

A weather-system perspective on forecast errors

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Many thanks to:

Maxi Böttcher, Christian Grams, Hanna Joos, Natalie Kuster,
Erica Madonna

ECMWF/WWRP Workshop: Model Uncertainty
11 April 2016

Weather systems and forecast errors: a two-way linkage

1. Weather system → forecast errors?

- How well can models represent & predict specific weather systems?
- Examples: tropical cyclones, extratropical cyclones, Rossby waves, warm conveyor belts, ...

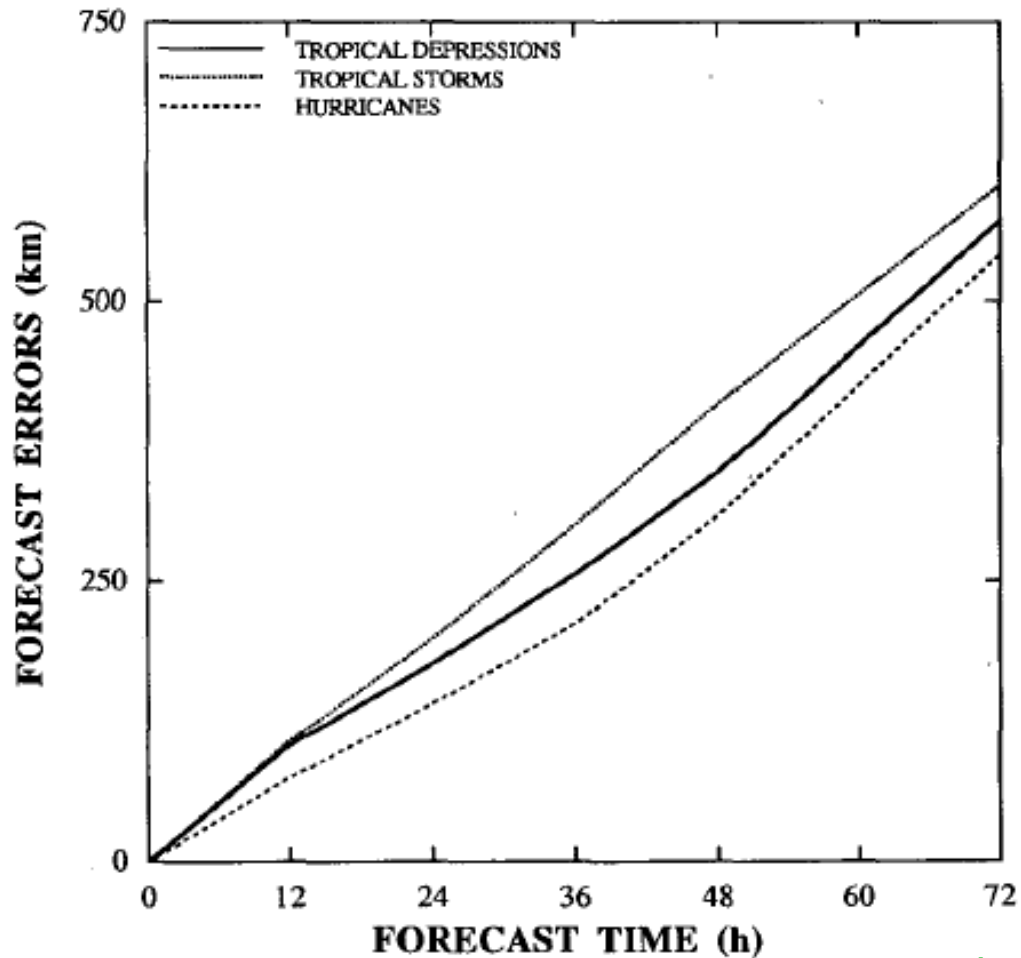
2. Forecast errors → weather systems?

- Are there specific weather systems involved in situations where forecasts errors are large?
- Examples: systematic studies, case study

3. Summary, challenges & questions

Verification of tropical cyclone tracks

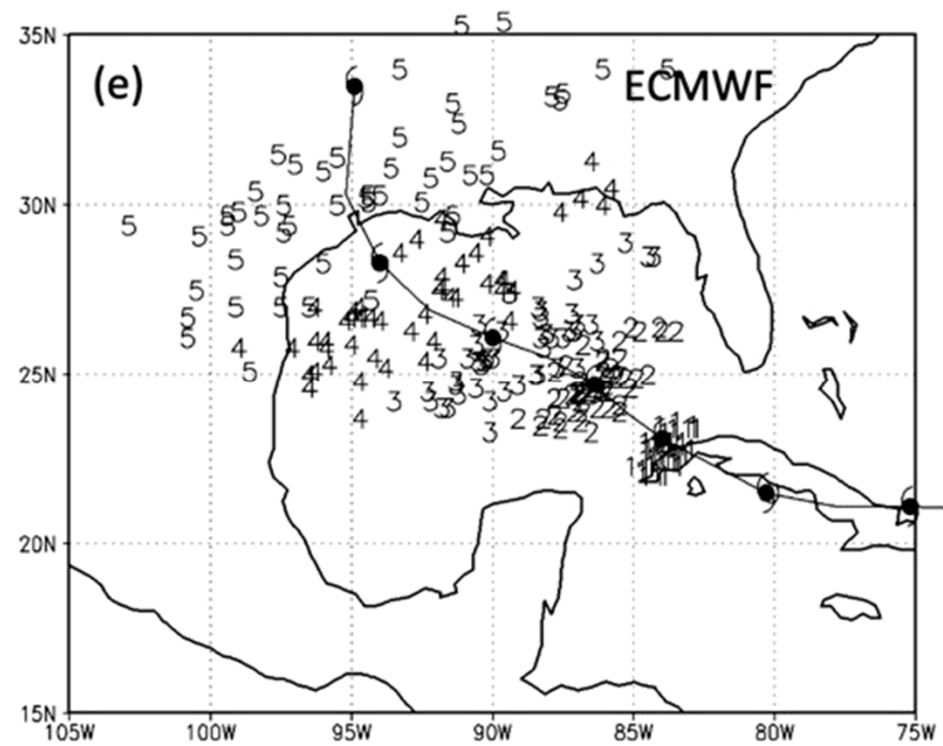
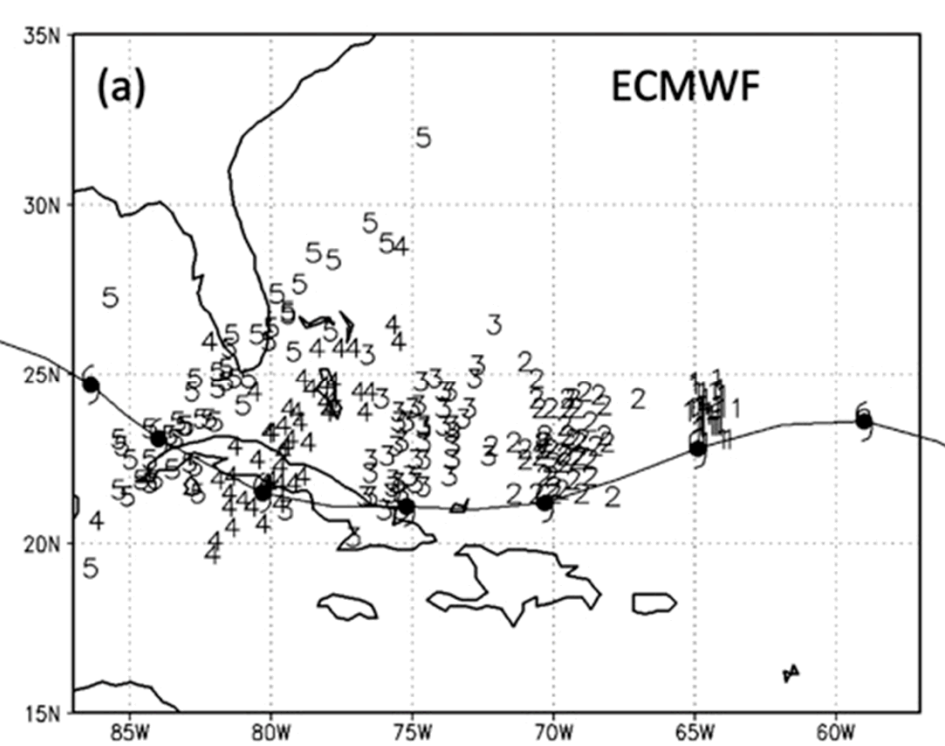
Averaged track position error for different categories of TCS



Aberson and DeMaria 1994 (MWR)

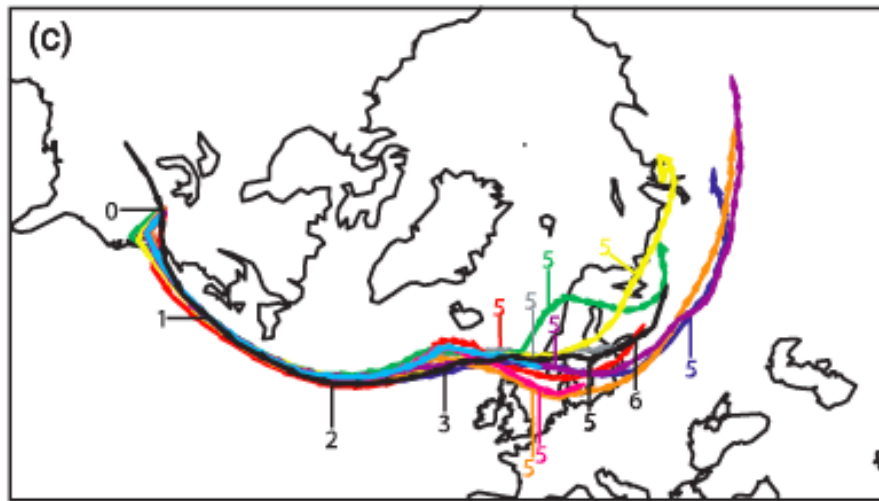
Verification of tropical cyclone tracks

Ensemble track forecast for Hurricane Ike (2008)

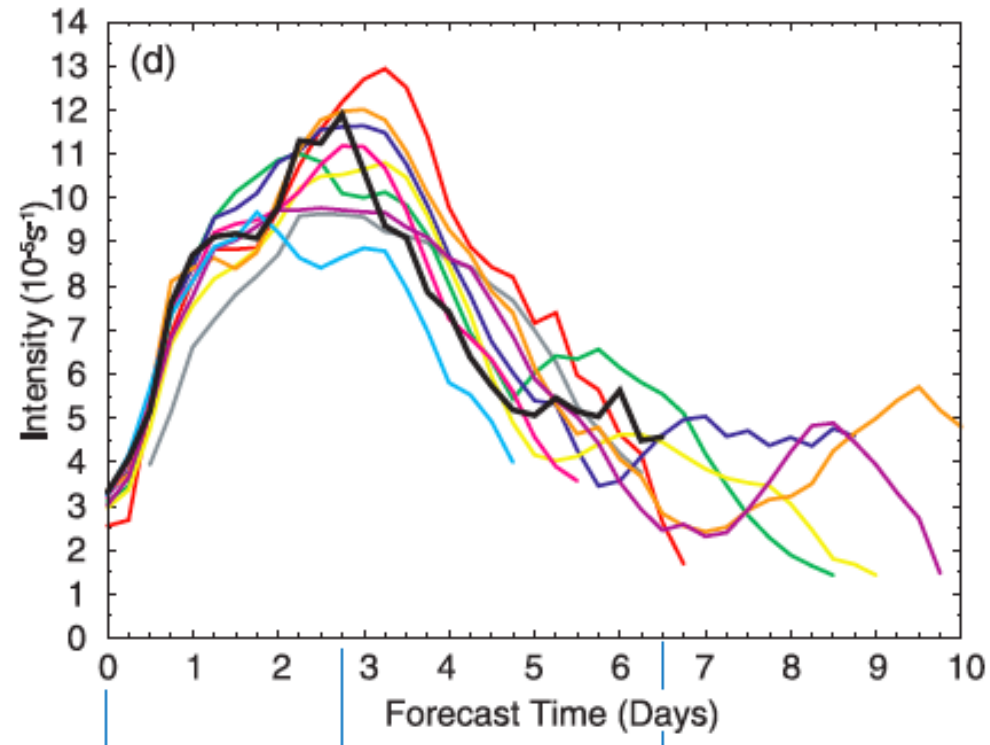
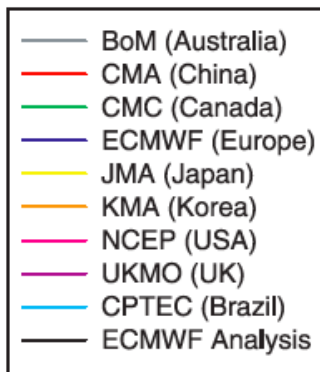


Verification of extratropical cyclone tracks

Example: control forecasts from TIGGE ensembles



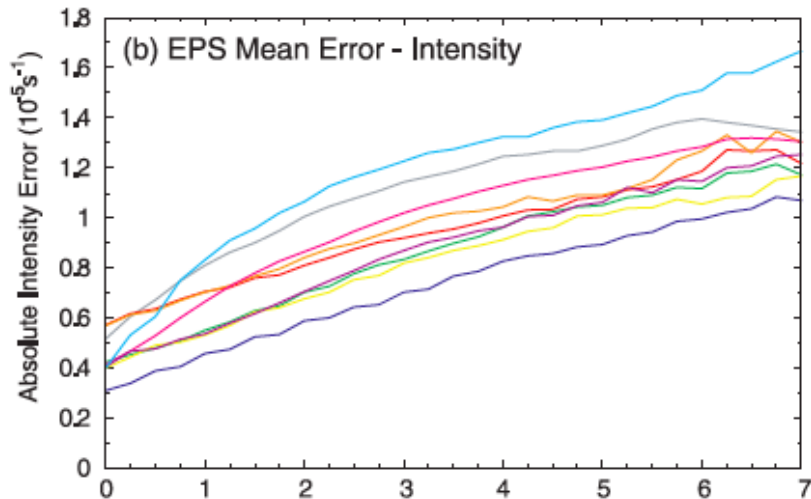
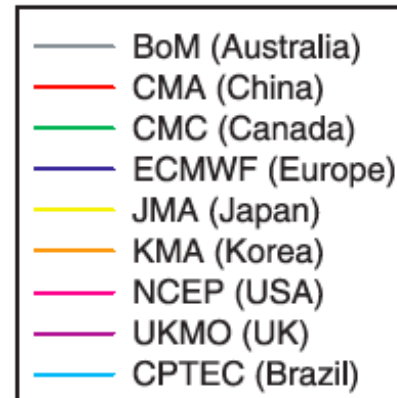
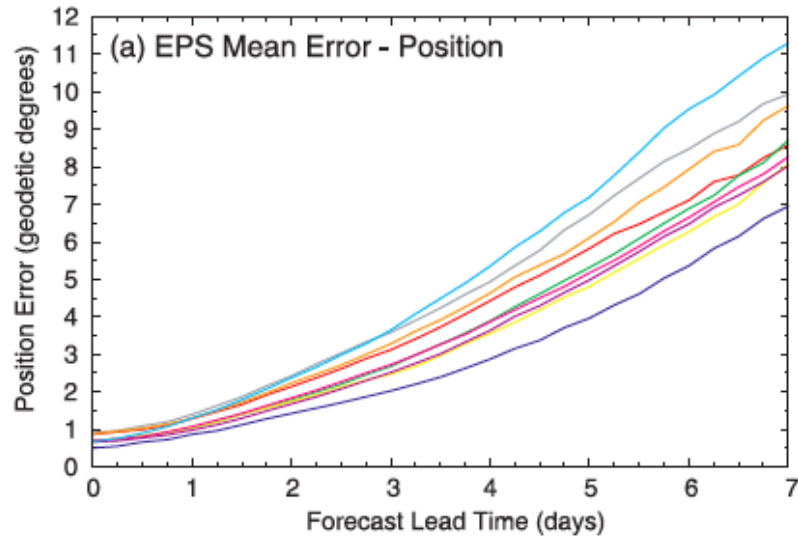
Forecast Started: 1200 UTC 22 Feb 2008
First point in analysis track: 0000 UTC 22 Feb 2008



Froude 2010 (WaF)

Verification of extratropical cyclone tracks

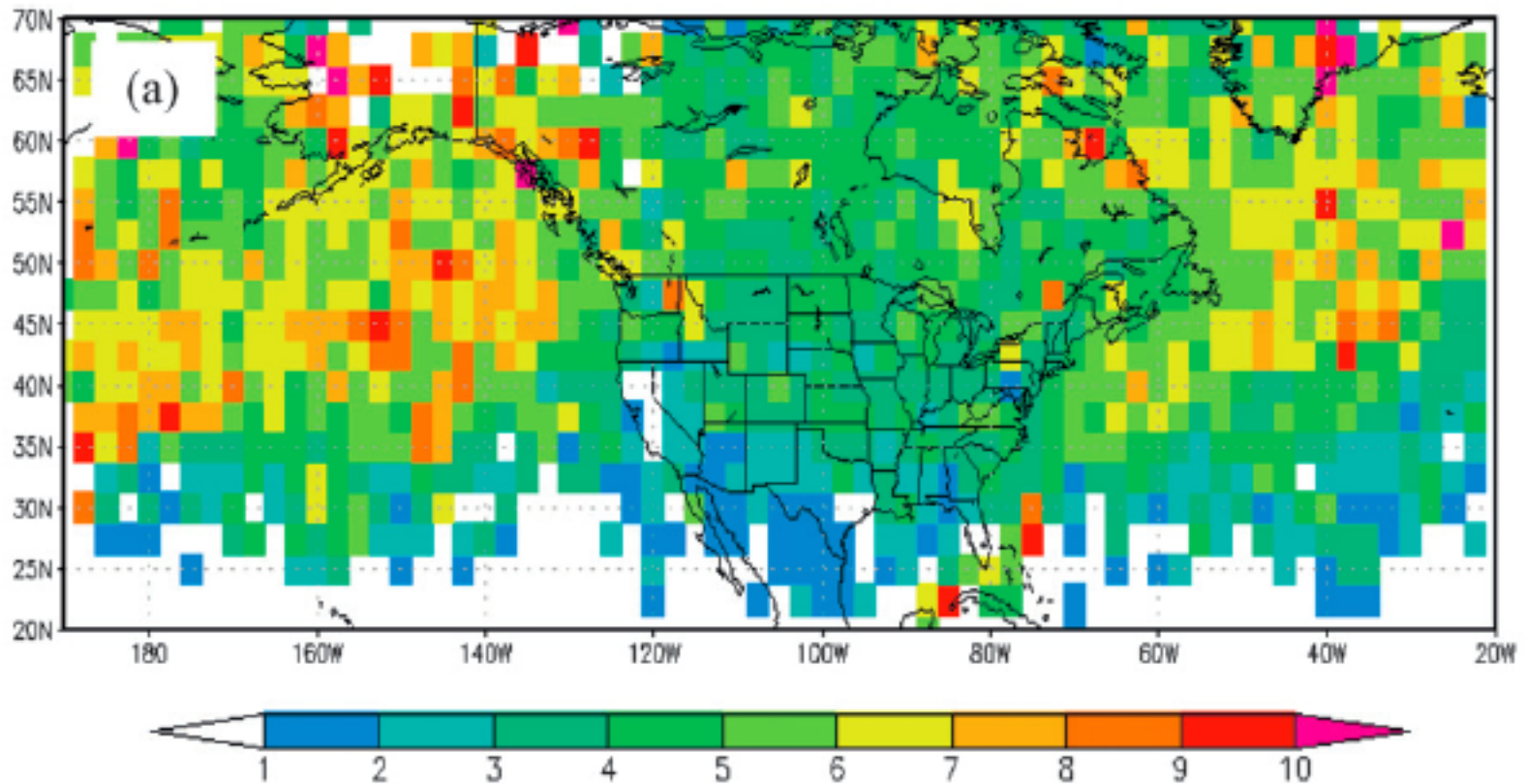
Systematic evaluation of cyclone tracks in TIGGE ensembles



Froude 2010 (WaF)

Verification of extratropical cyclone tracks

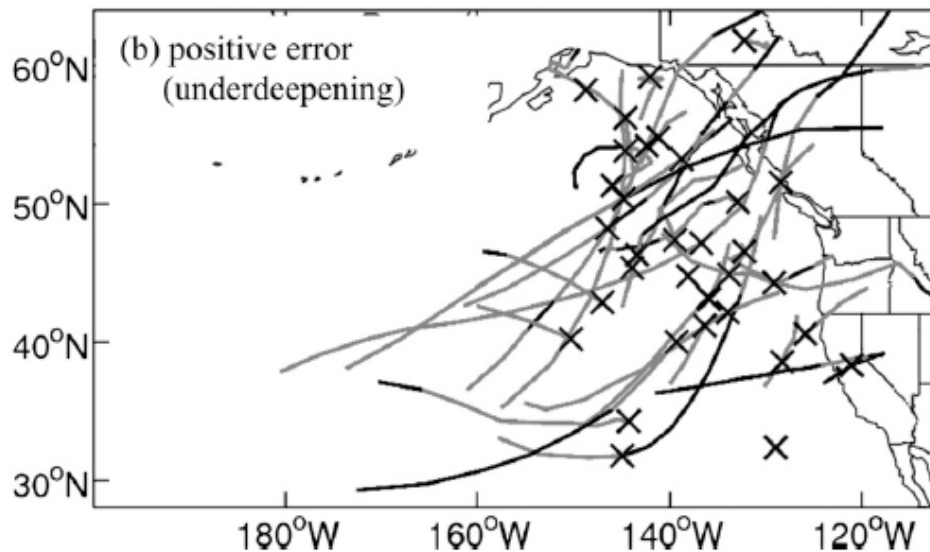
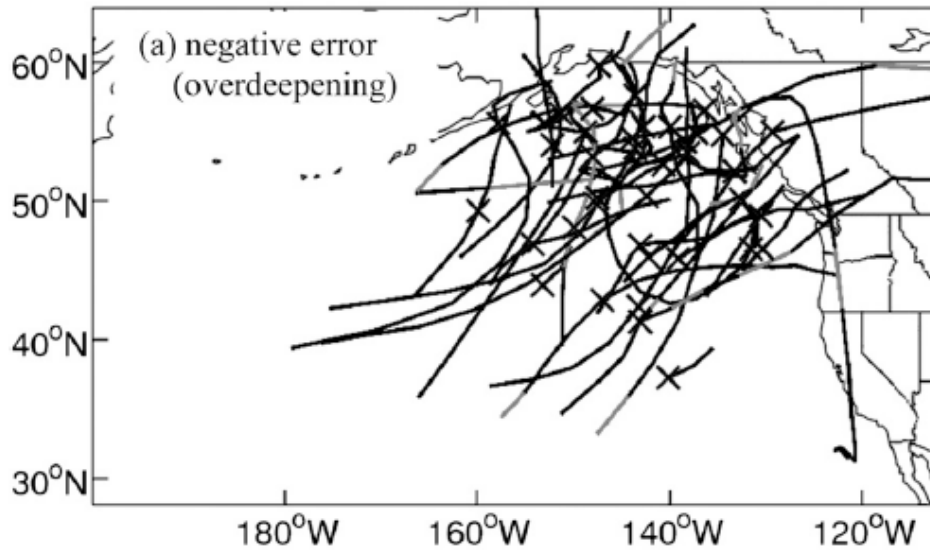
Mean absolute error of cyclone intensity (central SLP, in hPa) for day 3-5 GFS forecasts



Colle and Charles 2011 (WaF)

Verification of extratropical cyclone tracks

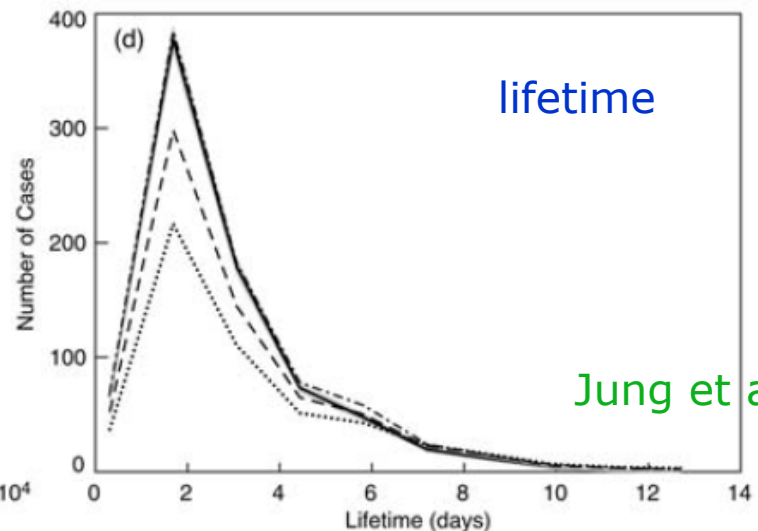
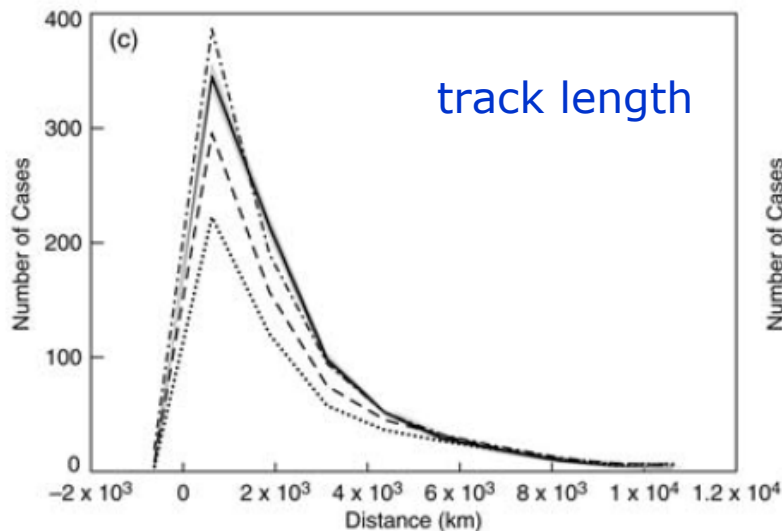
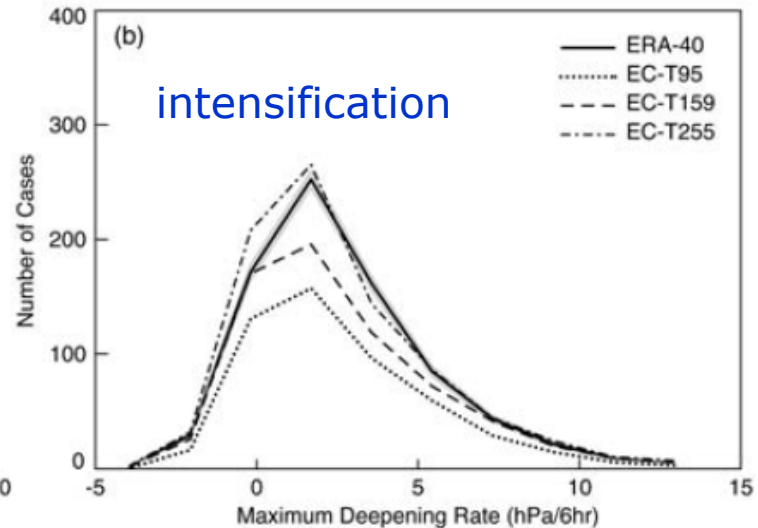
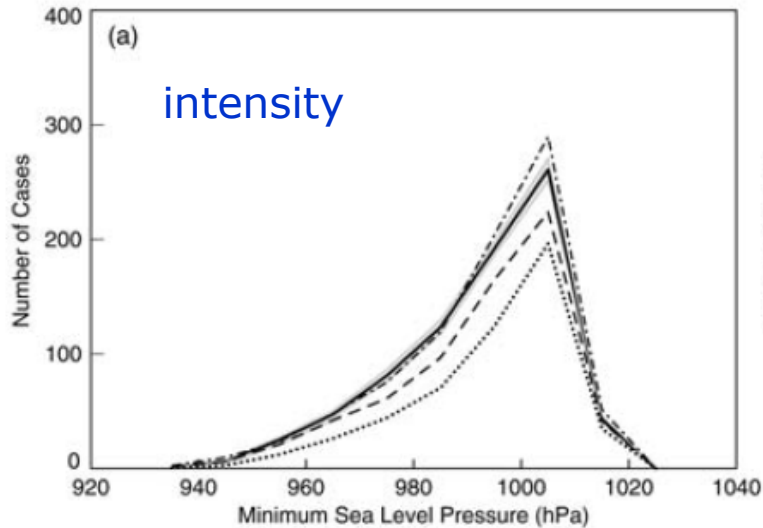
Eastern Pacific cyclone tracks with over- vs. under-deepening



Colle and Charles 2011 (WaF)

Verification of extratropical cyclone tracks

Effect of horizontal resolution of IFS on cyclone track characteristics

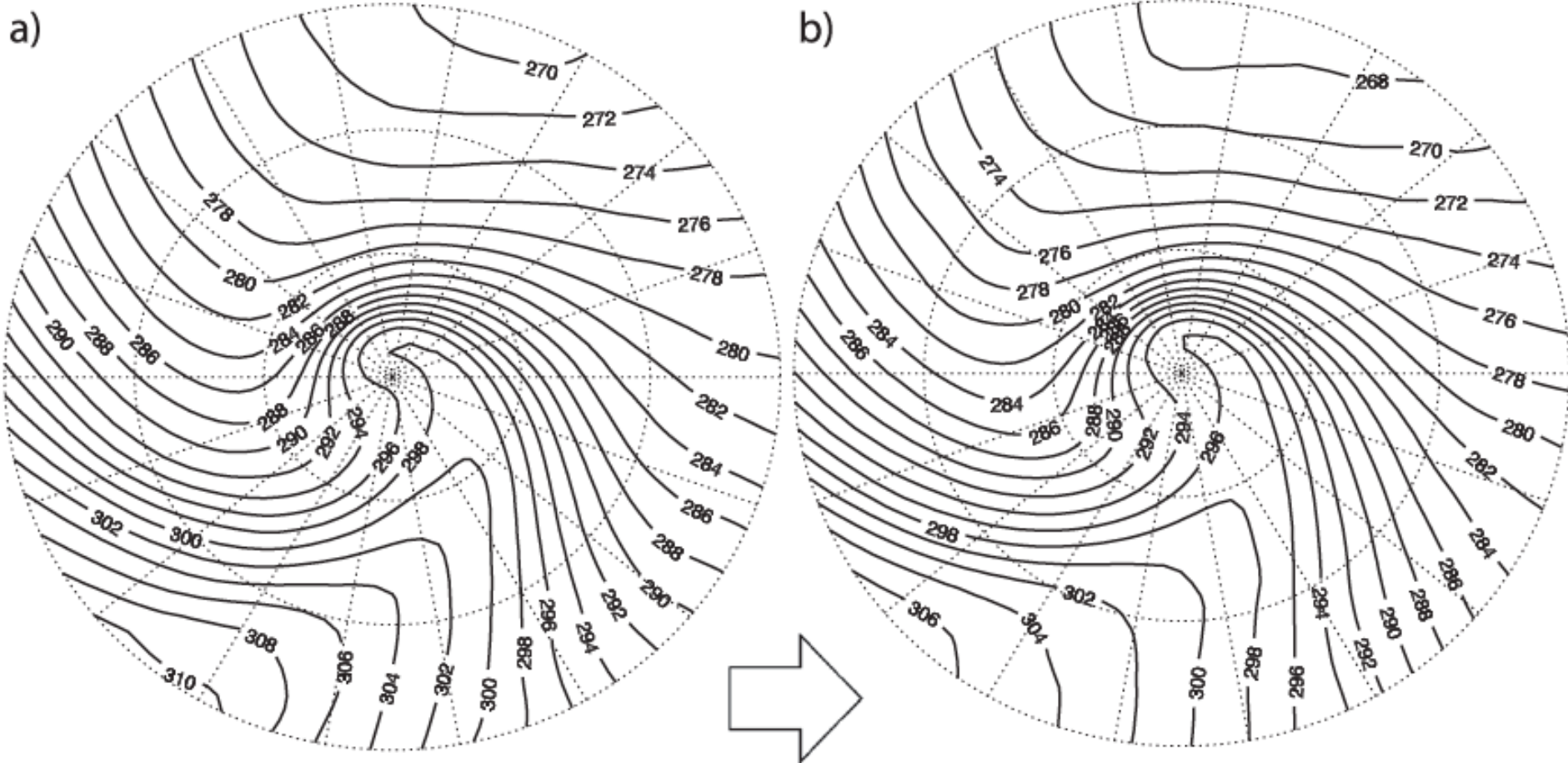


Jung et al. 2006 (QJ)

Verification of extratropical cyclone tracks

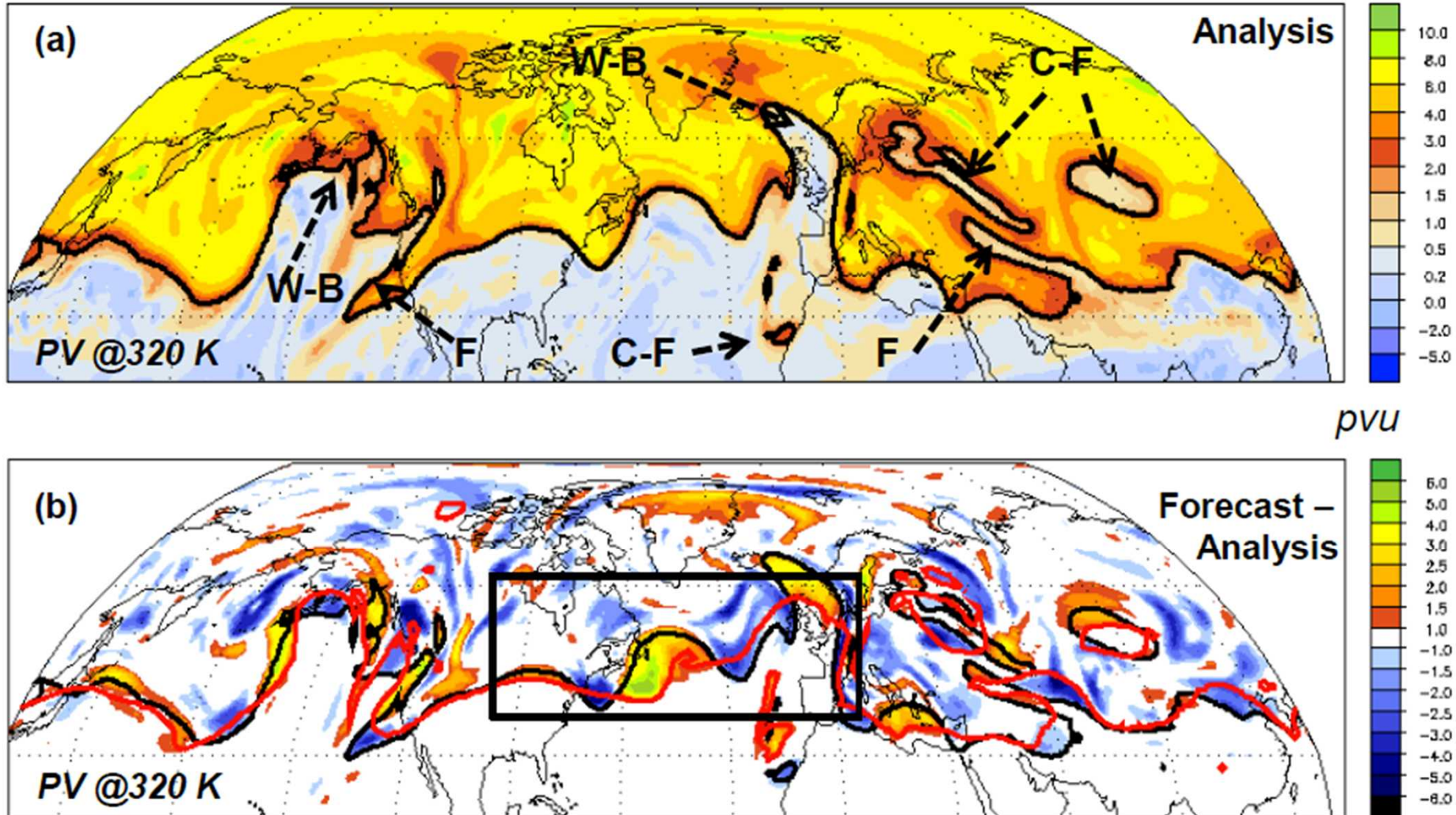
Cyclone structures in climate models?

Θ_e on 850 hPa for 50 strongest cyclones in ERA-40 and HiGEM



Catto et al. 2010 (JCLim)

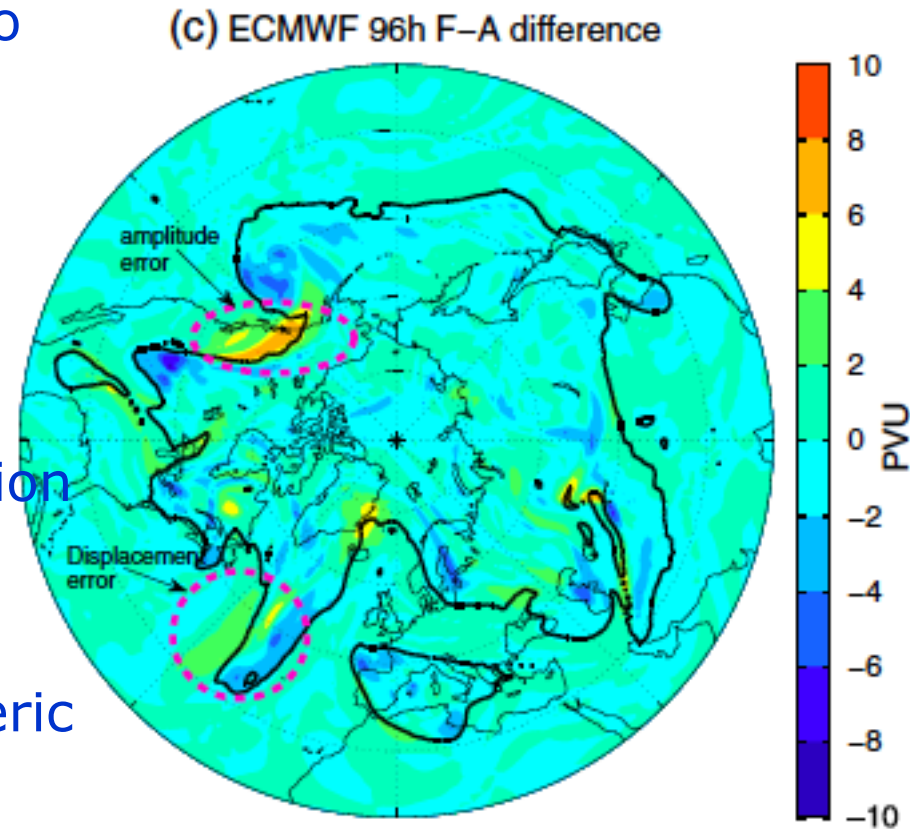
Rossby waves – troughs and ridges



Rossby waves – troughs and ridges

Tropopause sharpness adjacent to ridges decreases with forecast lead time.

Rossby wave amplitude reduces with lead time up to 5 days, consistent with underrepresentation of diabatic modification and transport of air from the lower troposphere into upper tropospheric ridges

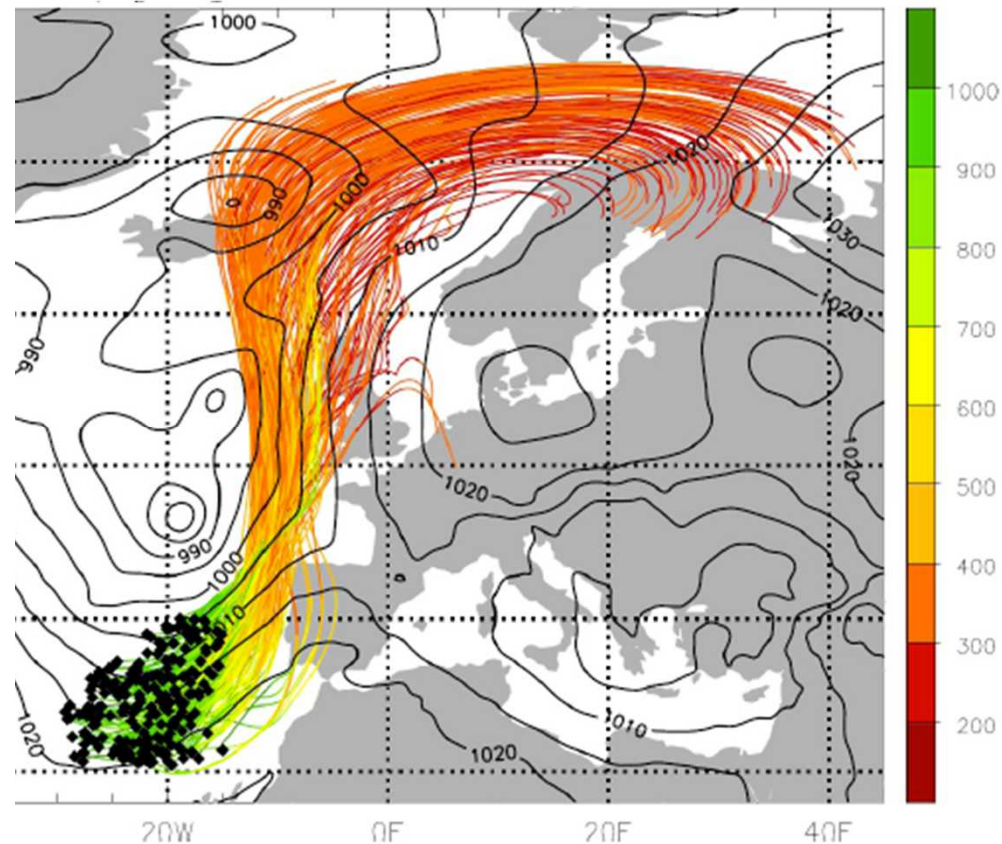


Key airstream in cyclones: warm conveyor belts

within 2 days:

- ascent > 600 hPa
- polew. transport > 3500 km
- latent heating > 20 K
- low PV in the outflow

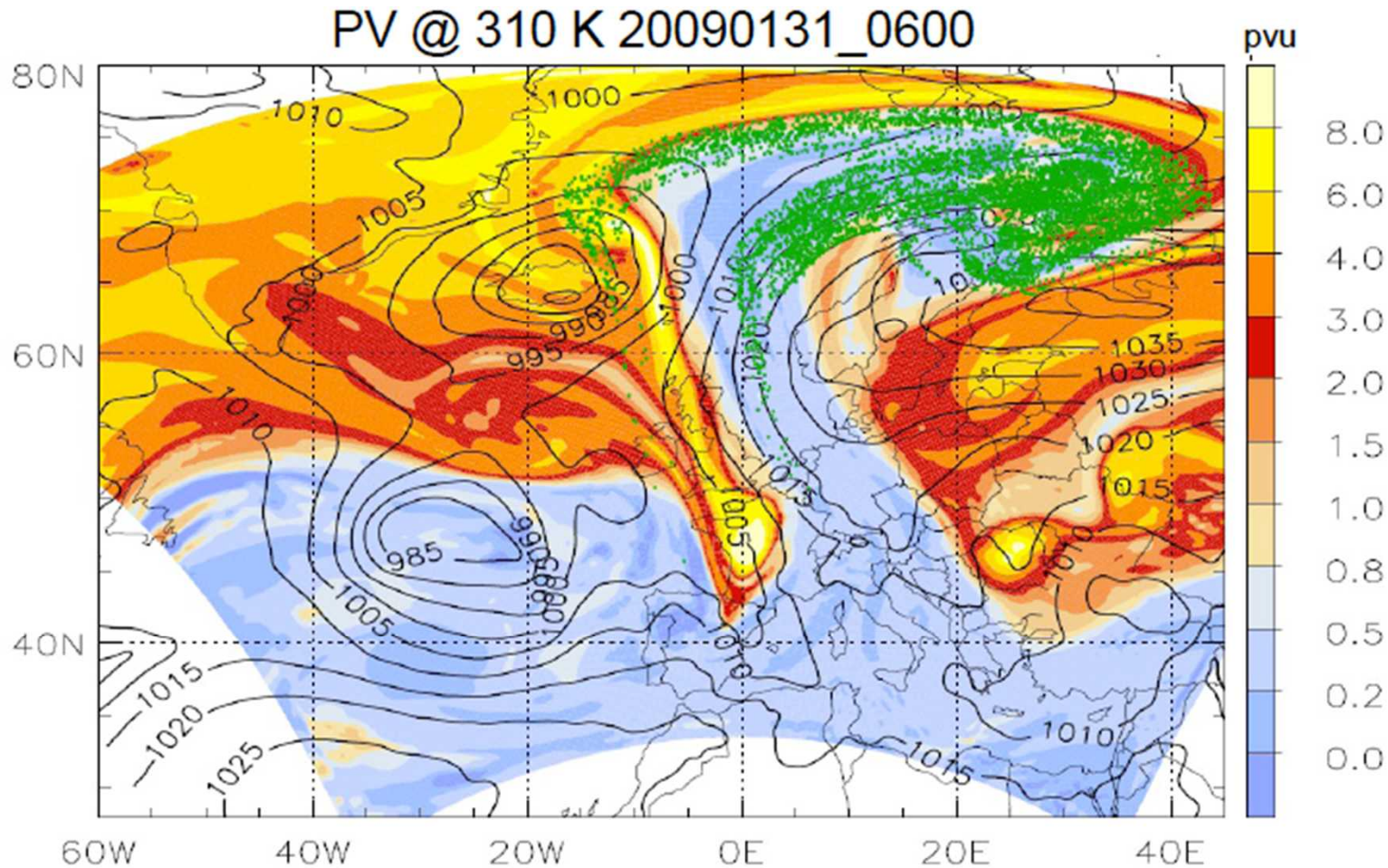
flow structure in extratropical cyclones with strongest latent heat release & precipitation



Joos and Wernli 2012 (QJ)

Warm conveyor belts

Important cross-isentropic transport of low-PV air

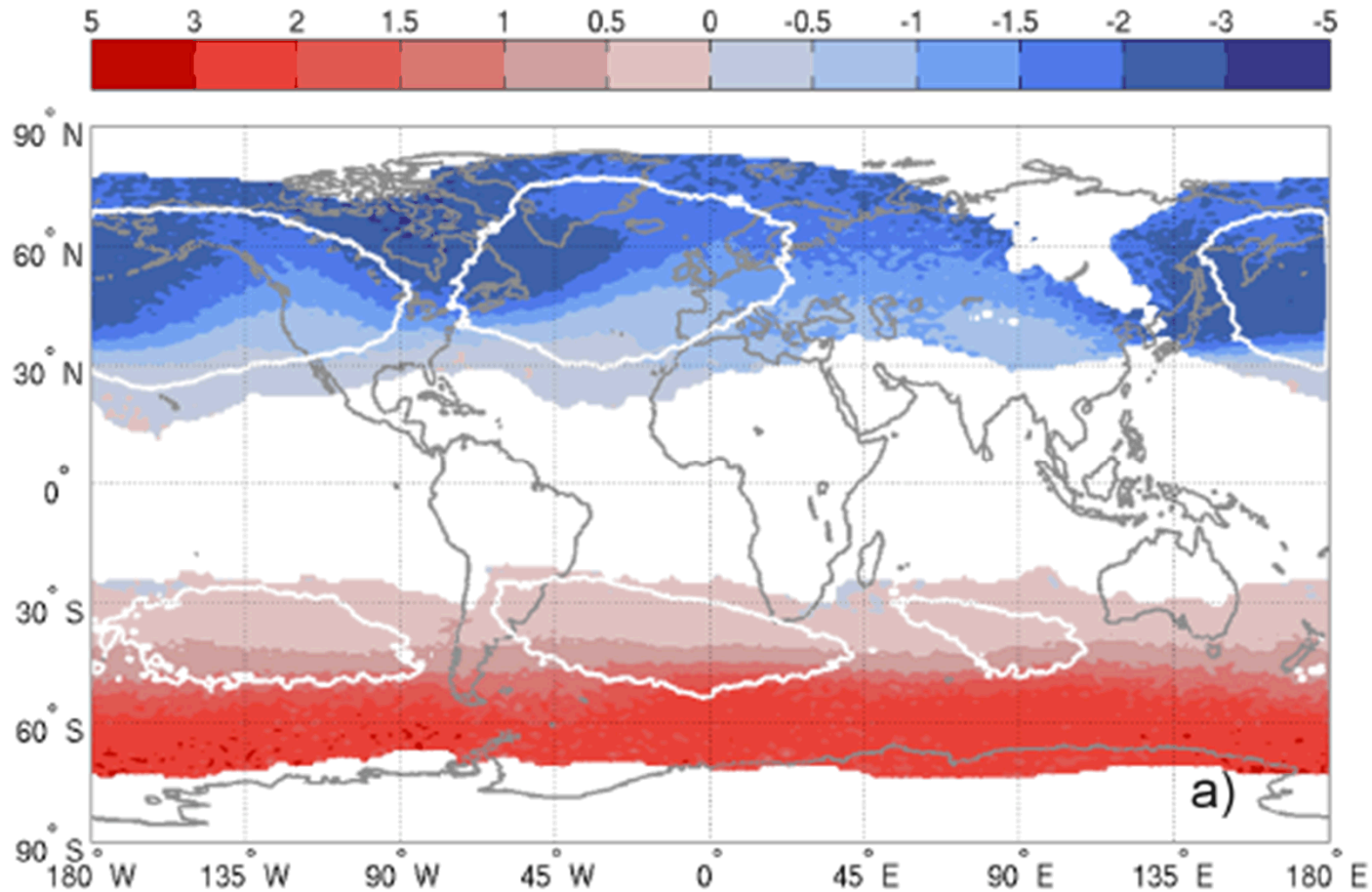


X = trajectory intersection points

Joos and Wernli 2012 (QJ), Pfahl et al. 2015 (Nature Geo)

PV anomalies in WCB outflows

PV anomaly in WCB outflows, averaged between 280-340 hPa in DJF



Madonna et al. 2014 (JCLim)

Verification of WCBs in operational ECMWF forecasts

Feature-based approach, considering 3 aspects of error in predicting WCB outflow:

- P strength of negative PV anomaly
- A amplitude of WCB (number of trajectories)
- L location of WCB outflow

perfect forecast: $P = A = L = 0$

*similar to SAL verification of precipitation forecasts
(Wernli et al. 2008, MWR)*

Verification of WCBs in operational ECMWF forecasts

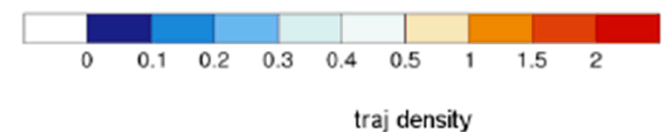
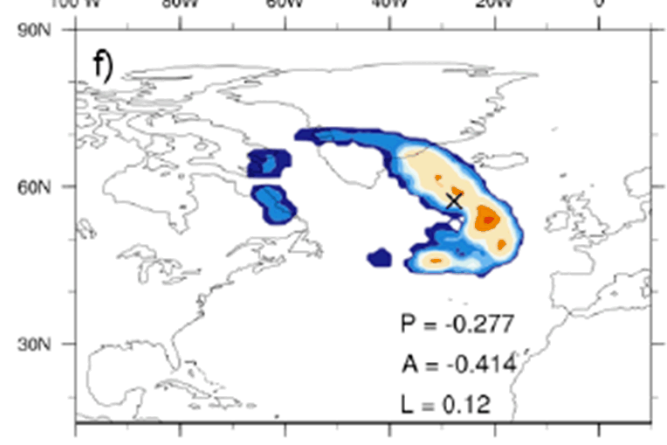
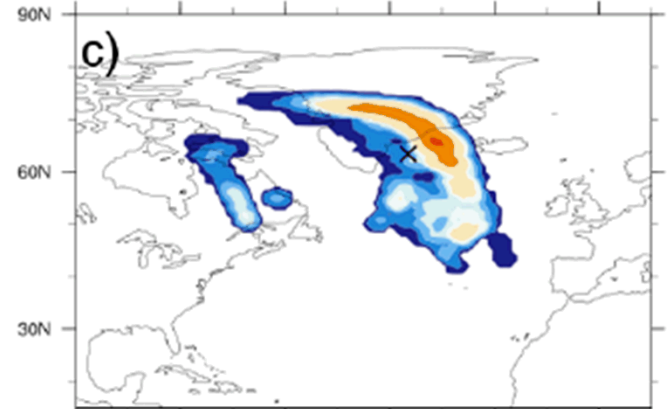
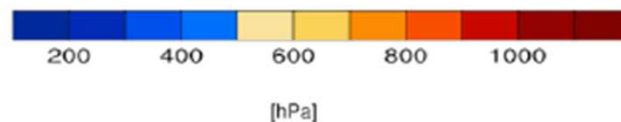
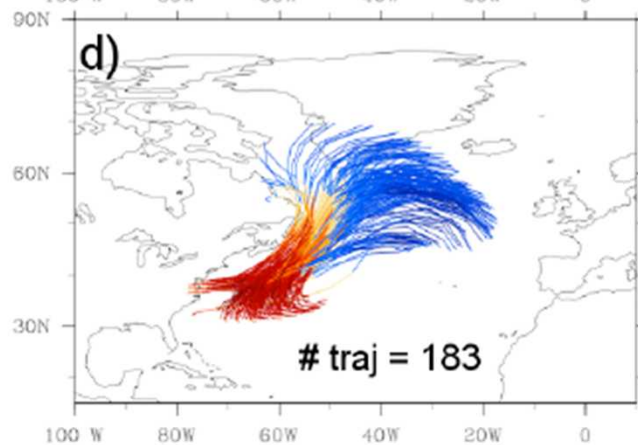
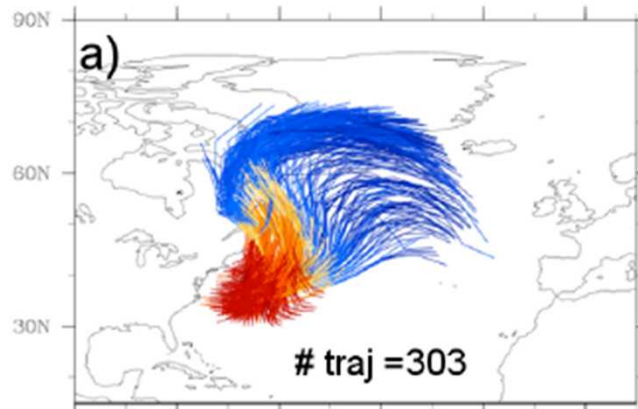
analysis

$P = -0.28$

$A = -0.41$

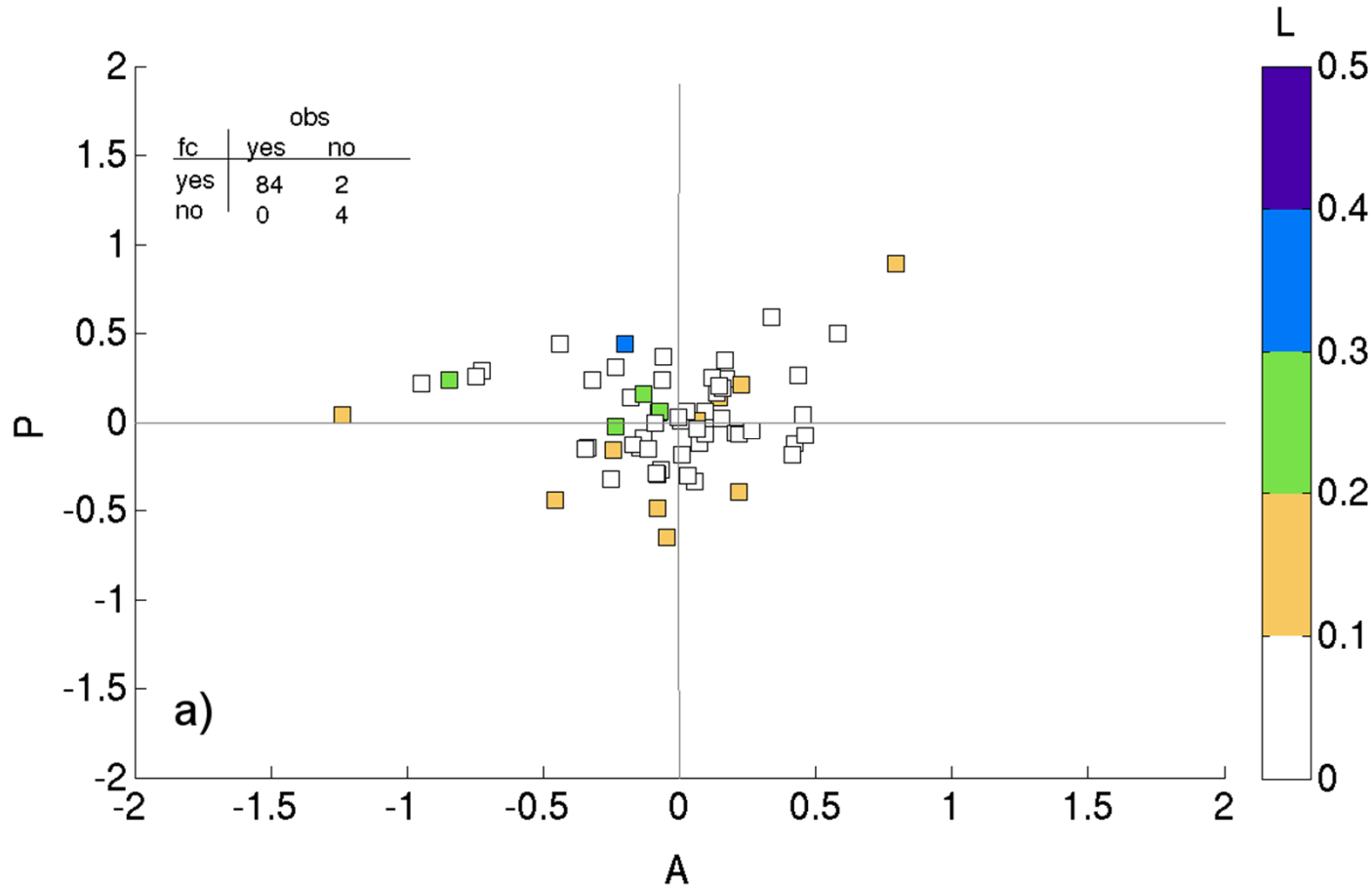
$L = 0.10$

forecast



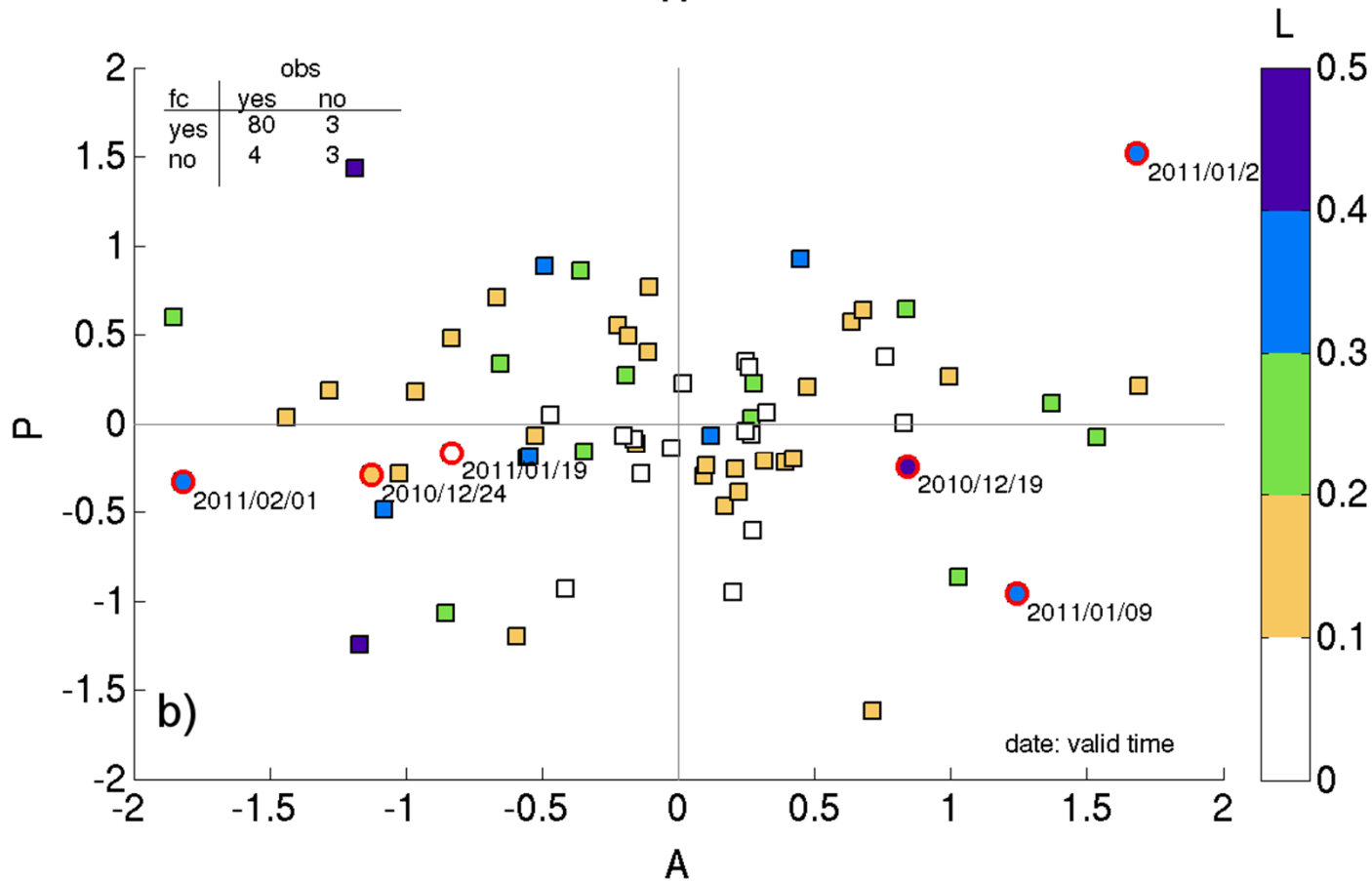
Verification of WCBs in operational ECMWF forecasts

PAL diagram for WCBs in 0-2 day forecasts in DJF 2010/2011



Verification of WCBs in operational ECMWF forecasts

PAL diagram for WCBs in 3-5 day forecasts in DJF 2010/2011

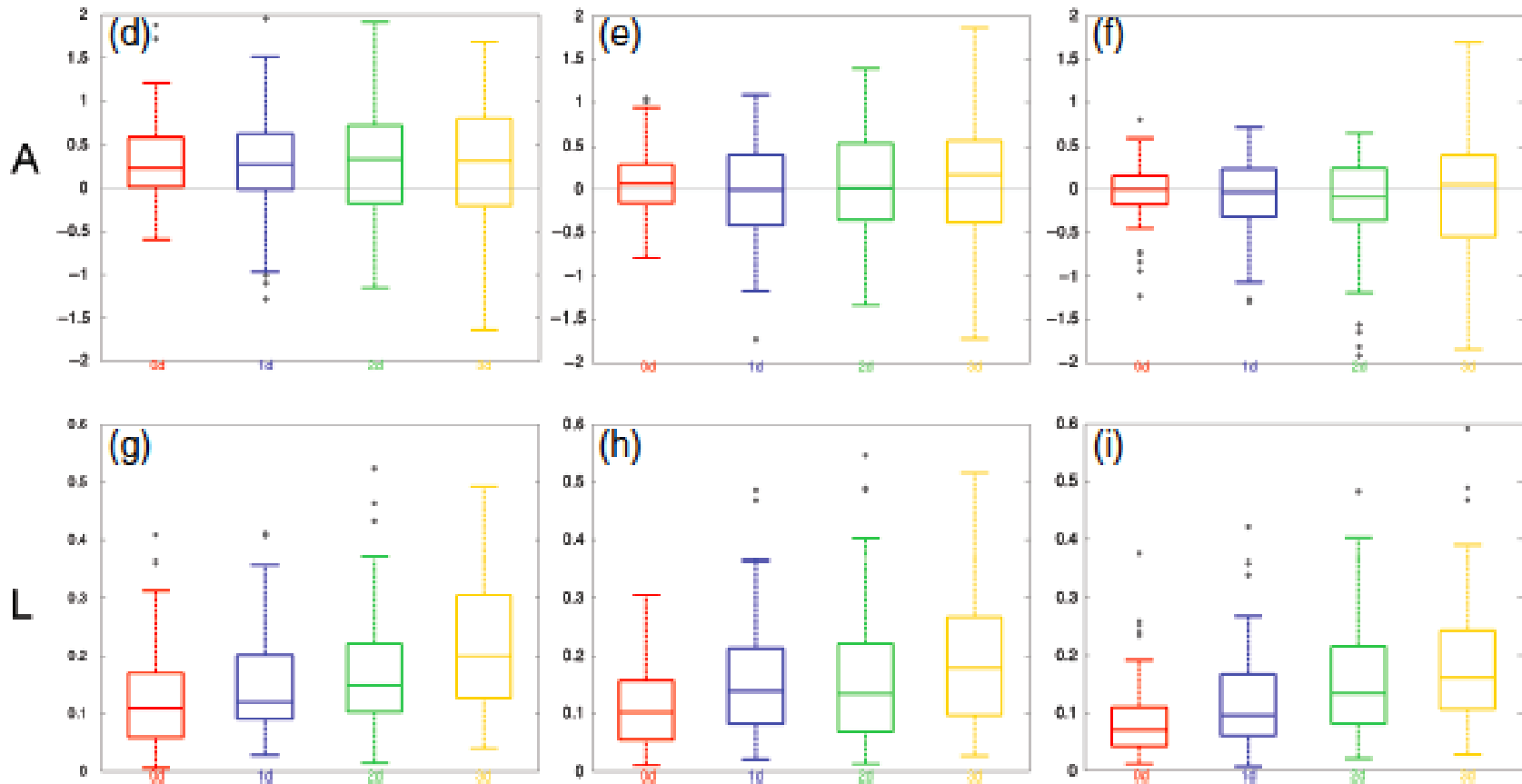


Verification of WCBs in operational ECMWF forecasts

Forecast improvement from
2002/03 to ...

2006/07 ...

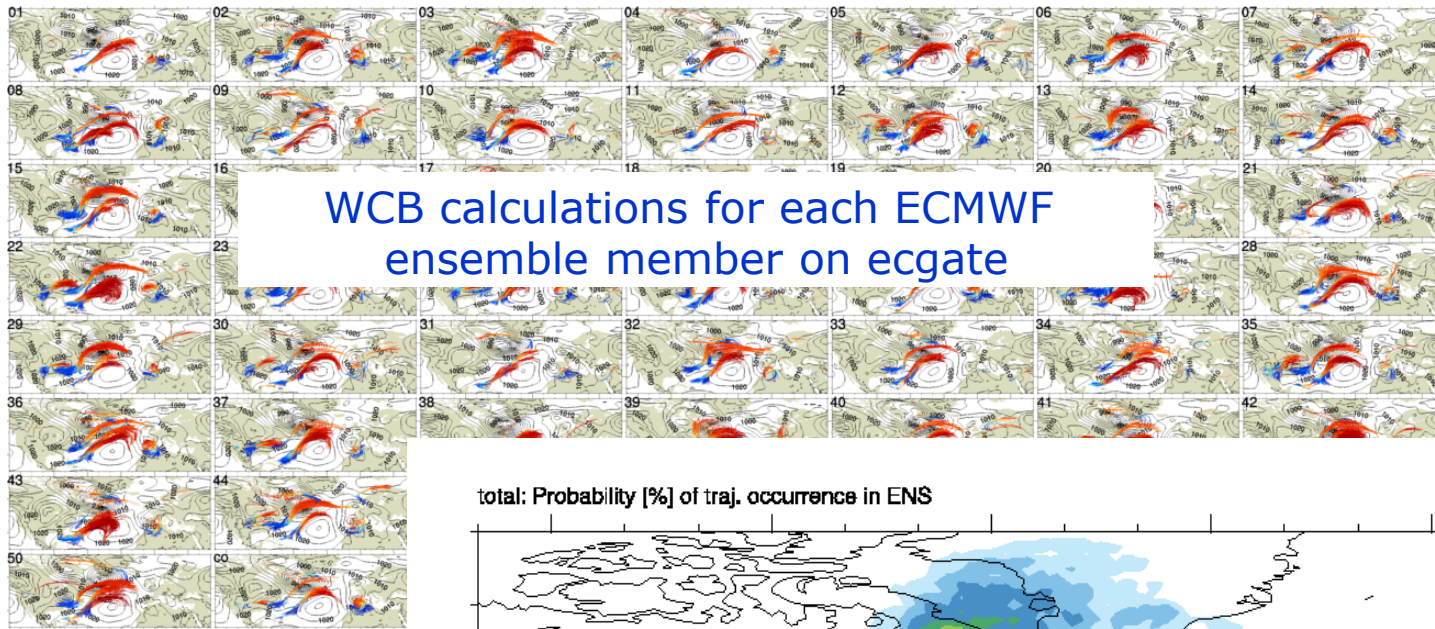
2010/11



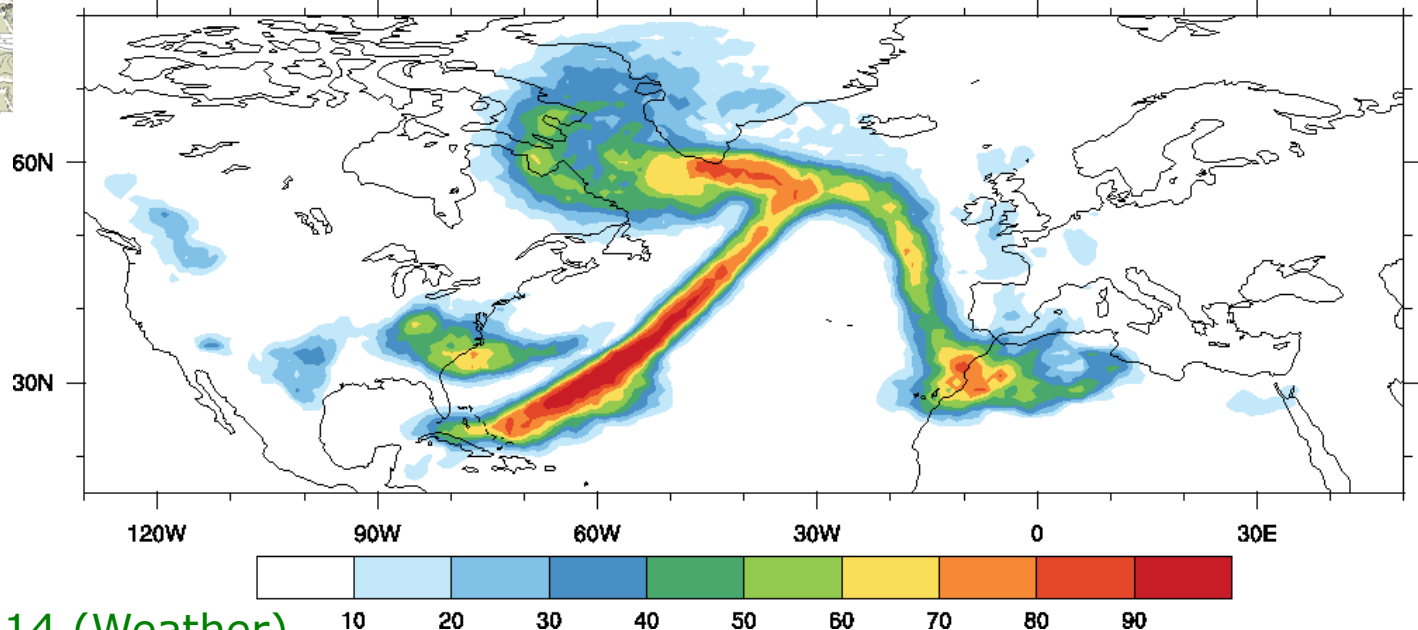
fc lead time

Madonna et al. 2015 (QJ)

WCBs in ensemble forecasts



total: Probability [%] of traj. occurrence in ENS



Schäfler et al. 2014 (Weather)
Rautenhaus et al. 2015, (GMD)

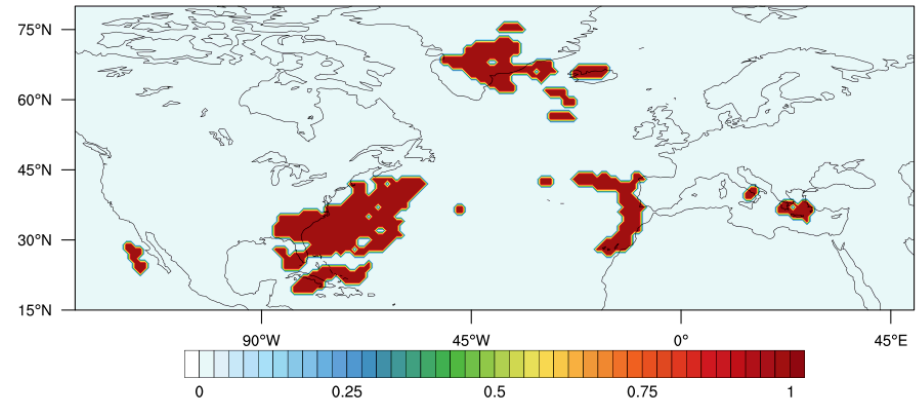
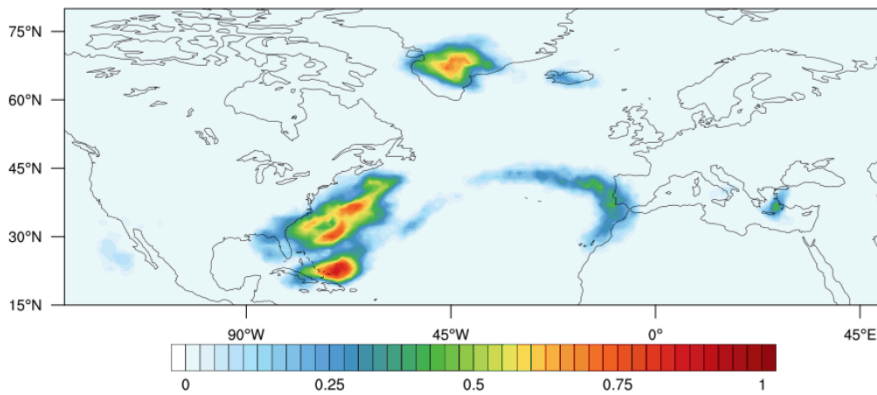
WCBs in ensemble forecasts: Brier Skill Score

Time period: October 2013 to June 2014

$$BS = \frac{1}{N} \sum_{k=1}^N (p_k - o_k)^2$$

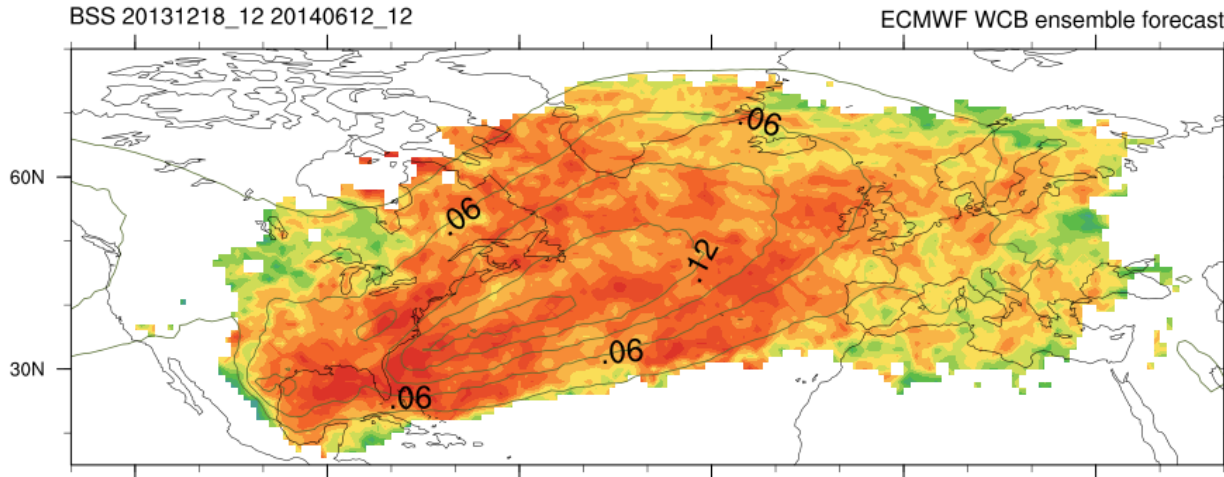
p_k = p(WCB) in ensemble

o_k = 1 if WCB in analysis, 0 if not.

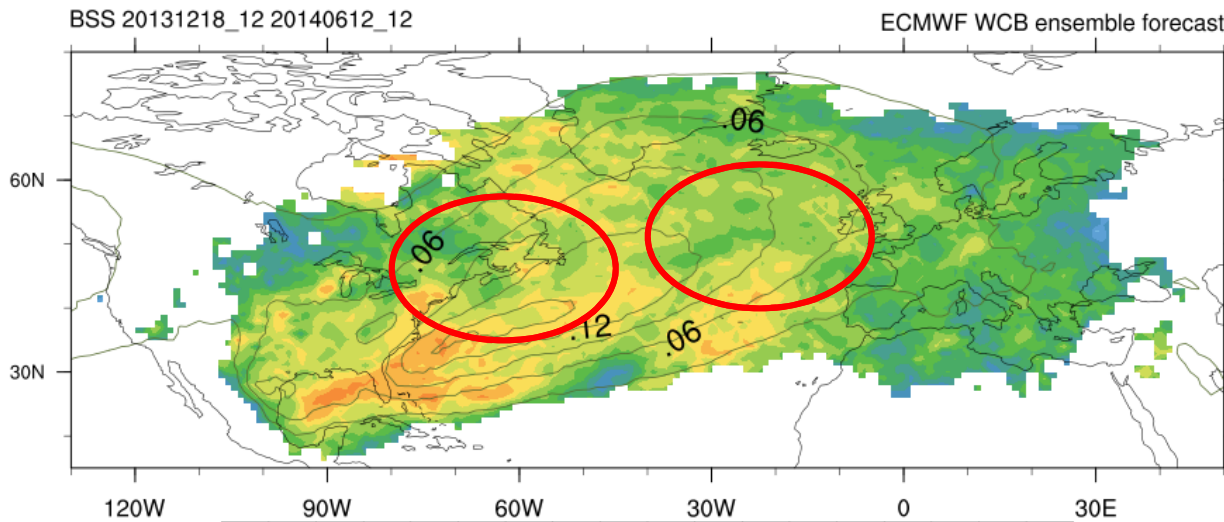


Master Thesis Natalie Kuster,
supervised by C. Grams, M. Boettcher, H. Binder

WCBs in ensemble forecasts: Brier Skill Score



+2 days

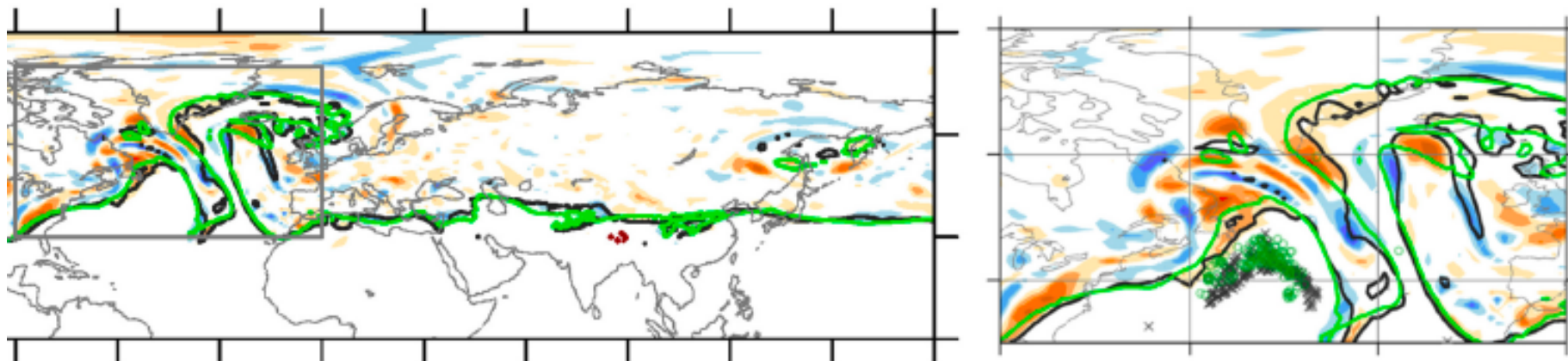


+5 days

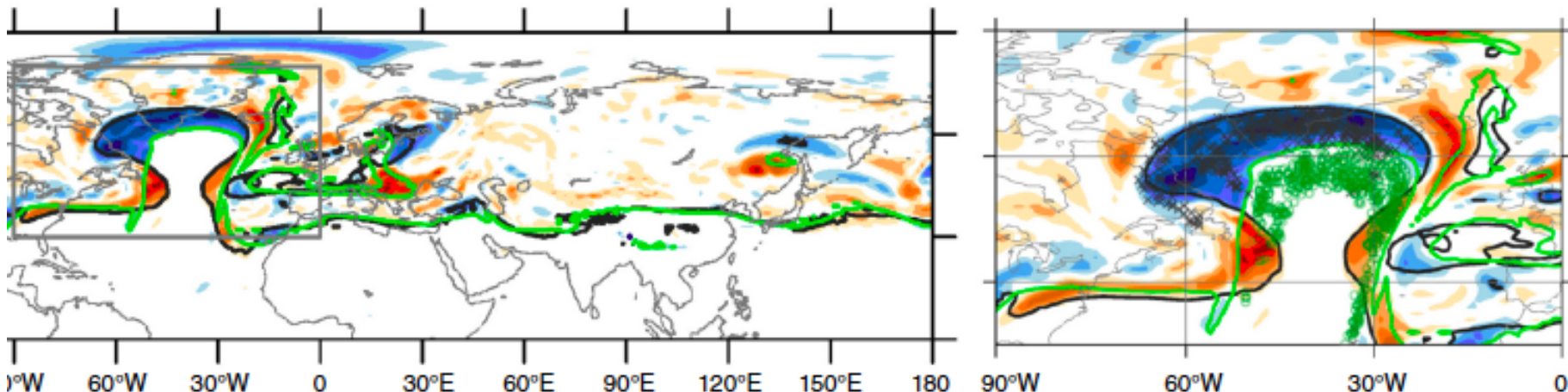


A route to systematic error in forecasts of Rossby waves

20110122_12 PV (pvu) on 320 k, D + 3

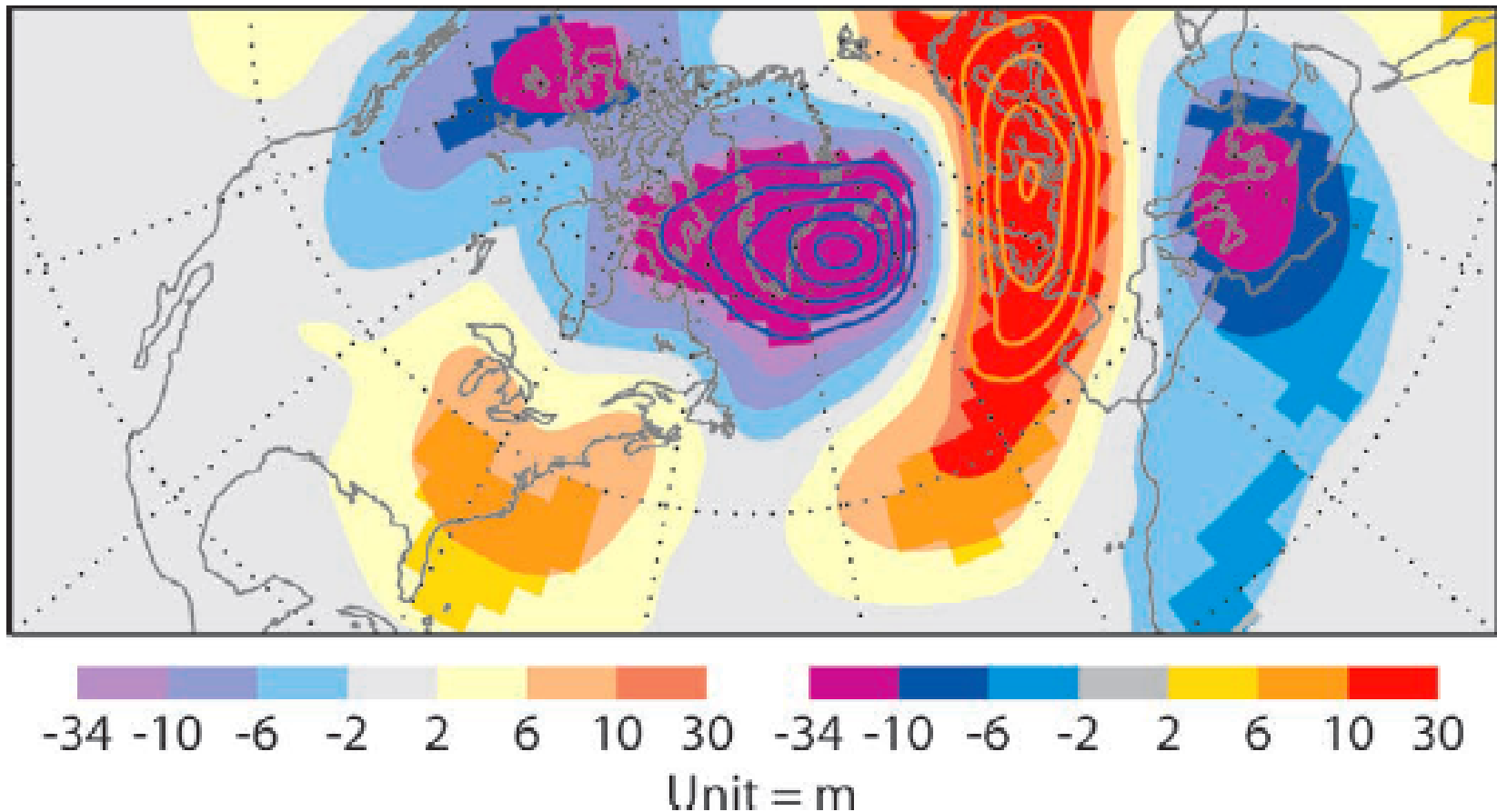


20110124_12 PV (pvu) on 320 k, D + 5



Systematic analysis of European forecast busts

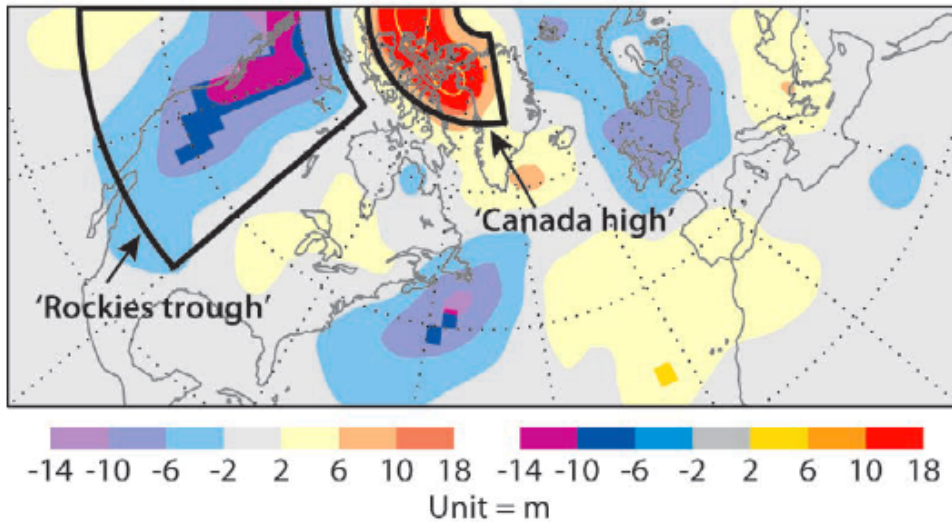
Composite Z500 analysis anomaly of "bust situations"



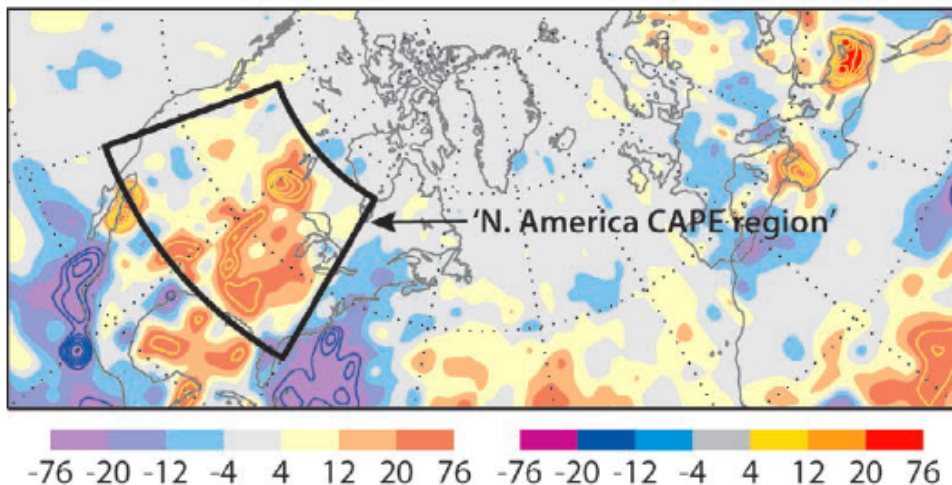
Systematic analysis of European forecast busts

Composite initial condition anomalies leading to busts

a Z500 anomaly



b CAPE anomaly



Recent European forecast bust

850hPa T ensemble forecast for Zurich BT 00Z 5 Oct 2013

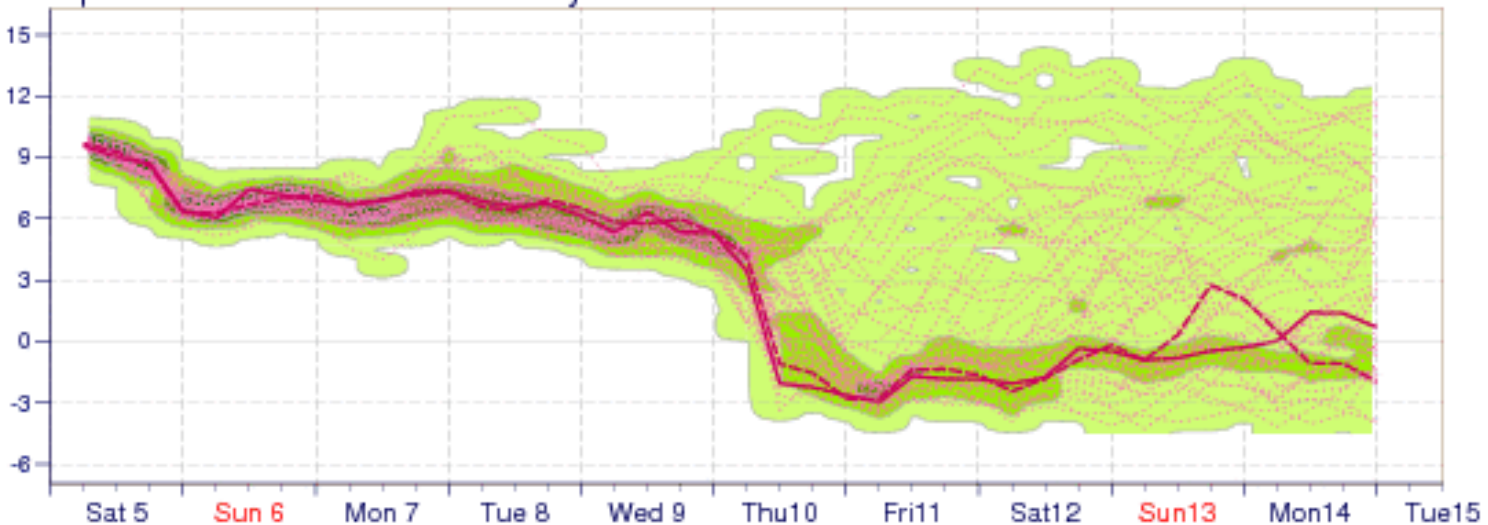
ECMWF Ensemble forecasts for SWITZERLAND - ZURICH

Location: 47.42°N 8.75°E

Base Time: Saturday 5 October 2013 00 UTC



Temperature at 850 hPa - Probability for 1°C intervals



courtesy ECMWF

Recent European forecast bust

850hPa T ensemble forecast for Zurich BT 12Z 4 Oct 2013

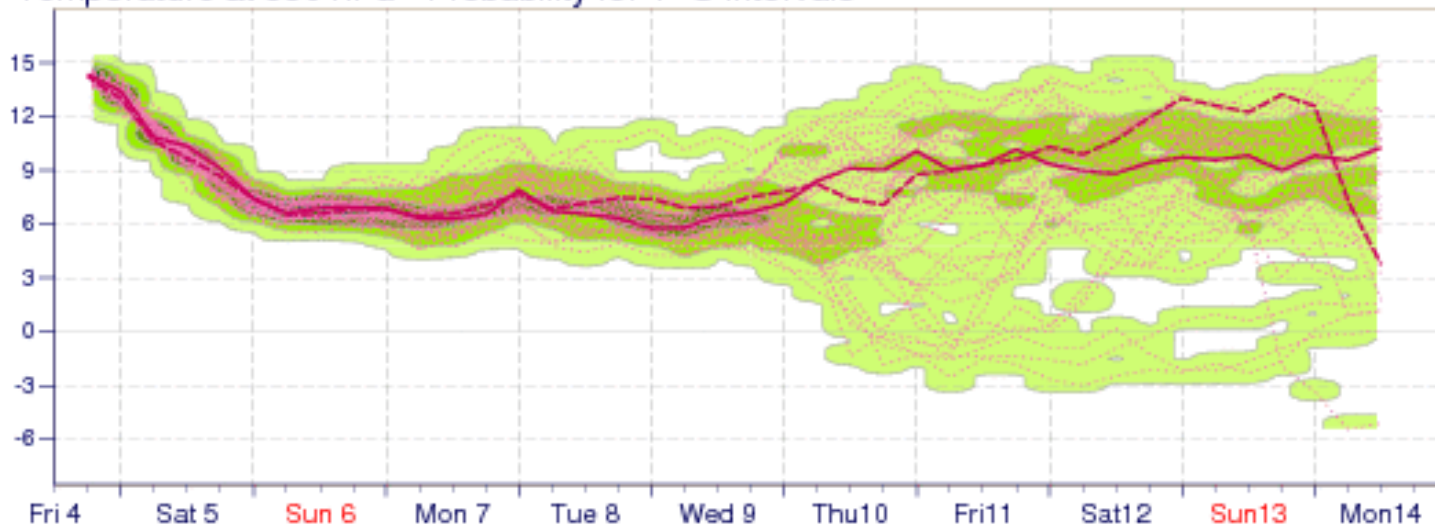
ECMWF Ensemble forecasts for SWITZERLAND - ZURICH

Location: 47.42°N 8.75°E

Base Time: Friday 4 October 2013 12 UTC



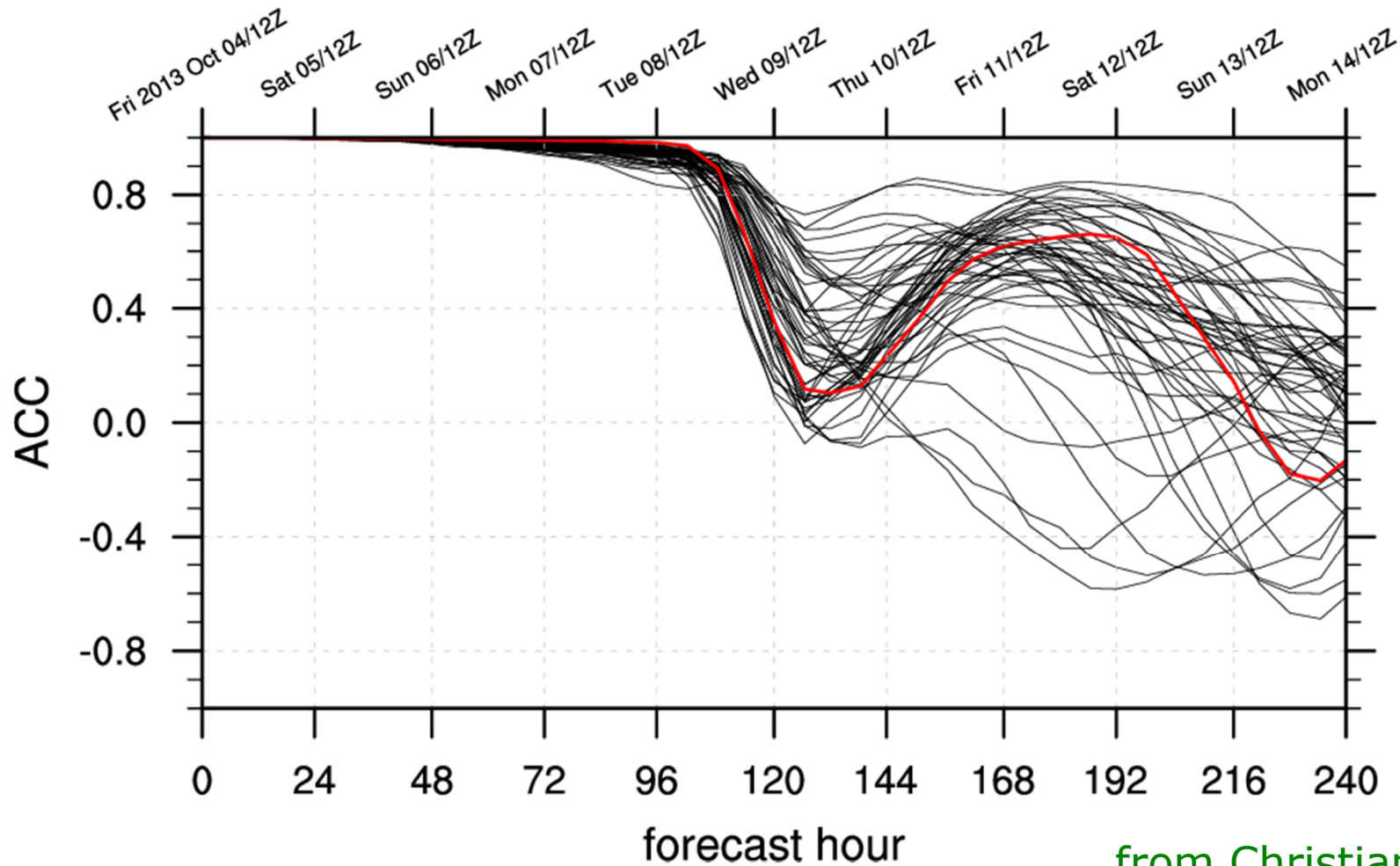
Temperature at 850 hPa - Probability for 1°C intervals



courtesy ECMWF

Recent European forecast bust

ACC Z200 region EUEC [75,-12.5,35,42.5]



from Christian Grams

Z200 perturbed forecasts mean & stdev

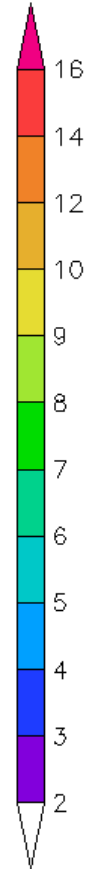
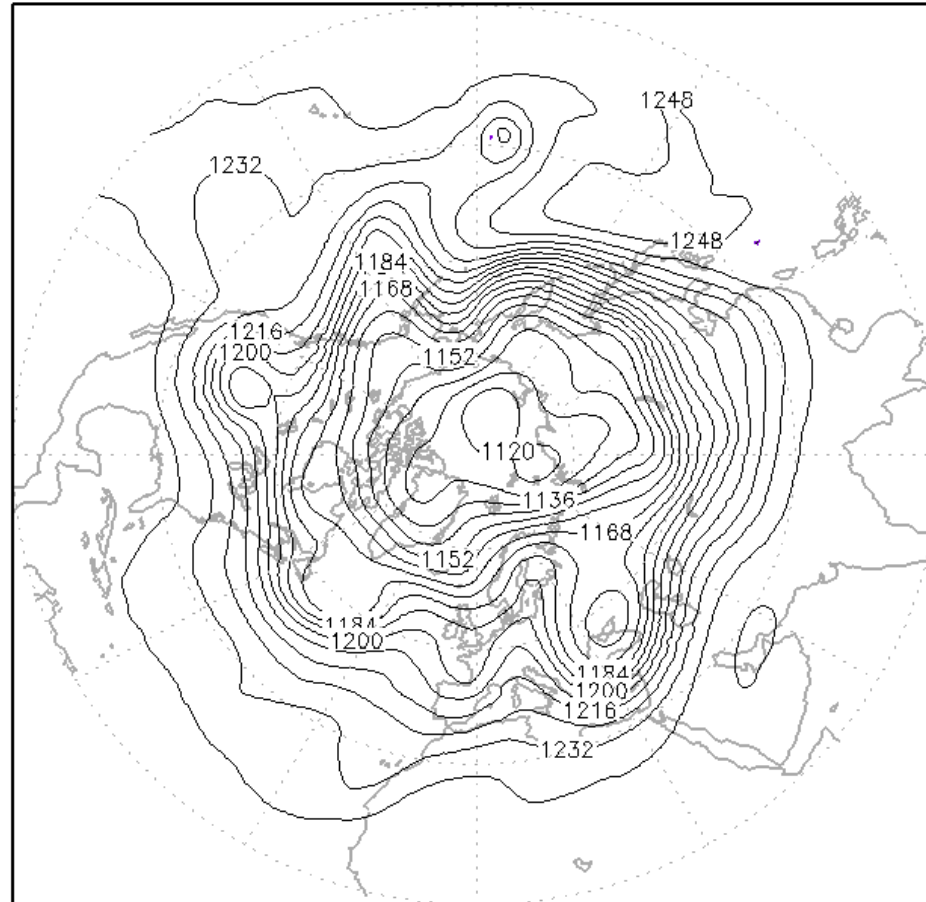
BT 12Z 04 Oct 2013

+012h 05/00Z

ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

+12h VT 00Z05102013



from Christian Grams

Z200 perturbed forecasts mean & stdev

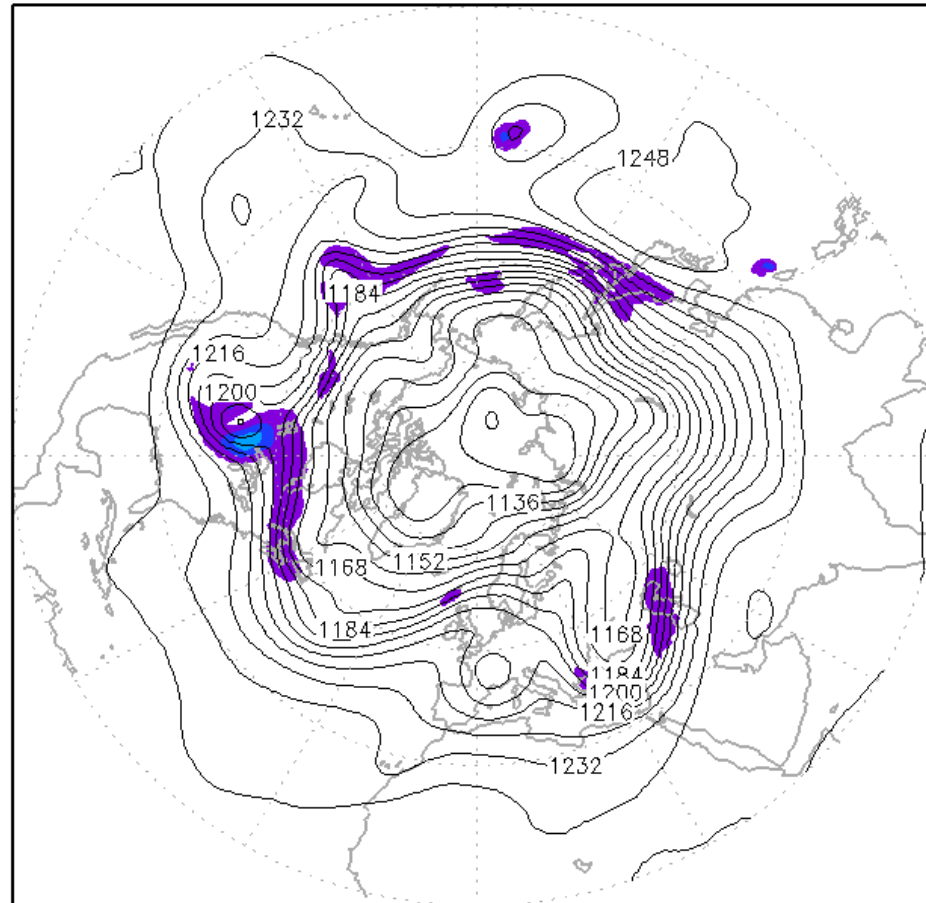
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

+36h VT 00Z06102013



from Christian Grams

Z200 perturbed forecasts mean & stdev

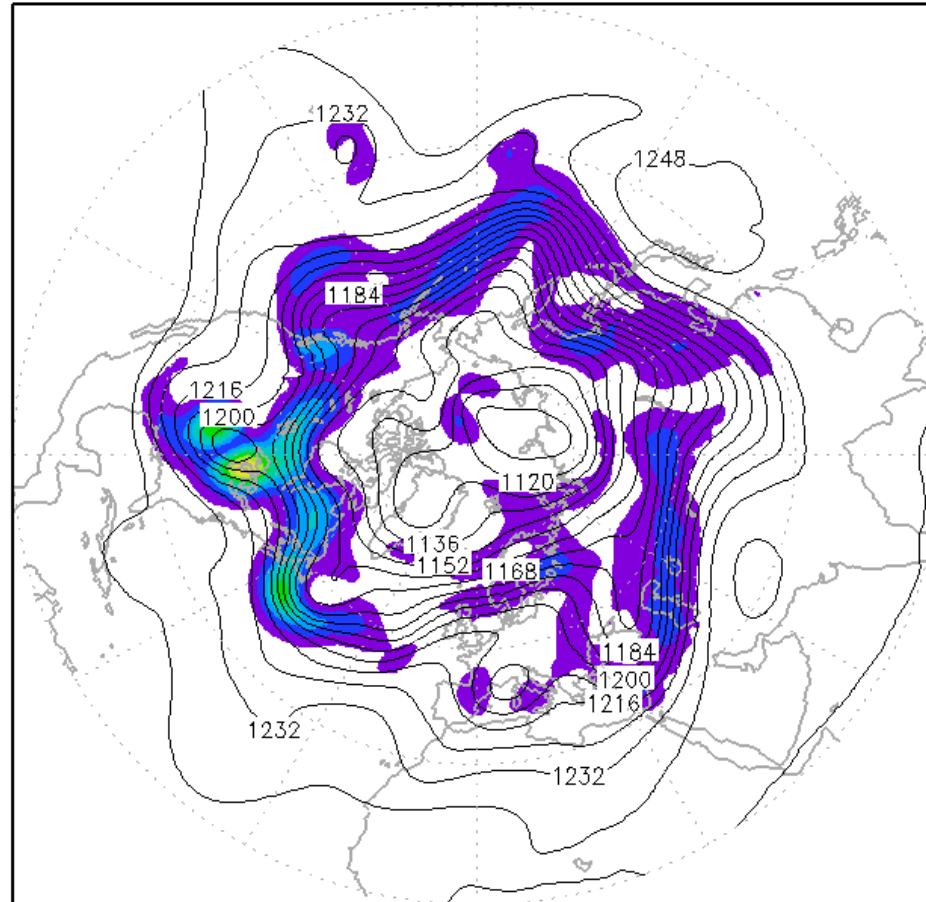
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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

+60h VT 00Z07102013



from Christian Grams

Z200 perturbed forecasts mean & stdev

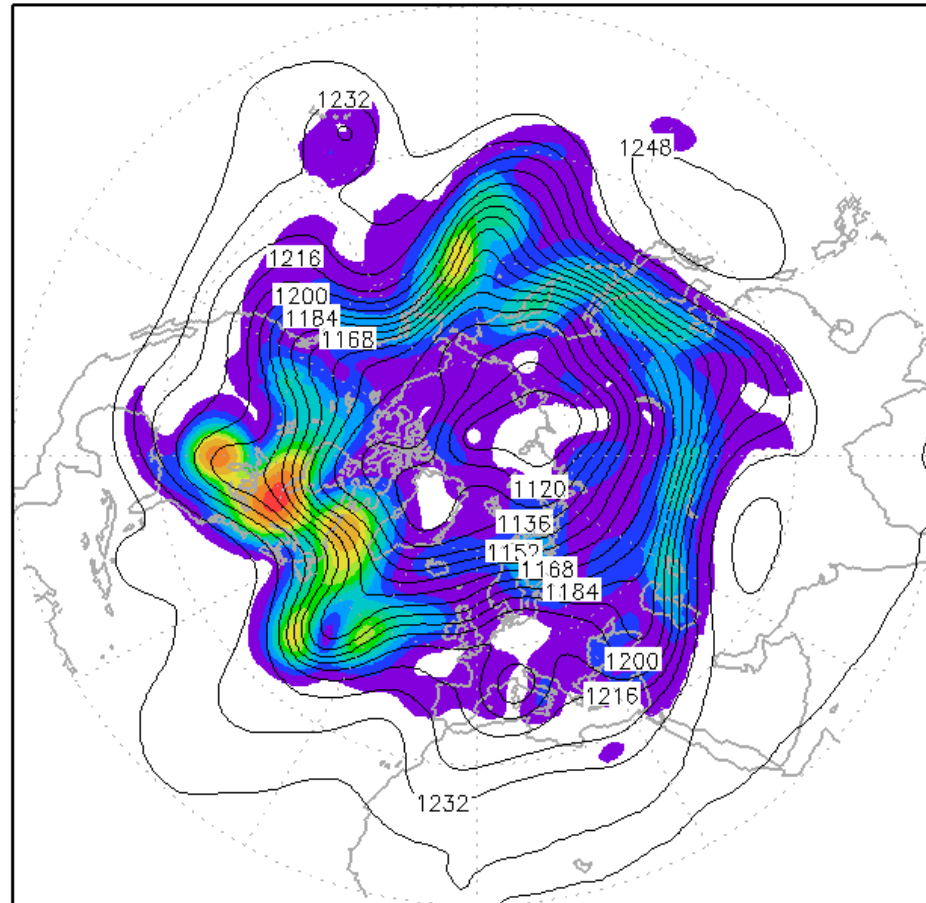
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

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from Christian Grams

Z200 perturbed forecasts mean & stdev

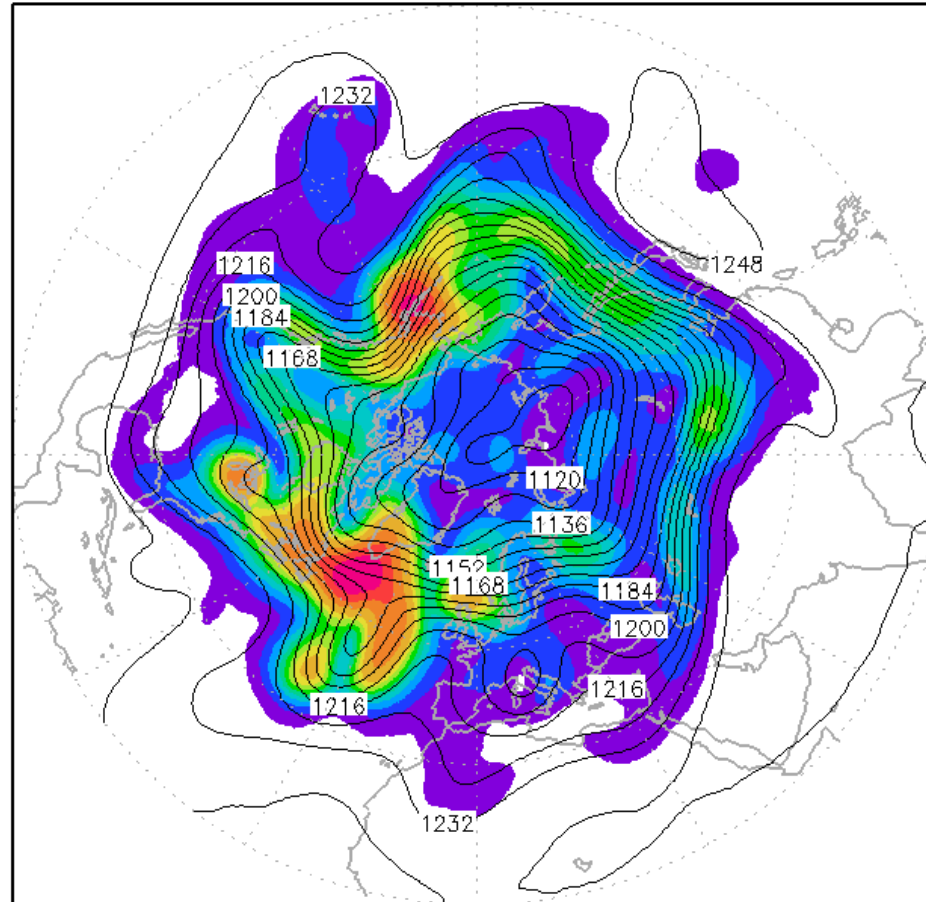
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

+108h VT 00Z09102013



from Christian Grams

Z200 perturbed forecasts mean & stdev

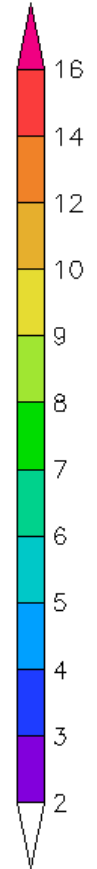
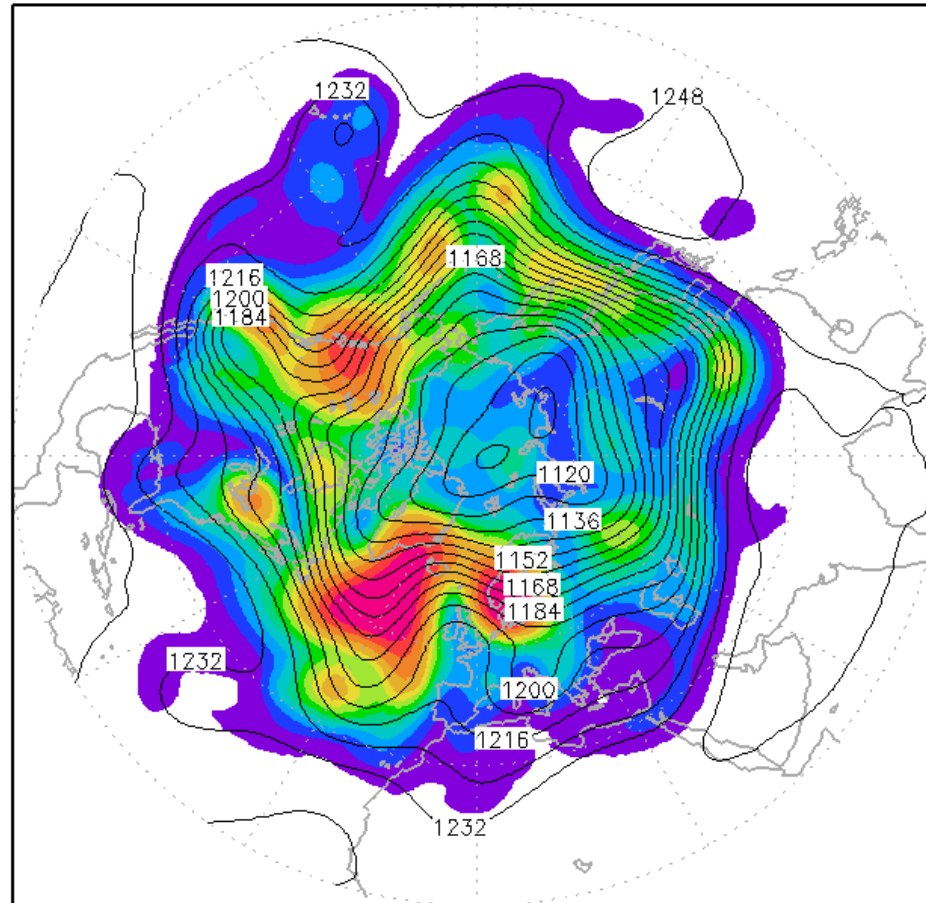
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

+132h VT 00Z10102013



from Christian Grams

Z200 perturbed forecasts mean & stdev

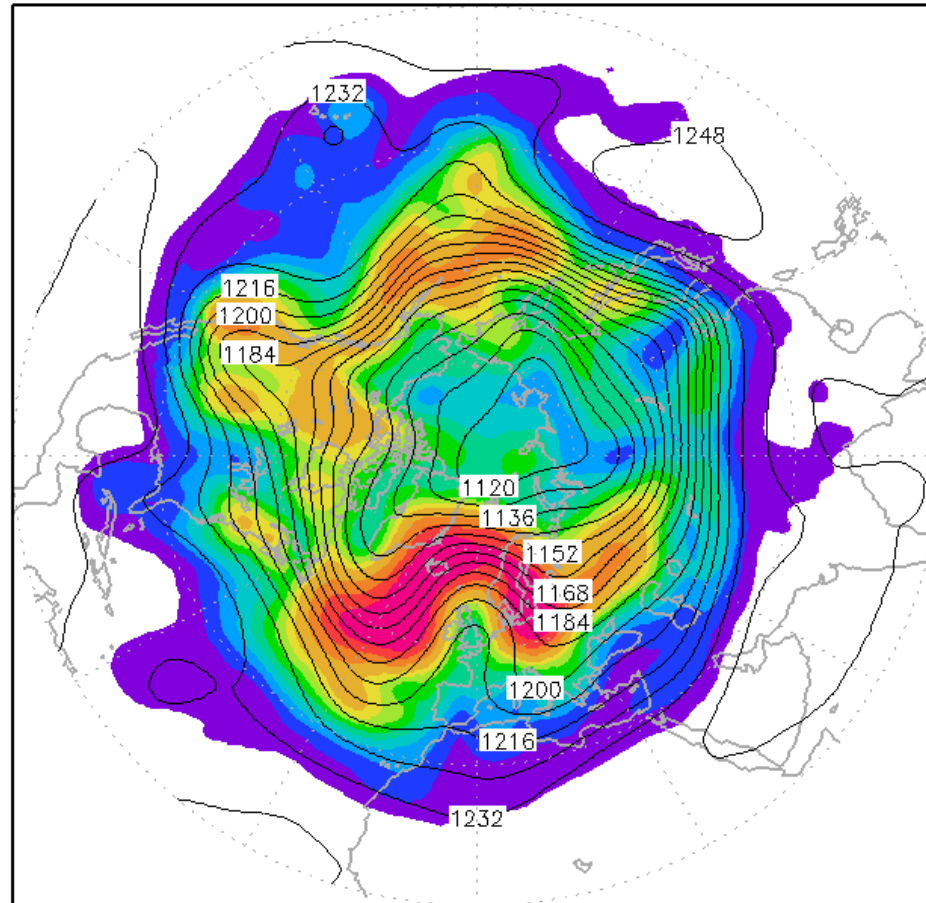
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

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from Christian Grams

Z200 perturbed forecasts mean & stdev

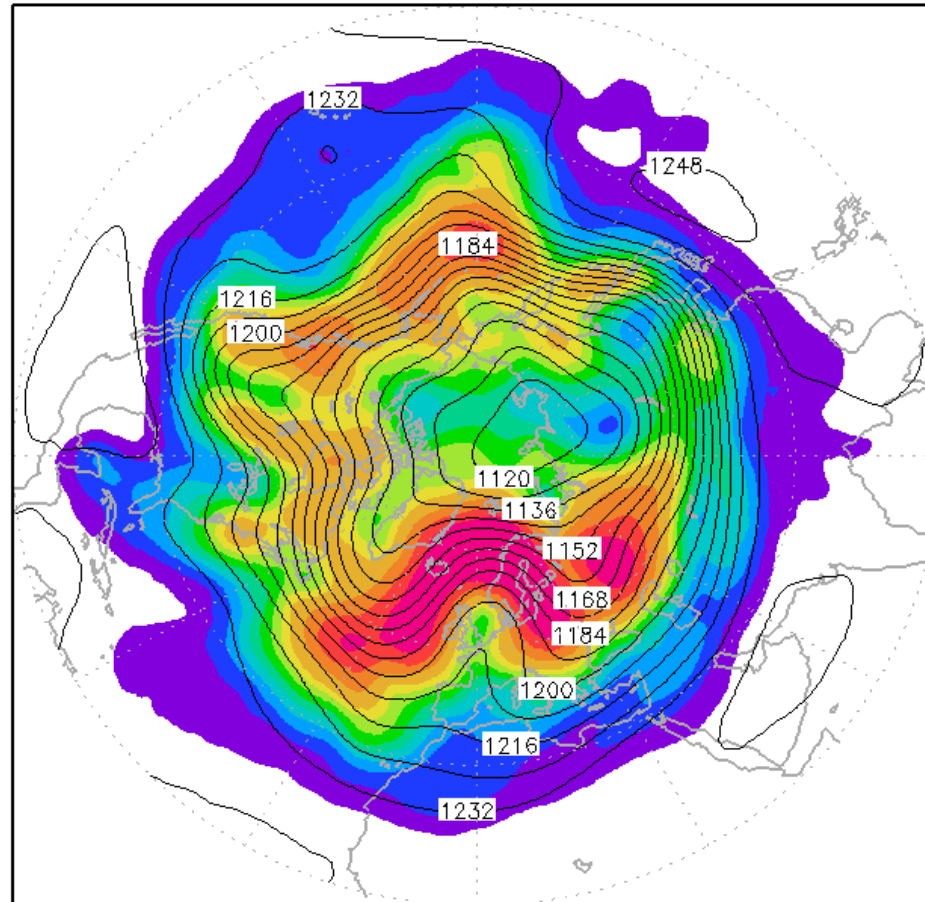
BT 12Z 04 Oct 2013

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ECMWF ENS (only PF) avg&stdev Geopotential [gpm] at 200hPa

BT 12Z20131004

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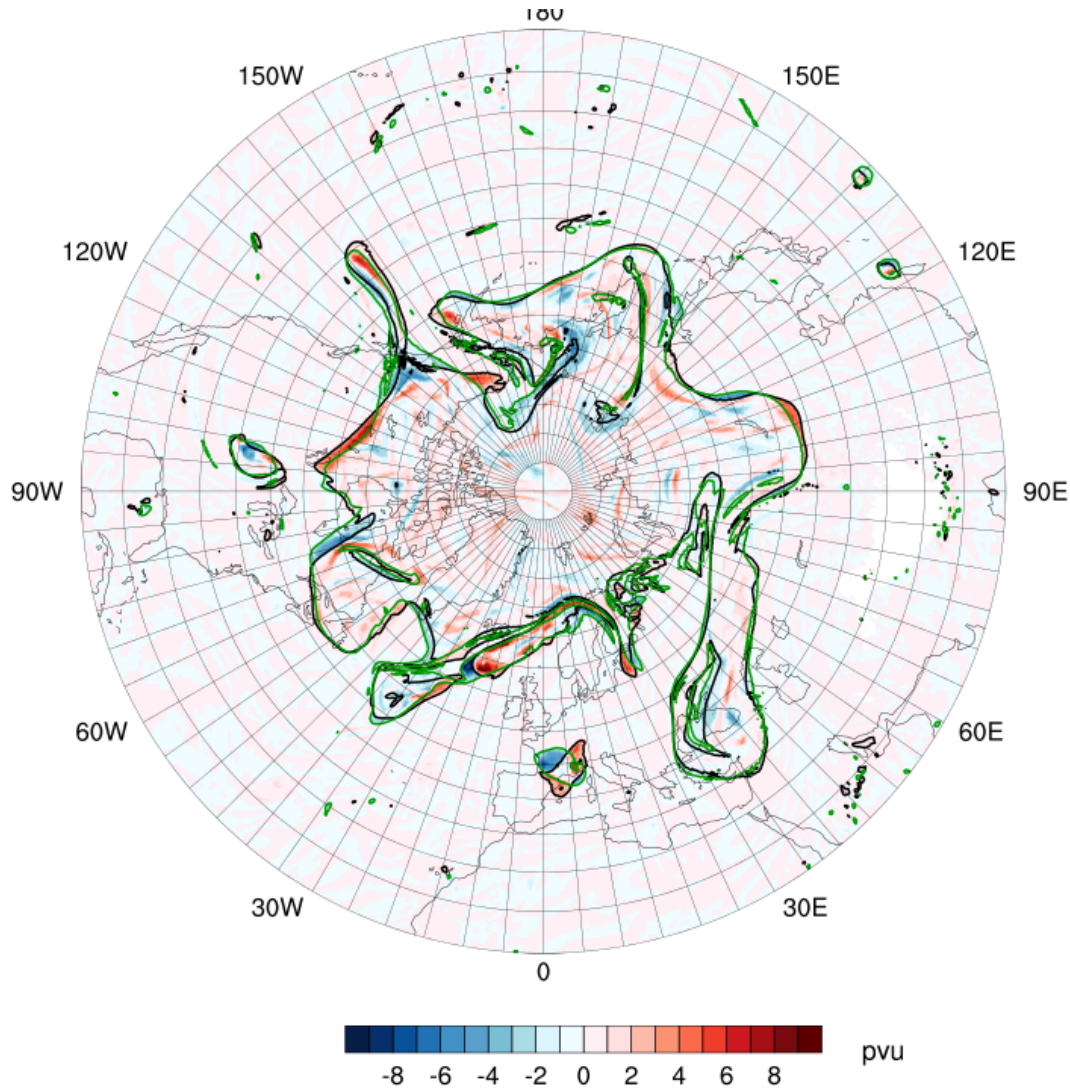


from Christian Grams

Recent European forecast bust

PV on 320 K ana – fc

06 UTC 06 Oct (+42 h)

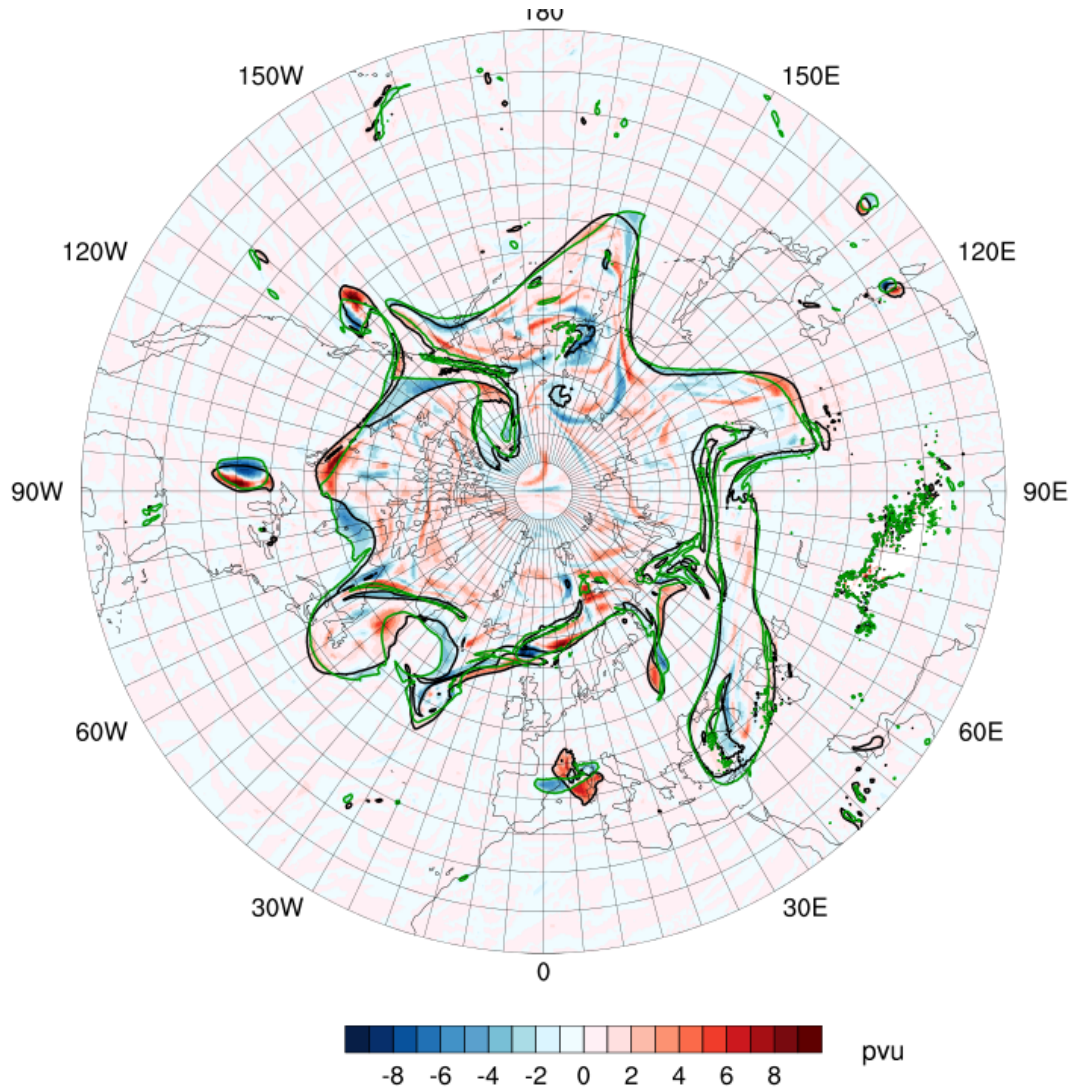


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

18 UTC 06 Oct (+54 h)

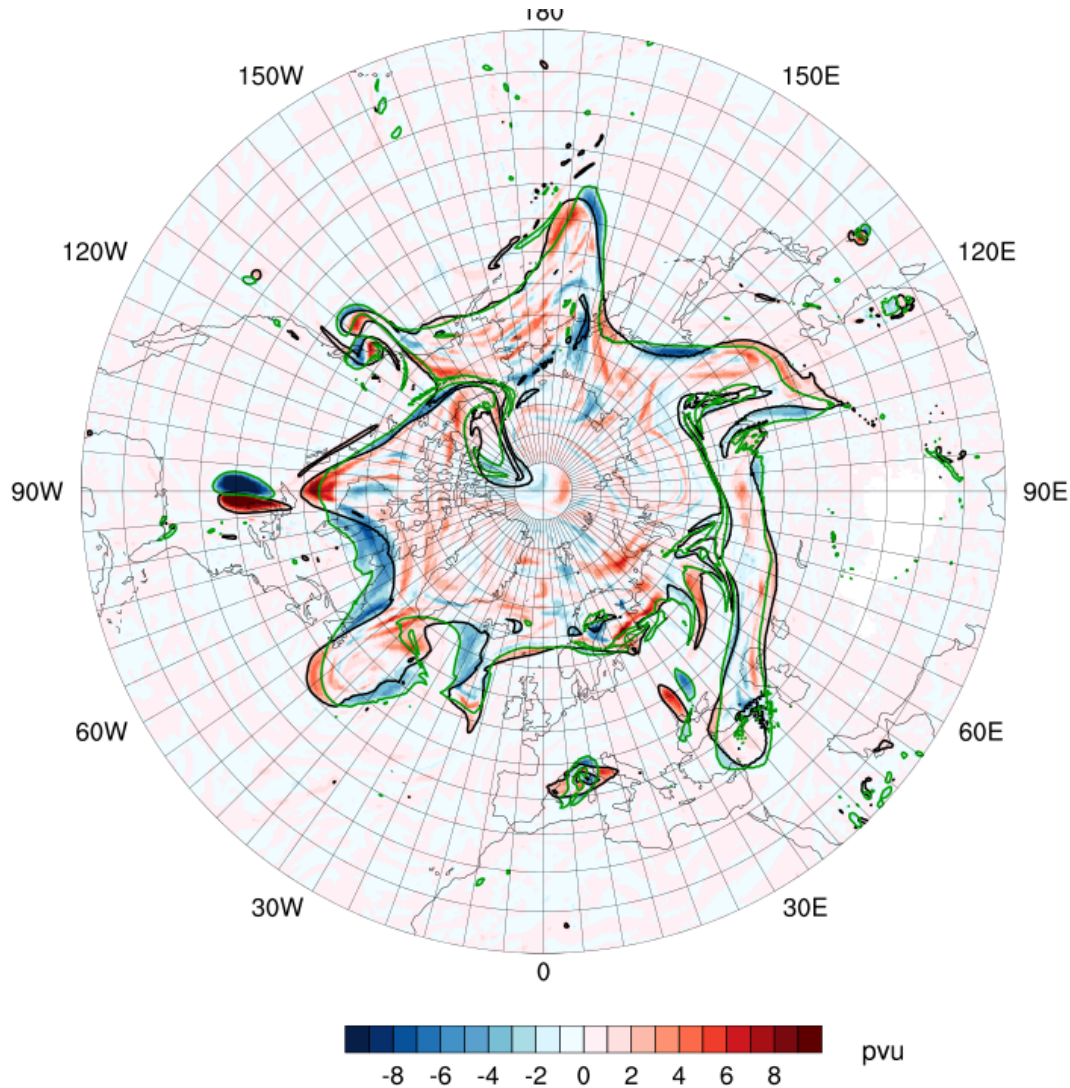


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

06 UTC 07 Oct (+66 h)

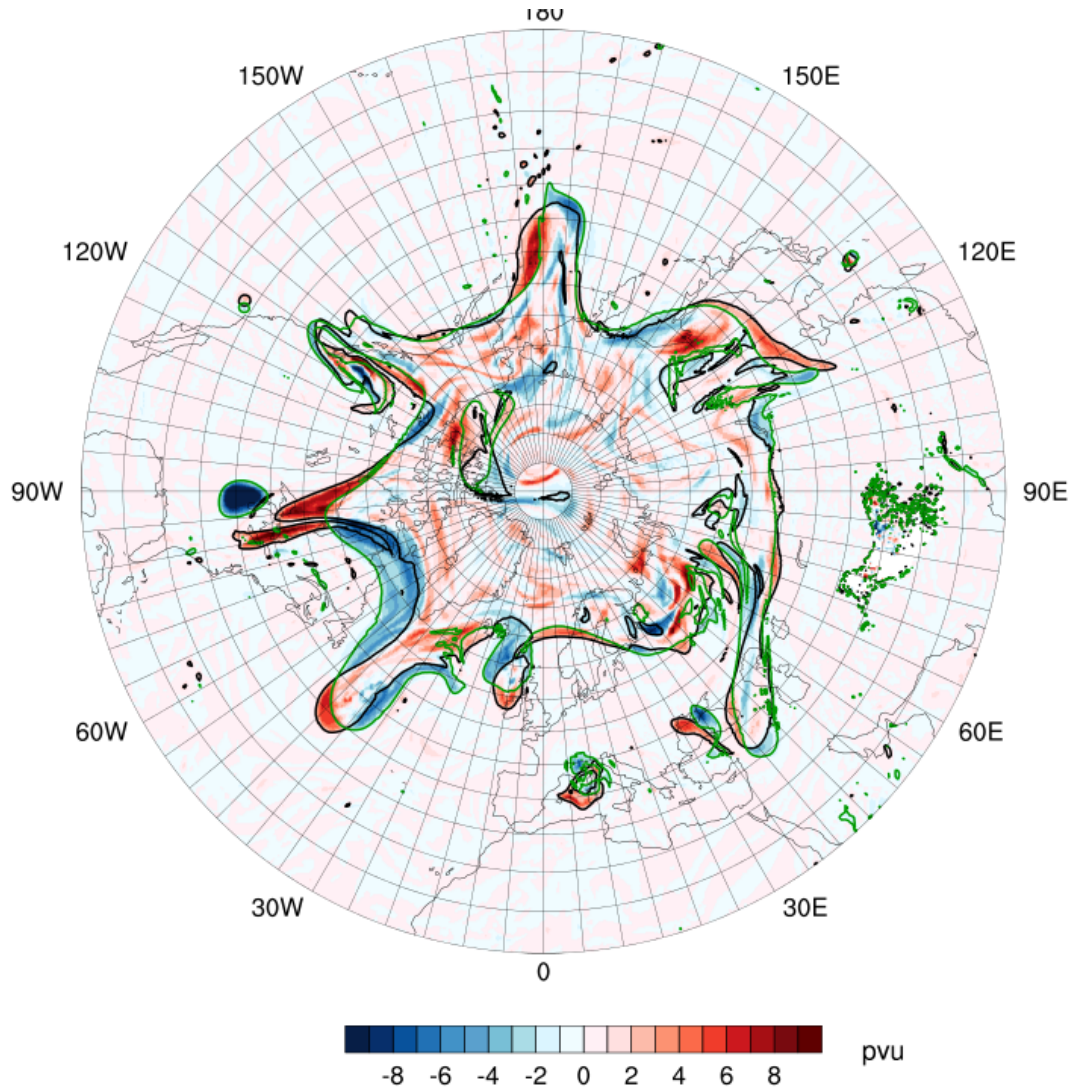


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

18 UTC 07 Oct (+78 h)

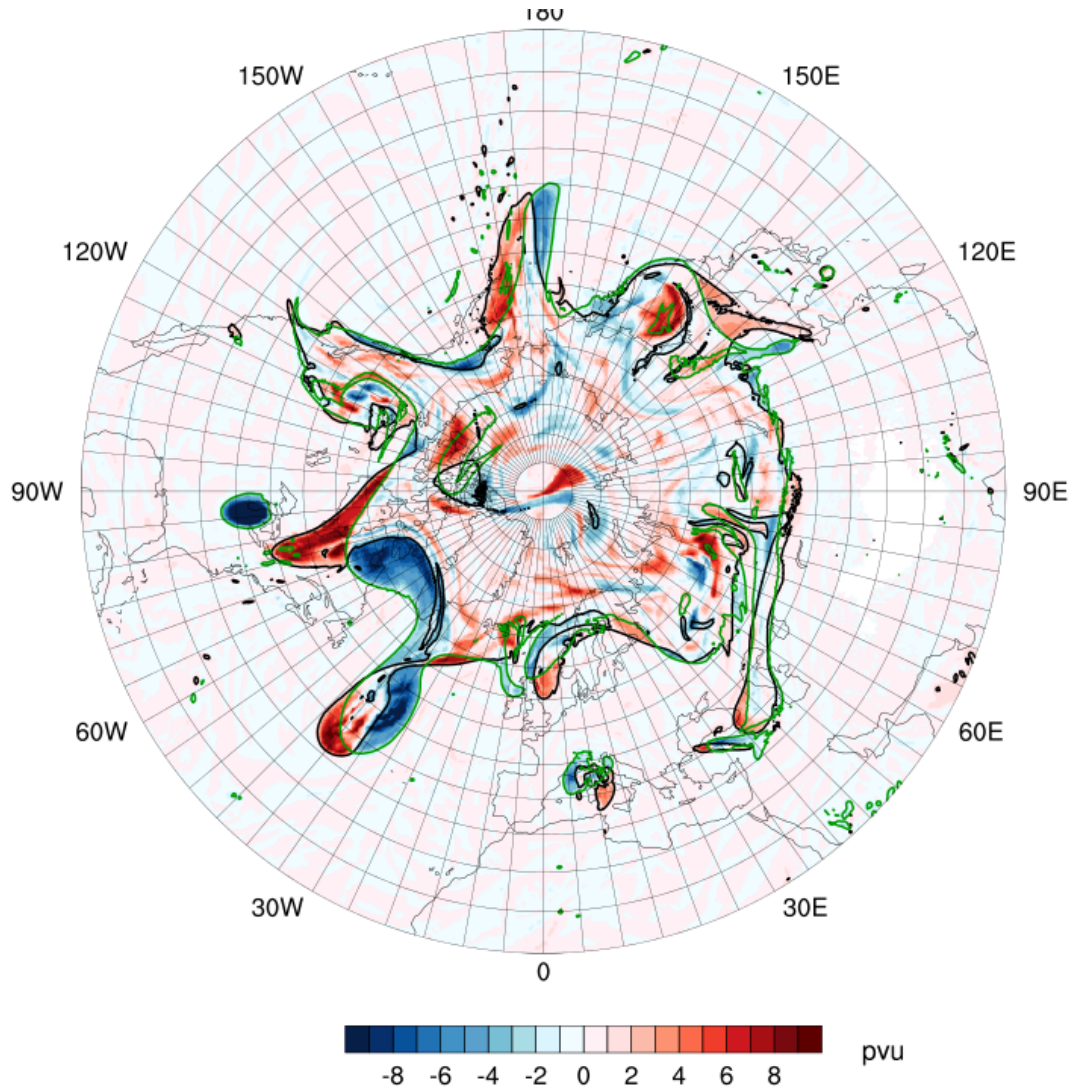


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

06 UTC 08 Oct (+90 h)

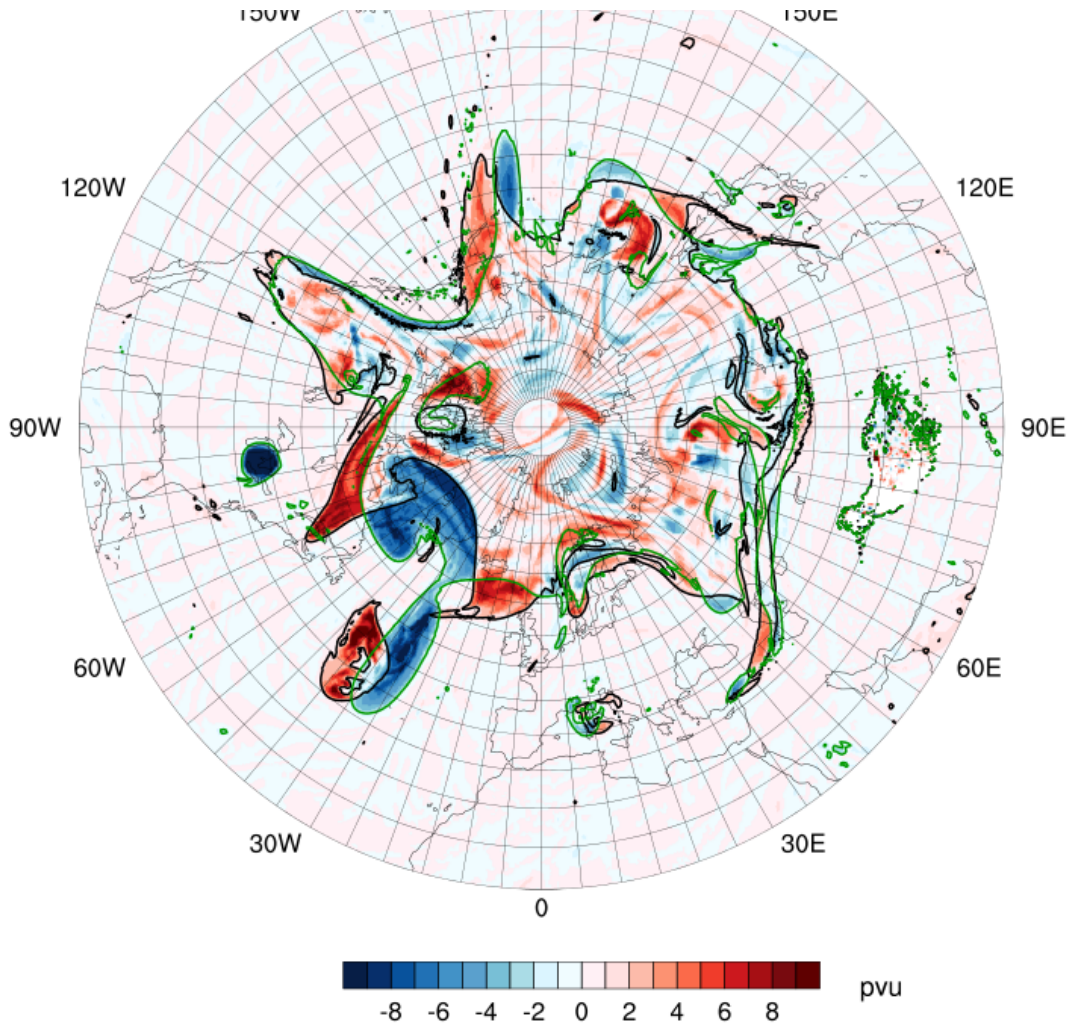


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc
h)

18 UTC 08 Oct (+102

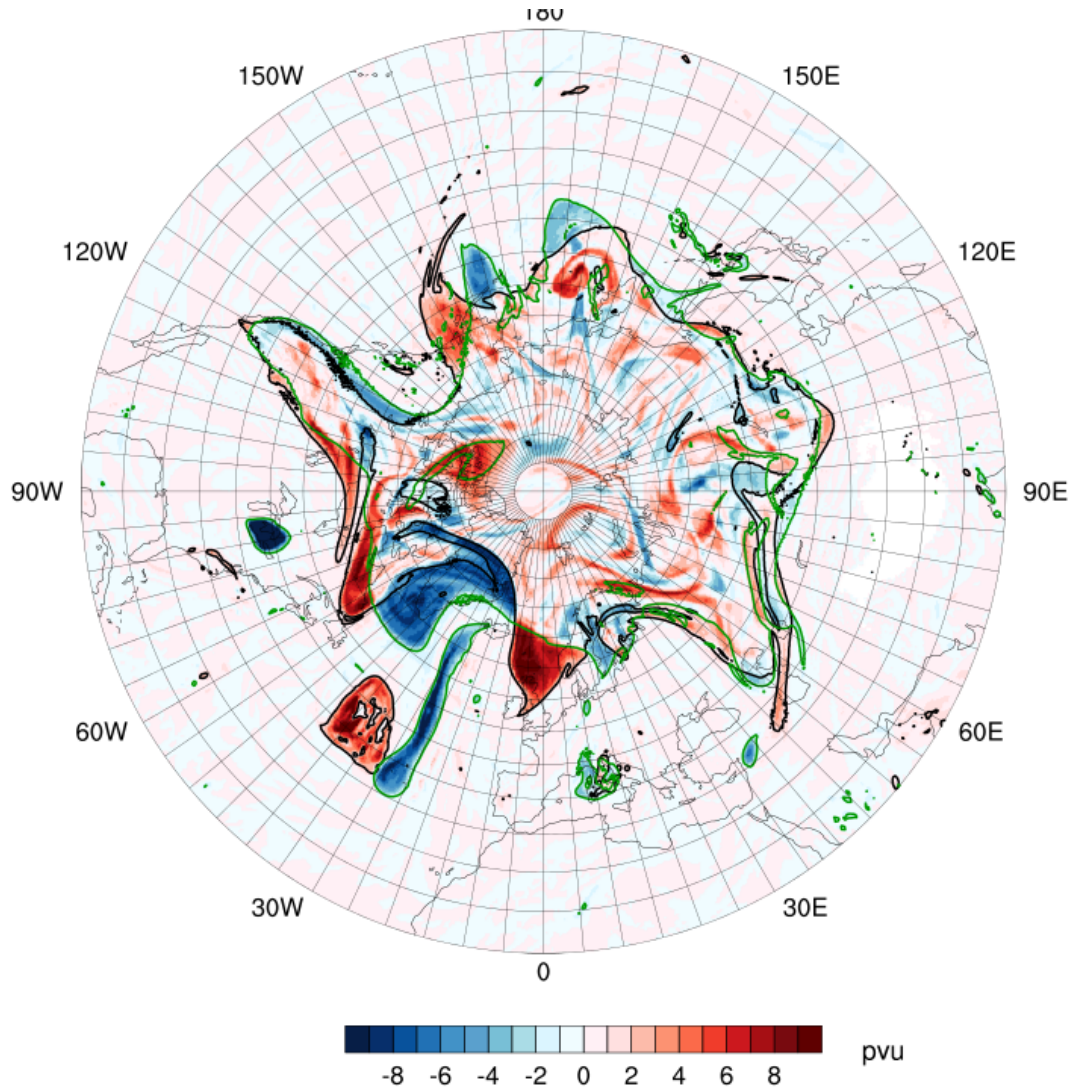


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

06 UTC 09 Oct (+114 h)

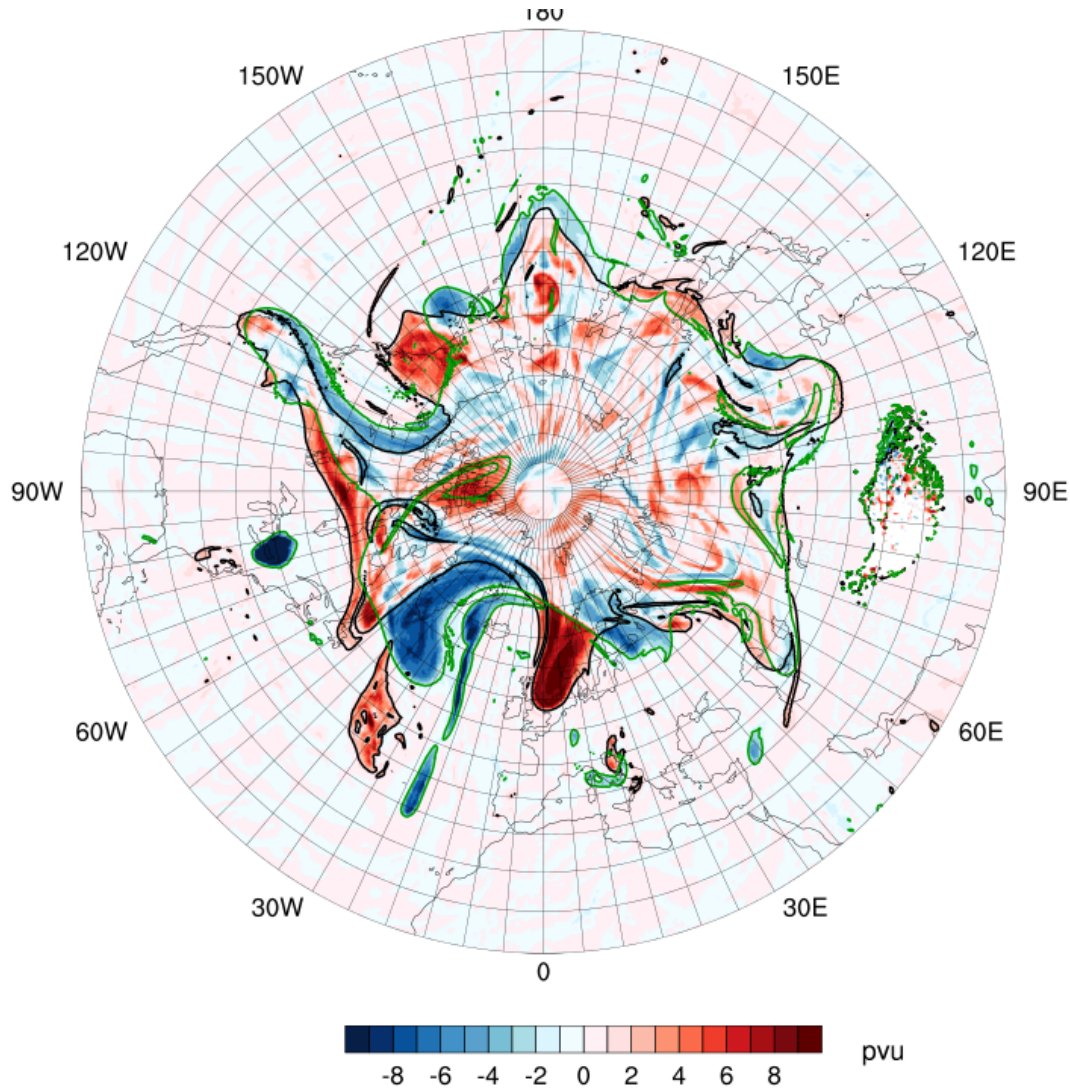


from Maxi Boettcher

Recent European forecast bust

PV on 320 K ana – fc

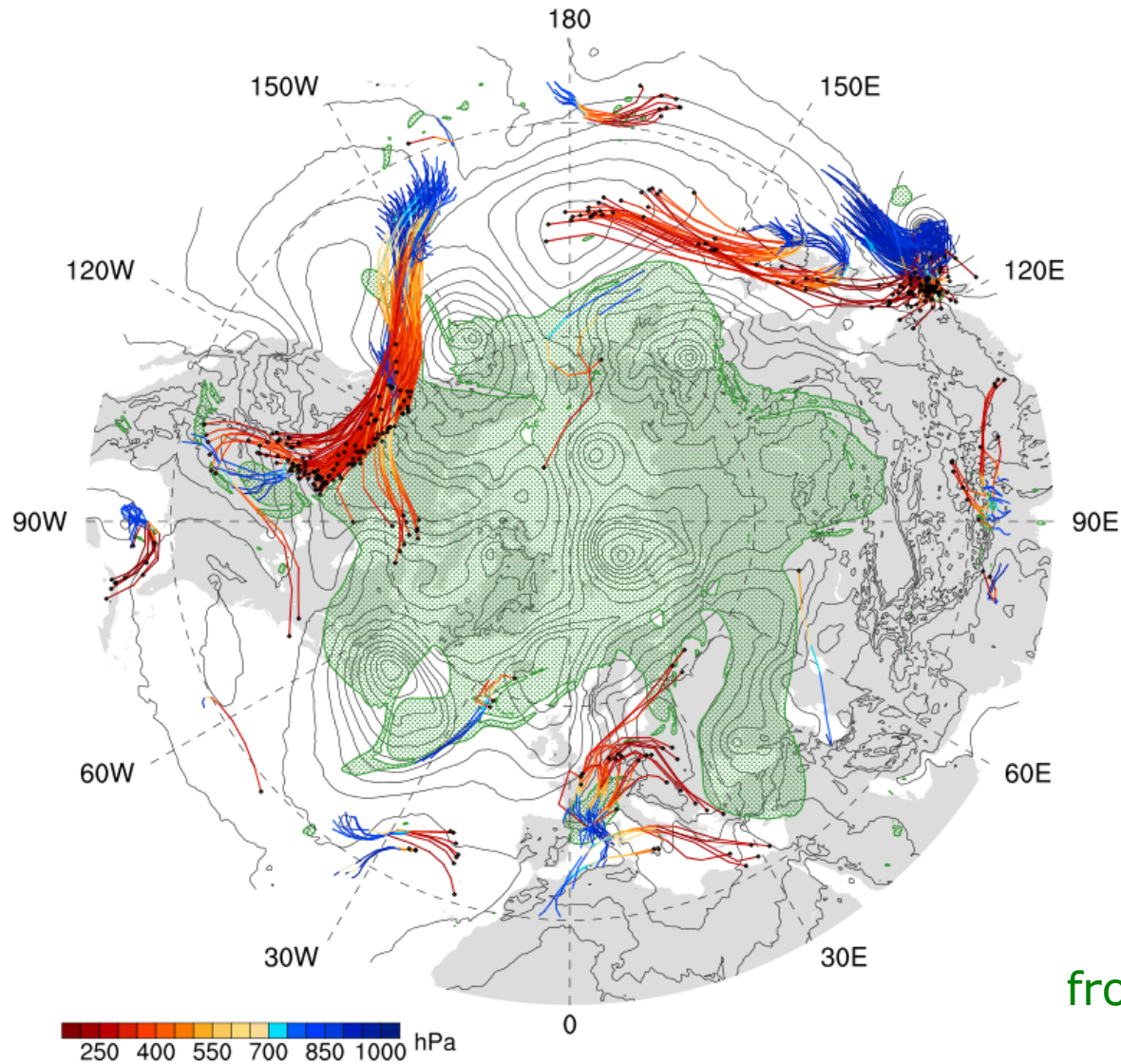
18 UTC 09 Oct (+126 h)



from Maxi Boettcher

Recent European forecast bust

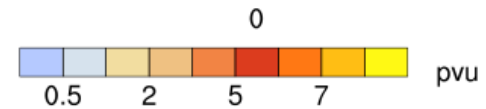
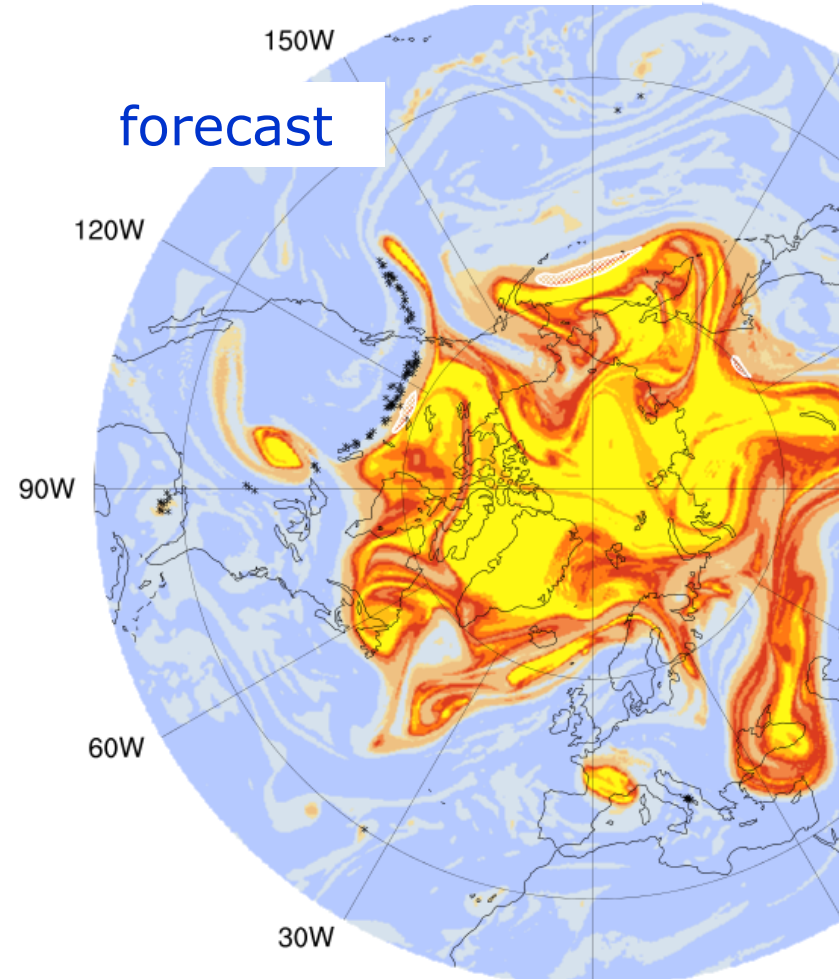
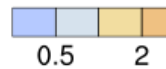
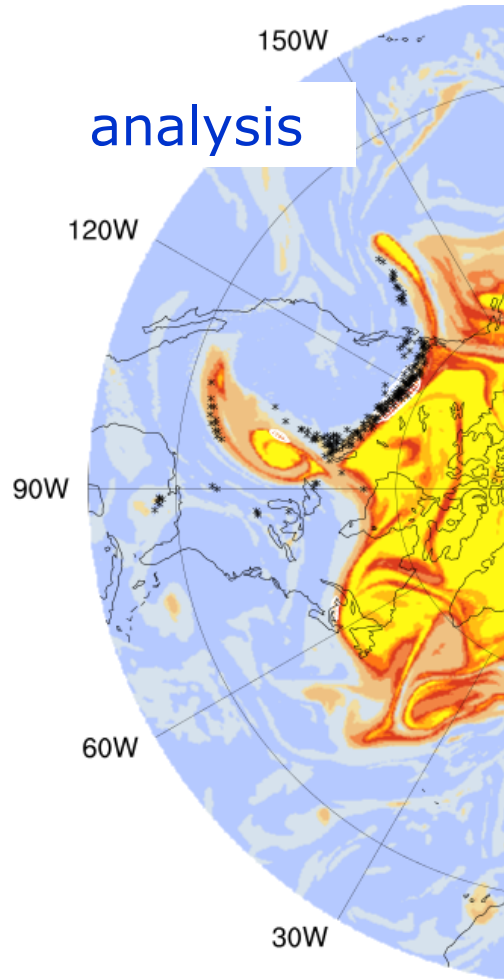
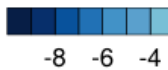
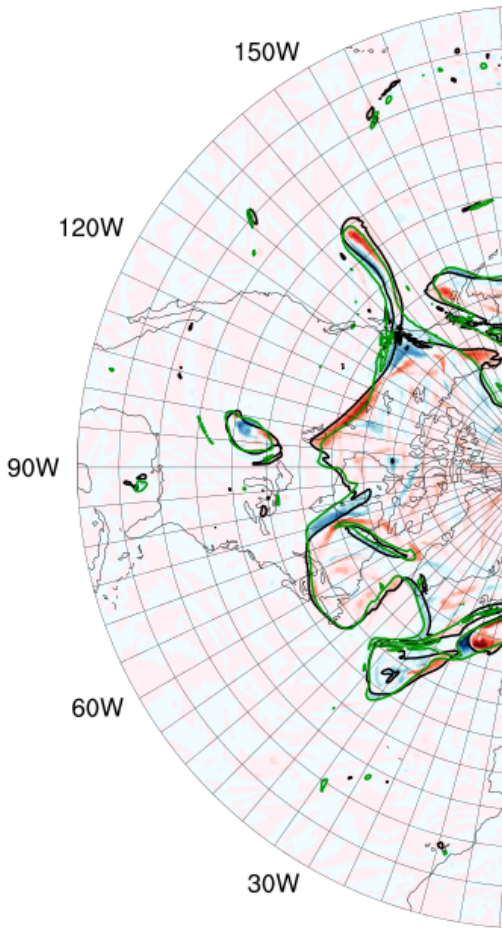
East Pacific WCB with outflow at 06 UTC 06 Oct in analysis



from Maxi Boettcher

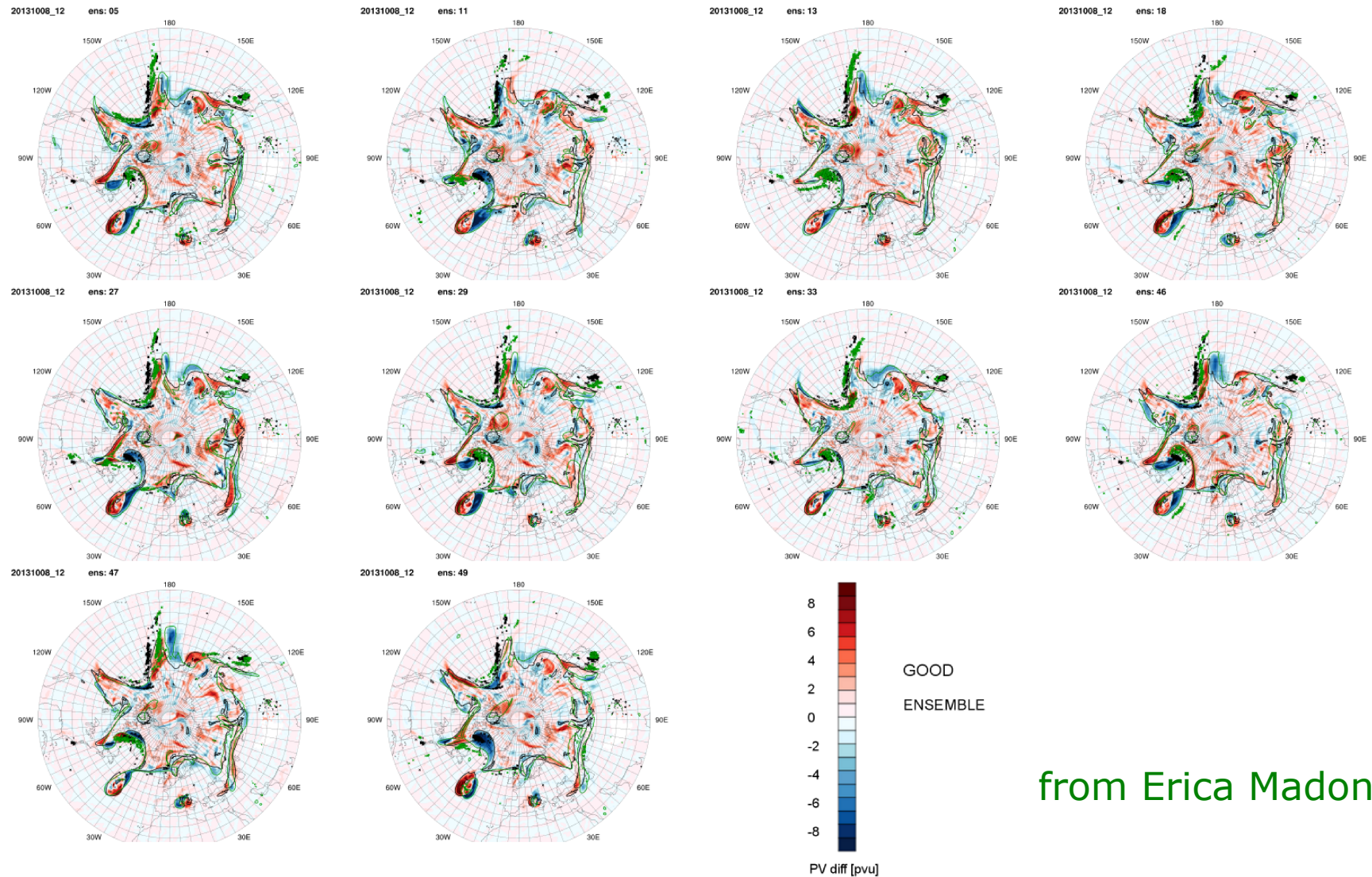
Recent European forecast bust

2 PV on 320 K and WCB outflows at 06 UTC 06 Oct



Recent European forecast bust

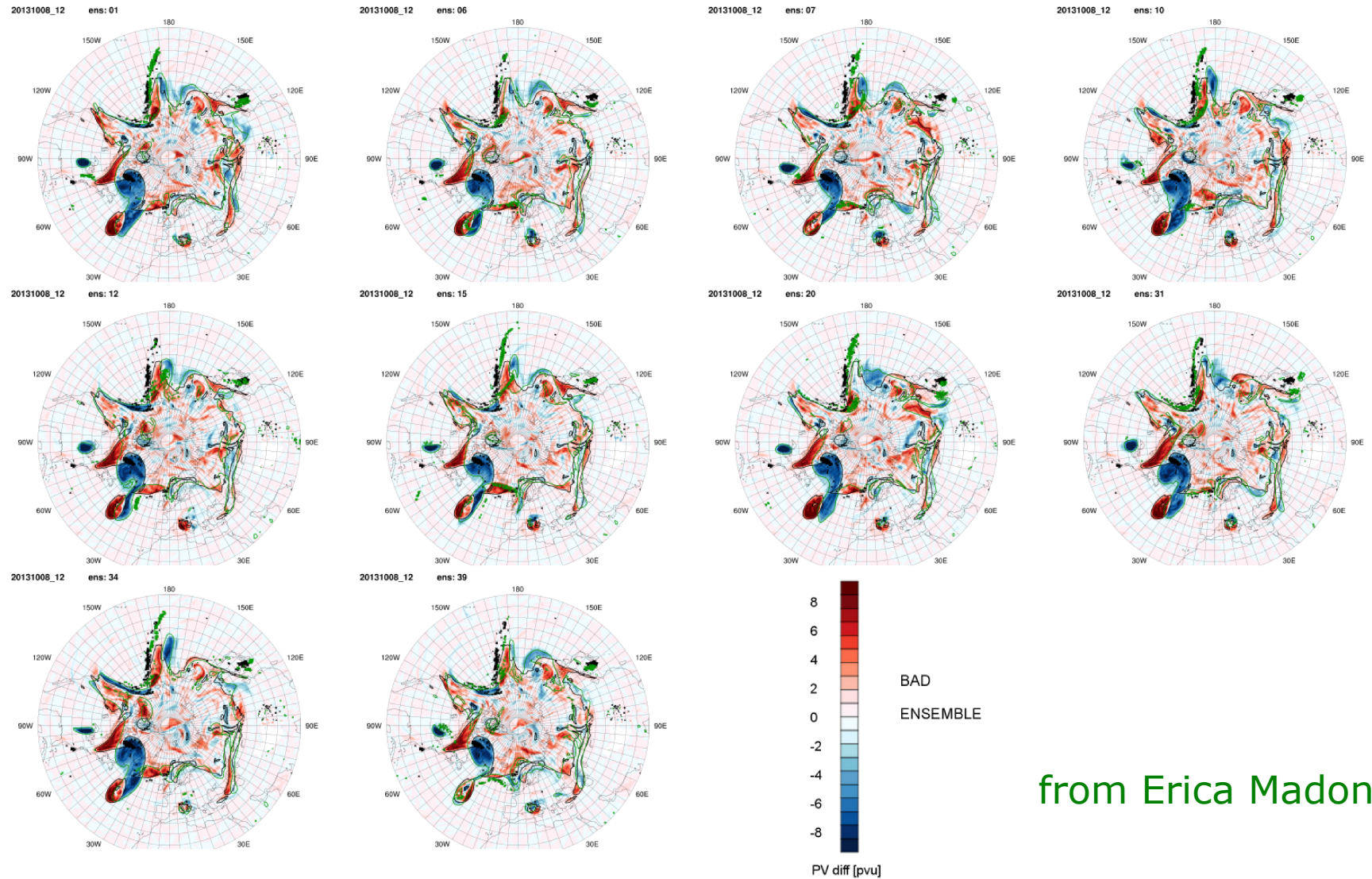
Look at **10 best** & 10 worst EPS members (according to ACC)



from Erica Madonna

Recent European forecast bust

Look at 10 best & **10 worst** EPS members (according to ACC)

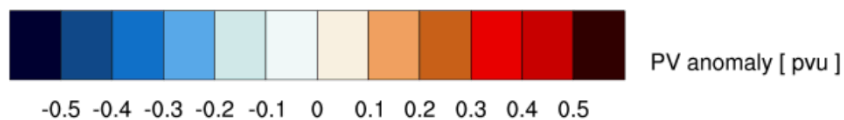
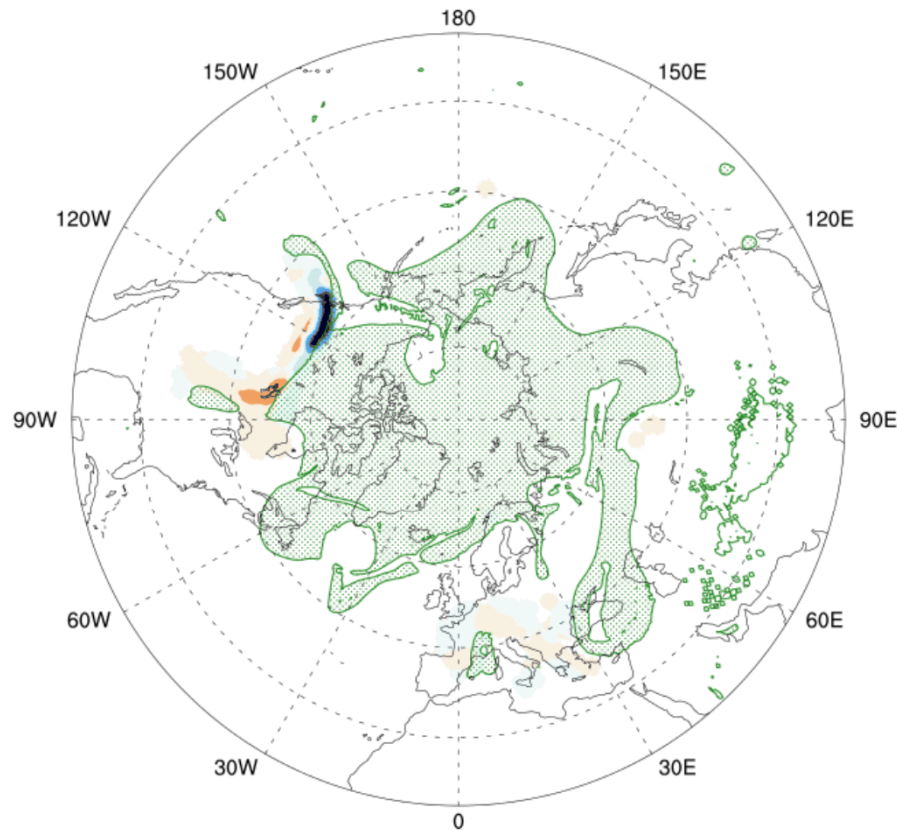


from Erica Madonna

Recent European forecast bust

Look at 10 best & 10 worst EPS members (according to ACC)

PV anomaly difference in WCB outflow (worst-best)



from Erica Madonna

Summary, challenges & questions (1 of 3)

From weather systems to forecast errors

- Meteorologically meaningful
- Requires specific identification algorithm and metric
- This involves subjective decisions & thresholds, which makes comparison of different studies sometimes difficult
- During the last years: several promising results
- But still a challenge to link results with model physics

Summary, challenges & questions (2 of 3)

From forecast errors to weather systems

- This approach has not yet been fully explored
- Forecast errors and uncertainties appear to be particularly large for certain flow conditions / weather systems
- Requires very good dynamical & physical understanding to interpret results
- Indications that moist processes (e.g., convection, WCBs) and nonlinear dynamics (e.g., absorption of PV cutoff) play an essential role
- Caveats: Detailed case studies are required – are they representative? Systematic studies with composites may hide some of the variability?

Summary, challenges & questions (3 of 3)

- What weather systems should we focus on?
- Is there a way to make diagnostics more objective / standardized / comparable?
- Systematic studies requires large amount of data → how to make data available to the community?
- Not well understood: when does error in ridge amplitude lead to large downstream error growth – and when not?
- Would it make sense to launch a project where a set of forecasts – for selected bust events and with varying model configurations (e.g., modified physical processes) would be evaluated by a team with complementary expertise?
- Etc.