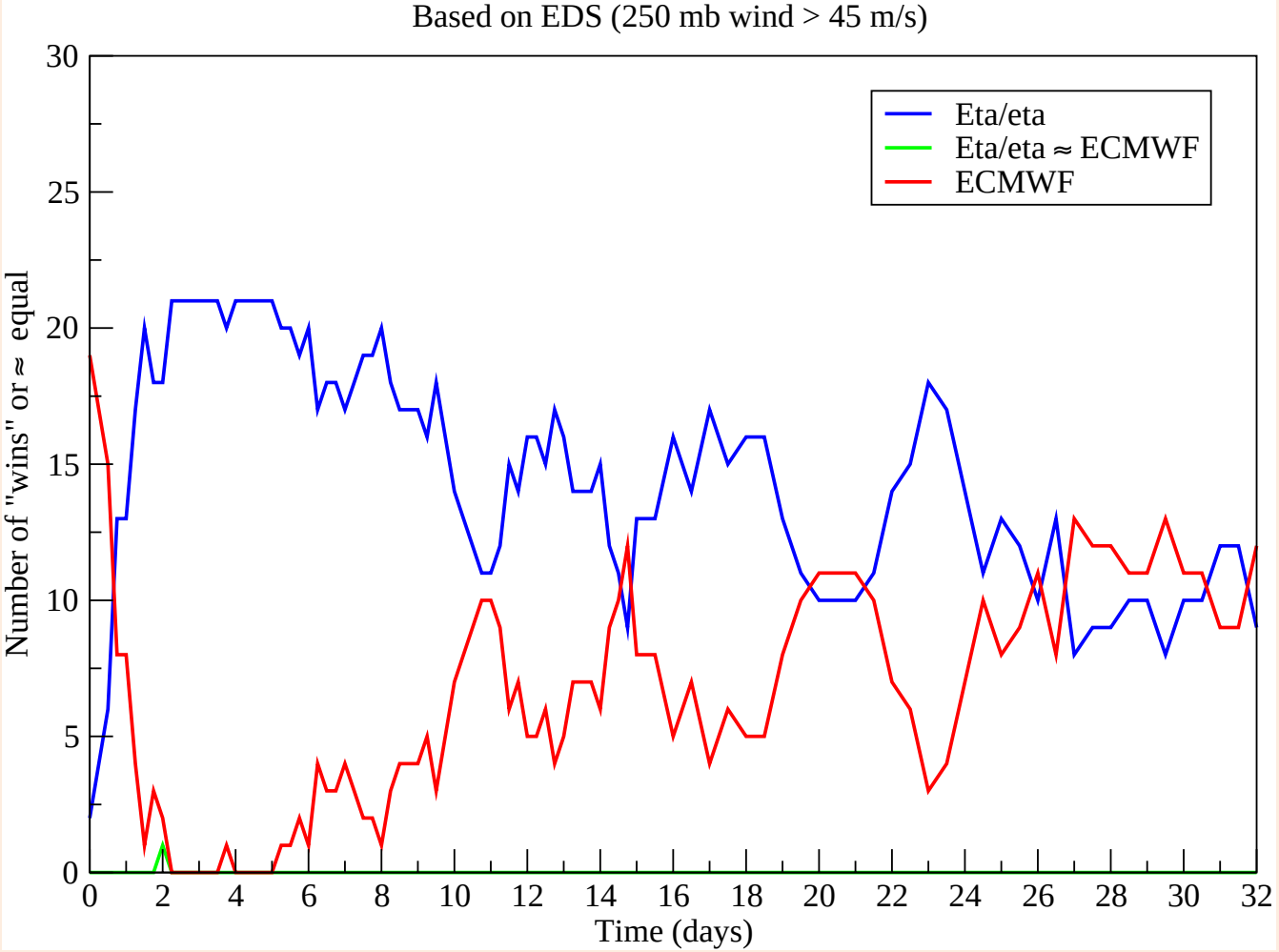
Four times from day 2.25 to day 4.5 every single Eta ensemble member, all 21 of them, had "jet stream" placed more accurately than their ECMWF driver members !

Eta vs. Eta/sigma:




Based on RMS difference
Eta/eta
Eta/eta ≈ ECMWF
ECMWF
Number of "wins" or ≈ equal
Time (days)
0
5
10
15
20
25
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

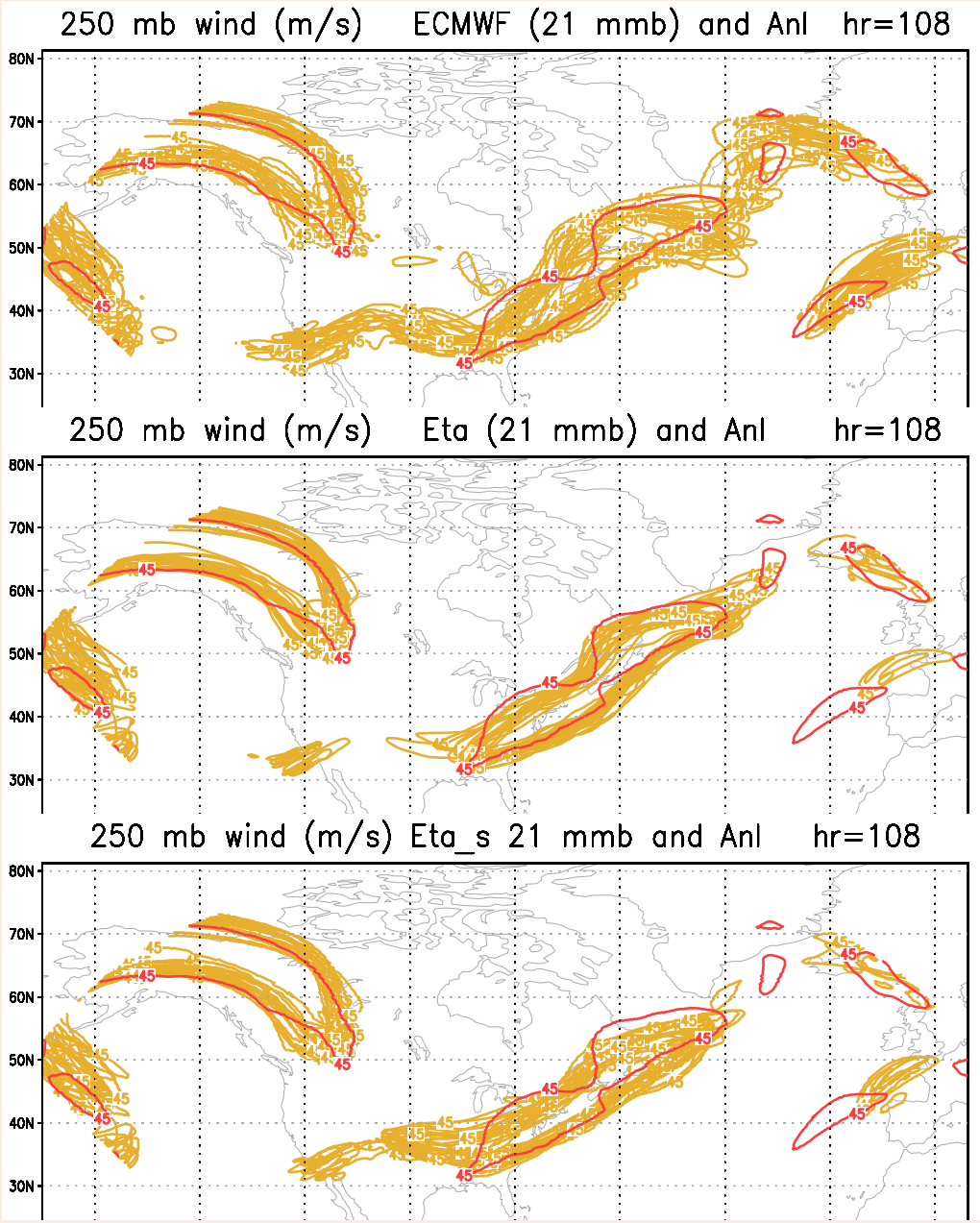
Based on the Extreme Dependency Score (EDS), designed for forecasts of rare binary-events (Stephenson et al., Meteor. Appl. 2008)



So far we looked at score numbers, and average maps of 21 members

Now:

Contours of all 21 members of areas of wind speeds > 45 m/s



Conclusions

- Strong evidence that coordinate systems intersecting topography are able to perform significantly better than terrain-following systems;

(in agreement with Steppeler et al. 2013)

PGF repair effort does exist (Zängl MWR 2012)

does it remove the problems shown ?

Conclusions

- The Eta must have additional components responsible for its increased accuracy against ECMWF

Candidate reasons:

- Arakawa horizontal advection scheme (Janjić 1984);
- Finite-volume van Leer type vertical advection of all variables (Mesinger and Jovic 2002);
- Very careful construction of model topography (MY2017), with grid cell values selected between their mean and silhouette values, depending on surrounding values, and no smoothing;
- Exact conservation of energy in space differencing in transformation between the kinetic and potential energy;
- . . . . . .