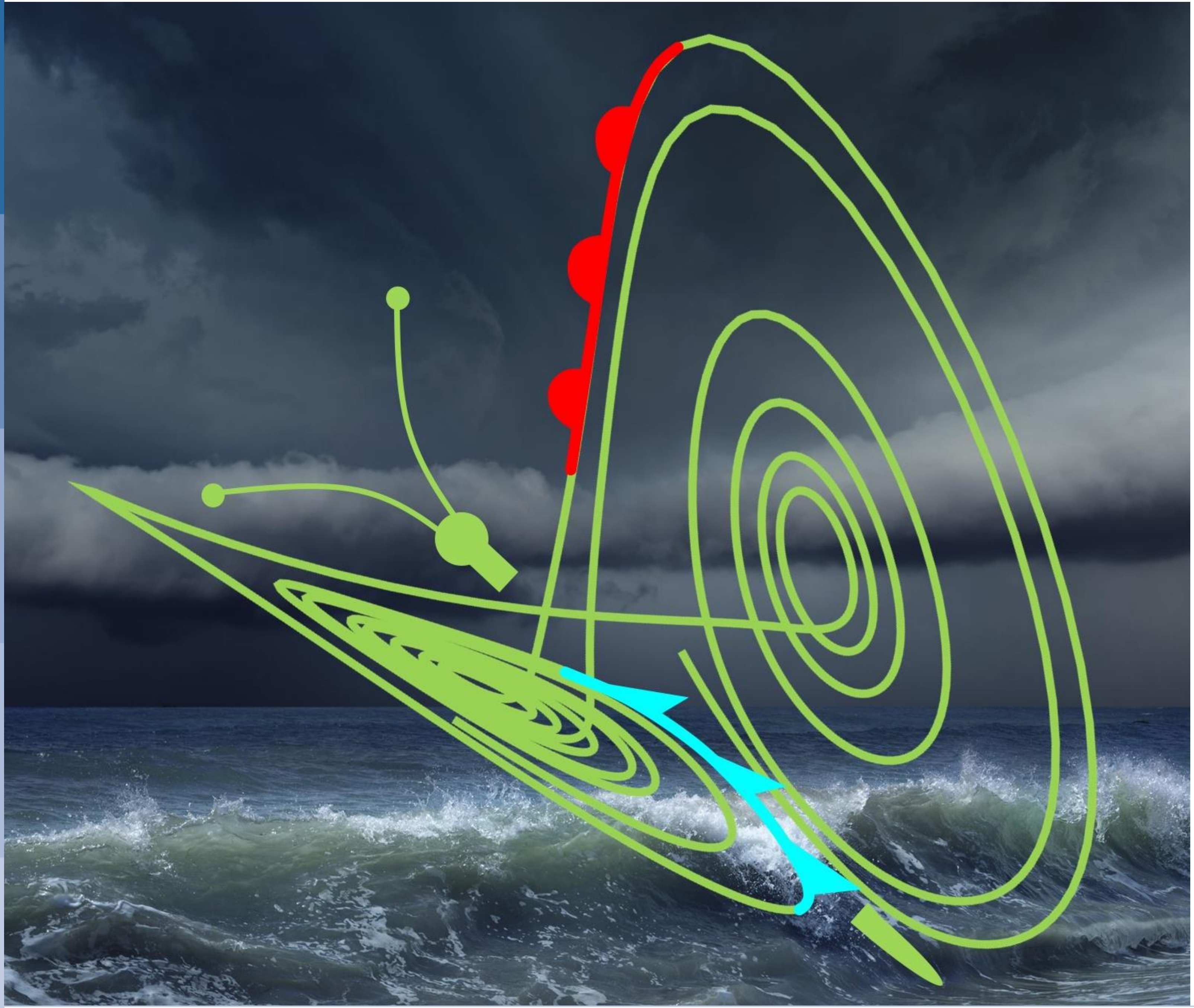


Diagnostics 1

Mark Rodwell

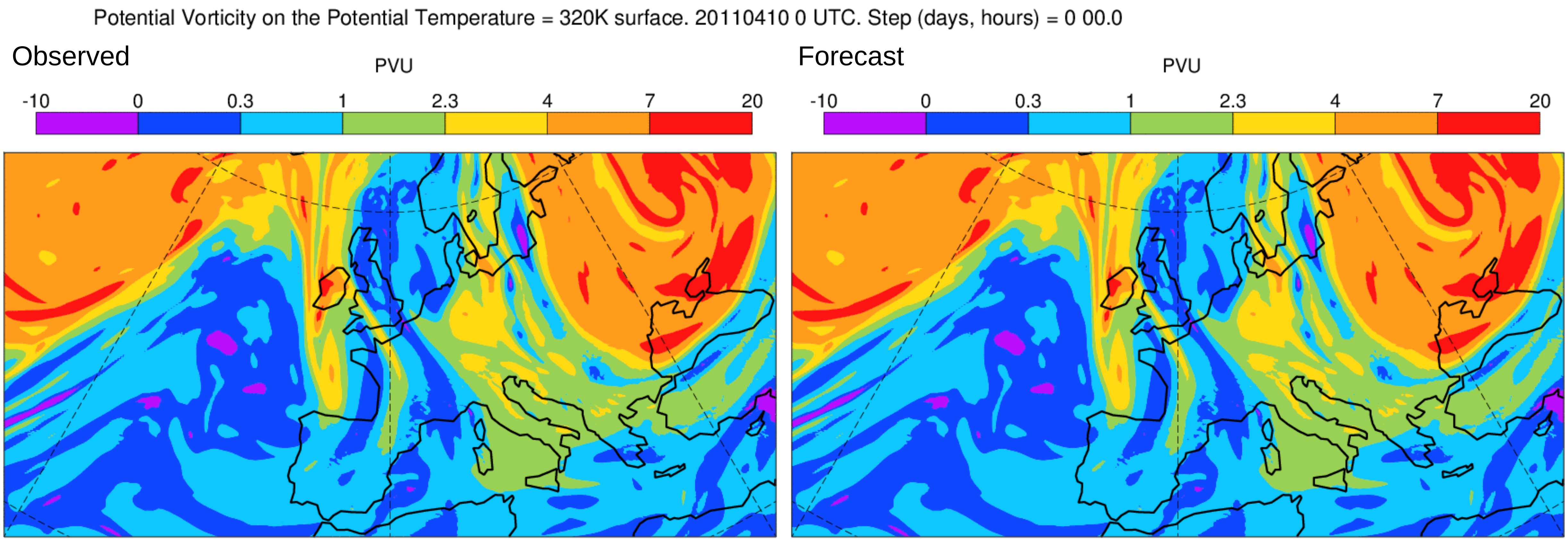
Collaborators
David Richardson, Dave Parsons,
Heini Wernli, Linus Magnusson, Elias Hólm

Training course: Predictability & ocean-atmosphere ensemble forecasting

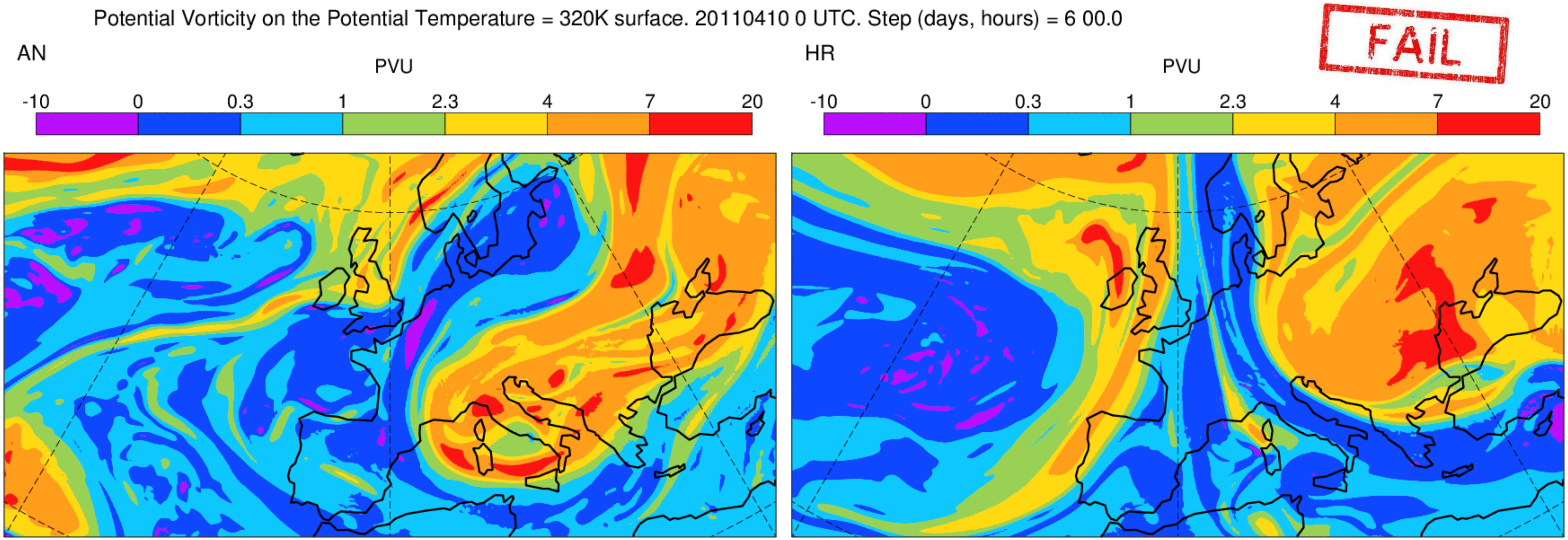
1 March 2019, ECMWF

Numerical Weather Prediction

Animation of a very poor medium-range single forecast



Animation of a very poor medium-range single forecast



We see the mixing of air masses. The eventual block (high pressure) over Northern Europe is not well predicted

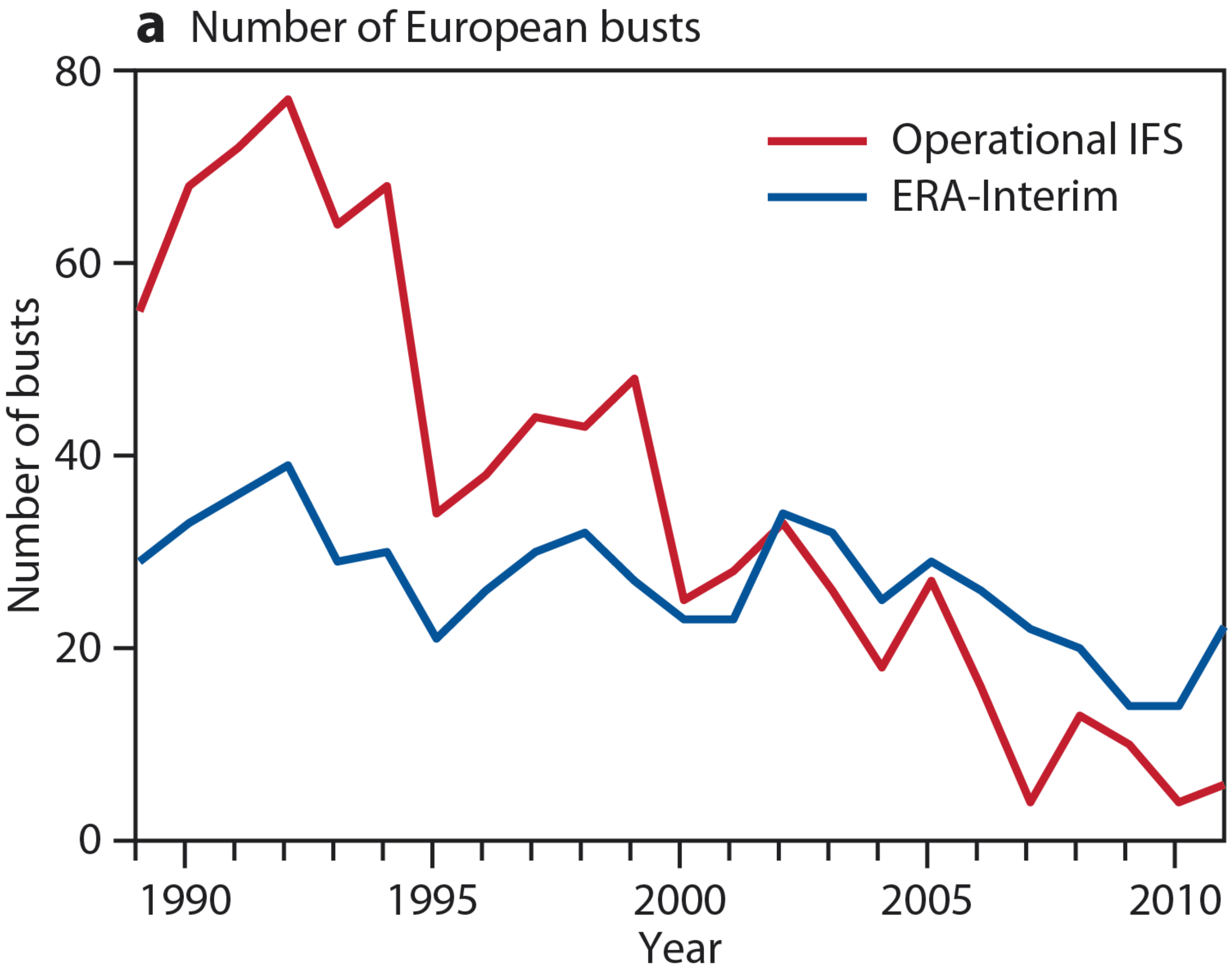
With a single forecast, it is easy to quantify the error (pointwise differences, pattern correlations etc.)

Trends in bust frequency

Rodwell et al, 2013, BAMS

Frequency of severe busts has dropped a lot in operational forecast

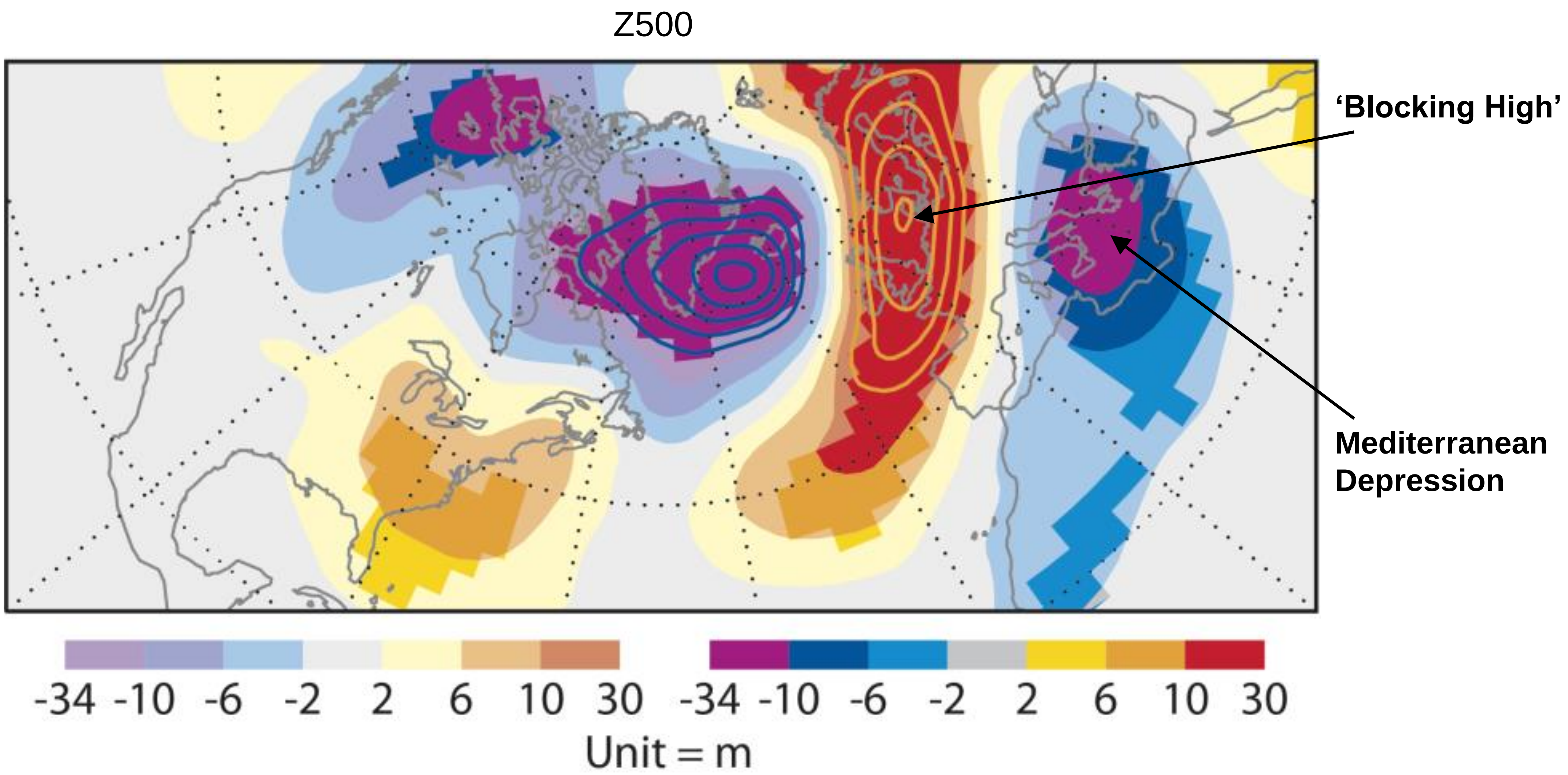
Can use busts within re-analysis to get a better picture of the salient aspects



A bust is defined as when the day-6 Z500 forecast has European RMSE>60m *<u>and</u>* *ACC<40%*

Composite conditions during a bust

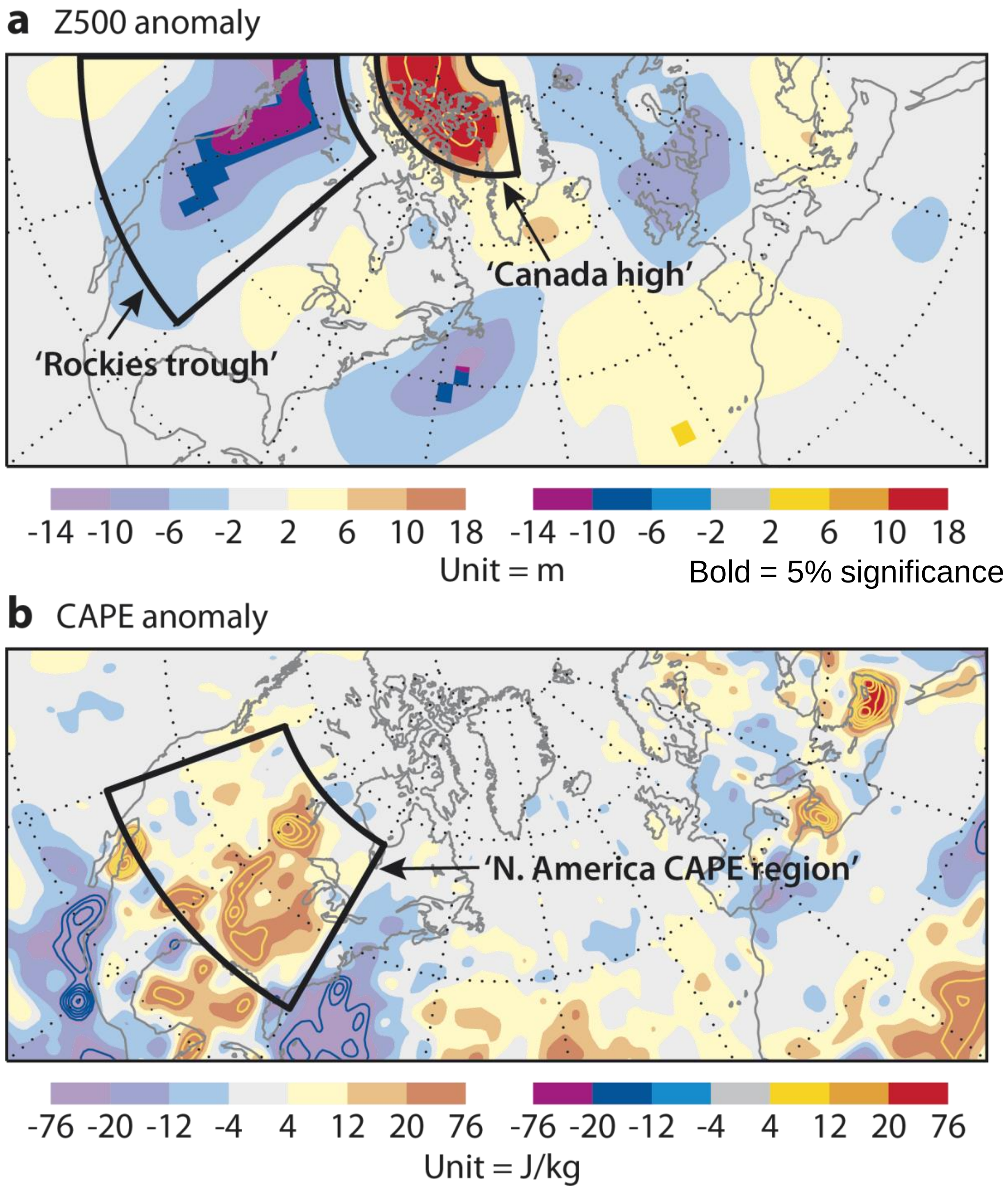
Rodwell et al, 2013, BAMS



Using all 584 ERA Interim busts that occurred between the dates 1 January 1989 - 24 June 2012.

Average initial conditions of 584 single forecast “busts” over Europe at day 6

Rodwell et al, 2013, BAMS



Trough over the Rocky mountains, with high convective potential ahead

Conducive to the formation of mesoscale convection

Analysis highlights geographically-fixed factors. Other flow-features (extratropical transition of tropical cyclones and cyclogenesis) have also been shown to be important for some busts.

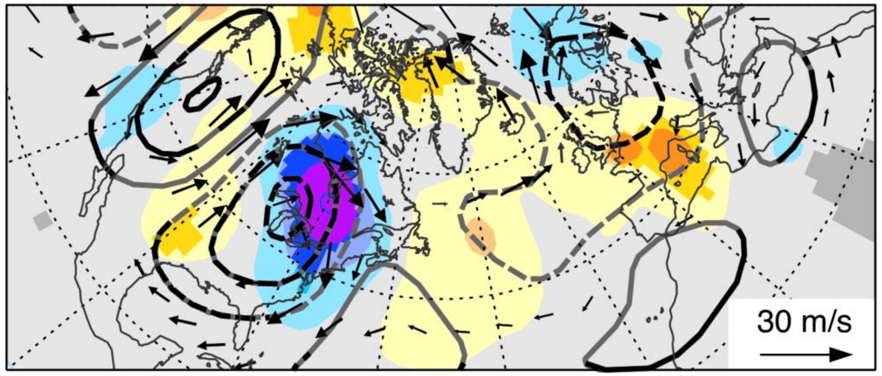
‘CAPE’ = Convective Available Potential Energy

PV budget at 330K for trough/CAPE composite

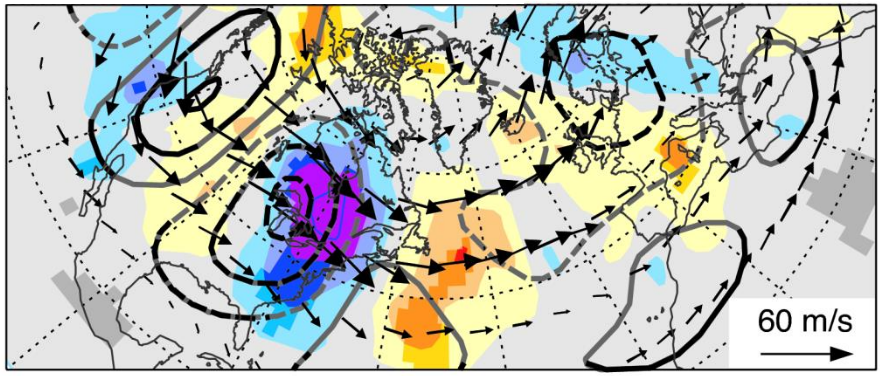
Rodwell et al, 2013, BAMS

Contours : PV anomaly
Shading : PV tendency

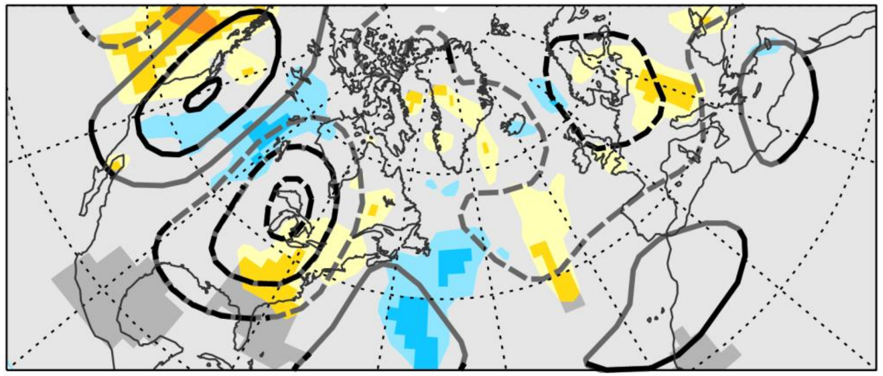
Local PV tendency and anomalous winds

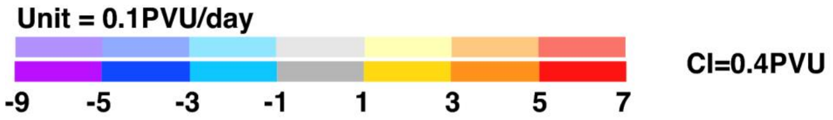


PV advection and full winds



Diabatic and frictional PV tendency





Largely the wave is being advected downstream

But, by modifying the stratification, diabatic processes appear to oppose the advection term and slow the propagation of the wave

Not just a symptom of the wave, but an active ingredient in the downstream bust

Composite over 95 trough/CAPE events 25 June 2010 – 20 March 2012 (0 or 12UTC) where operational analysis has projection onto Rockies trough > 3 and onto CAPE > 1. Contours show Potential Vorticity (PV) anomaly, shading shows (a) local tendency, (b) adiabatic advection and (c) material PV tendency (due to diabatic & frictional processes; deduced as the residual in the PV budget) on the 330K surface (≈250hPa)

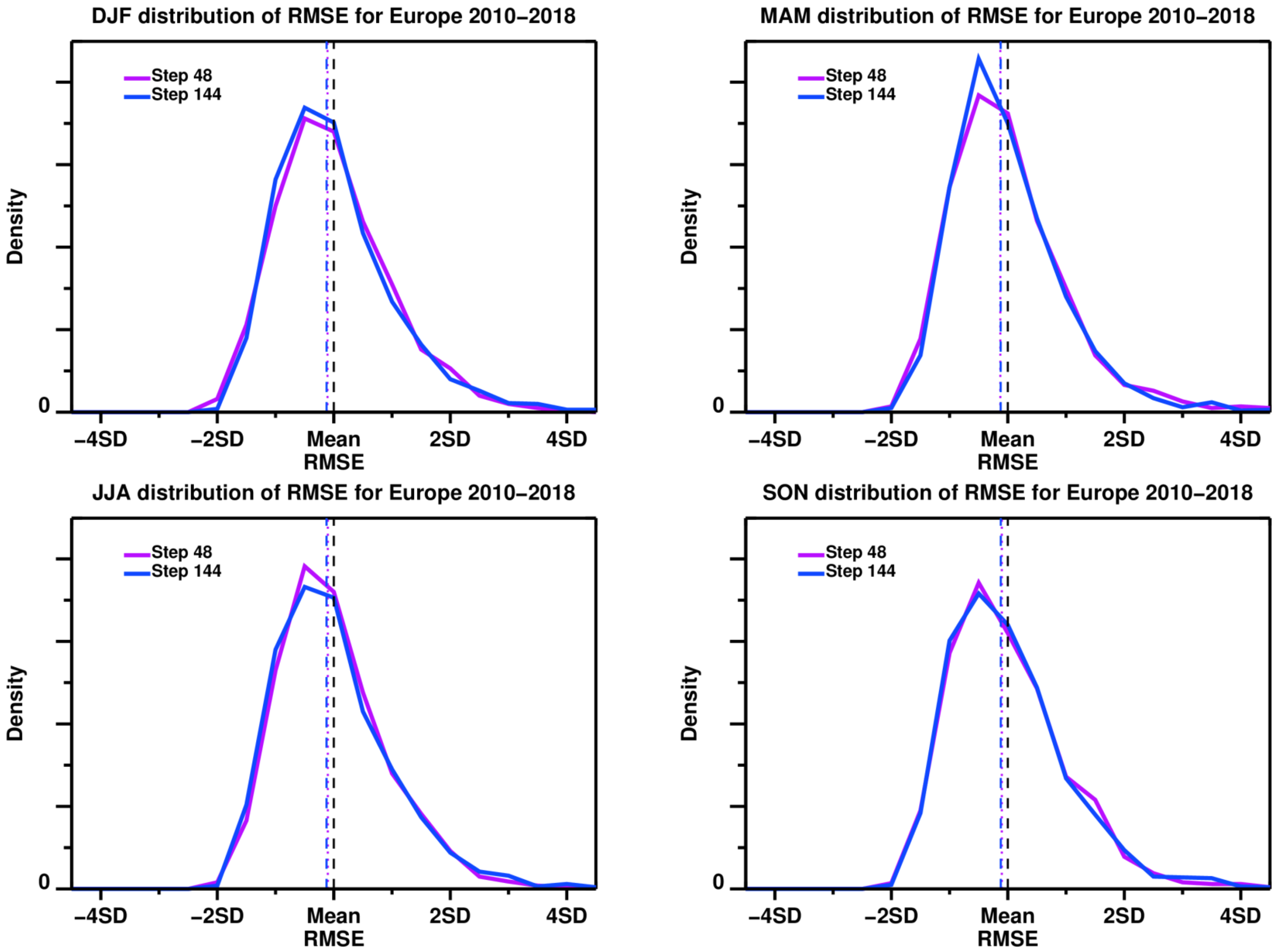
Distribution of RMSE Z500 over Europe

With Heini Wernli

Shape of distribution is independent of lead-time

Limited by zero error, so inevitably a longer tail at large error

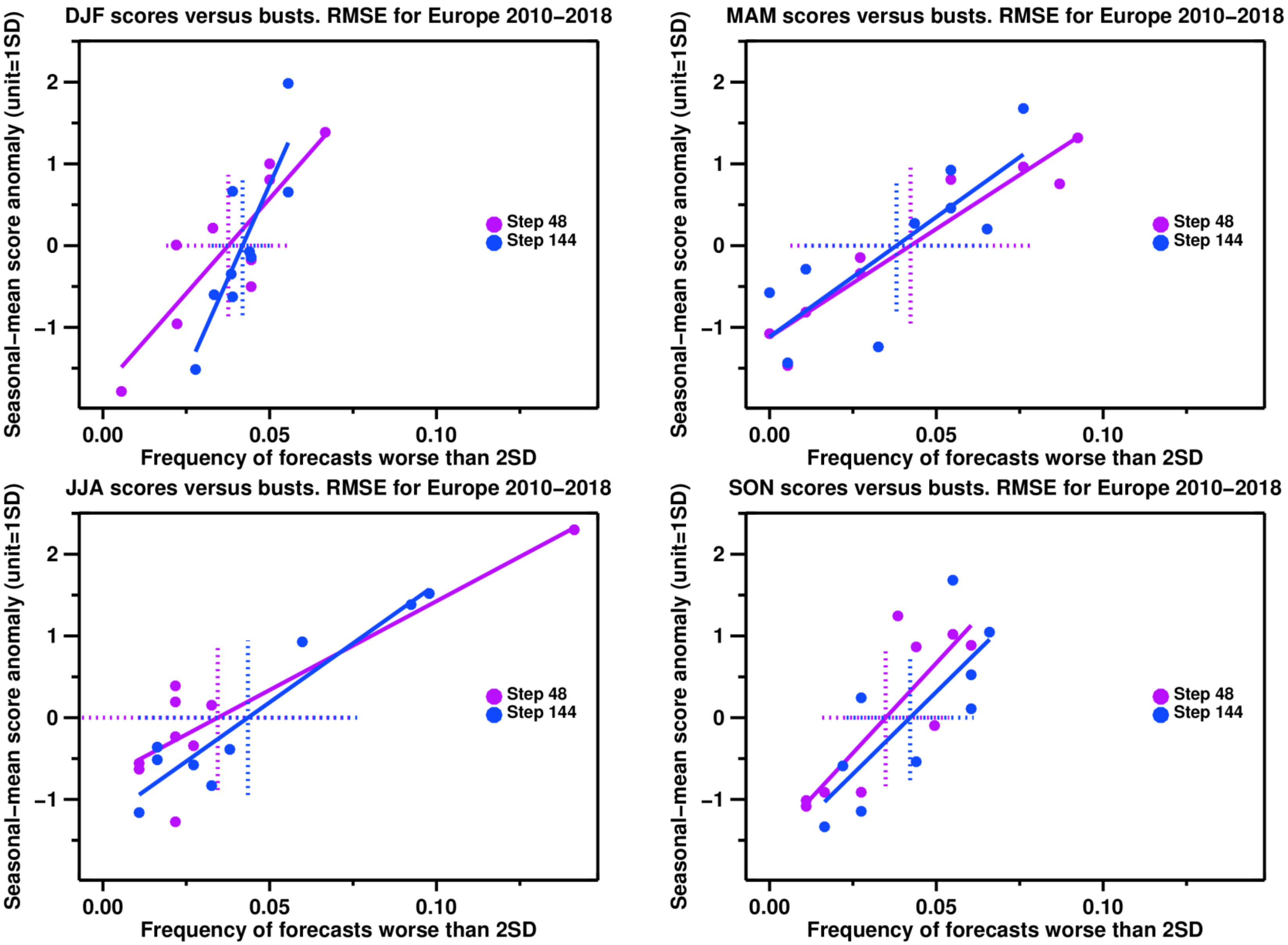
How important for the seasonal-mean score are cases where the error > 2SD?



Impact of frequency of poor forecasts on seasonal-mean Z500 RMSE over Europe

The impact of 1SD in poor forecast frequency equates to close to 1SD in seasonal-mean score

With Heini Wernli



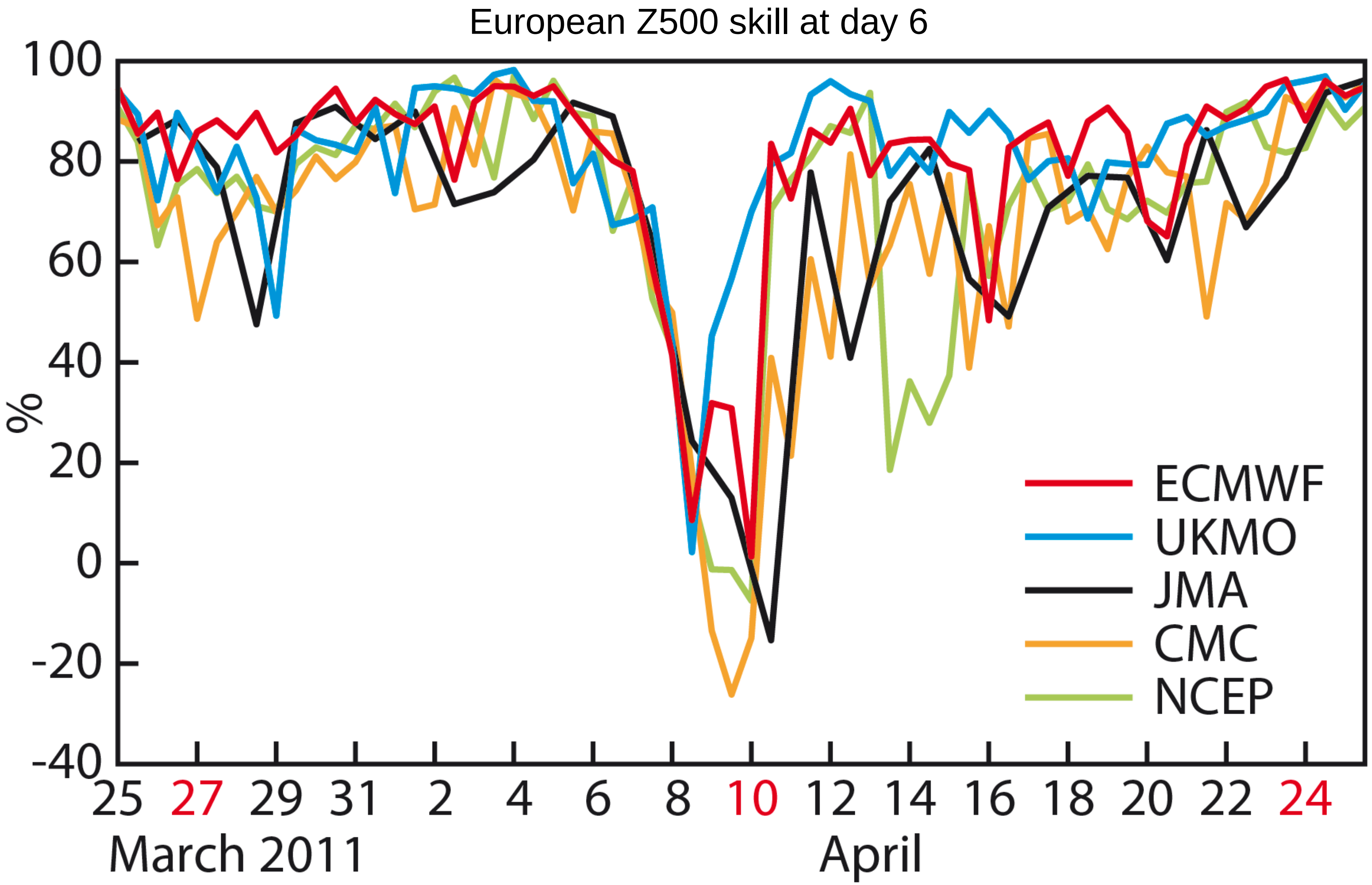
Back to the single bust case: All forecast centres suffered

Rodwell et al, 2013, BAMS

All centres suffered

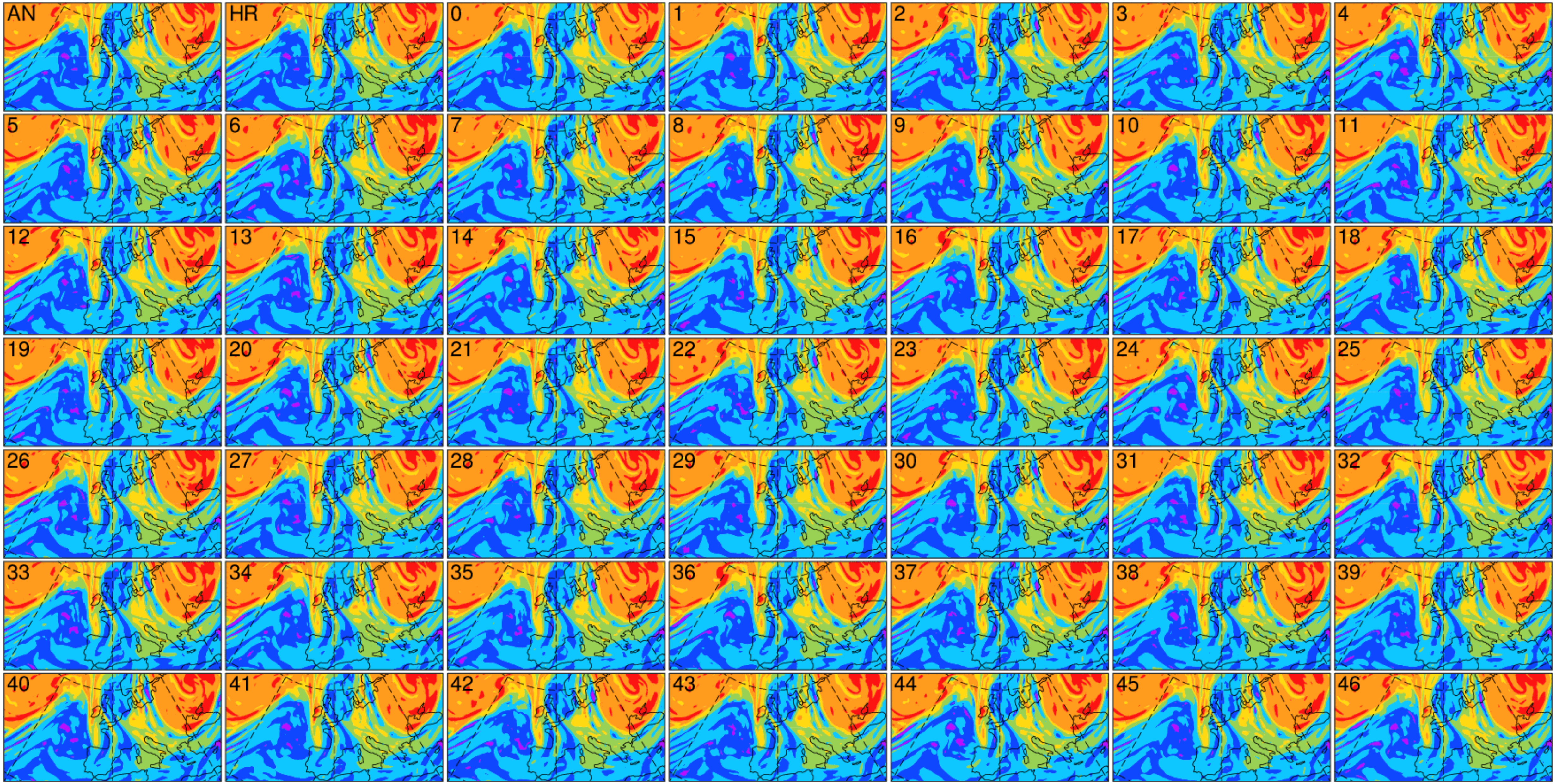
Suggests an issue of reduced "predictability"

Look at the ensemble

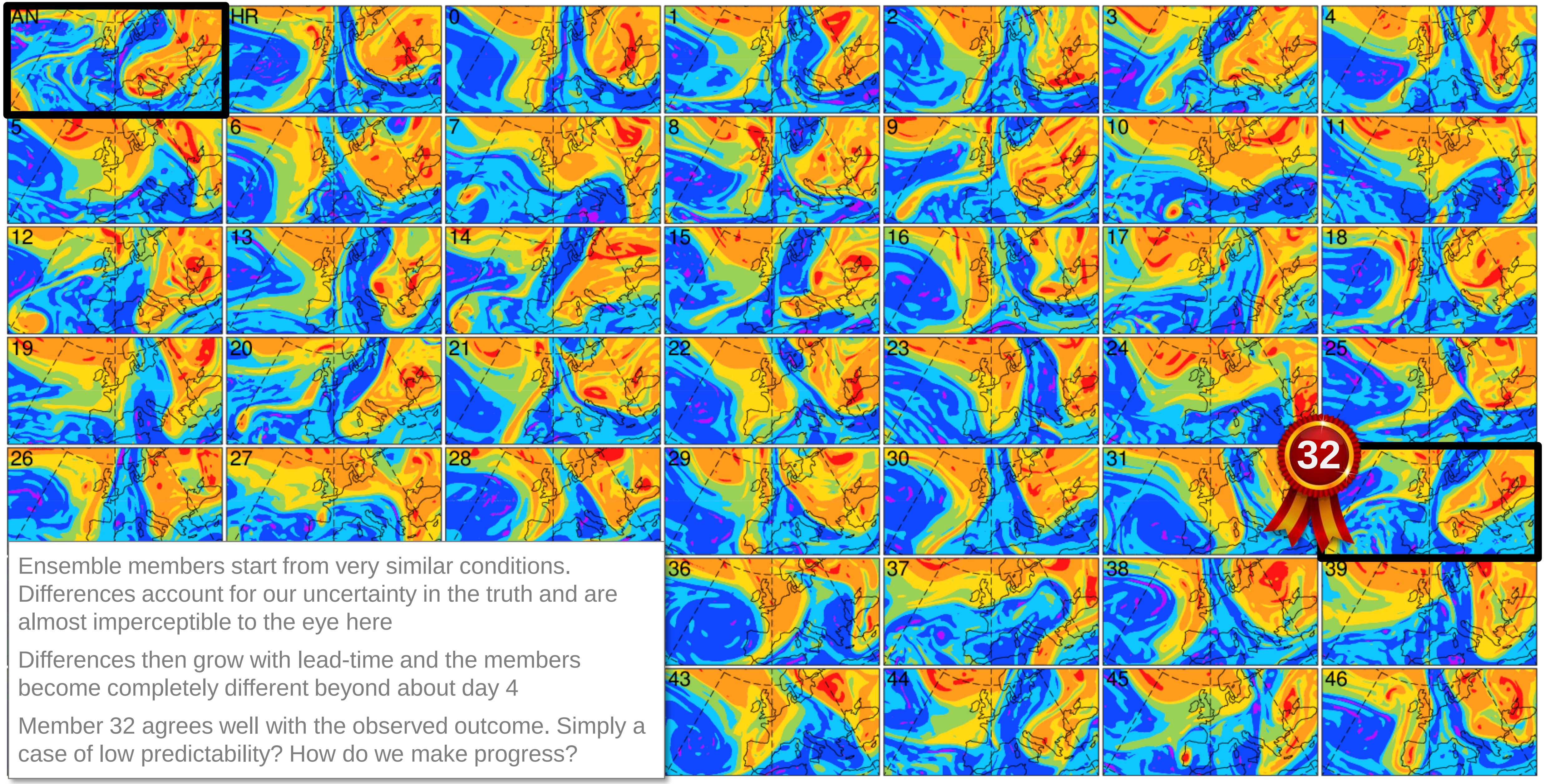


Spatial Anomaly Correlation Coefficient for 500 hPa geopotential height in [12.5ºW –42.5ºE, 35ºN–75ºN]. Date is forecast start

Potential Vorticity on the Potential Temperature = 320K surface. 20110410 0 UTC. Step (days, hours) = 0 00.0



Potential Vorticity on the Potential Temperature = 320K surface. 20110410 0 UTC. Step (days, hours) = 6 00.0

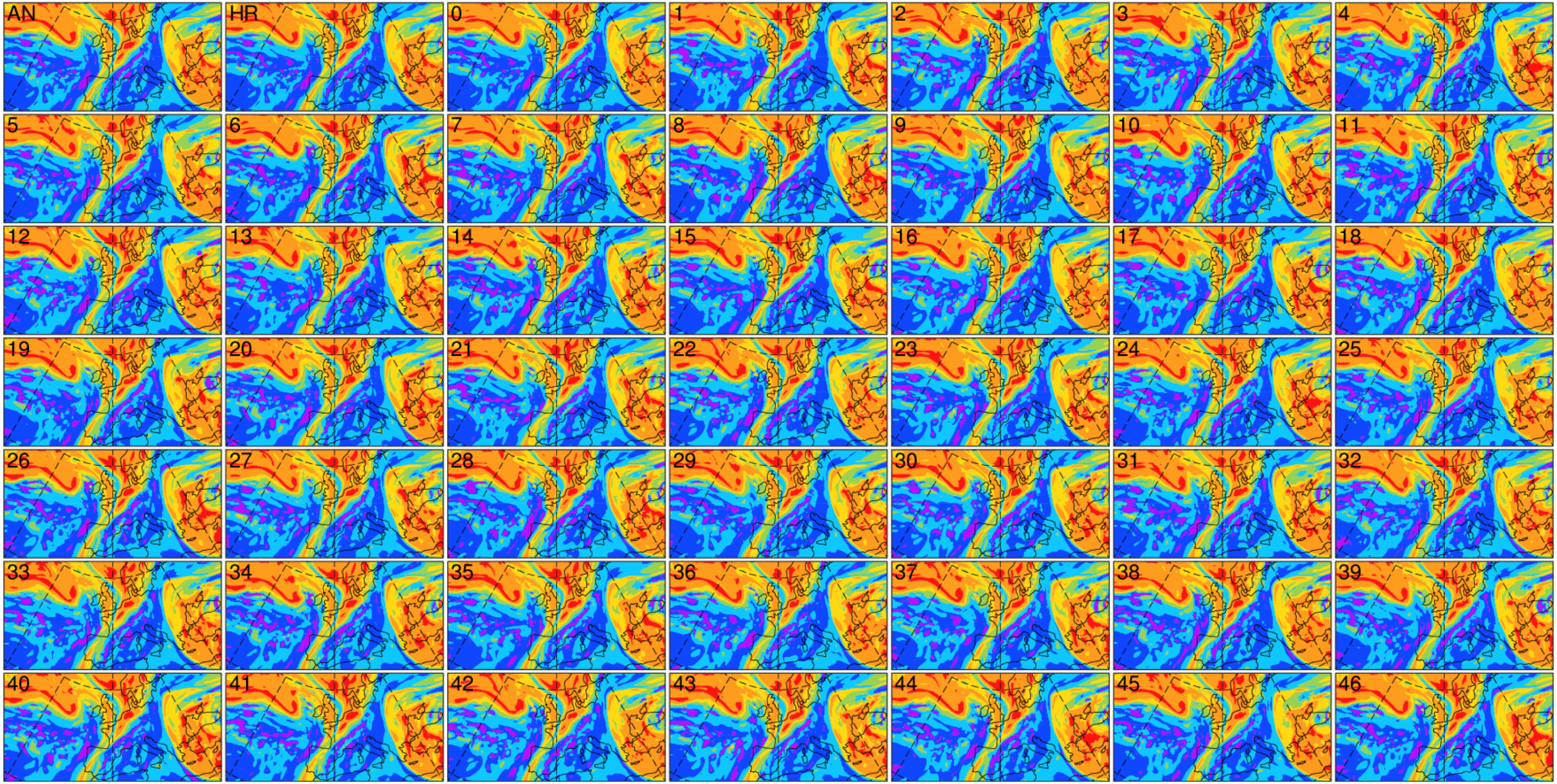


Ensemble members start from very similar conditions. Differences account for our uncertainty in the truth and are almost imperceptible to the eye here

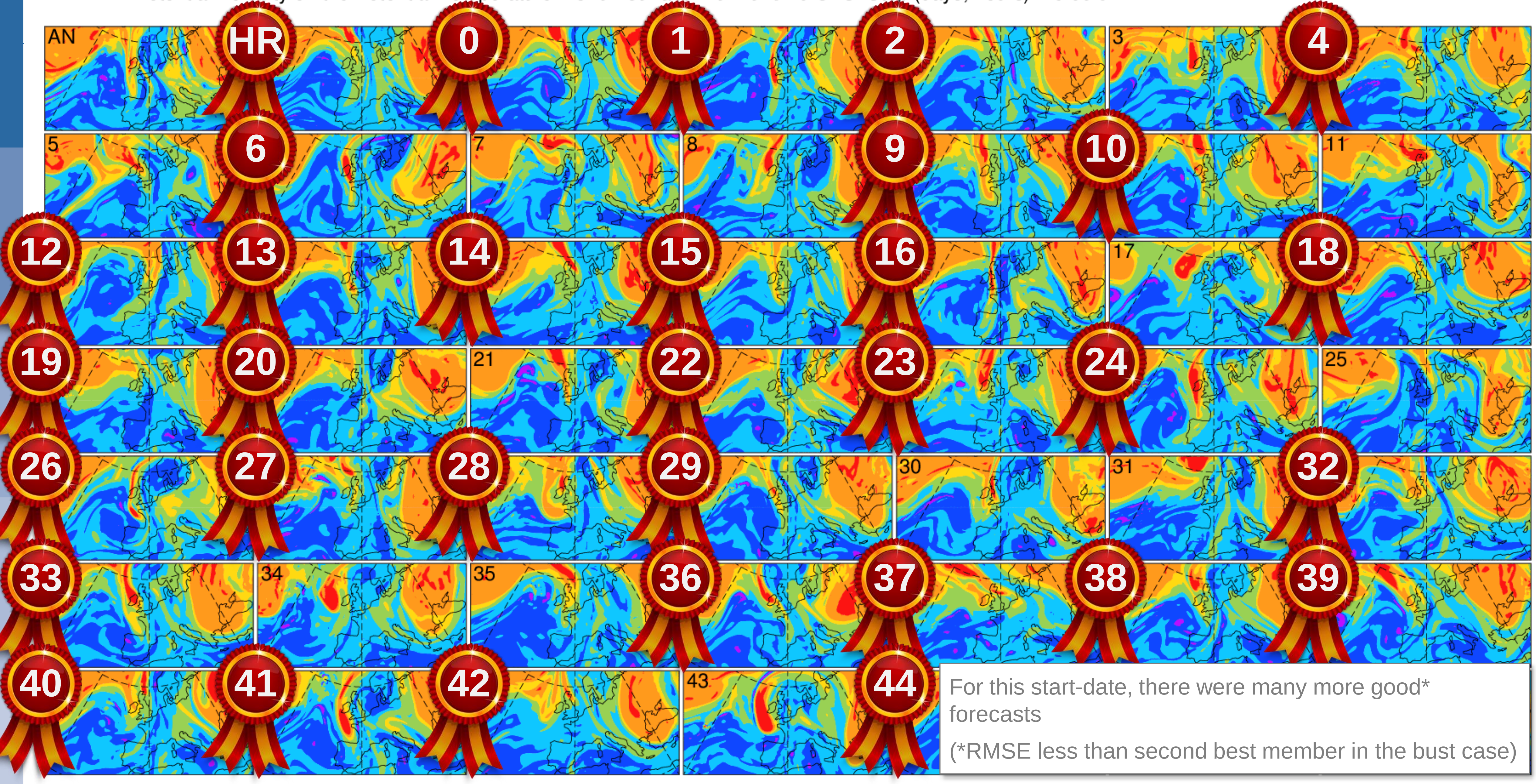
Differences then grow with lead-time and the members become completely different beyond about day 4

Member 32 agrees well with the observed outcome. Simply a case of low predictability? How do we make progress?

Potential Vorticity on the Potential Temperature = 320K surface. 20110404 0 UTC. Step (days, hours) = 0 00.0



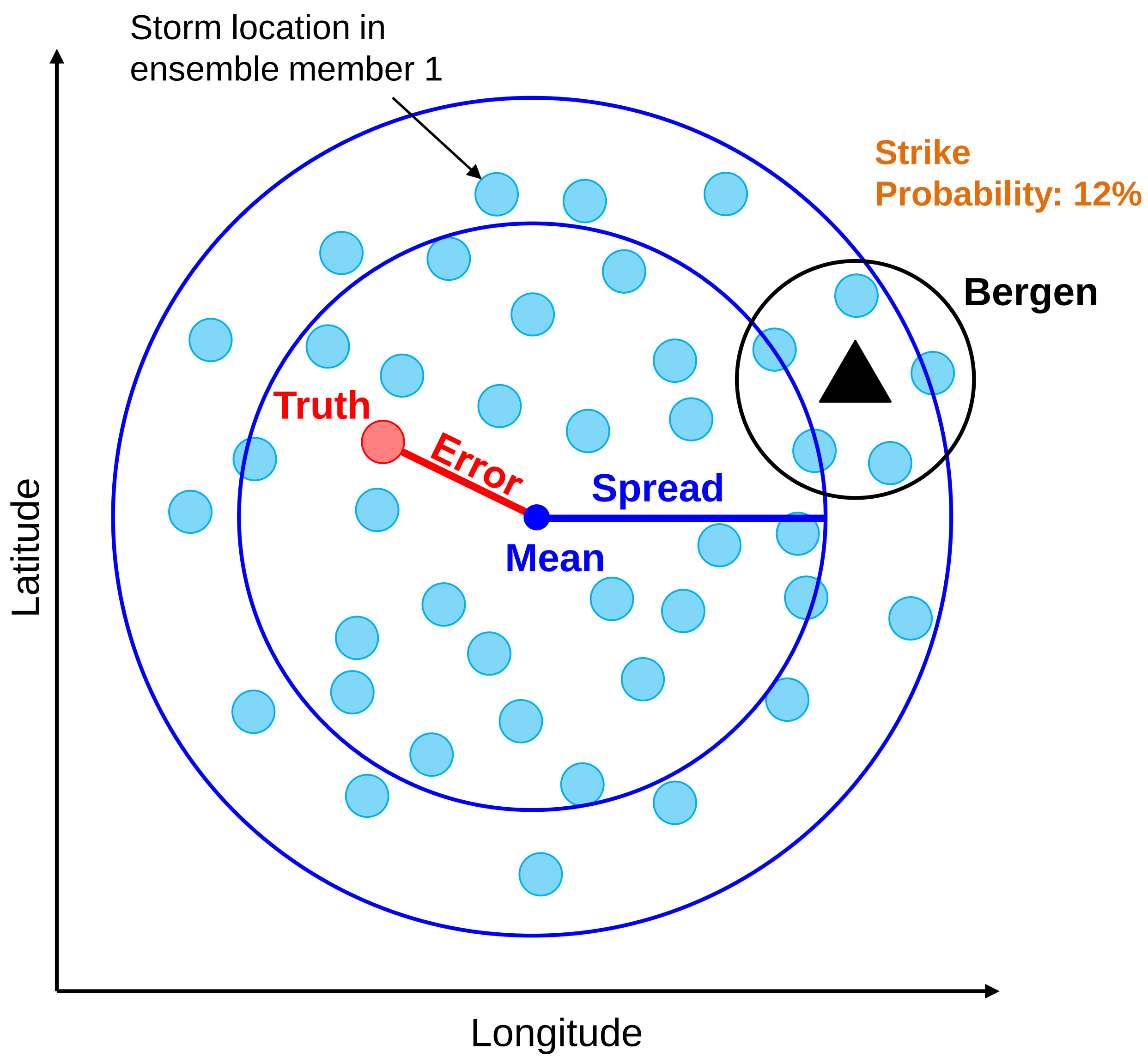
Potential Vorticity on the Potential Temperature = 320K surface. 20110404 0 UTC. Step (days, hours) = 6 00.0



For this start-date, there were many more good* forecasts

(*RMSE less than second best member in the bust case)

Motivation: Reliability and Sharpness



In a **reliable** forecast system, the truth should be statistically indistinguishable from the individual ensemble members

Reliability is very useful: an event predicted to occur with probability 12% will happen with frequency 12%

An easily testable consequence of reliability is that

$$\overline{\mathbf{Error}^2} = \overline{\mathbf{Spread}^2}$$

(averaged over many forecast start dates)

"The task of NWP research is to maintain/improve reliability while decreasing spread (improving refinement)"

Q. Can we develop diagnostics which efficiently (optimally?) guide us in this task?

Ensemble spread and error

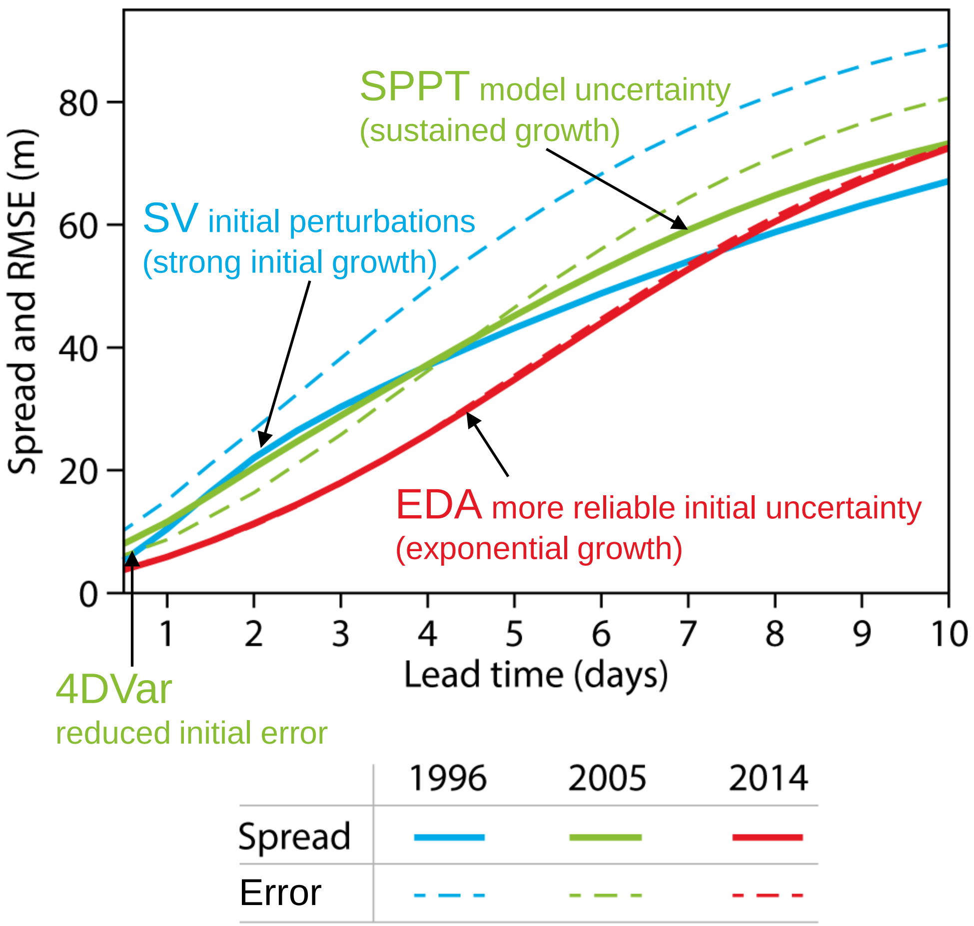
Z500

Rodwell et al. 2018, BAMS

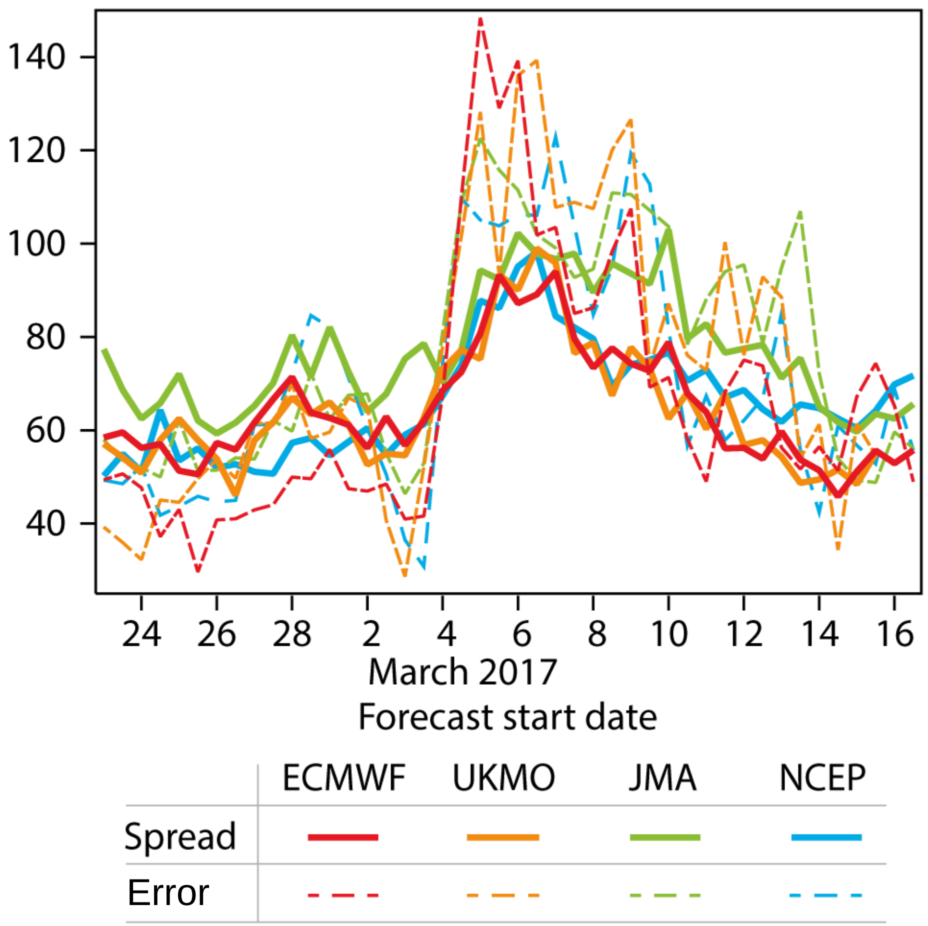
Overall Error and Spread have reduced and come into alignment; due to better observations, initial conditions, forecast model and better representation of uncertainty

…but we make ensemble forecasts to represent the day-to-day variations in predictability and uncertainty. Can we evaluate it in our forecasts?

Annual means N.Hem. (ECMWF)



Timeseries for Europe at D+6 (TIGGE)



500 hPa geopotential height (Z500). "Error" is RMS of ensemble-mean error

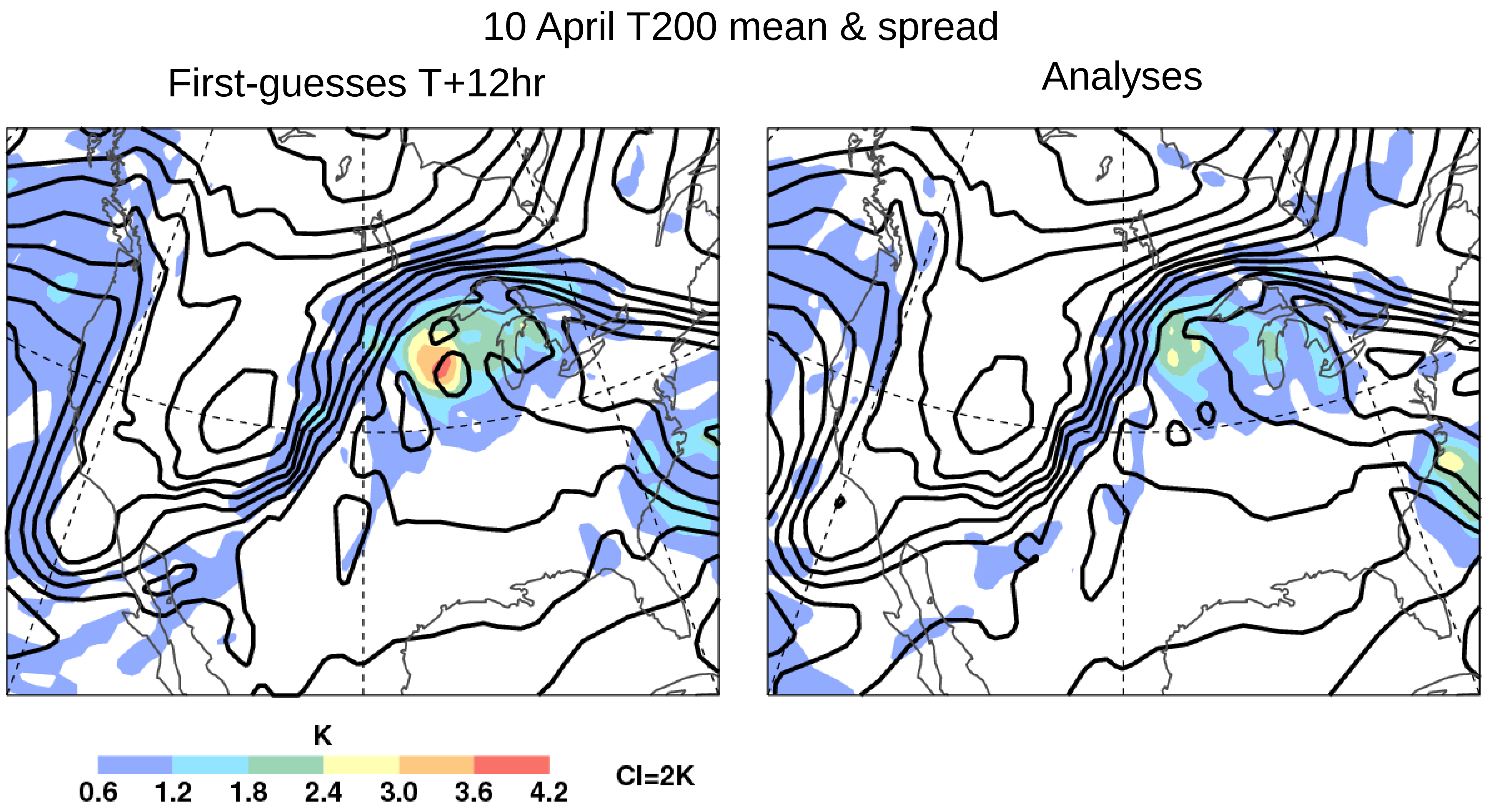
Spread = ensemble standard deviation (scaled to take account of finite ensemble size)

Improving sharpness through ensemble data assimilation

Rodwell et al, 2013, BAMS

Uncertainties in the prediction of mesoscale convection magnify first-guess spread

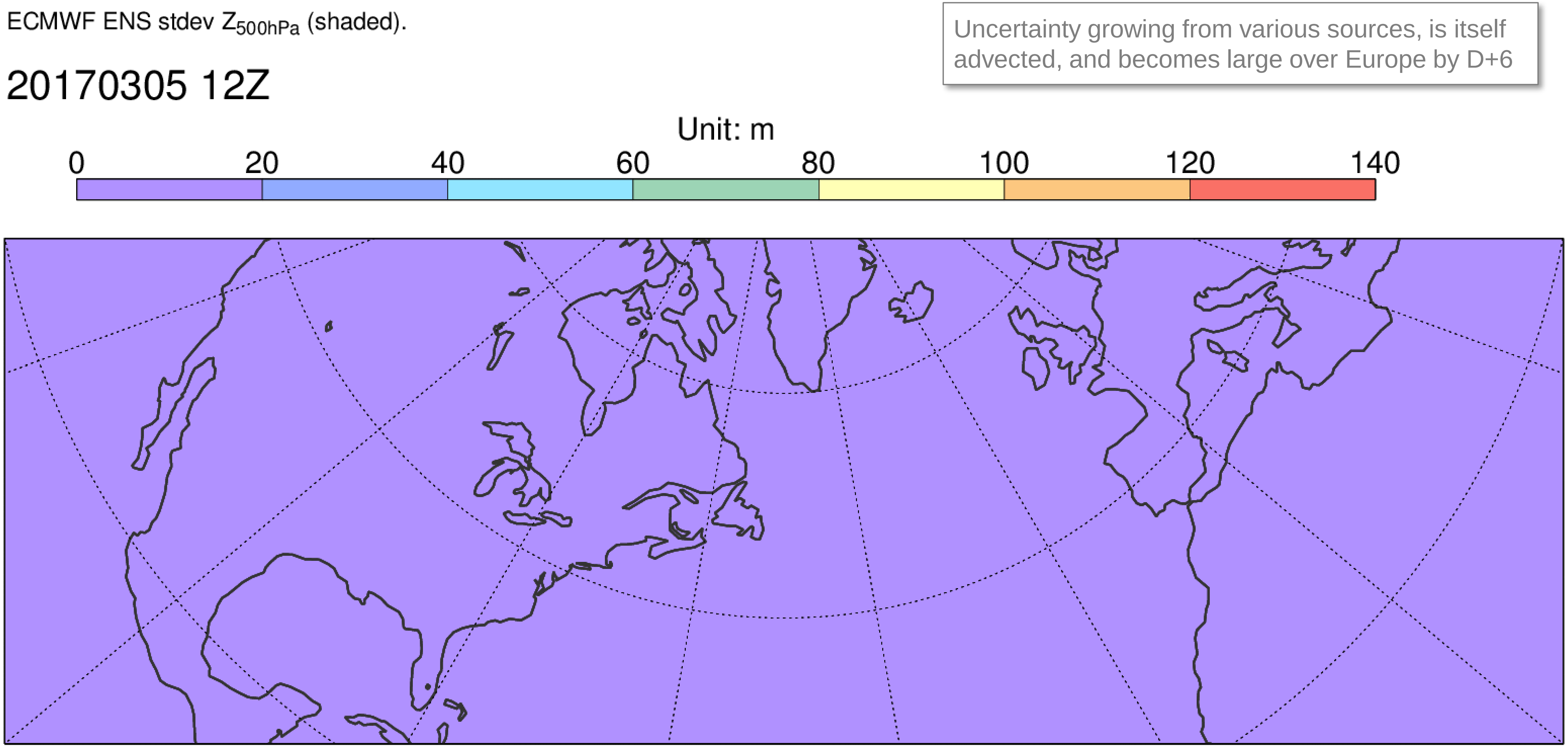
Assimilation of new observations acts to sharpen the distribution



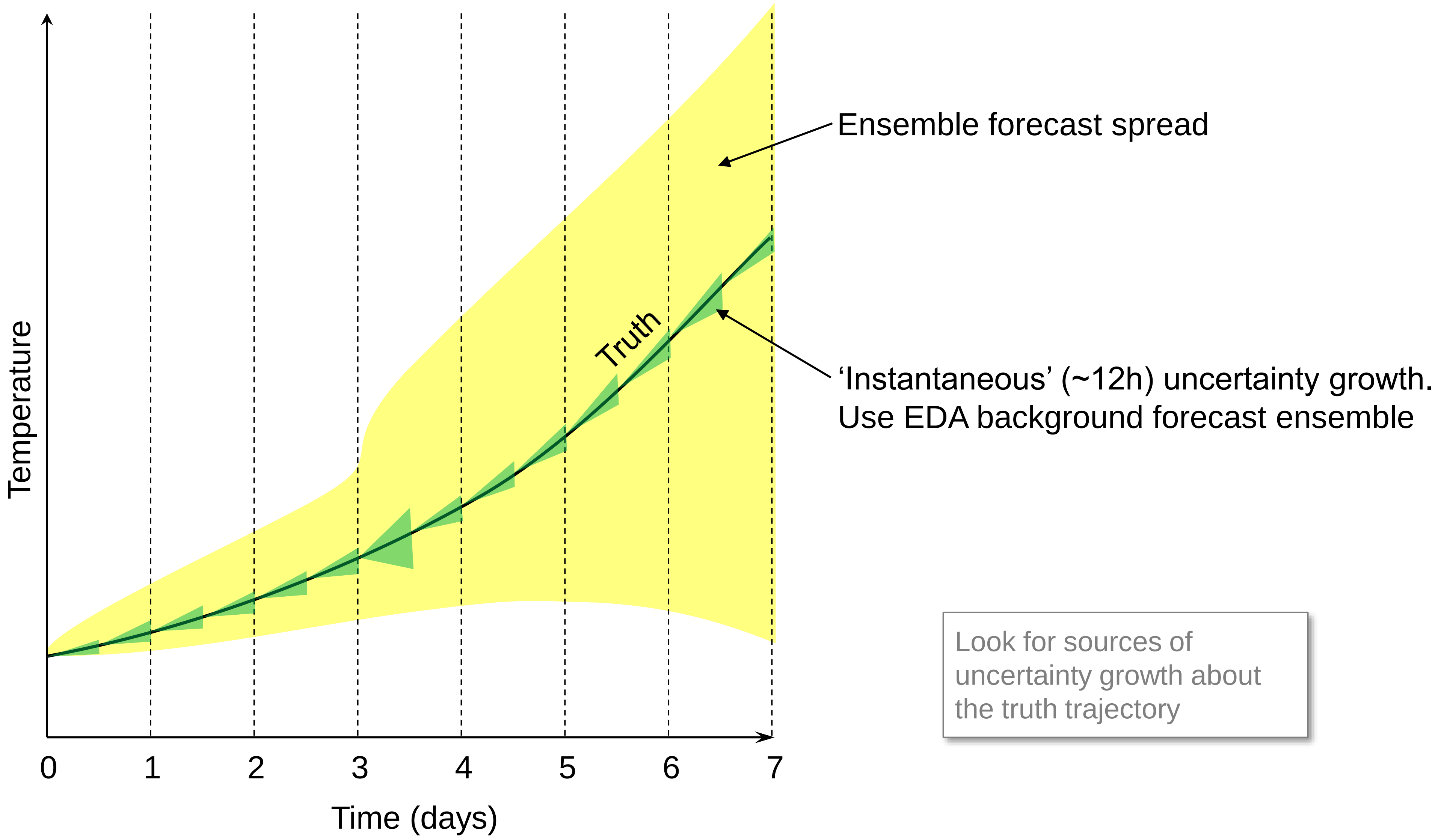
Data: Temperature at 200 hPa from 10-member EDA, valid at 6UTC

Animation of ECMWF ensemble forecast spread 20170305 12Z D+0 to 6: σ_{Z500}

Uncertainty growing from various sources, is itself advected, and becomes large over Europe by D+6



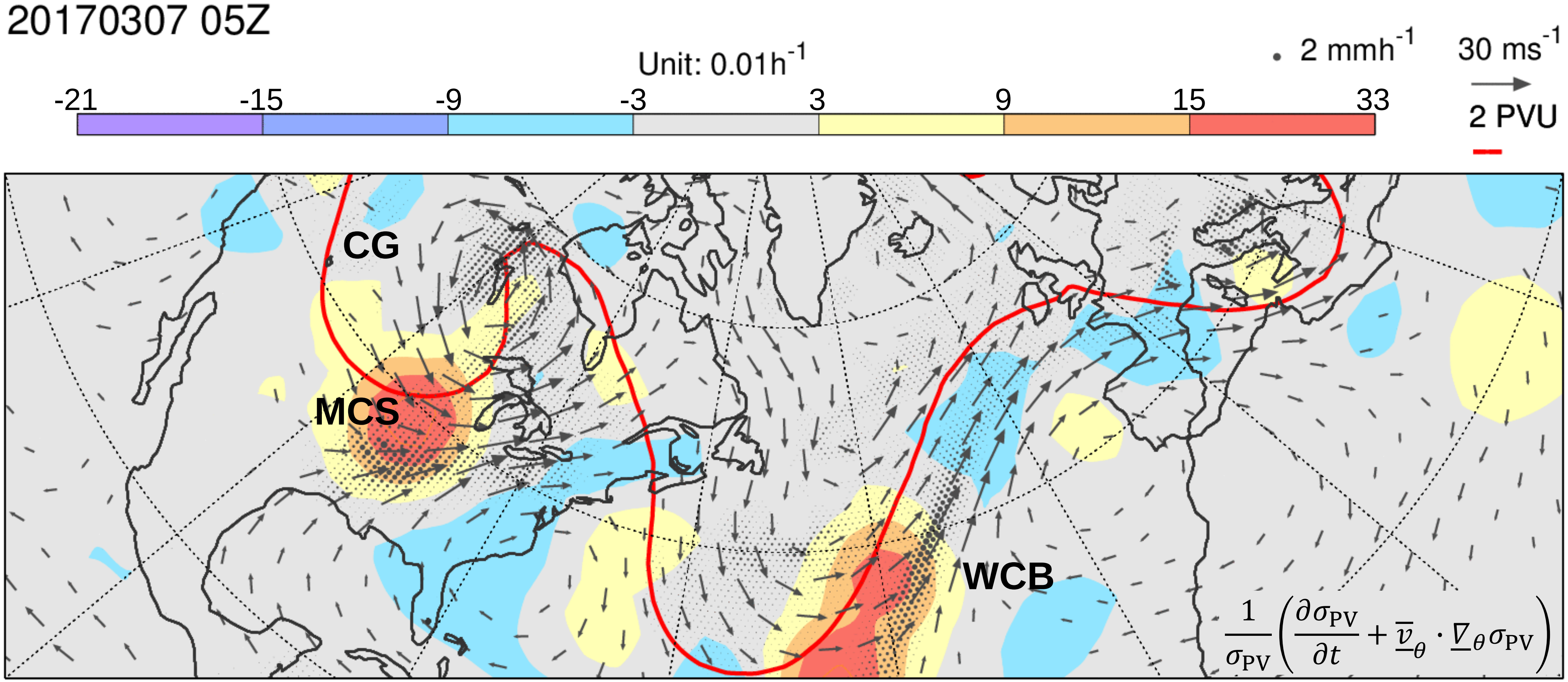
Ensemble forecast spread and the quasi-instantaneous growth of uncertainty



Look for sources of uncertainty growth about the truth trajectory

“Lagrangian” growth-rate (following EnsMn horizontal flow) for EDA background $\sigma_{PV_{315}}$

Much uncertainty growth associated with moist processes: **W**arm **C**onveyor-**B**elts, and **M**eso-**S**cale **C**onvection	Interaction of uncertain features, large ENS spread & poor prediction of Euro blocking at D+6	Aim: Evaluate short-range synoptic flow-dependent representation of uncertainty	Q: Is sensitivity to moist processes real or due to deficiencies in model uncertainty representation? TIGGE?



$$\frac{1}{\sigma_{\rm PV}}\left(\frac{\partial \sigma_{\rm PV}}{\partial t} + \underline{\overline{v}}_\theta \cdot \underline{\nabla}_\theta \sigma_{\rm PV}\right)$$

PV_{315}=2 & $\underline{v}_{850}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed

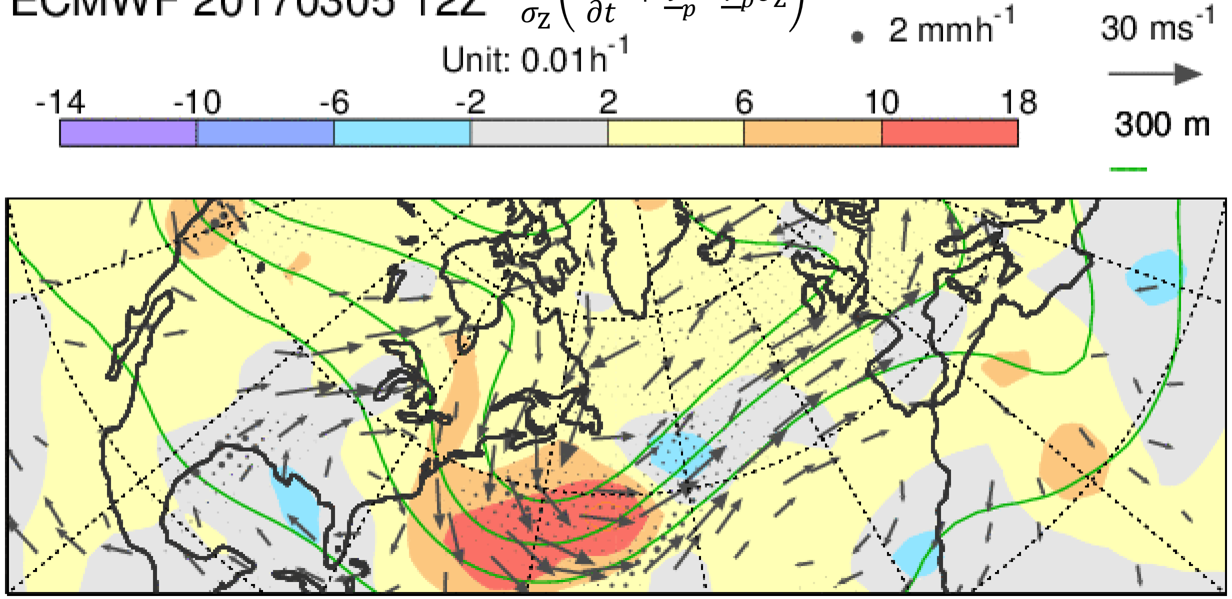
TIGGE 12h "Lagrangian" growth rate (following Ens-mean horizontal flow) for Z_{250hPa} (shaded)

CF 850hPa winds (vectors), CF Z_{250} (green contour) and EM precip (dots). 1d running-mean applied.

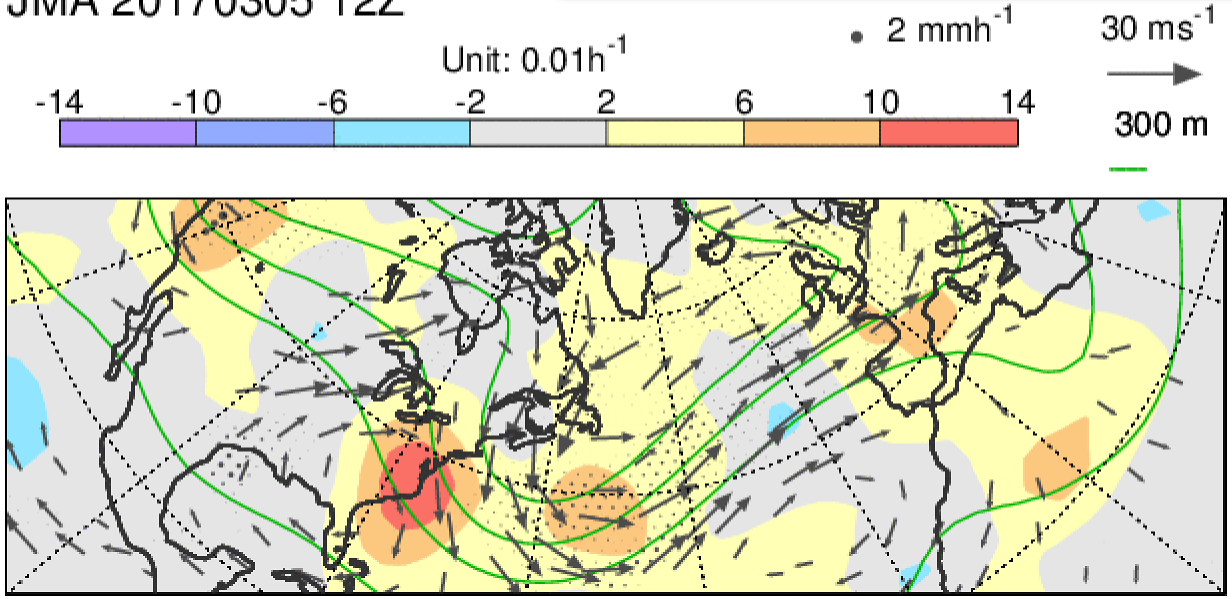
EDA(PV_{315K}) ≈ ENS(Z_{250hPa}) ≈ JMA. UKMO: MCS less, Europe more. KMA less everywhere(?) Which is best?

ECMWF 20170305 12Z

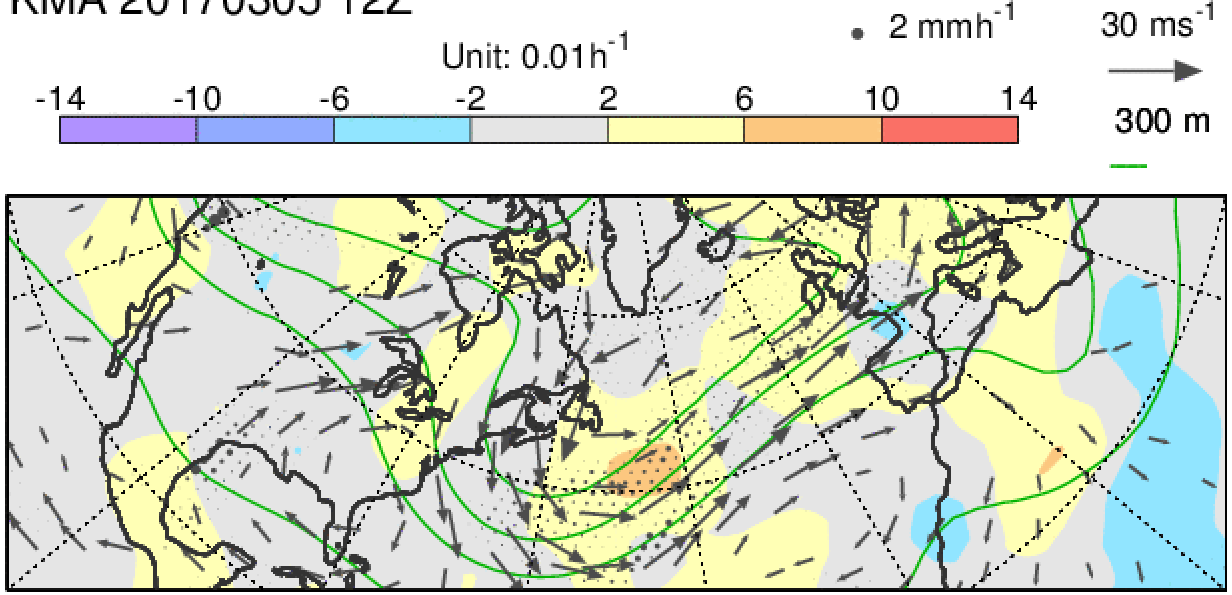
$$\frac{1}{\sigma_Z}\left(\frac{\partial \sigma_Z}{\partial t} + \overline{v}_p \cdot \nabla_p \sigma_Z\right)$$



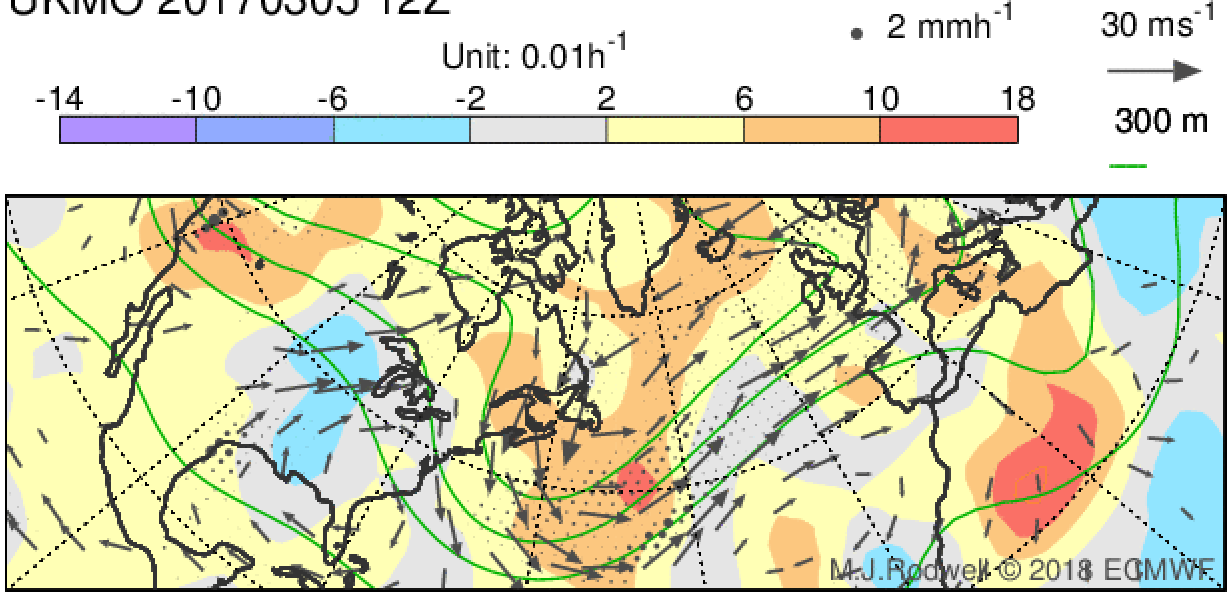
JMA 20170305 12Z



KMA 20170305 12Z



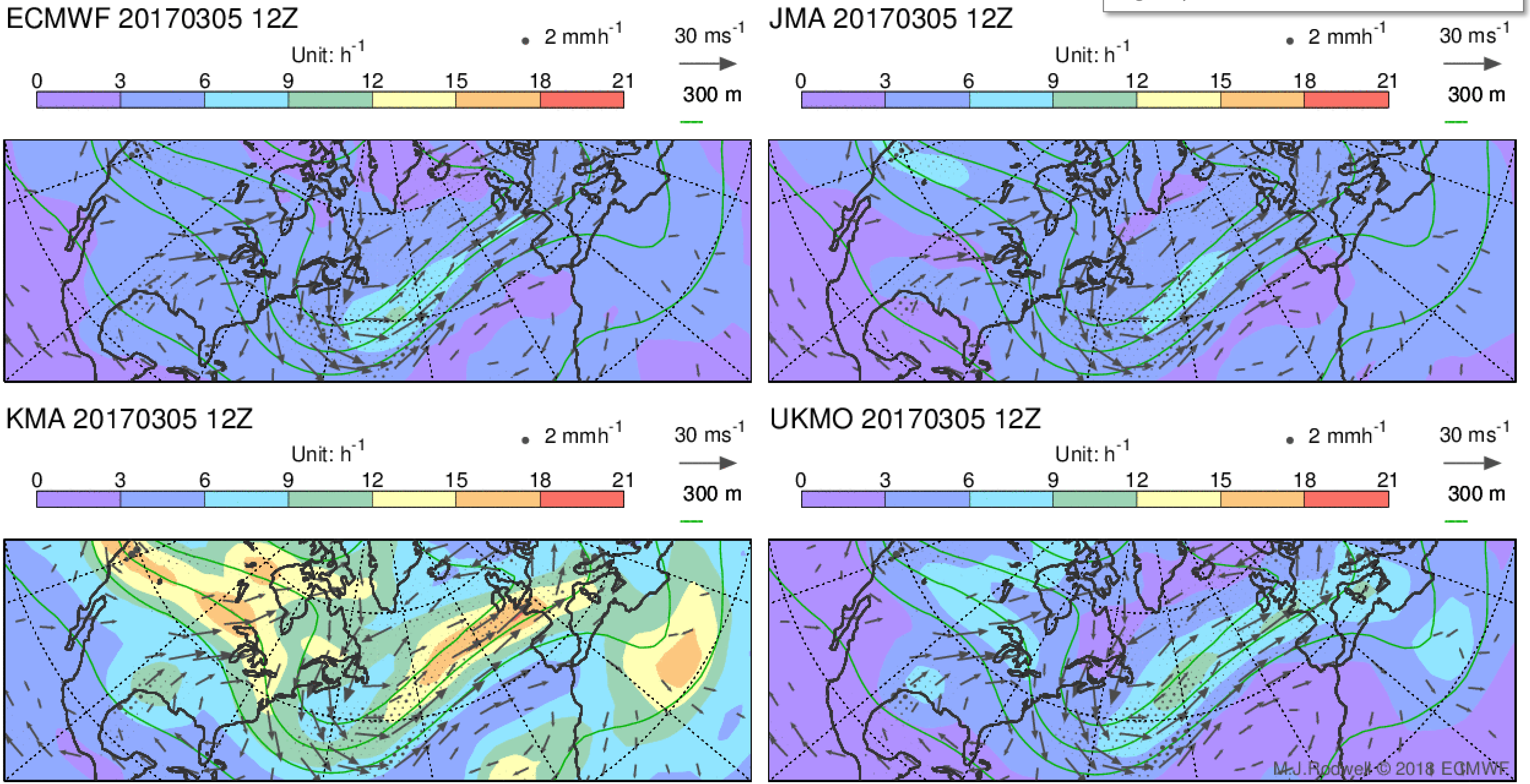
UKMO 20170305 12Z



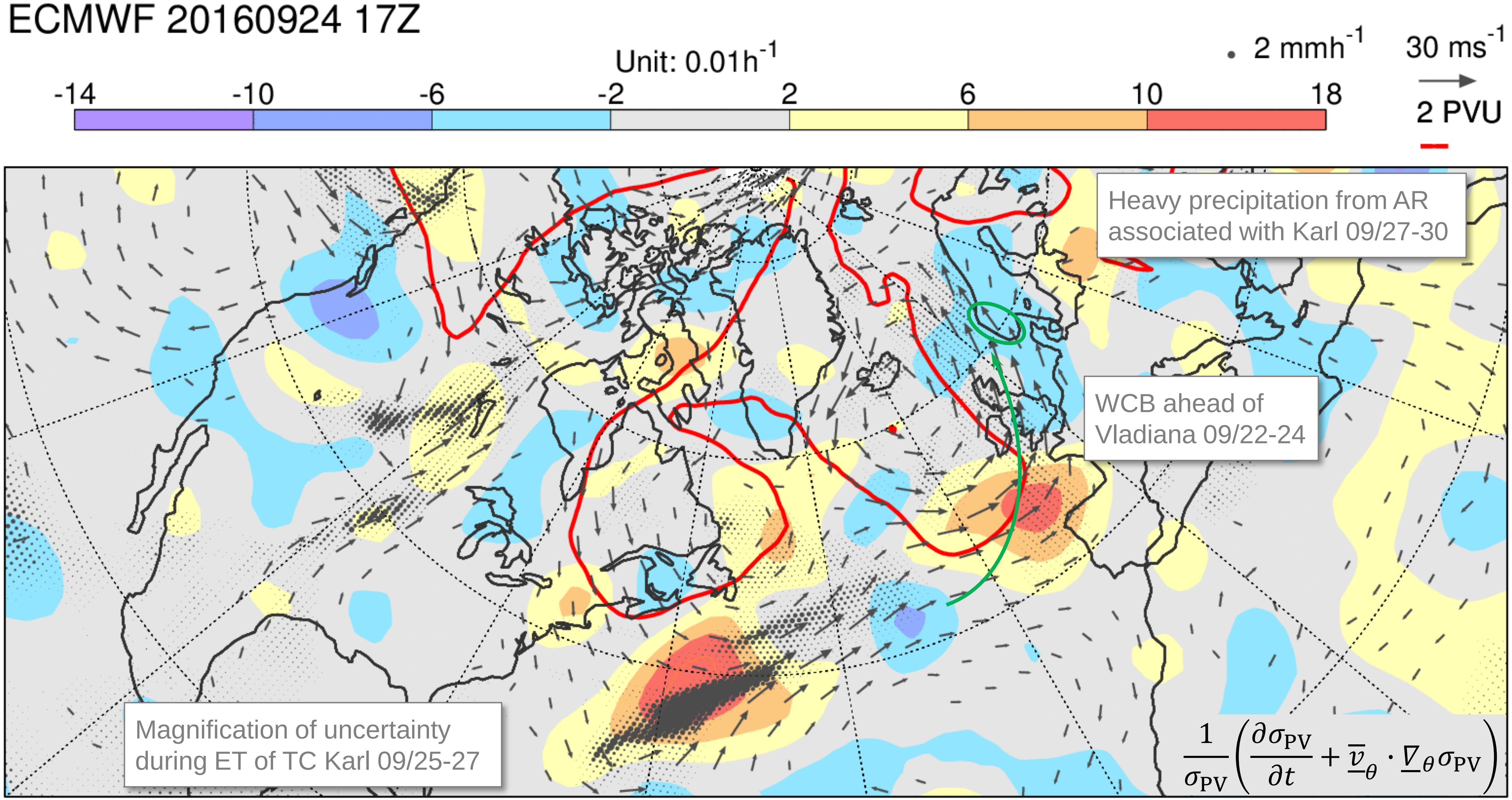
TIGGE 12h Standard deviation in Z_{250hPa} (shaded) ~Initial uncertainty of ensemble

CF 850hPa winds (vectors), CF Z_{250} (green contour) and EM precip (dots). 1d running-mean applied.

Ensembles start from a different initial uncertainties, but growth-rate (in linear regime) should be unaffected



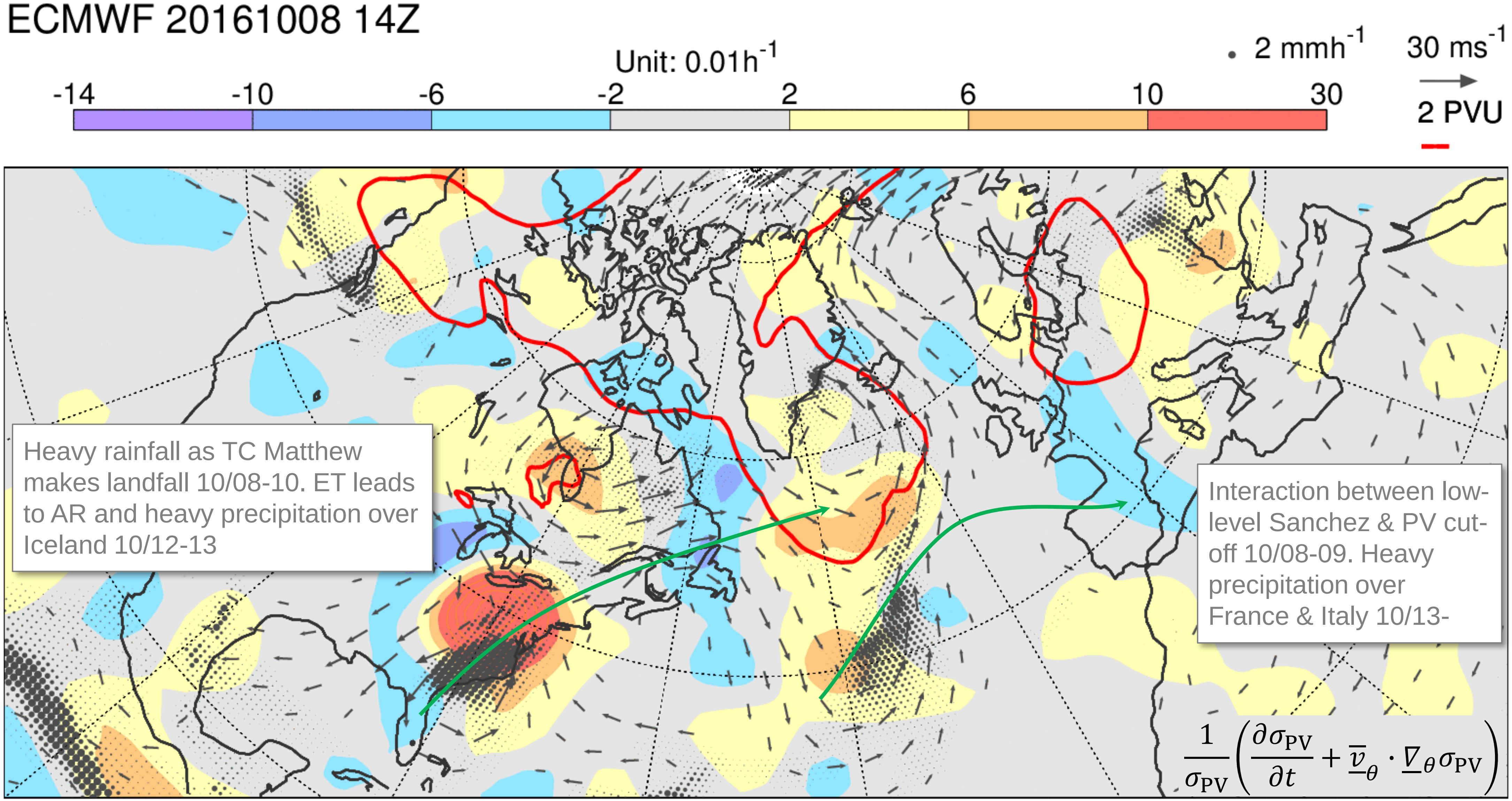
“Lagrangian” growth-rate for $\sigma_{PV_{315}}$: NAWDEX Vladiana & TC Karl



$$\frac{1}{\sigma_{PV}}\left(\frac{\partial \sigma_{PV}}{\partial t} + \underline{\bar{v}}_{\theta} \cdot \underline{\nabla}_{\theta} \sigma_{PV}\right)$$

PV_{315}=2 & $\underline{v}_{850}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed

“Lagrangian” growth-rate for $\sigma_{PV_{315}}$: NAWDEX Sanchez



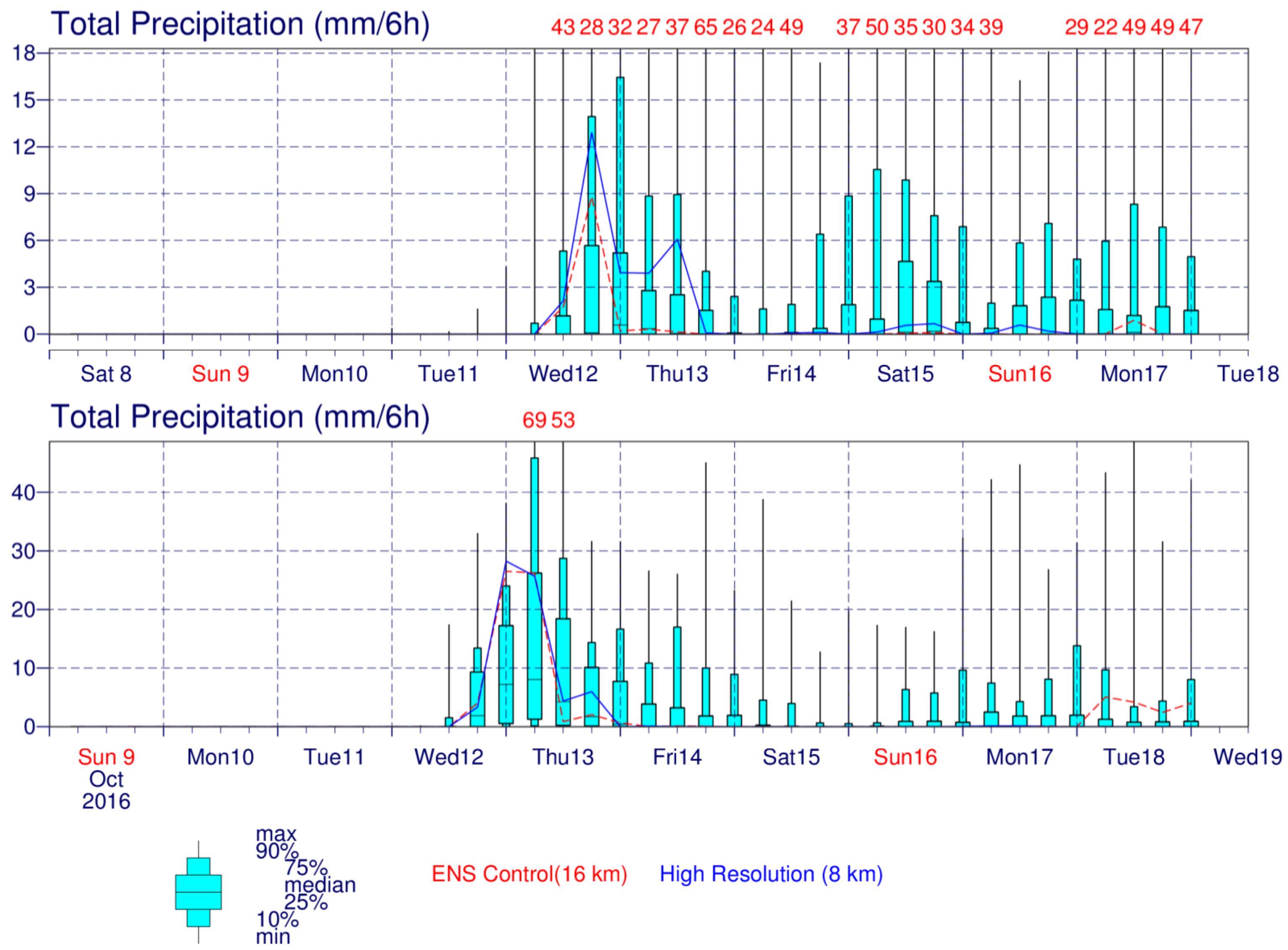
$$\frac{1}{\sigma_{\mathrm{PV}}}\left(\frac{\partial \sigma_{\mathrm{PV}}}{\partial t} + \underline{v}_\theta \cdot \underline{\nabla}_\theta \sigma_{\mathrm{PV}}\right)$$

PV_{315}=2 & $\underline{v}_{850}$ from control forecast, precipitation is ensemble-mean. 1d running-mean gives 12h-integrated growth rate with any diurnal cycle removed. T21 smoothed

Forecast for precipitation in Montpellier, southern France

FC start 10/08

FC start 10/09



Once uncertainties associated with the interaction between Sanchez and the upper-level PV cut-off are resolved, the probability for strong precipitation over southern France firms-up. Note the different y-axes.