The North Atlantic Waveguide

Dynamics and Predictive Skill of North Atlantic Weather Systems

Heini Wernli – ETH Zurich, Switzerland

With contributions from:

Maxi Böttcher, Andreas Dörnbrack, Christian Grams, Sarah Jones, Hanna Joos, Andreas Schäfler

ECMWF Seminar “Predictability in the European and Atlantic regions”, 6 September 2010

THORPEX

WMO
OMM

Outline of the talk

The concept of an upper-tropospheric waveguide and waveguide disturbances

Poleward disturbances: Stratospheric PV anomalies

Equatorward disturbances: Warm conveyor belts

A case study in September 2008

WCBs and forecast quality

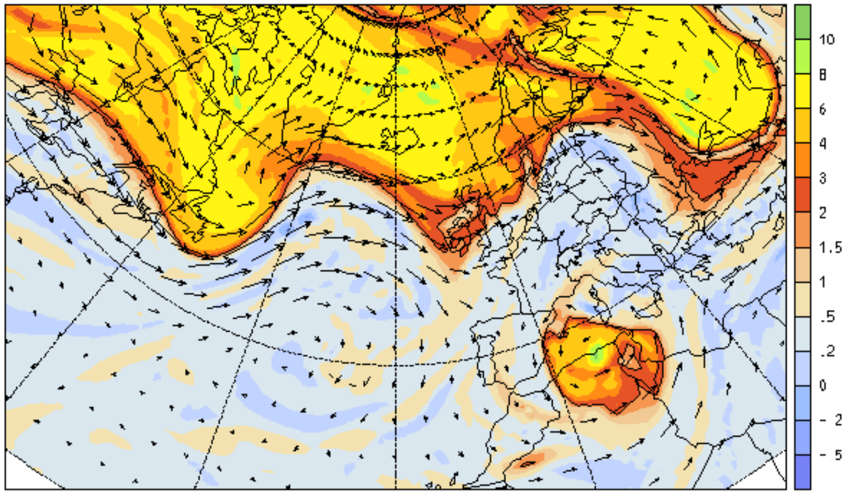
Low-tropospheric disturbances: Diabatic Rossby waves

DRWs and forecast quality

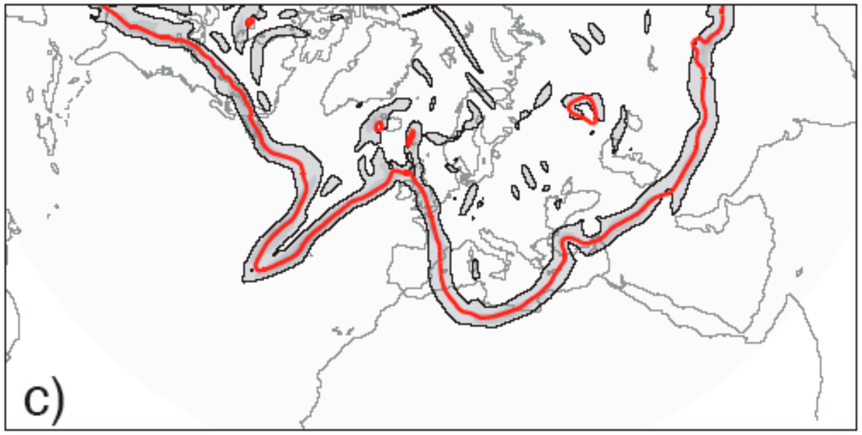
Outlook: Field experiment T-NAWDEX / DIAMET

The concept of extratropical waveguides

Instantaneous PV distribution on 320K



Normalized PV gradient on 320K



Structure of the atmosphere's isentropic PV gradient comprises a narrow meandering band, which acts as a strongly laterally confined space-time evolving waveguide

PV wave-guides play a key role in the dynamics of waves on a jet (generation, propagation & downstream development)

Martius et al. 2010 (JAS)

The concept of extratropical waveguides

How to measure intensity of waveguide?

- Ertel PV: strong asymmetry in amplitude of pos and neg anomalies

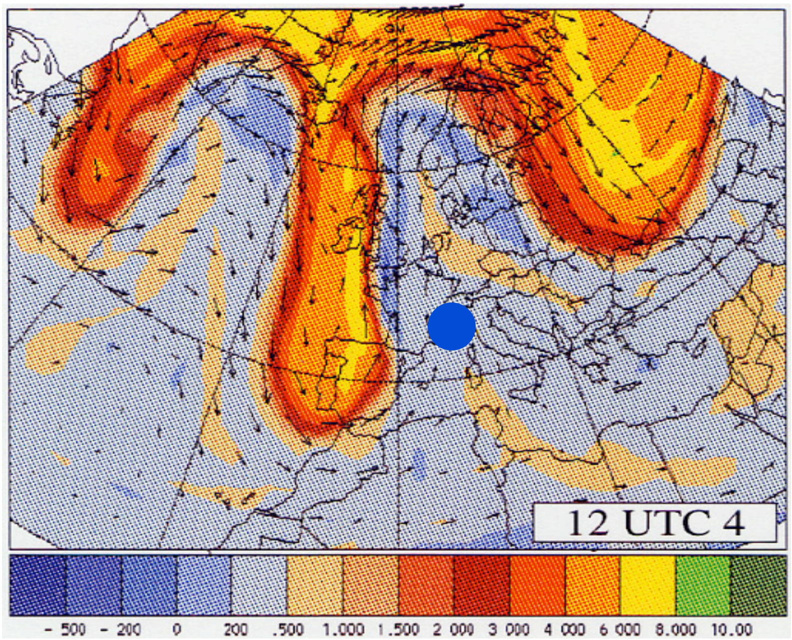
- QG PV (q): velocity perturbations ~ l q-anomalies l

$$\nabla_\theta[\ln(\mathrm{IPV})] \approx \frac{1}{f_0}\nabla_\theta q.$$

Note also that $\nabla_\theta^2 U = -\nabla_\theta q.$

Martius et al. 2010 (JAS)

Why are we interested in PV waveguides?

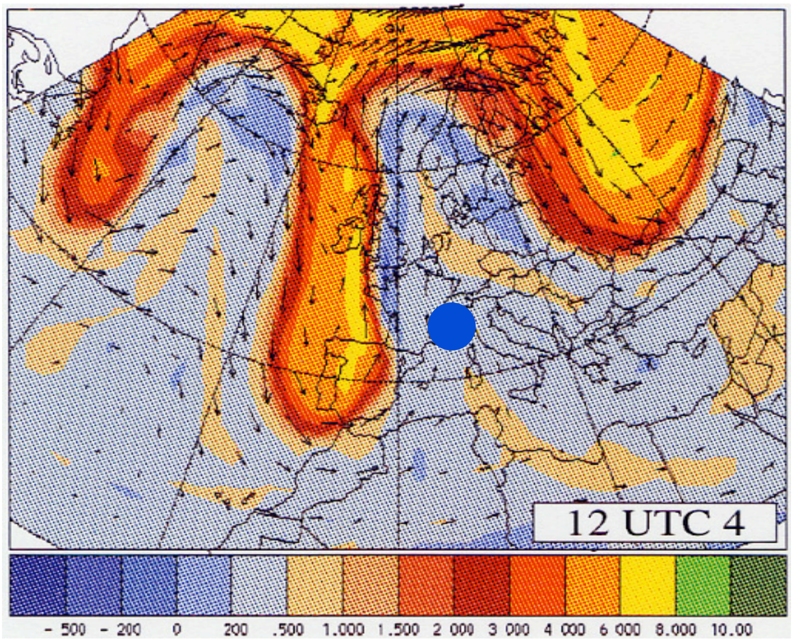


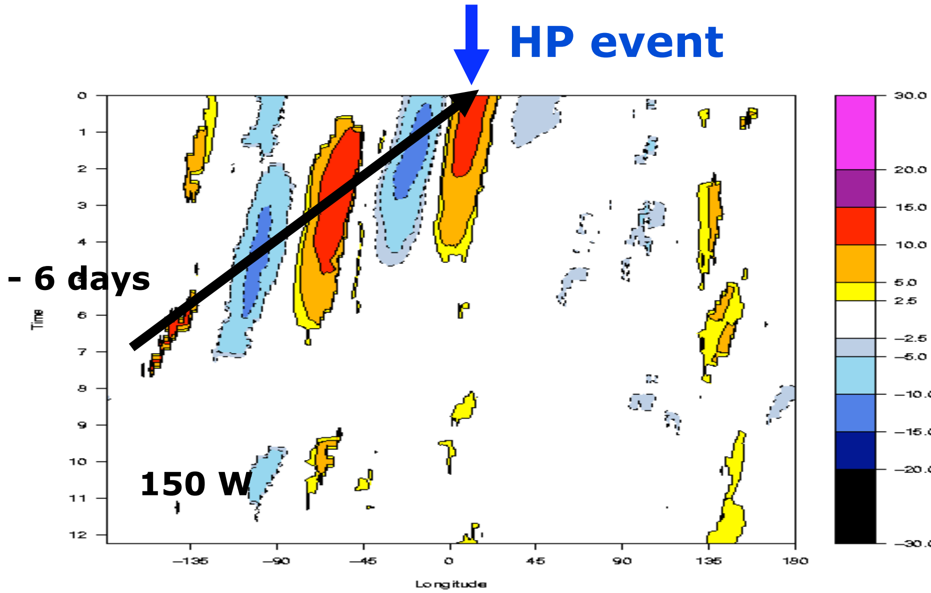
Consider heavy precipitation events on the Alpine Southside as an **example for high-impact weather systems** …

… they are typically associated with a PV-streamer resulting from a RW breaking

Massacand et al. 1998; Martius et al. 2005

Why are we interested in PV waveguides?



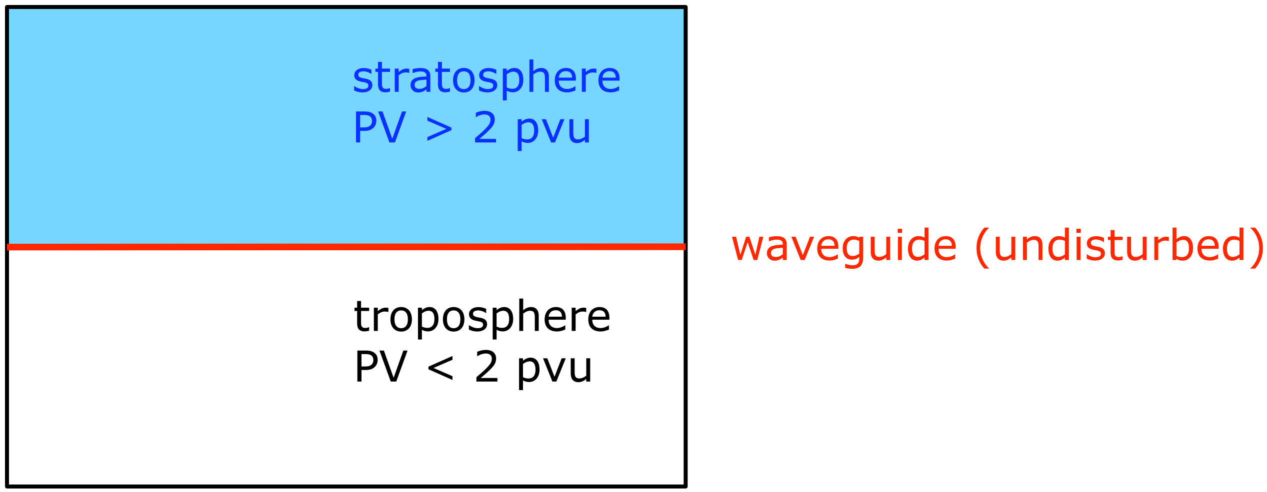


Consider heavy precipitation events on the Alpine Southside as an **example for high-impact weather systems** …

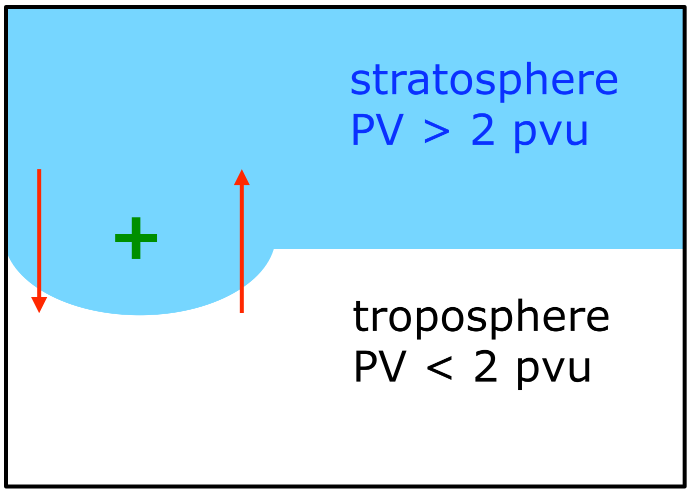
Hovmoller composite for many autumn HP events shows a **coherent upstream wave-train!**

Martius et al. 2008

Waveguide disturbances and downstream development



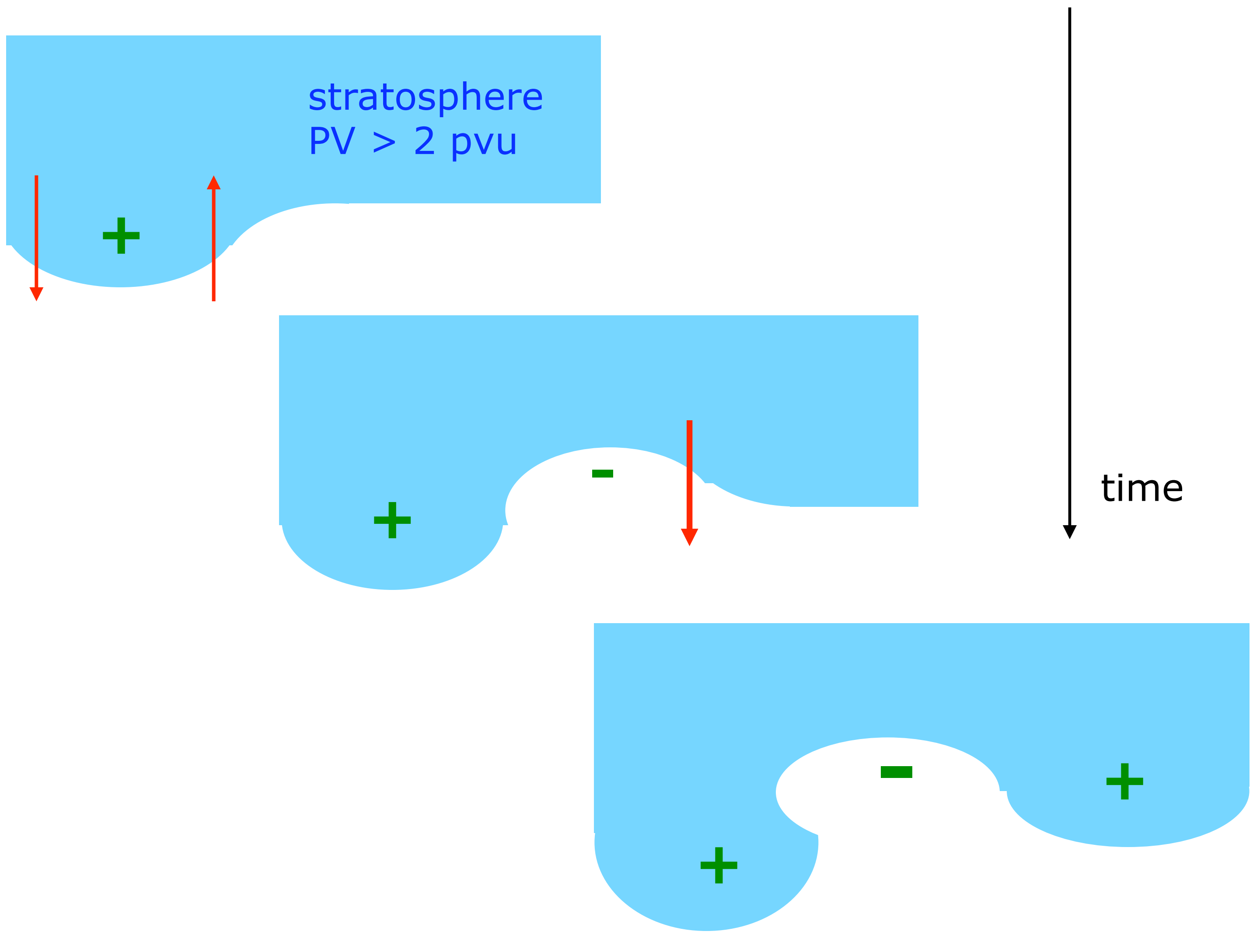
Waveguide disturbances and downstream development



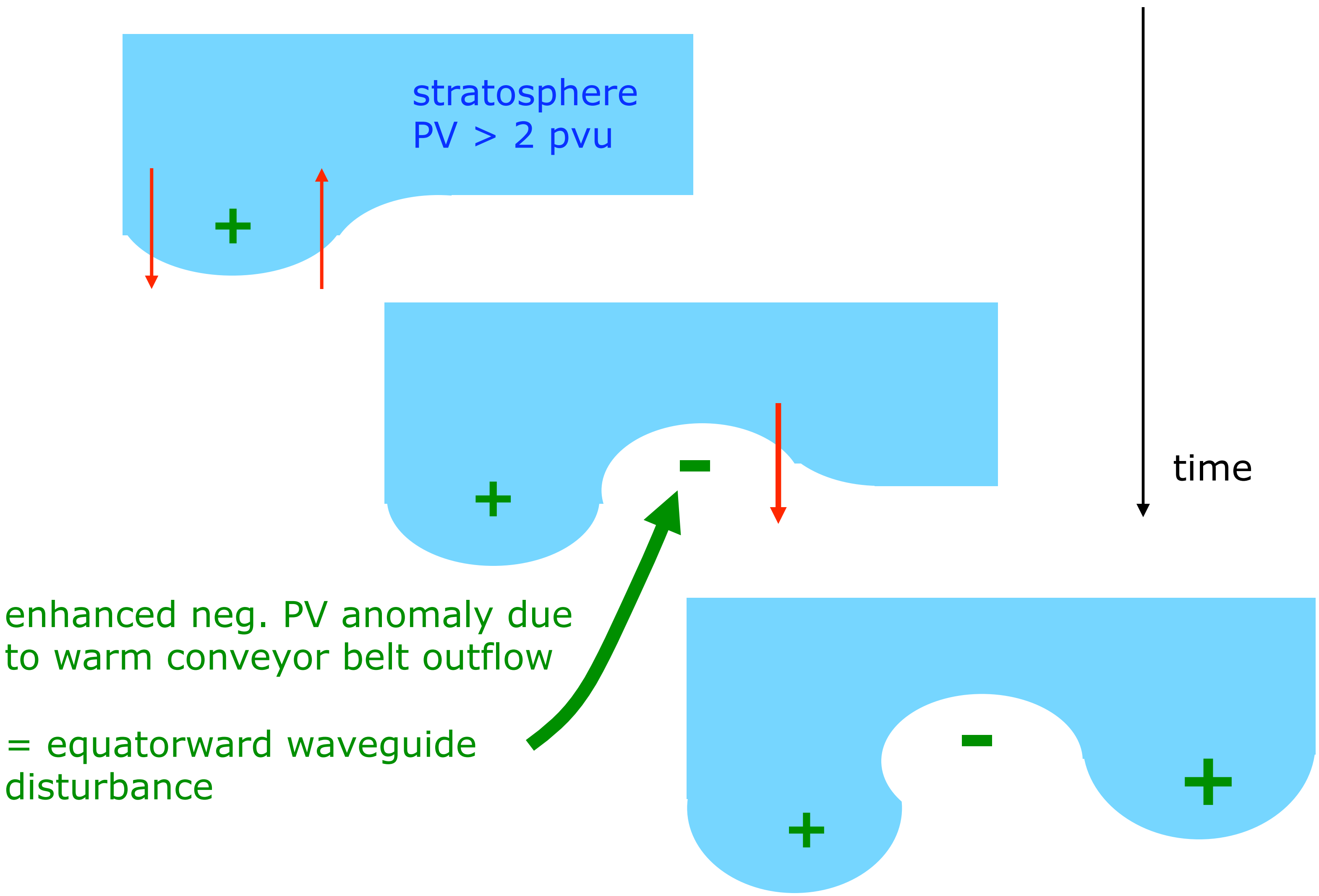
stratospheric PV anomaly

= poleward waveguide disturbance

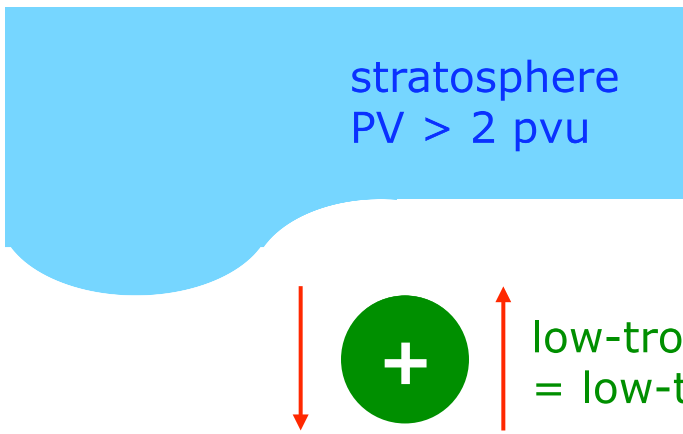
Waveguide disturbances and downstream development



Waveguide disturbances and downstream development



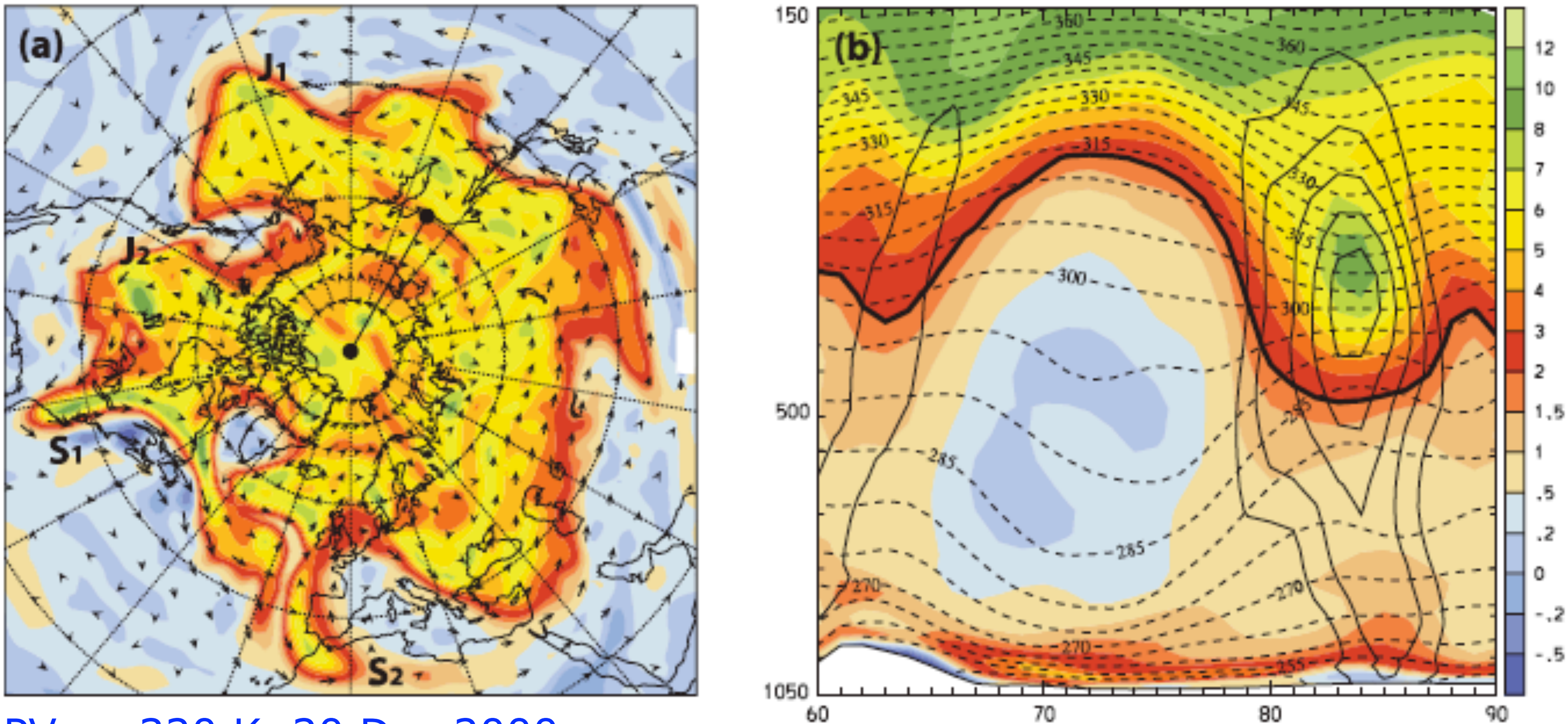
Waveguide disturbances and downstream development



low-tropospheric positive PV anomaly
= low-tropospheric waveguide disturbance

e.g., tropical cyclone undergoing extratropical transition, diabatic Rossby wave, …

Stratospheric PV anomalies

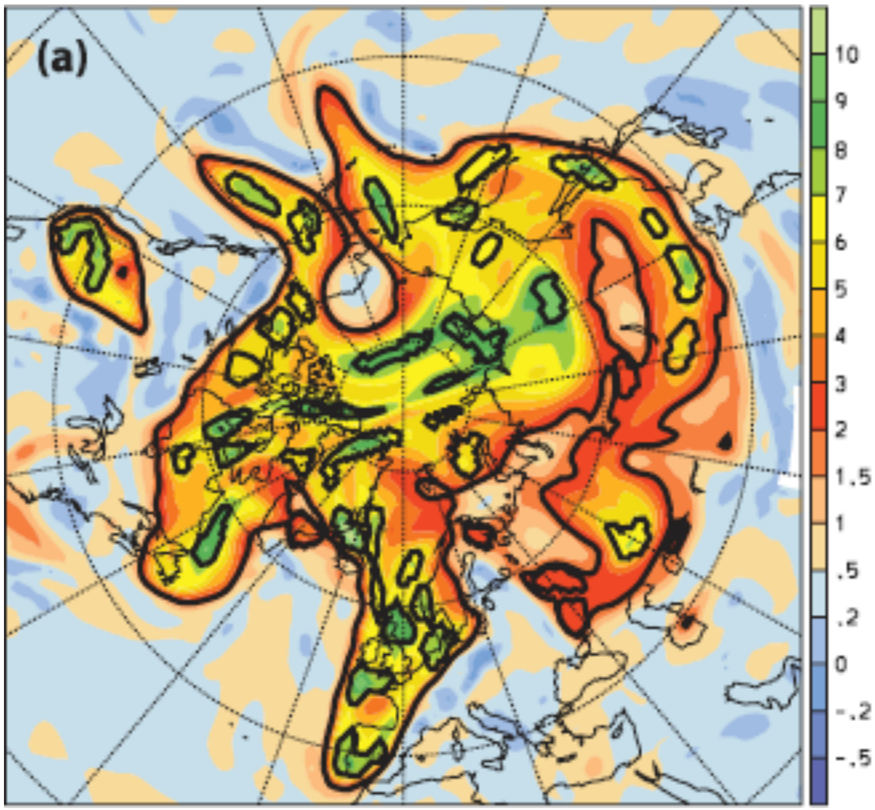


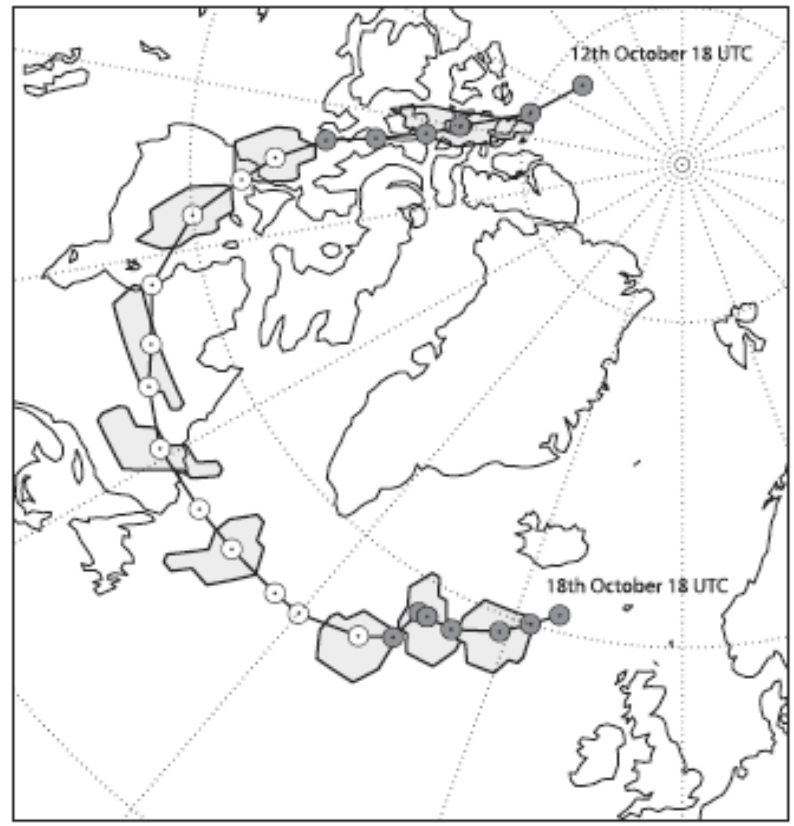
PV on 320 K, 20 Dec 2000

Kew et al. 2010 (MWR)

Stratospheric PV anomalies

Objective identification and tracking of PV anomalies

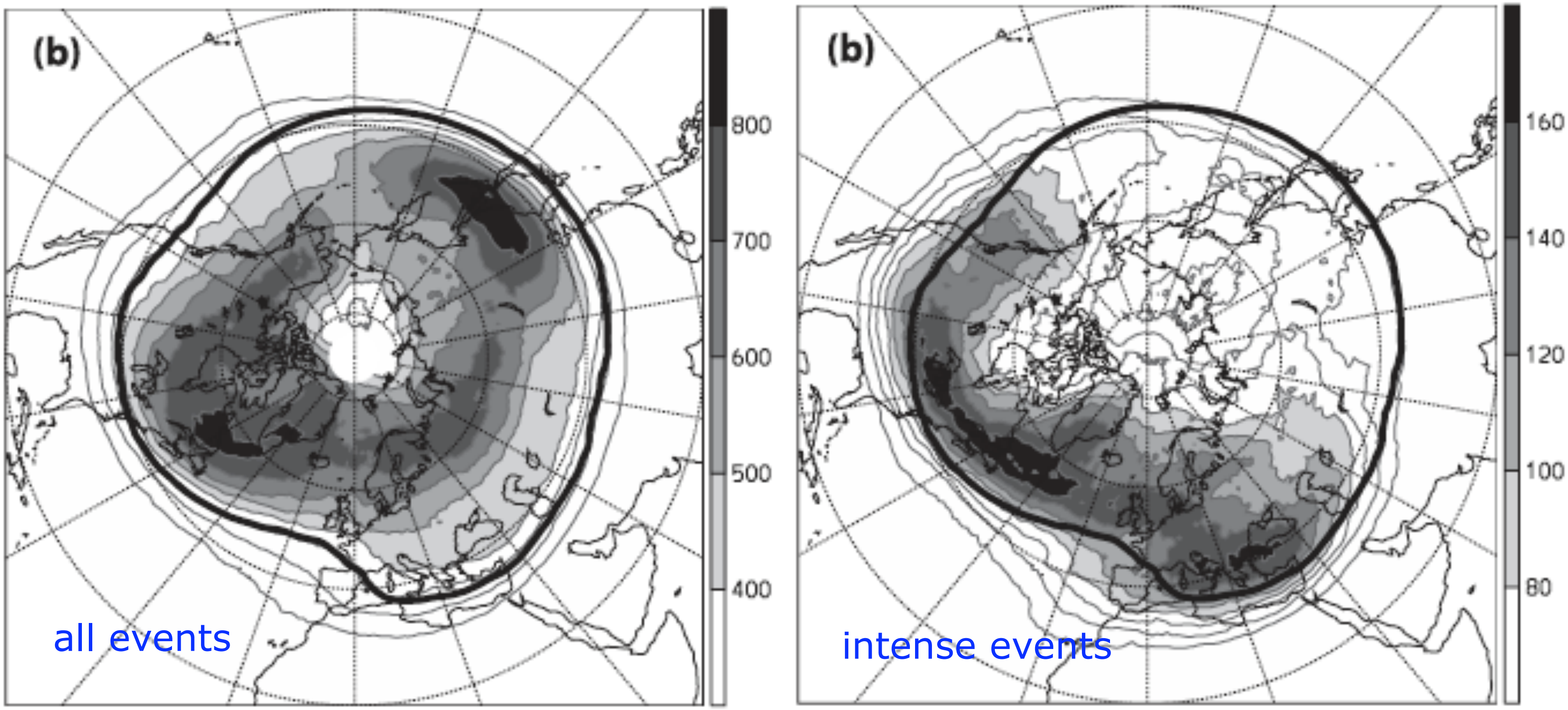




Kew et al. 2010 (MWR)

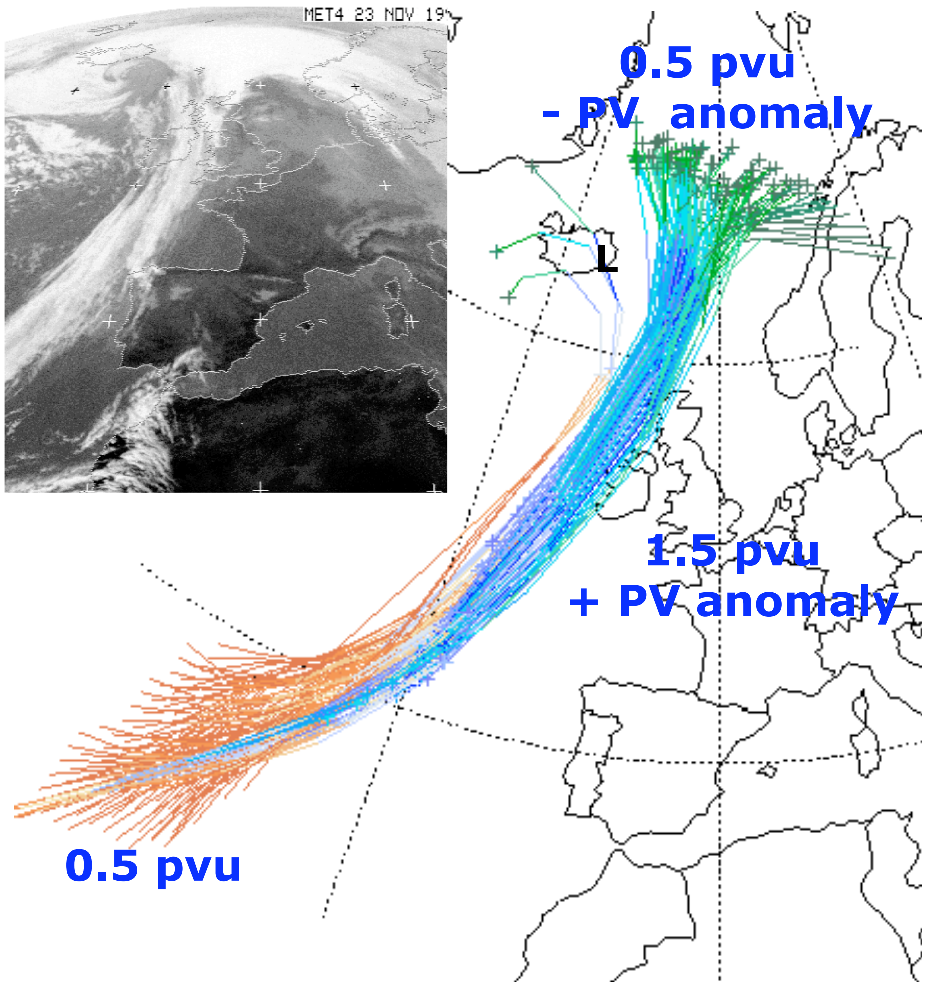
Stratospheric PV anomalies

Track density on 320 K, 10 winters, minimum lifetime 1 day



Kew et al. 2010 (MWR)

Warm conveyor belts



intense latent heating (>20K), i.e., strong cross-isentropic flow

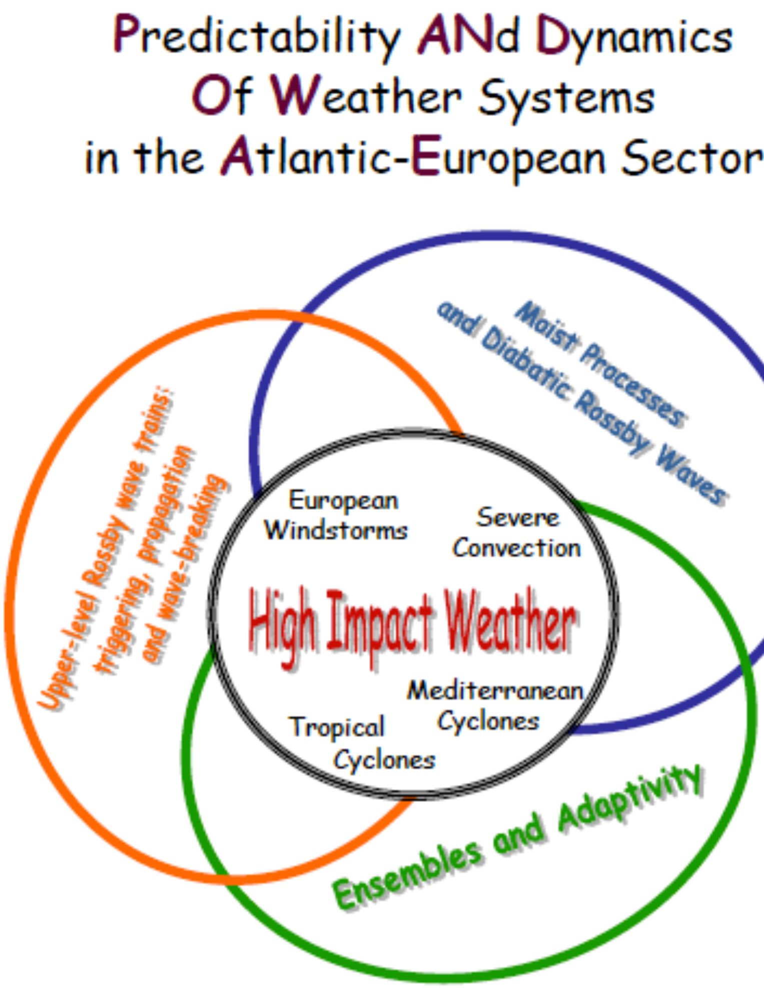
characteristic modification of potential vorticity (PV):

in low troposphere:
increase ~0.5 → ~1.5 pvu
due to dH/dz > 0

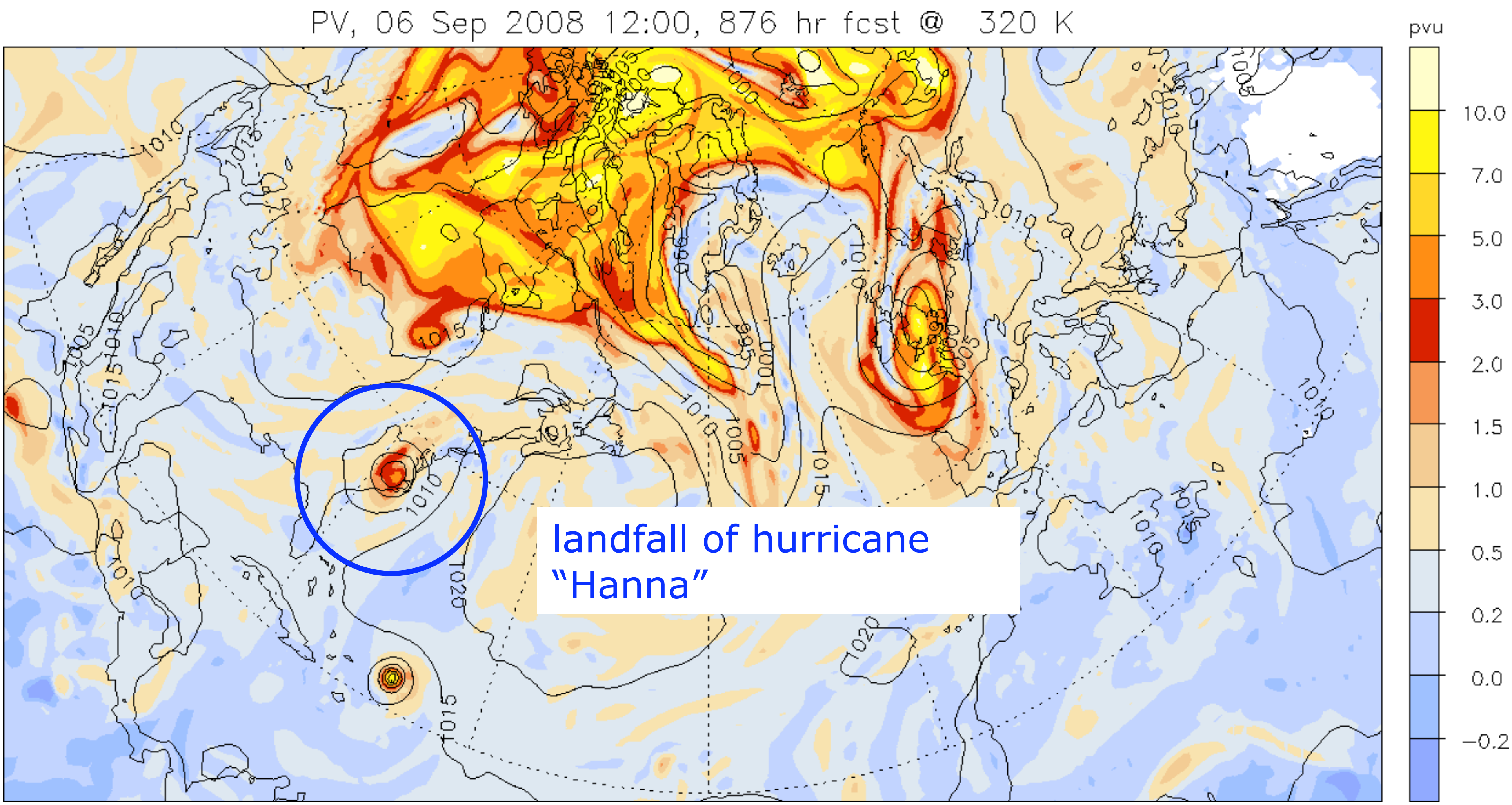
in upper troposphere:
decrease ~1.5 → ~0.5 pvu
due to dH/dz < 0

WCB modification of North Atlantic waveguide

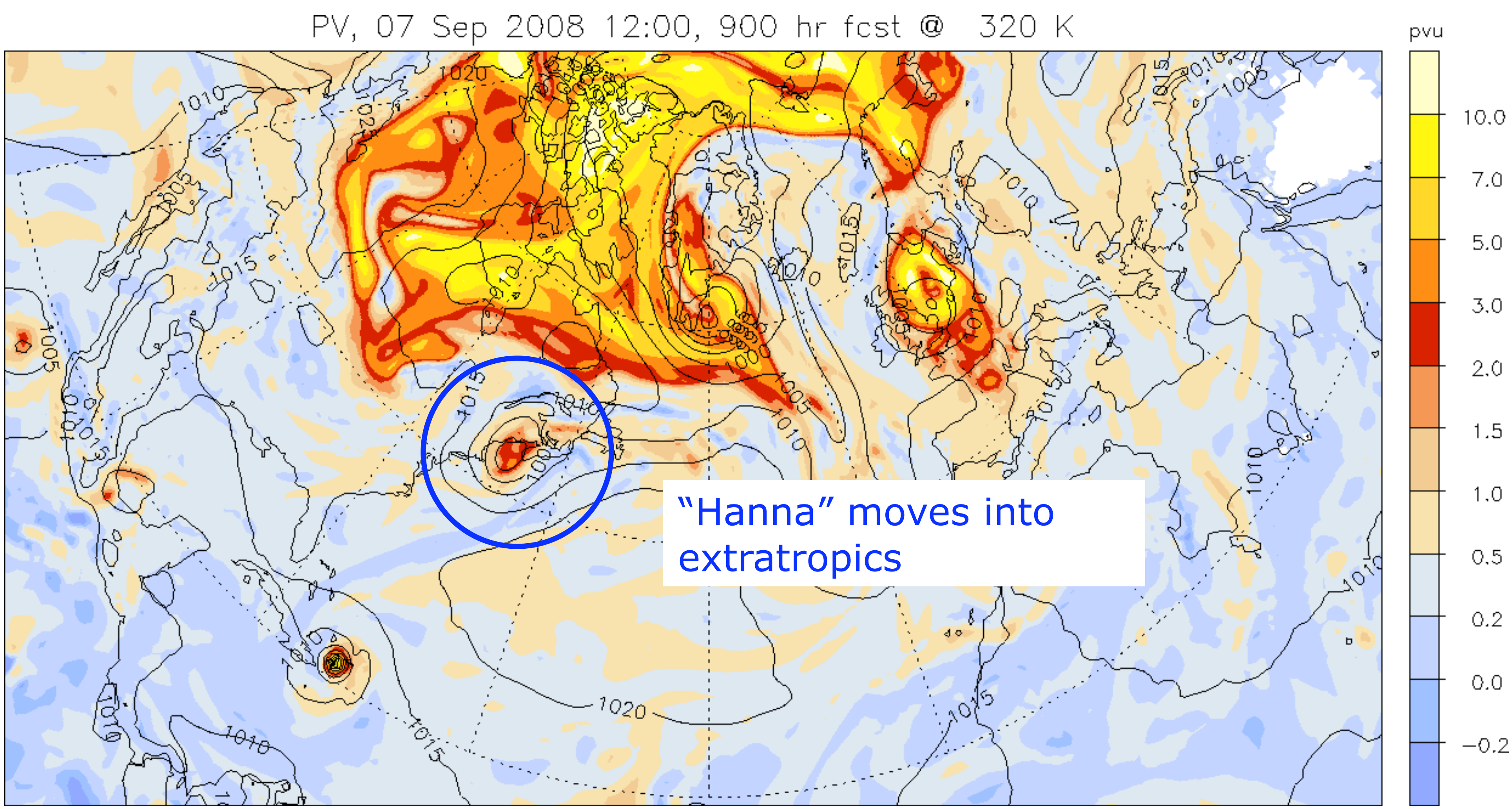
Case study September 2008
by C. Grams et al. (DFG research group PANDOWAE)



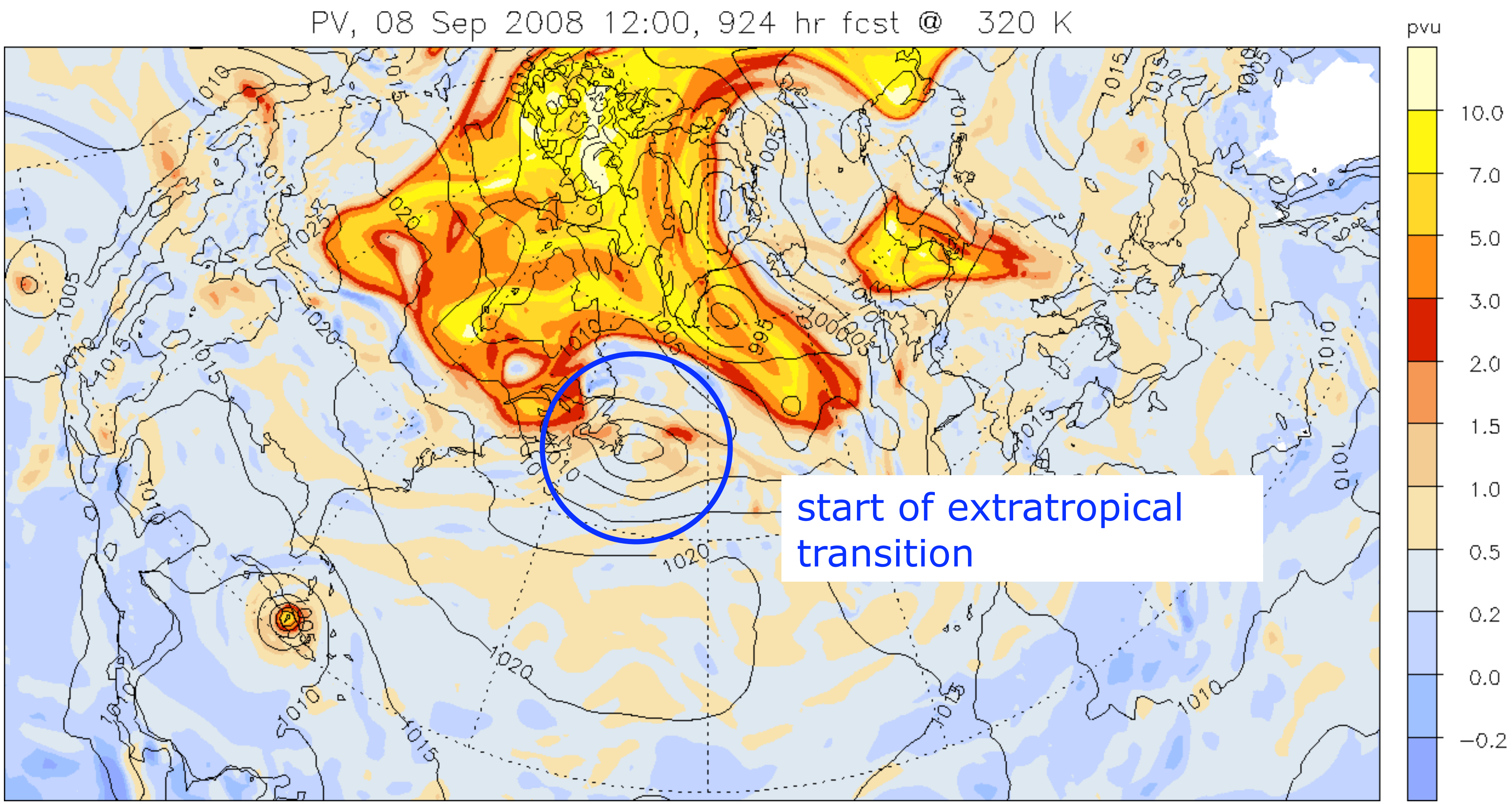
WCB modification of North Atlantic waveguide



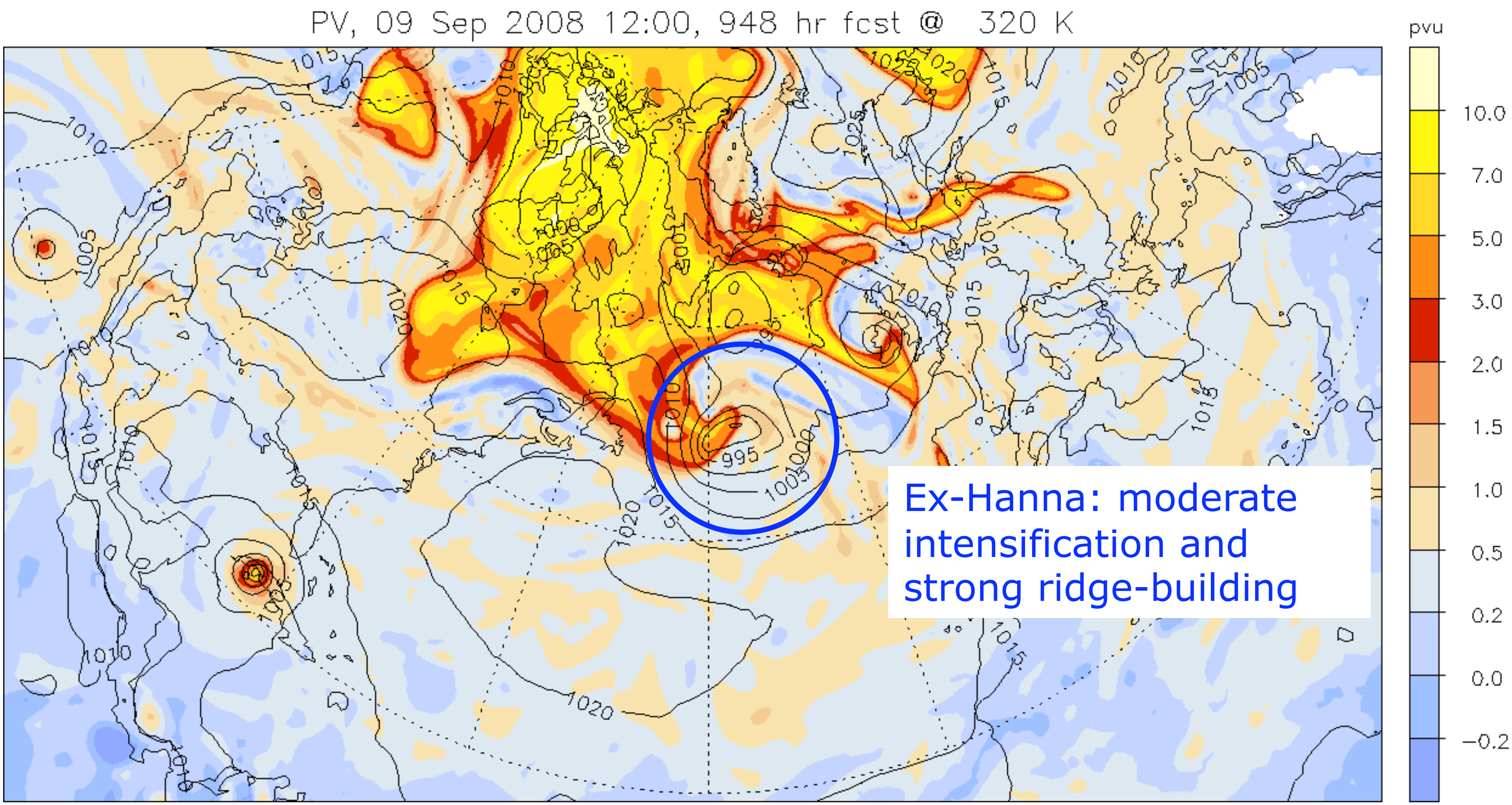
WCB modification of North Atlantic waveguide



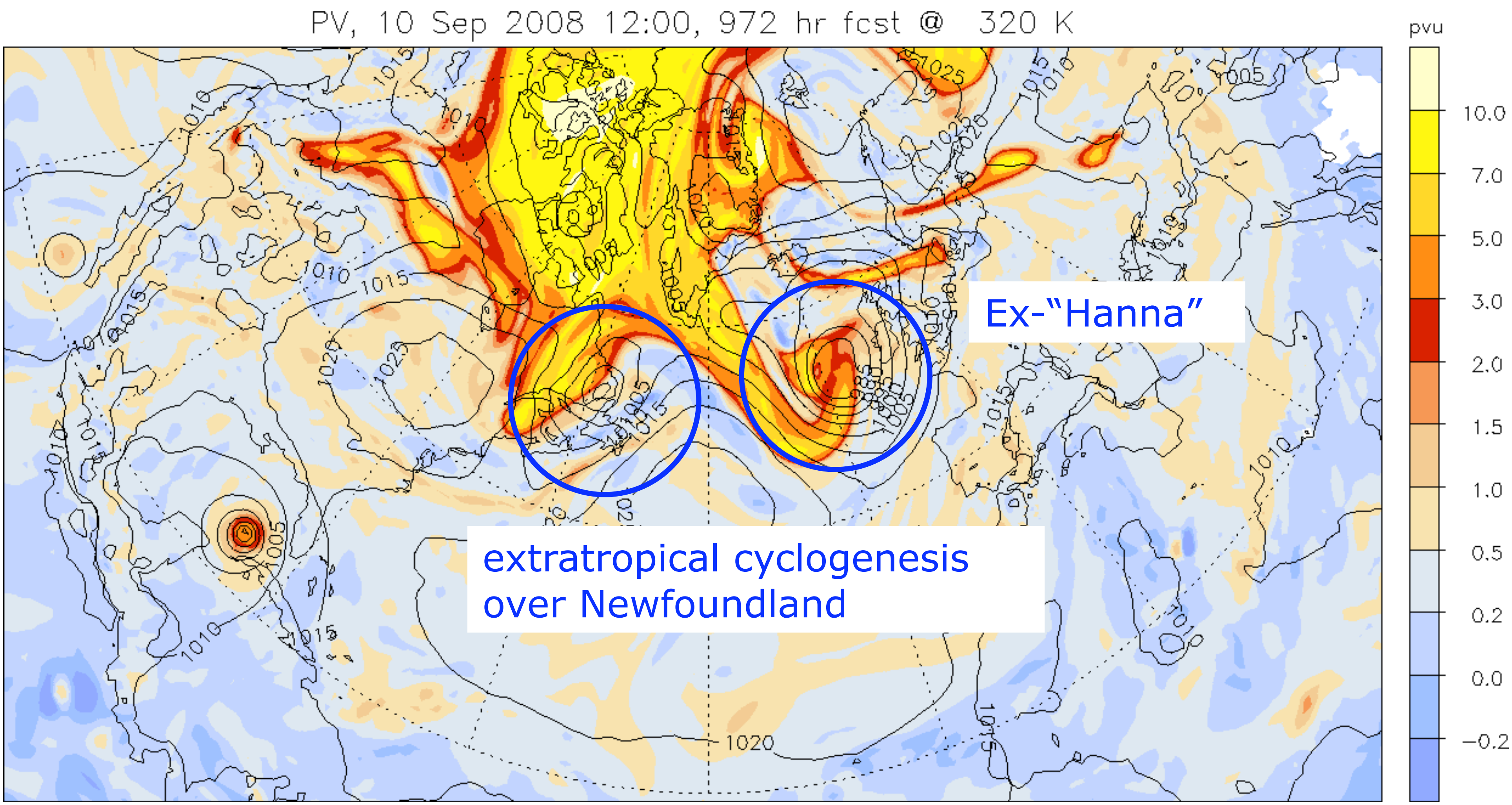
WCB modification of North Atlantic waveguide



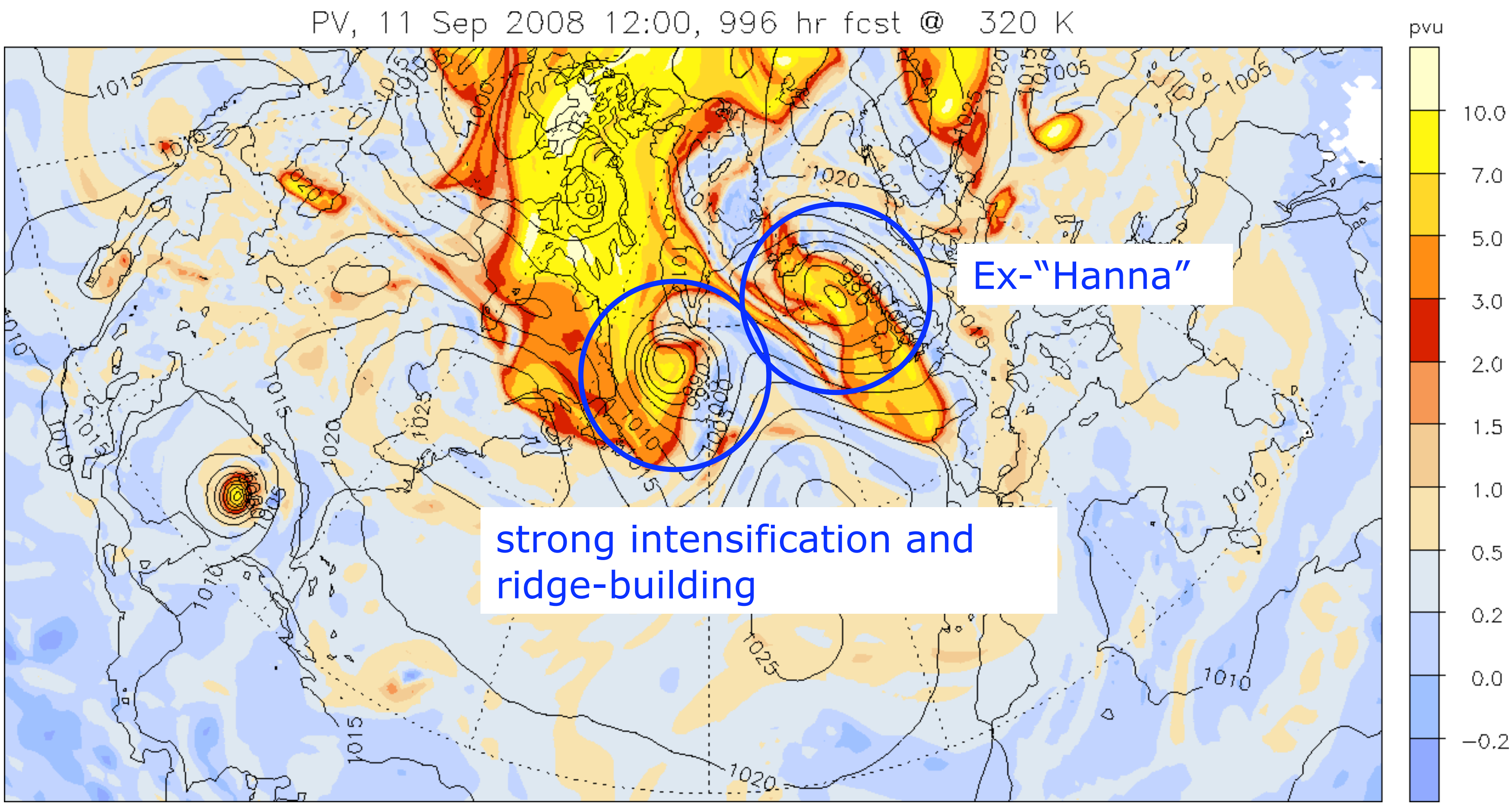
WCB modification of North Atlantic waveguide



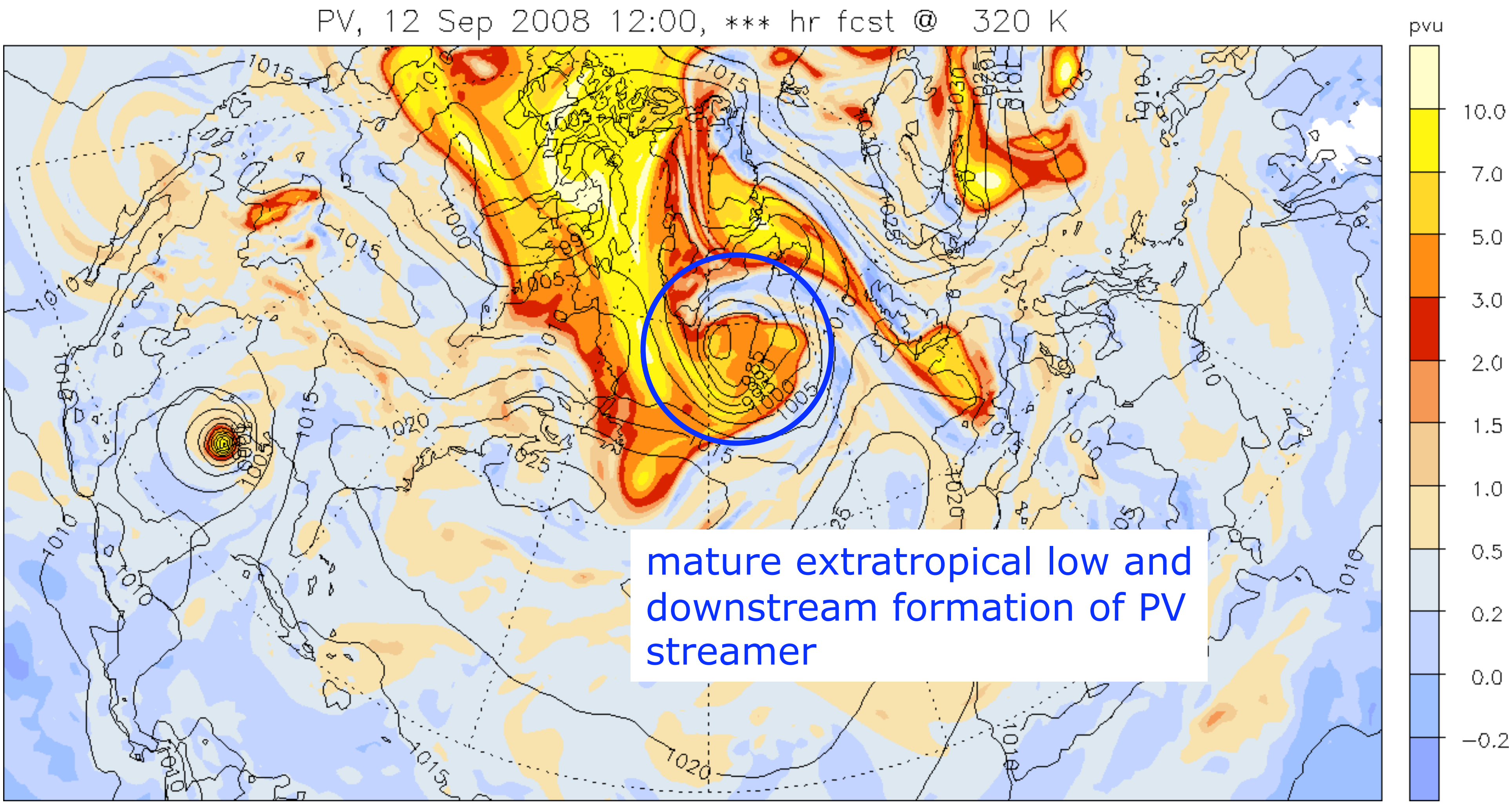
WCB modification of North Atlantic waveguide



WCB modification of North Atlantic waveguide

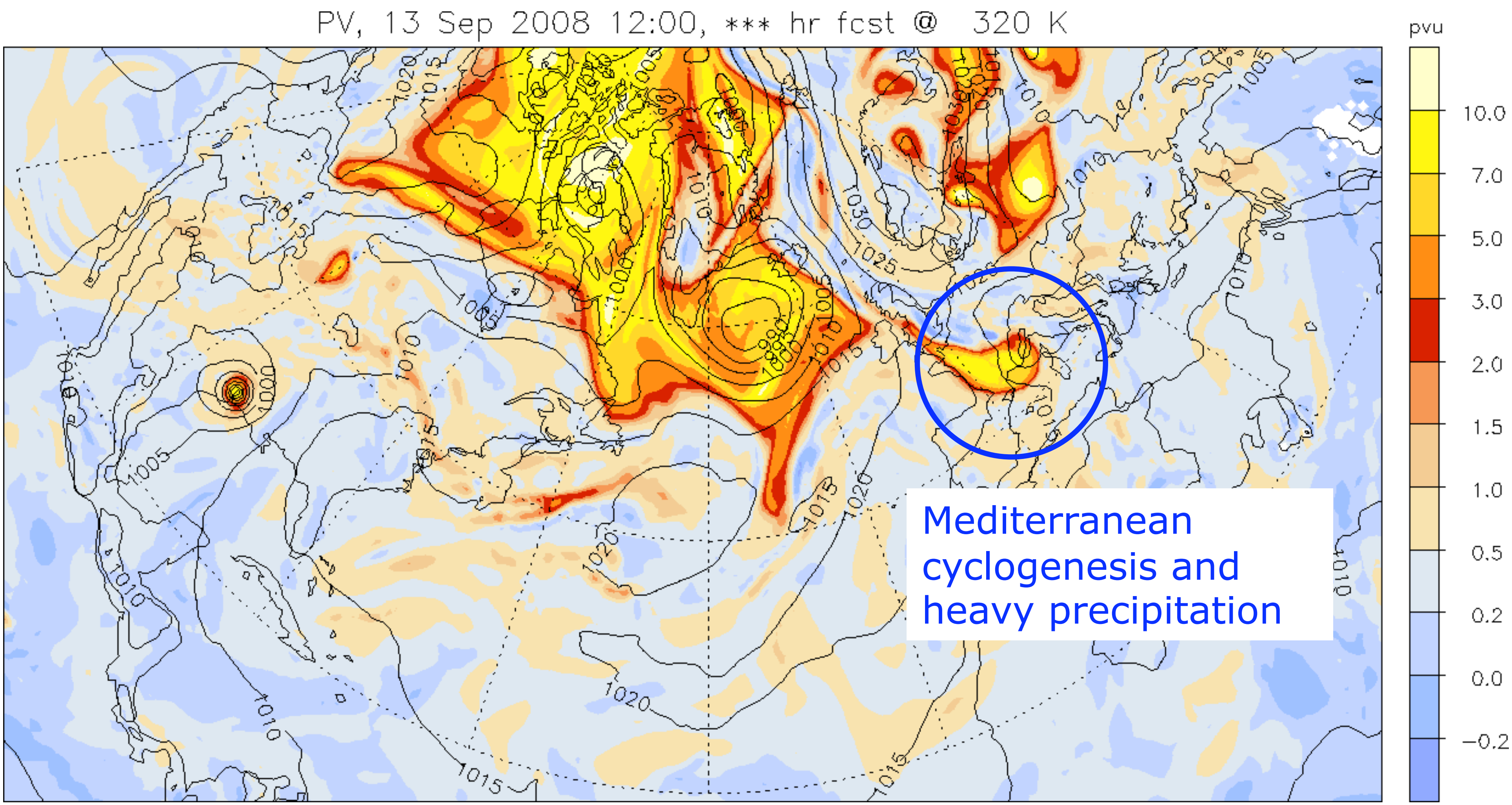


WCB modification of North Atlantic waveguide

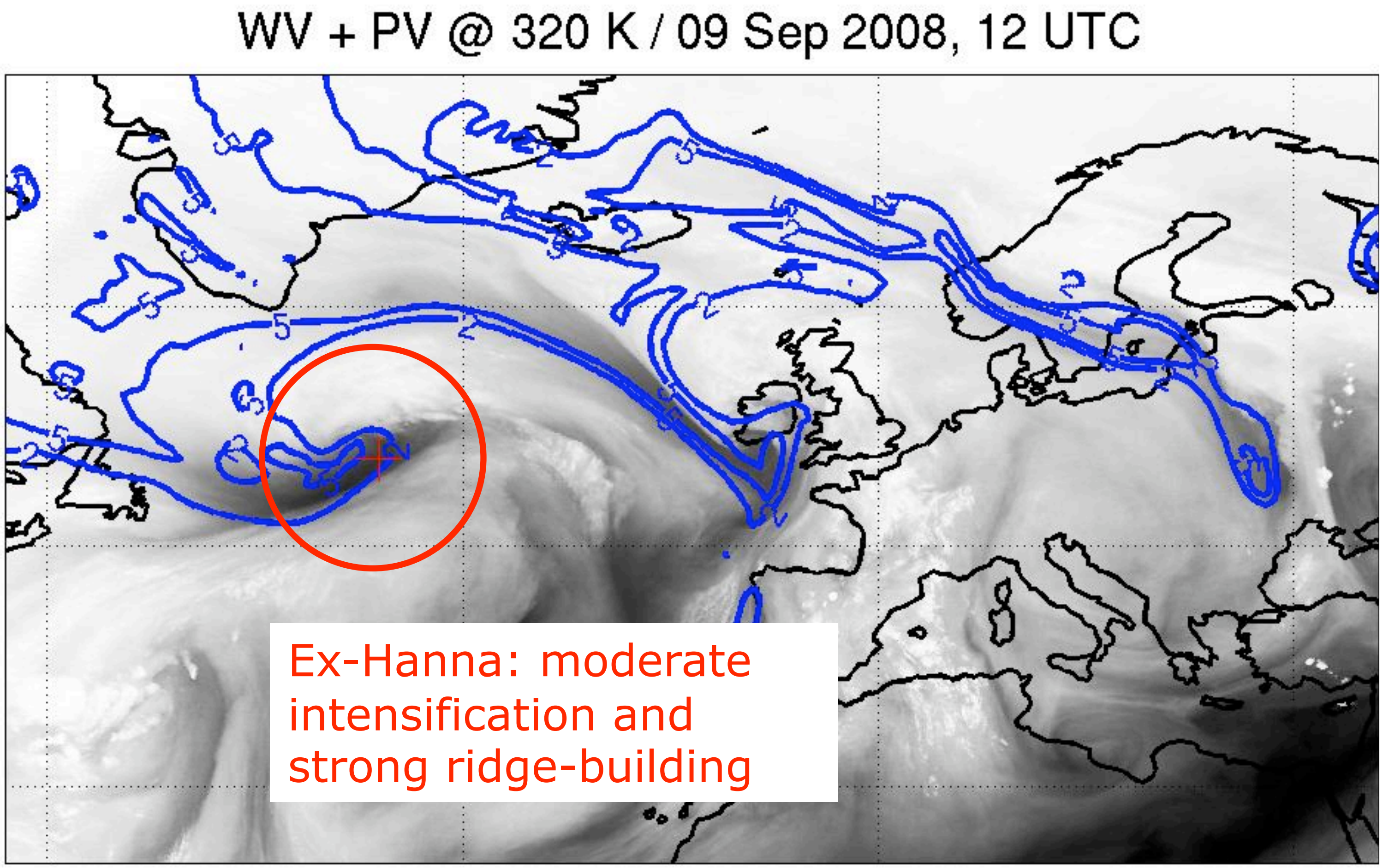


mature extratropical low and downstream formation of PV streamer

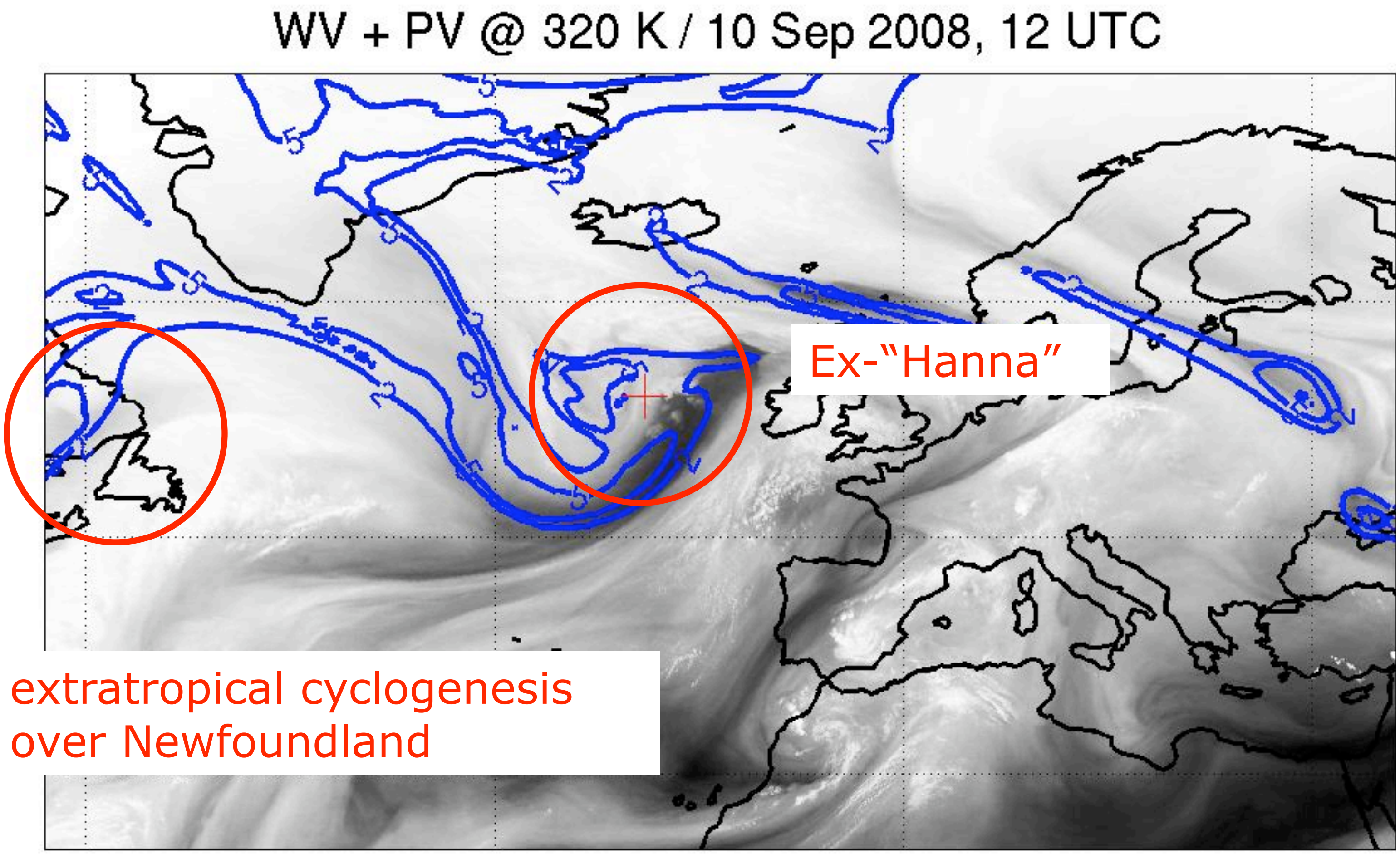
WCB modification of North Atlantic waveguide



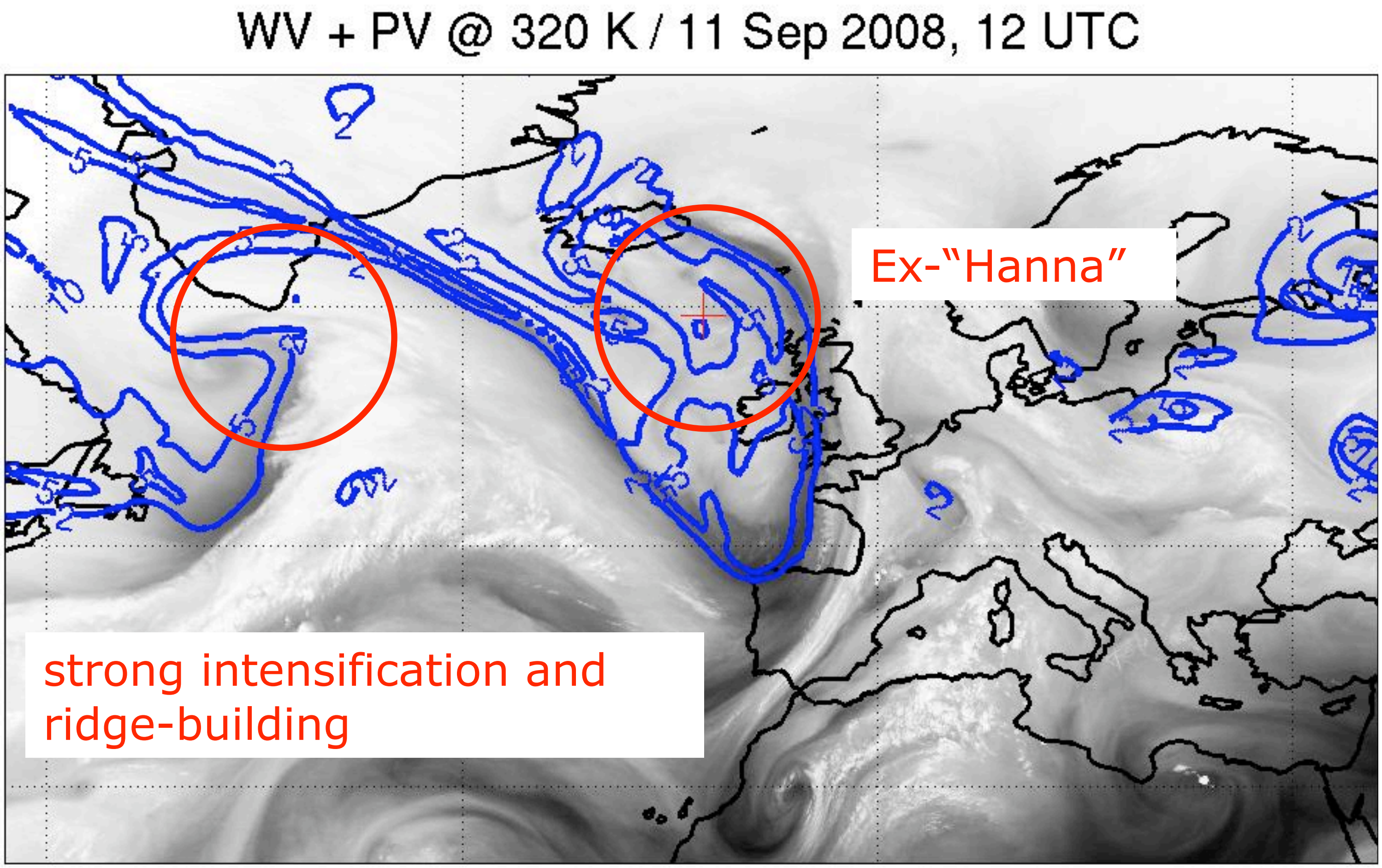
WCB modification of North Atlantic waveguide



WCB modification of North Atlantic waveguide

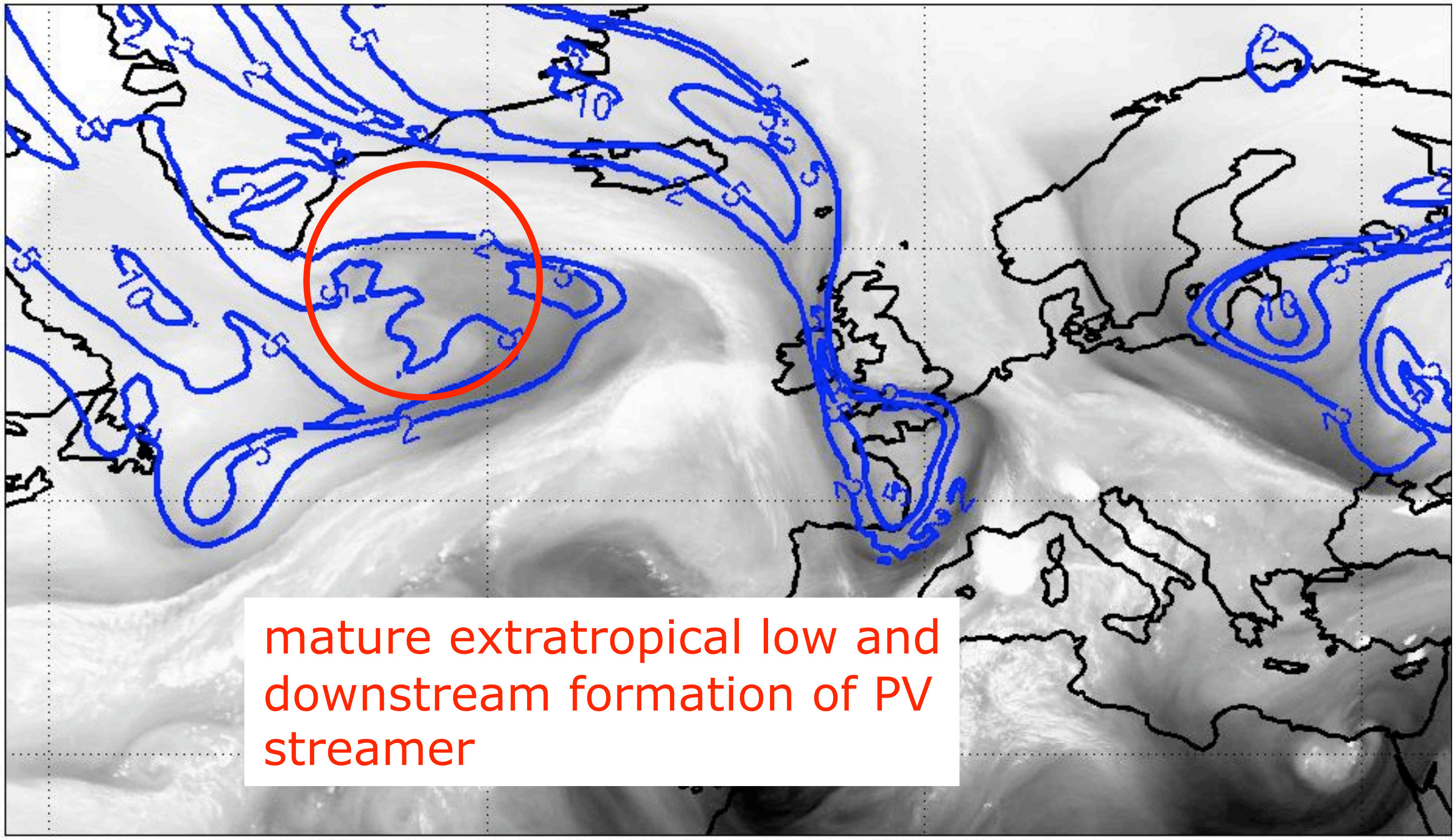


WCB modification of North Atlantic waveguide

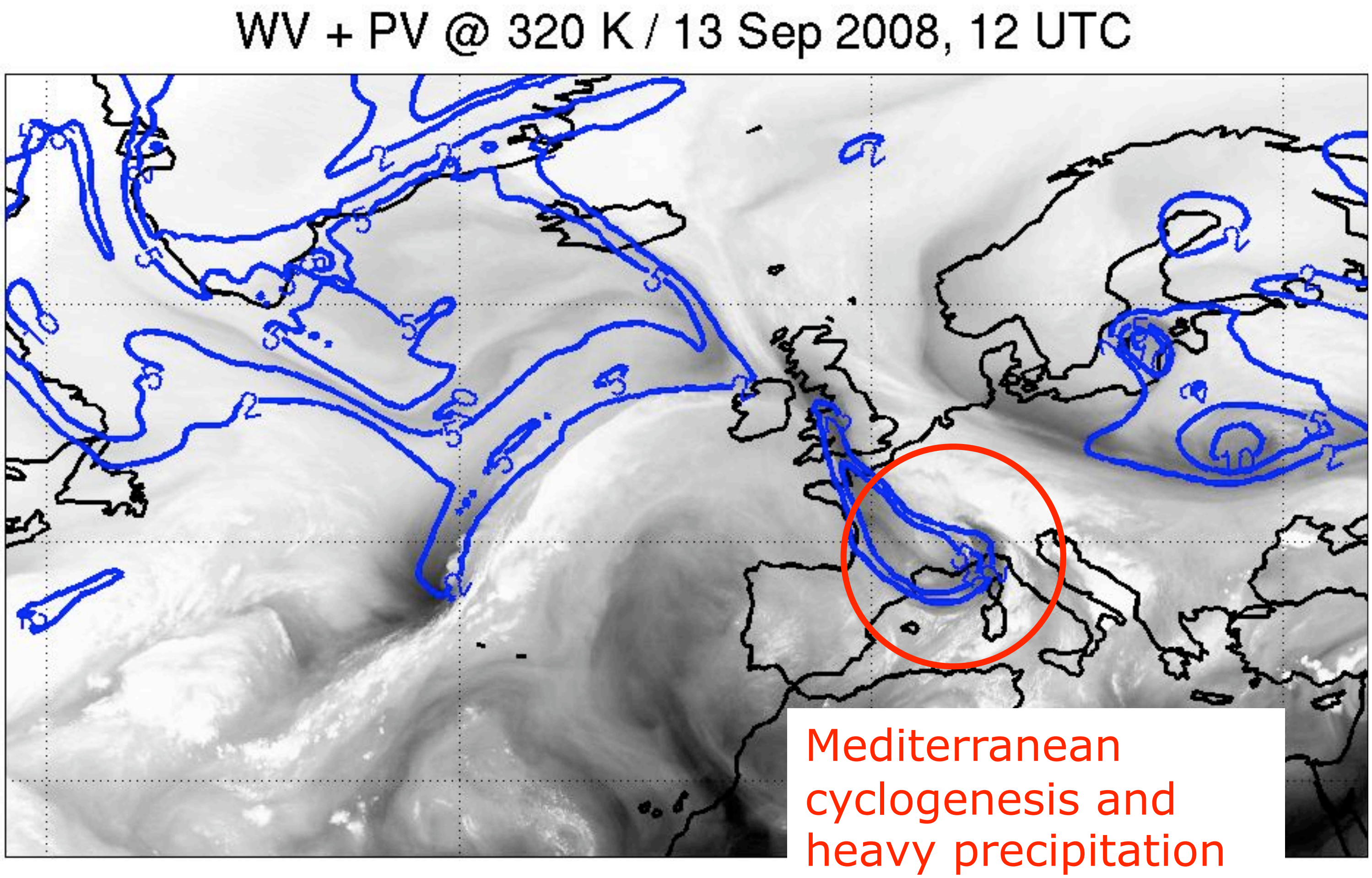


WCB modification of North Atlantic waveguide

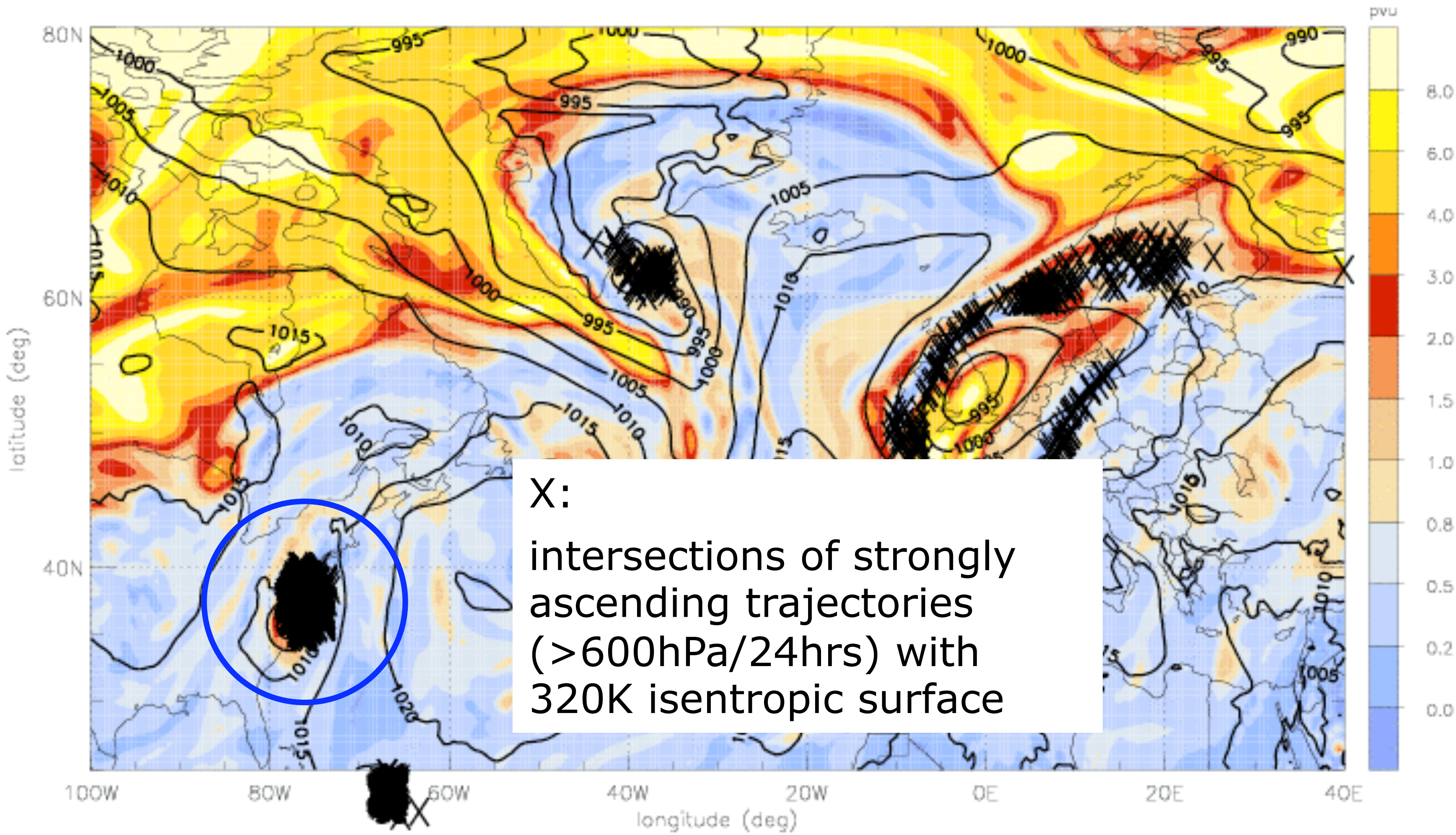
WV + PV @ 320 K / 12 Sep 2008, 12 UTC



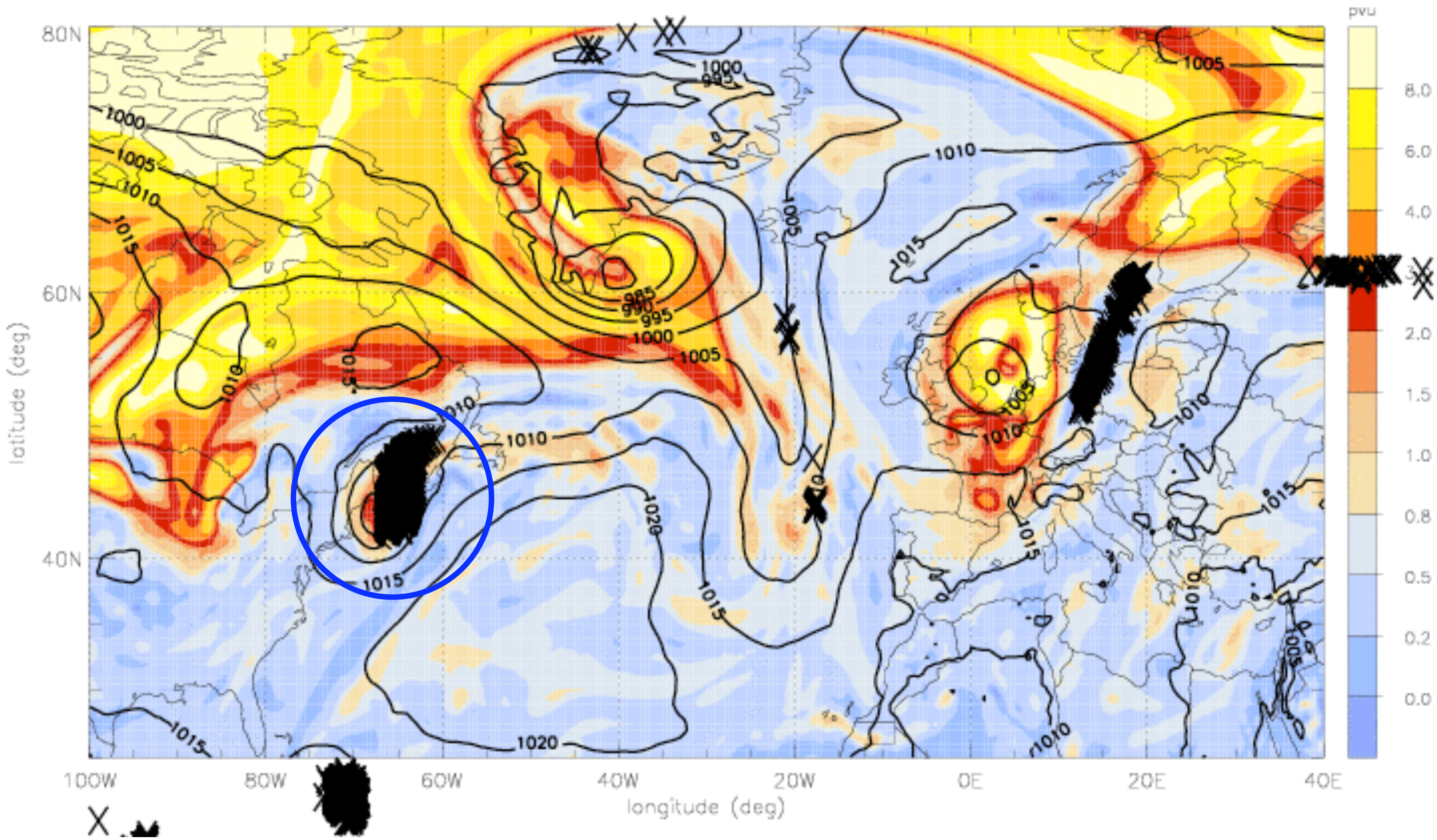
WCB modification of North Atlantic waveguide



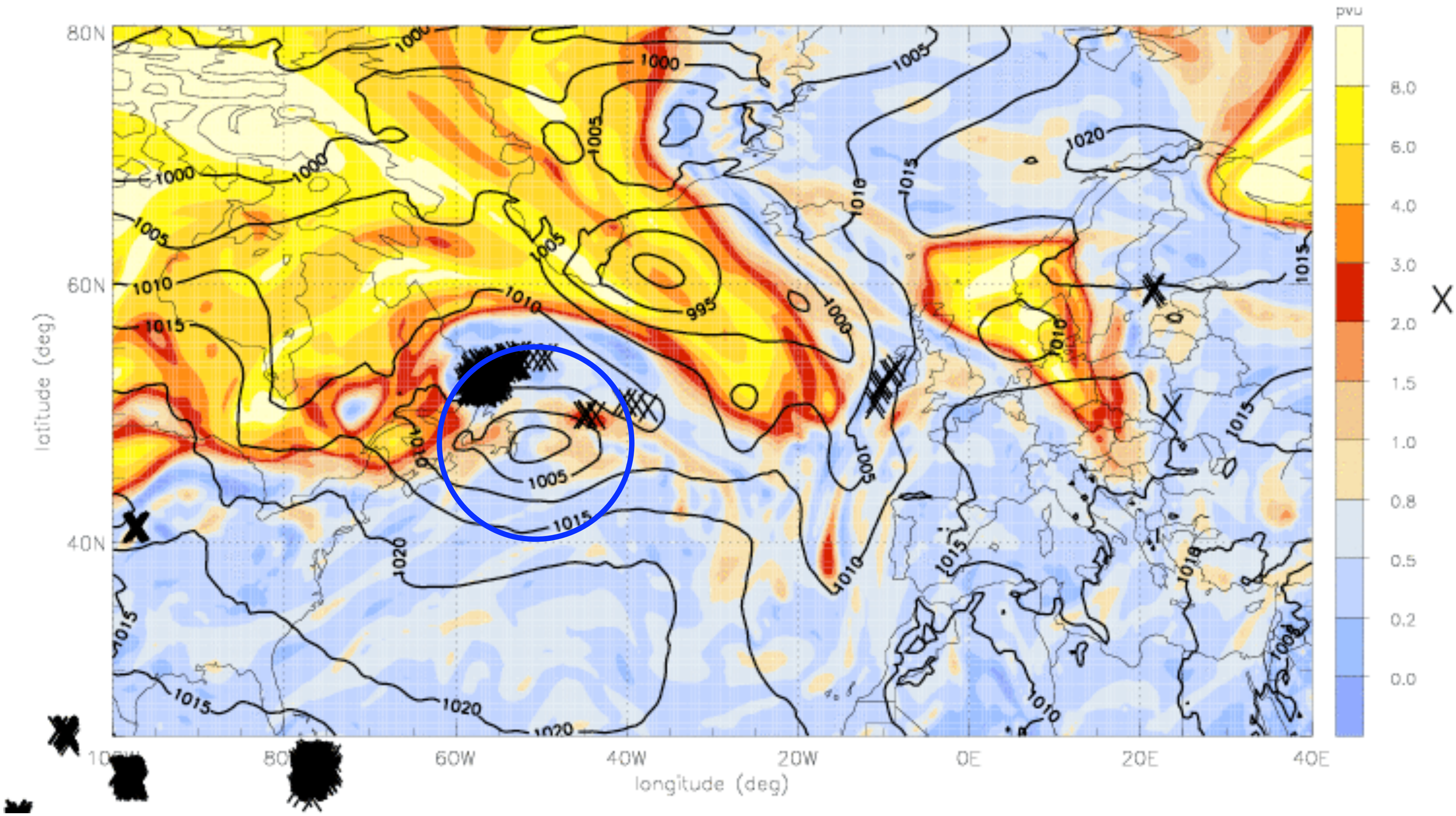
WCB modification of North Atlantic waveguide



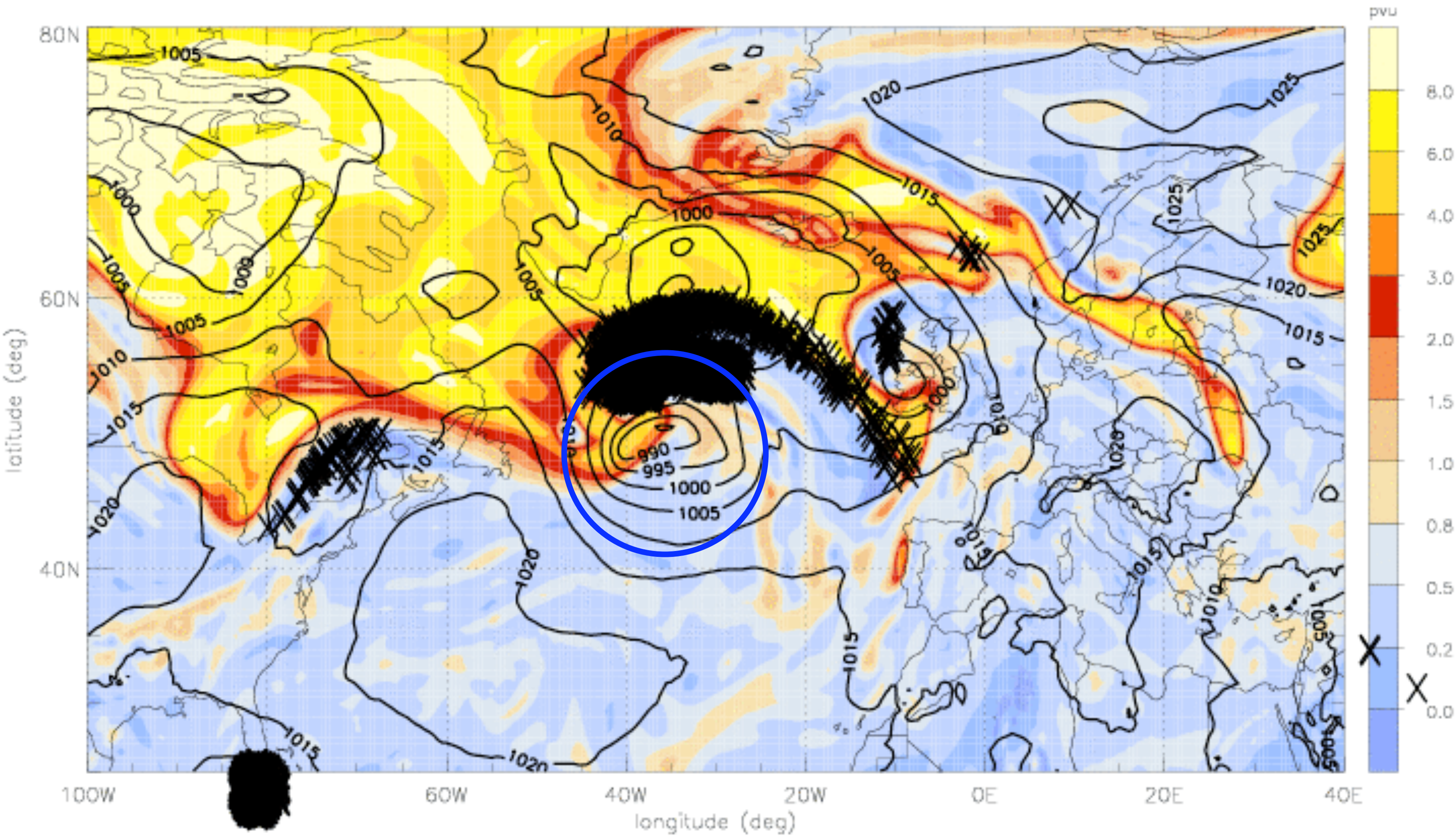
WCB modification of North Atlantic waveguide



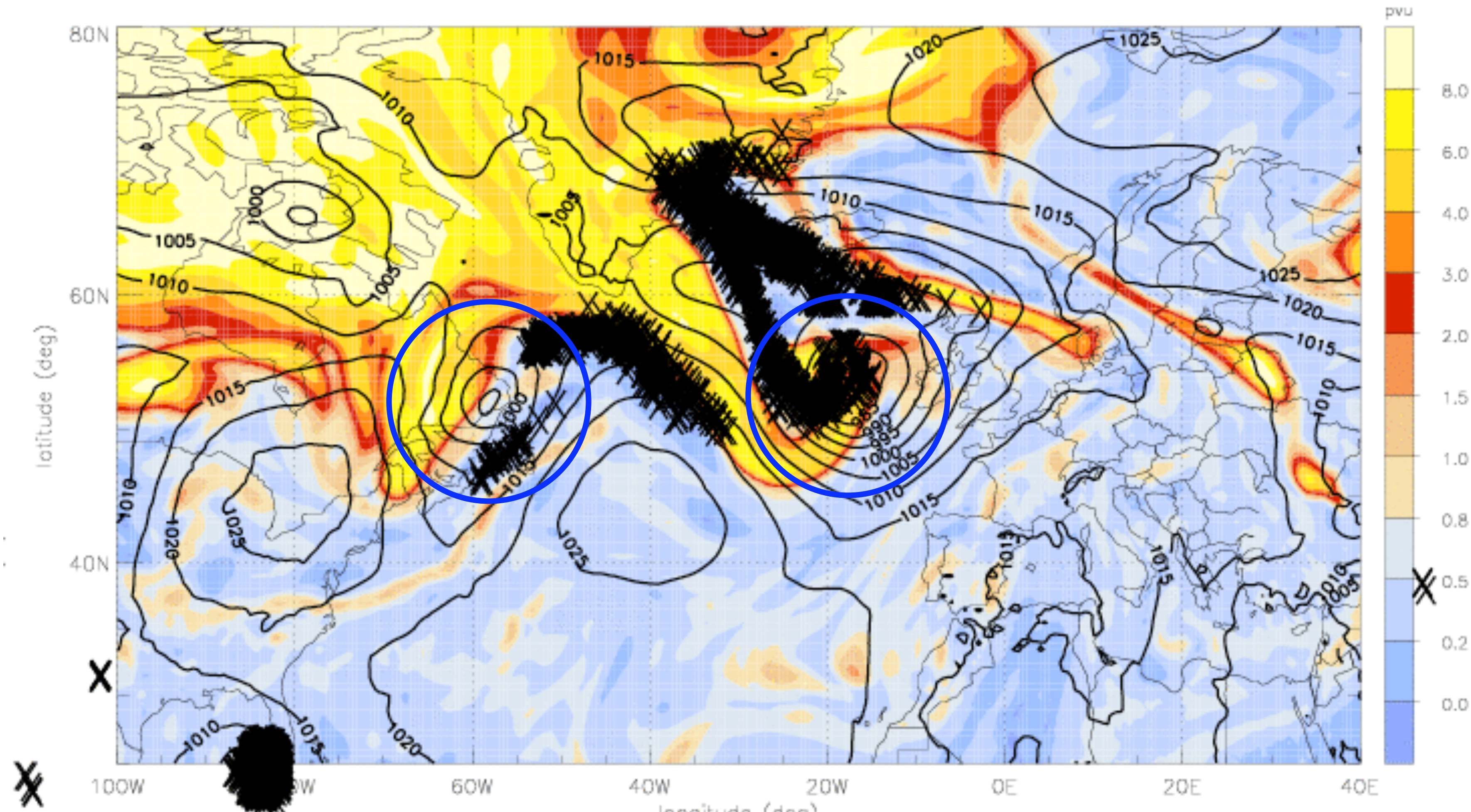
WCB modification of North Atlantic waveguide



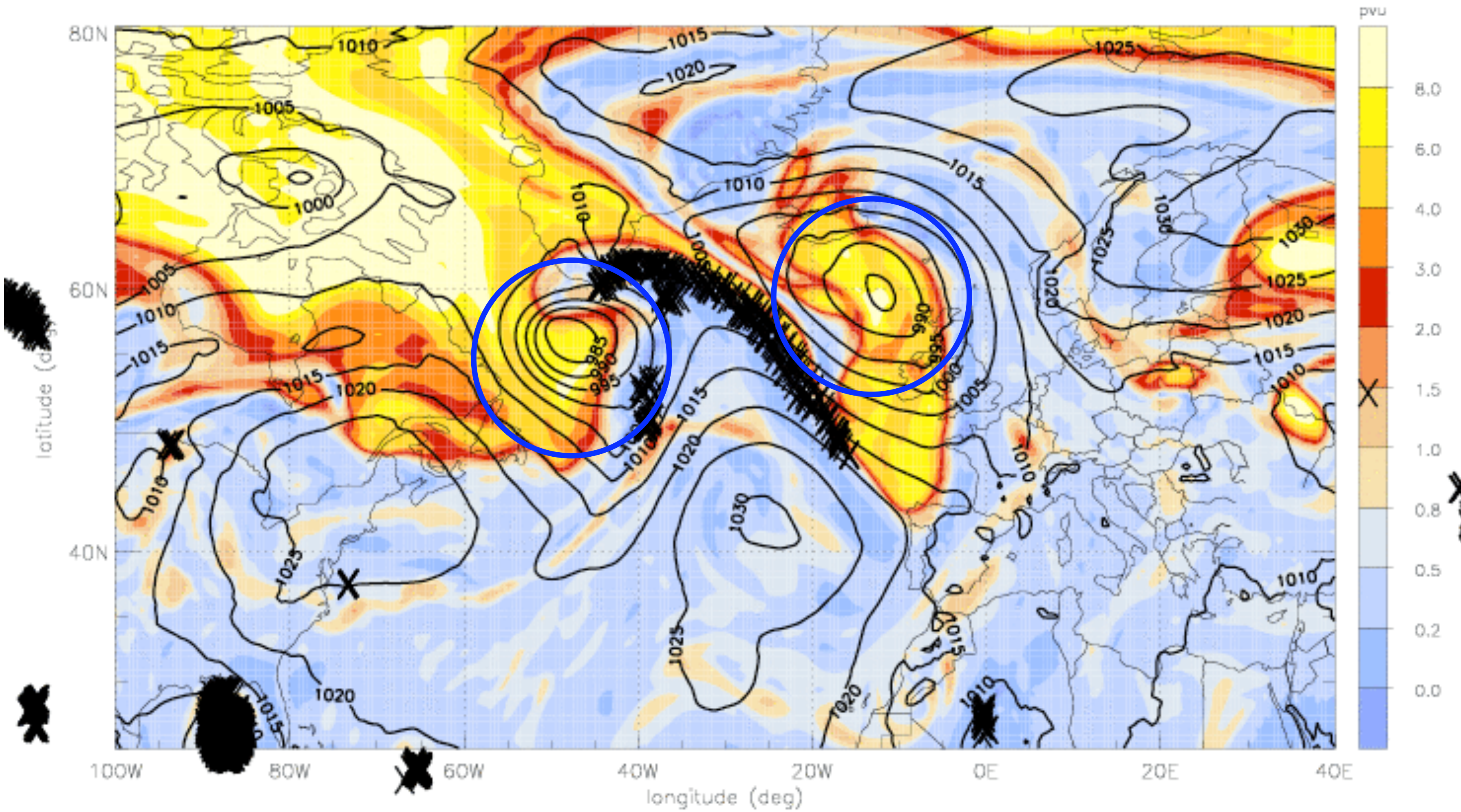
WCB modification of North Atlantic waveguide



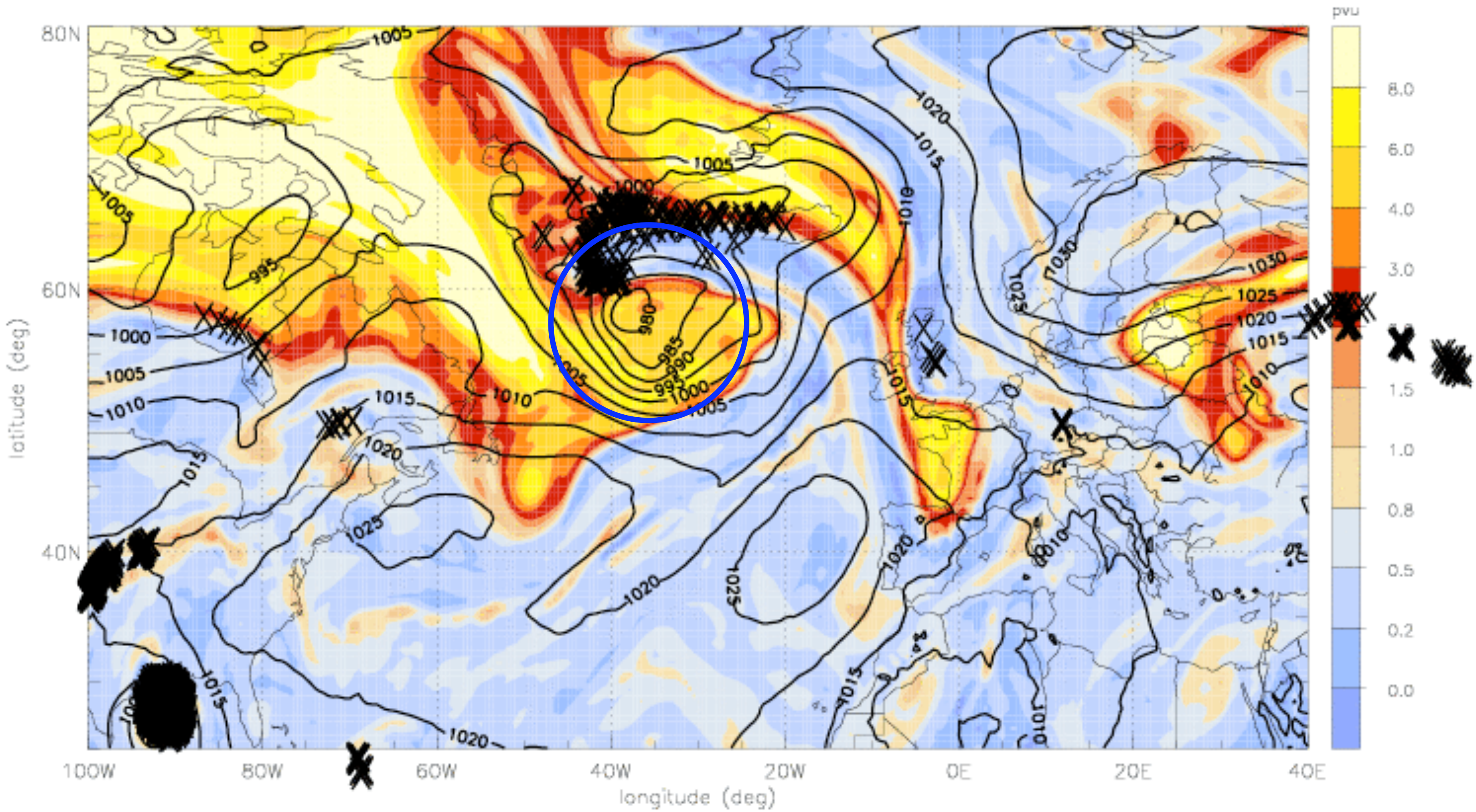
WCB modification of North Atlantic waveguide



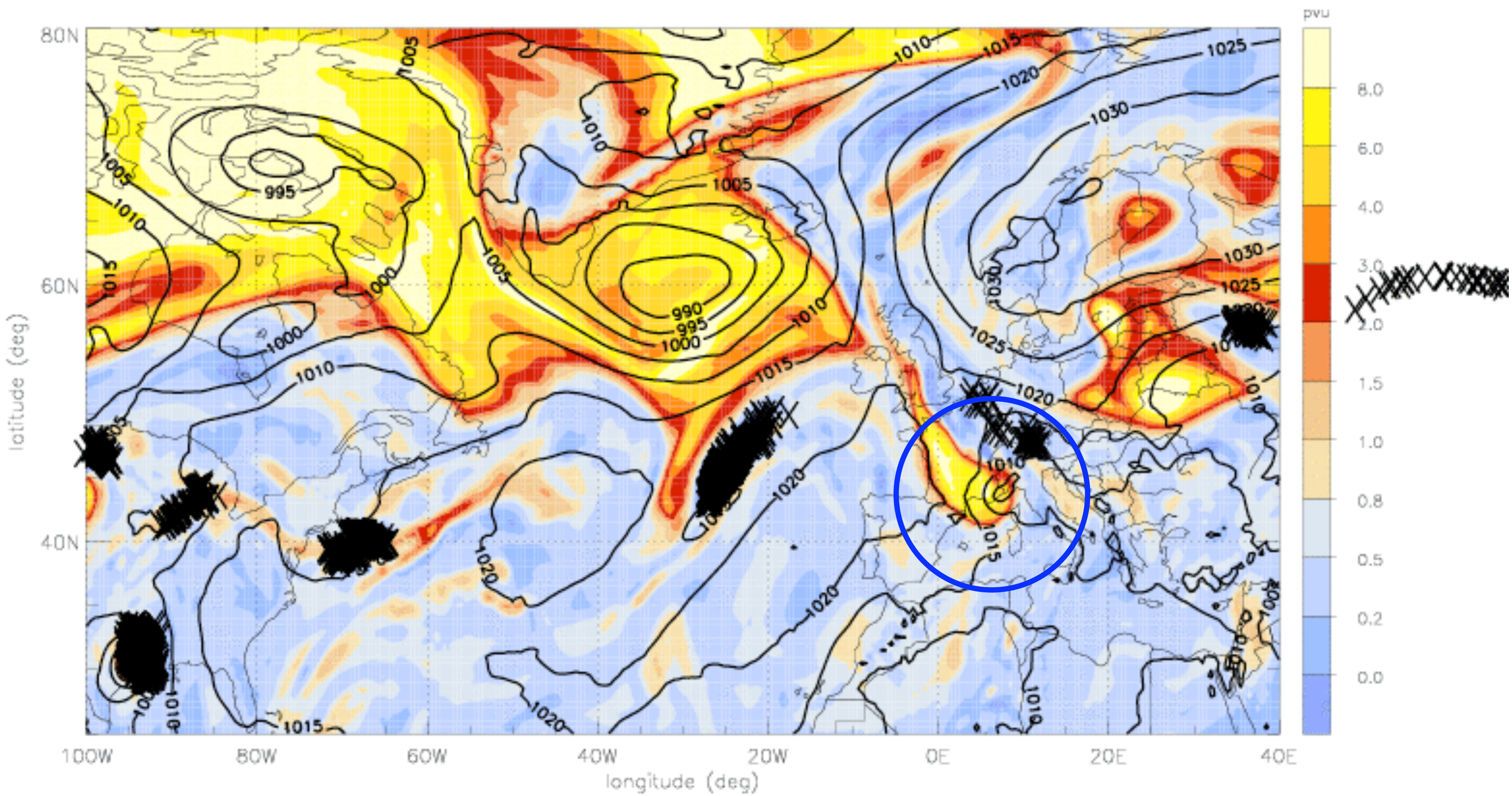
WCB modification of North Atlantic waveguide



WCB modification of North Atlantic waveguide



WCB modification of North Atlantic waveguide



WCB modification of North Atlantic waveguide

September 2008 case study:

- Hurricane “Hanna”
- ET of “Hanna”
- Extratropical cyclogenesis of “Olivia”

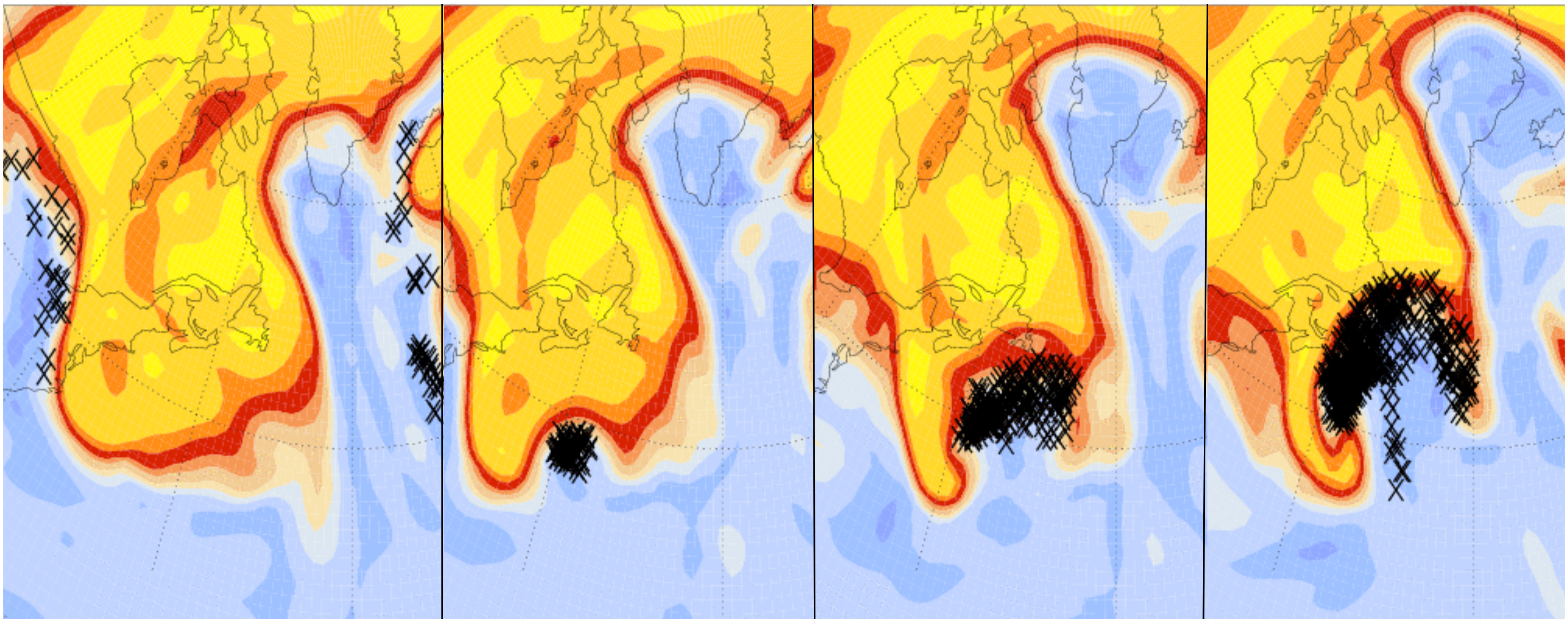
all associated with significant modification of PV pattern on 320K by diabatic processes (cross-isentropic flow)

Claim: diabatic processes contribute to Rossby wave breaking, formation of PV streamer and Mediterranean cyclogenesis

Also: “chain of events” (from ET to Mediterranean storm) develops along PV waveguide

WCB modification of North Atlantic waveguide

Another example: rapid formation of small-scale wave by WCB



0 h **+6 h** **+12 h** **+18 h**

Identification of top-10 Central European forecast busts in ECMWF 5-day forecasts during 2003-2005

based upon simple error measure:
SLP-error = difference in domain-averaged SLP (fc - ana)

domain: Central Europe (0-30E, 45-60N)

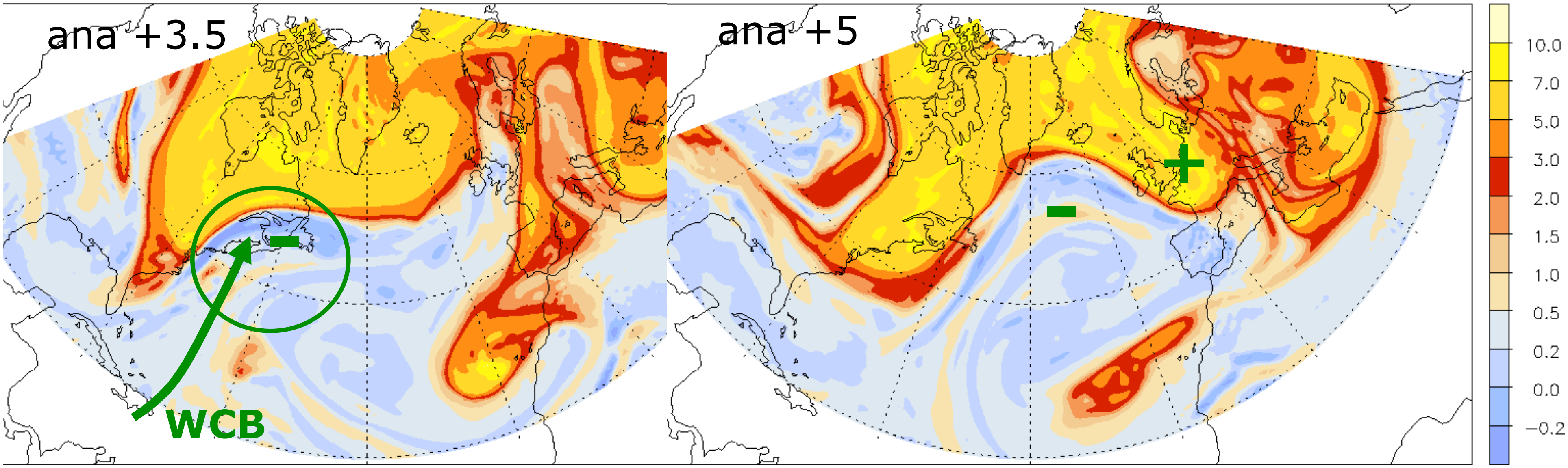
note: This measure does not necessarily identify *severe* weather events over Central Europe - might be “only” shift of high-low SLP pattern.

Identification of top-10 Central European forecast busts in ECMWF 5-day forecasts during 2003-2005

select forecasts with 5 largest positive and 5 largest negative SLP errors over Central Europe

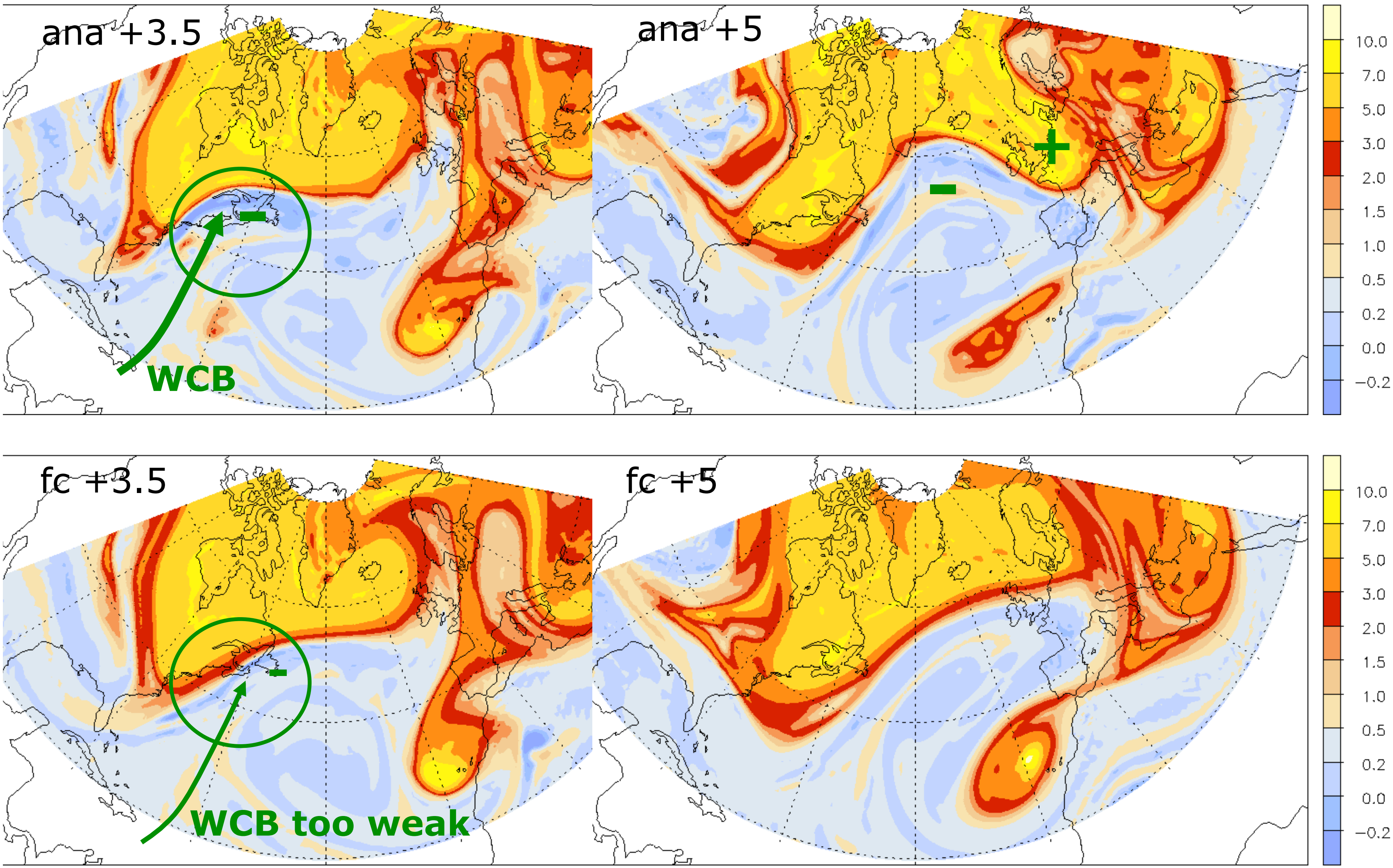
YEAR	MONTH	DAY/HH		
2003	01	26/12	-15.9 hPa	
	02	02/00	-13.4 hPa	
	12	07/12	-13.8 hPa	
	12	27/12	-15.6 hPa	
2004	12	23/12	+15.7 hPa	winter forecasts
2005	01	13/12	+20.1 hPa	
	01	14/00	+17.6 hPa	
	02	08/12	+18.1 hPa	
	02	09/00	+18.2 hPa	
	10	21/12	-14.0 hPa	ET of “Wilma”

Warm conveyor belts & forecast busts



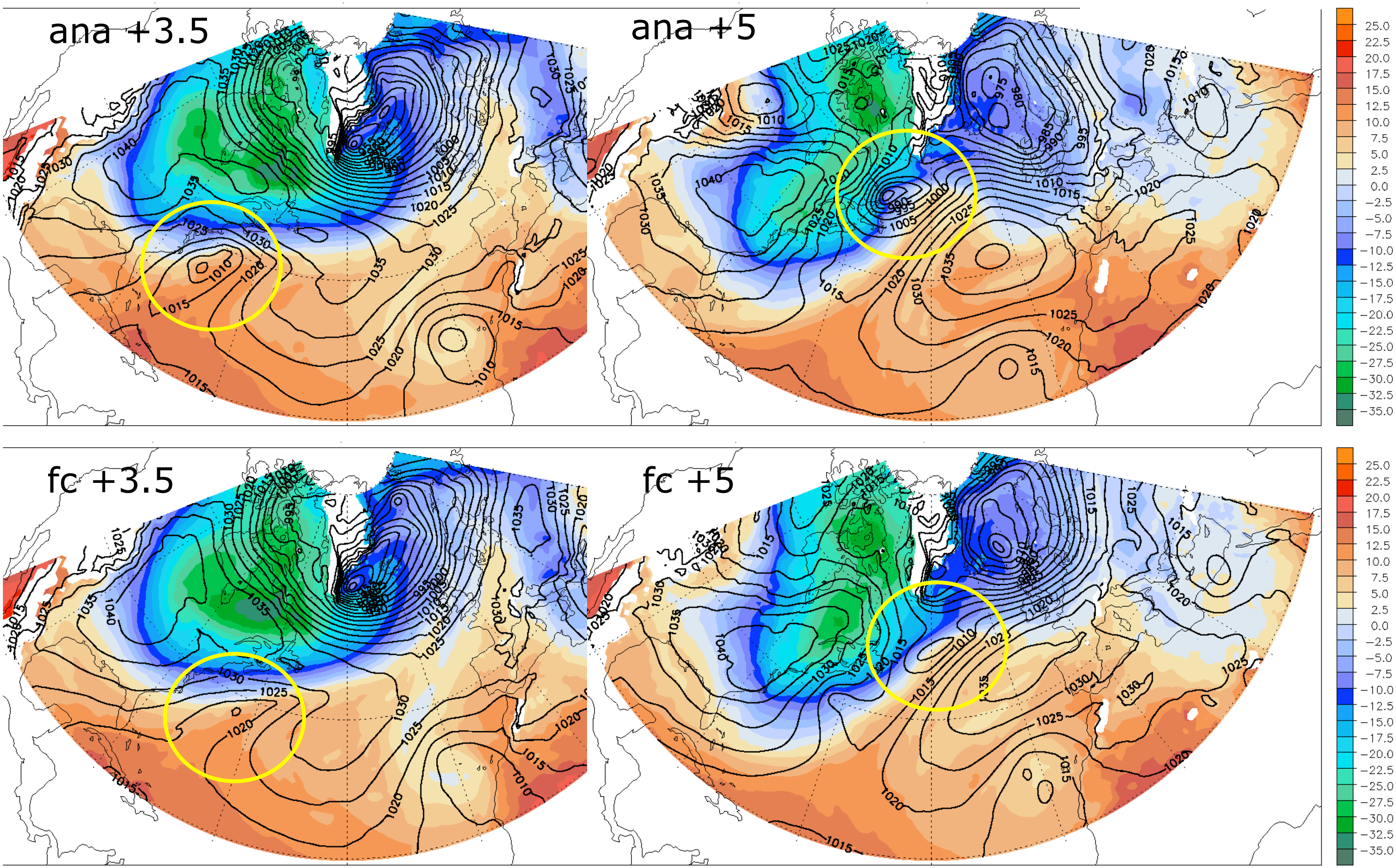
PV on 320 K

Warm conveyor belts & forecast busts



Warm conveyor belts & forecast busts

T850 and SLP



Forecast busts: common dynamical pattern?

In all cases: forecasts have too weak UT ridges (not broad enough, PV values not low enough)

Backward trajectory analysis of these UT ridges, look for “WCB-like ascent” into ridges (criterion $\Delta\theta > 15K$)

			# of “WCB-like” trajectories	
			ana	fc
2003	01	26/12	64	31
	02	02/00	19	5
	12	07/12	164	134
2004	12	23/12	291	152
2005	01	13/12	115	2
	02	08/12	45	0
	10	21/12	31	14

Forecast busts: common dynamical pattern?

In all cases: forecasts have too weak UT ridges (not broad enough, PV values not low enough)

Backward trajectory analysis of these UT ridges, look for “WCB-like ascent” into ridges (criterion $\Delta\theta > 15K$)

			ana	fc
2003	01	26/12	64	31
	02	02/00	19	5
	12	07/12	164	134
2004	12	23/12	291	152
2005	01	13/12	115	2
	02	08/12	45	0
	10	21/12	31	14

Hypothesis: forecast busts have too weak WCBs over North Atlantic $\Rightarrow$ too weak UT ridges $\Rightarrow$ wrong/too weak downstream development $\Rightarrow$ wrong phase of UT trough/ridge pattern over CE

What leads to too weak WCB activity in forecasts?

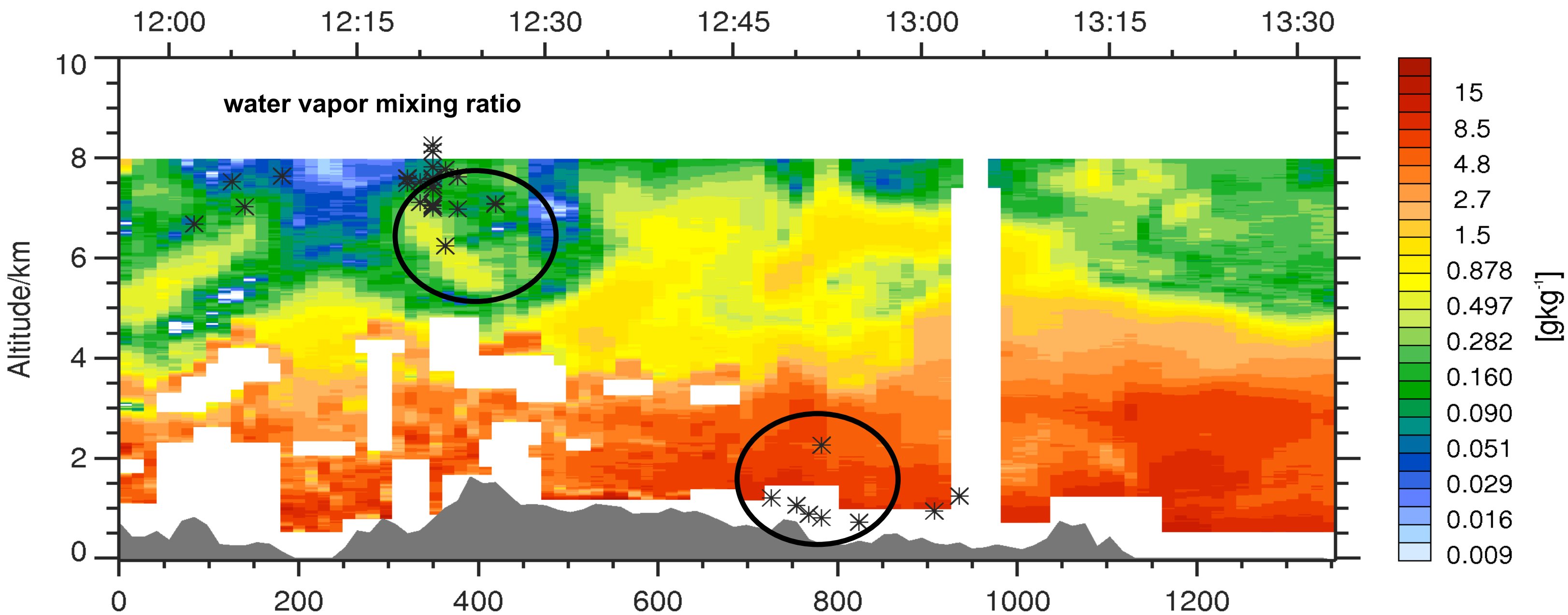
Missing low-level moisture?

Compare specific humidity in origin region of WCBs in analyses:

Case	q0 [g/kg] ana	fc
1	8.5	8.6
2	8.2	6.5
3	7.5	7.6
4	8.9	8.5
5	7.5	7.7
6	5.5	6.4
7	13.1	13.2

no systematic error in
low-level moisture!

Lidar observations of WCBs



Example from COPS July 2007

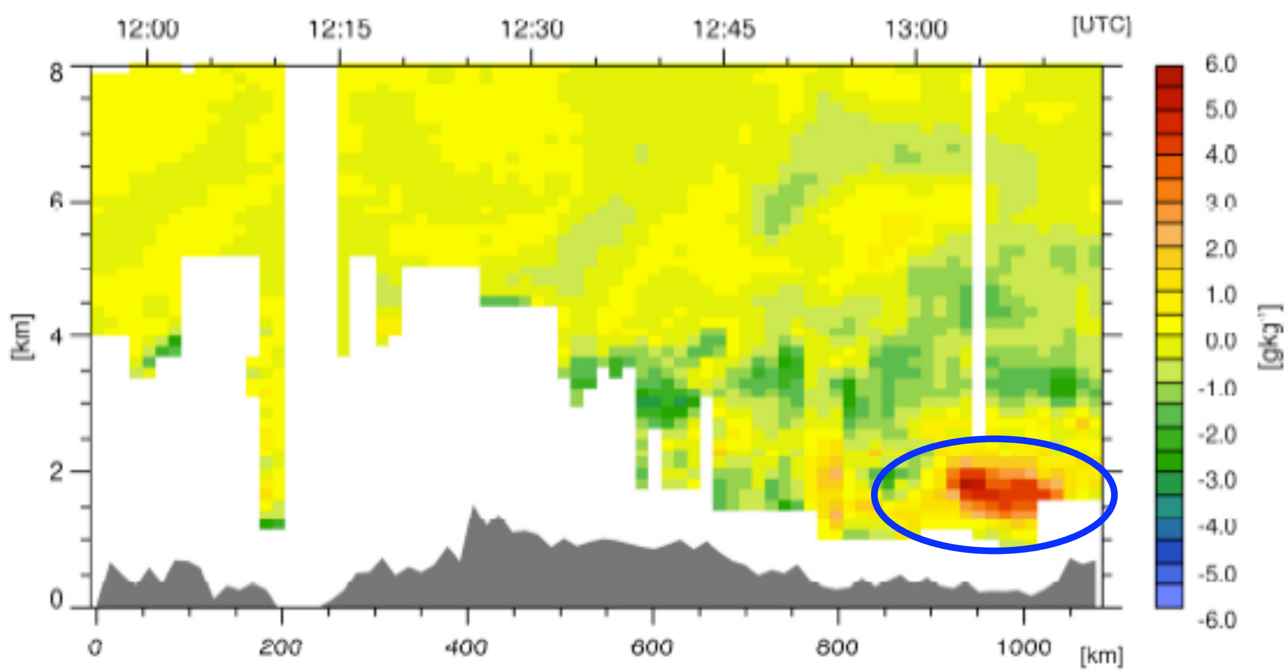
- 2 main WCB crossings with the lidar section
- boundary layer measurements of rising air parcels (700 - 2500 m)
- WCB crossings in the upper troposphere (7 -8 km): 2 days after the ascent

from Andreas Schäfler

Lidar observations of WCBs

Questions:

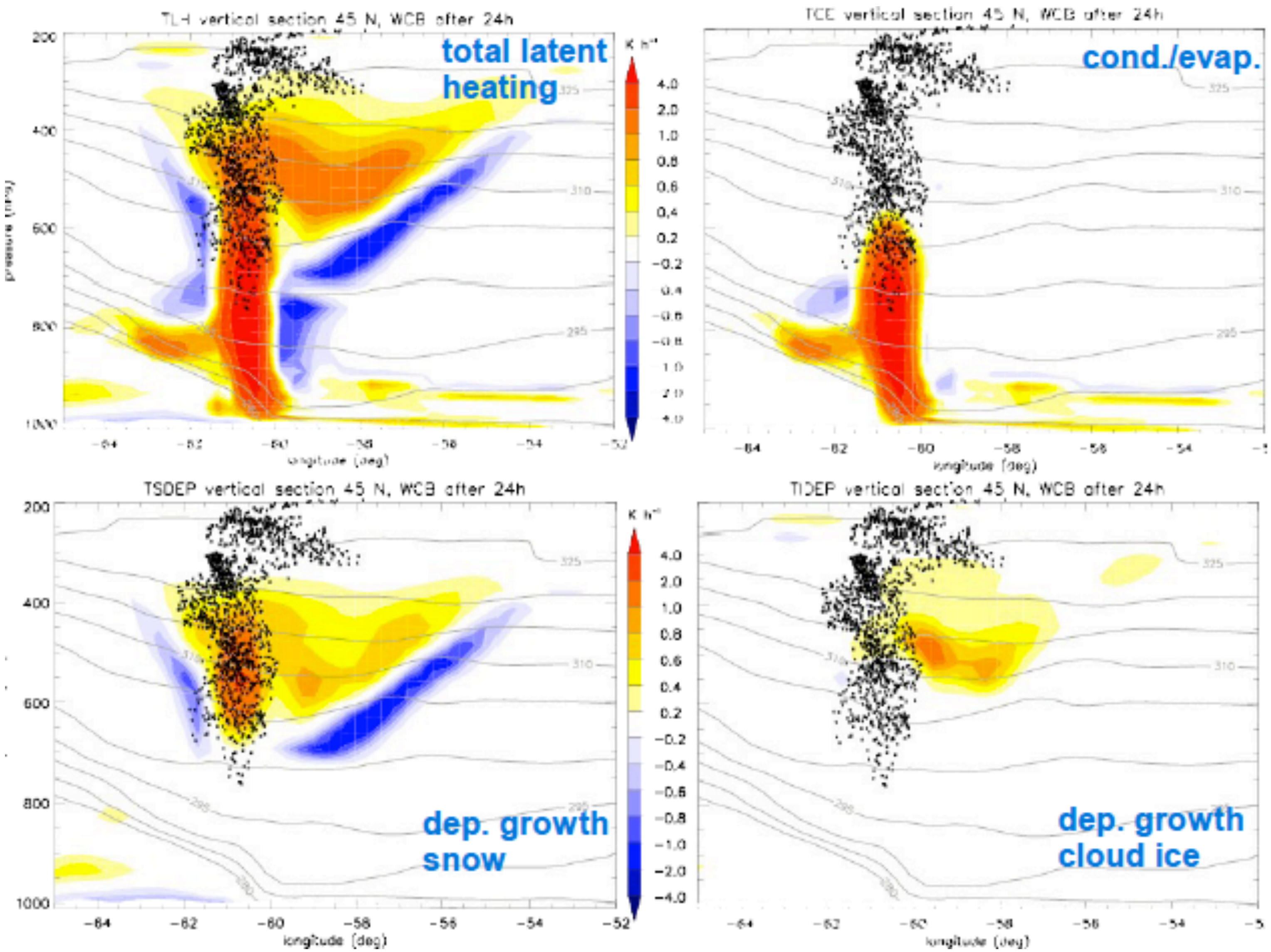
- How accurate are analyses / forecasts in WCB inflow & outflow regions?
- How relevant are errors for prediction of downstream flow evolution?



significant analysis error in WCB inflow region

from Andreas Schäfler

Cloud physics and PV evolution in WCBs

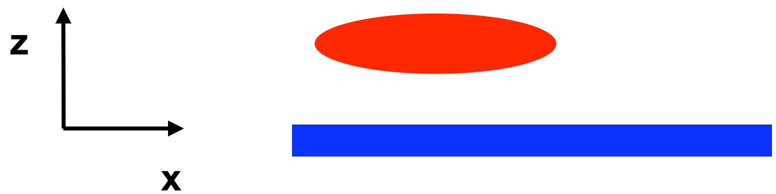


from Hanna Joos

Diabatic Rossby Waves

The mechanism

Schematic vertical cross-section along baroclinic zone:



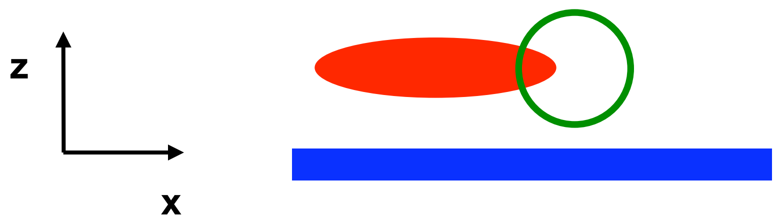
Low-level positive PV-anomaly over baroclinic zone

Snyder and Lindzen 1991 (JAS)
Parker and Thorpe 1995 (JAS)

Diabatic Rossby Waves

The mechanism

Schematic vertical cross-section along baroclinic zone:



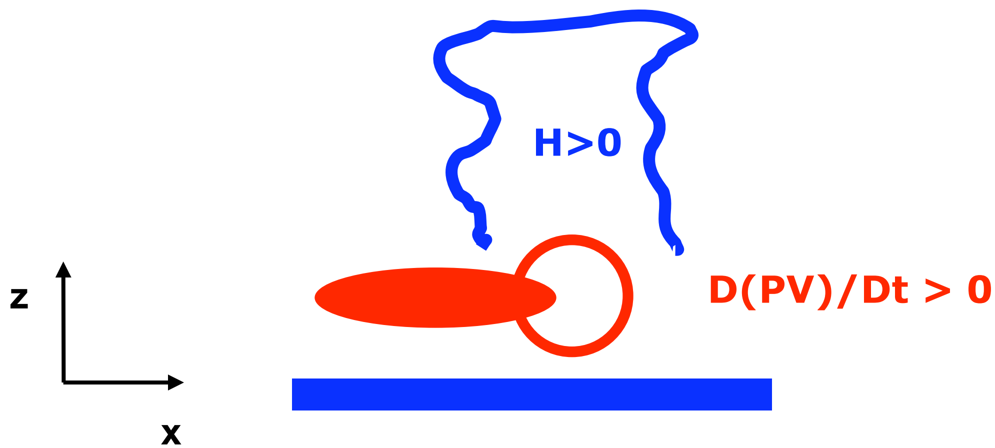
Low-level positive PV-anomaly over baroclinic zone

Poleward ascending jet of warm & moist air

Diabatic Rossby Waves

The mechanism

Schematic vertical cross-section along baroclinic zone:



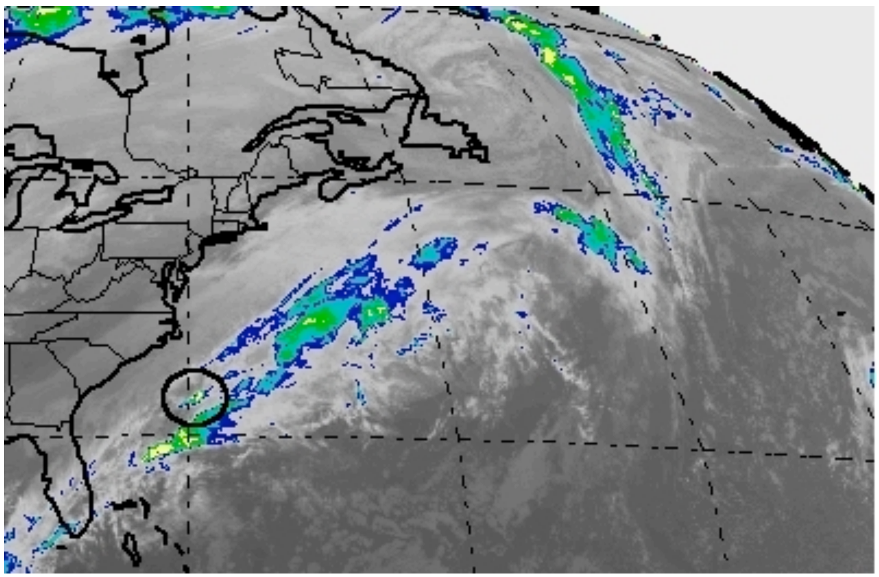
Low-level positive PV-anomaly over baroclinic zone

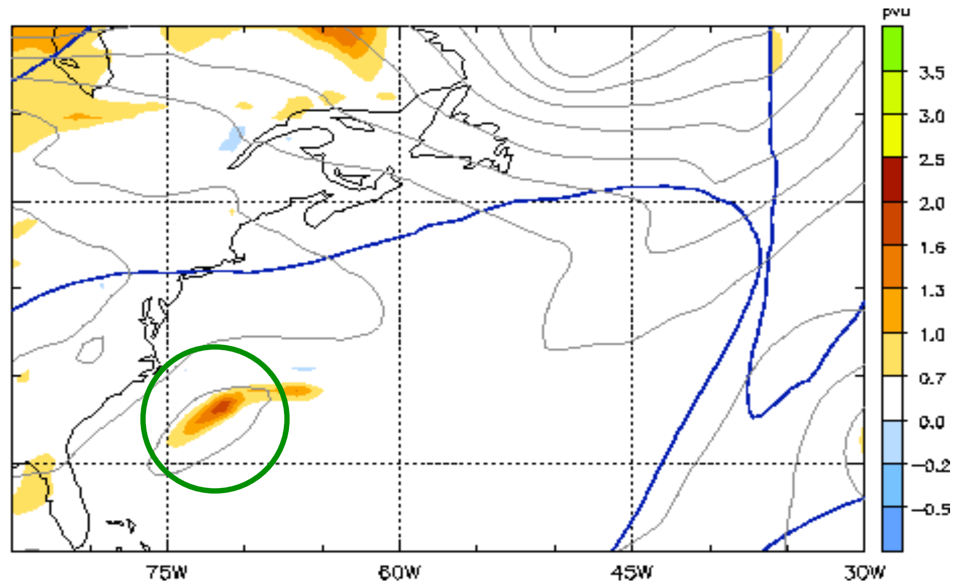
Poleward ascending jet of warm air

Diabatic heating → PV production downstream of PV vortex

Diabatic Rossby waves

18 Dec 2005 18 UTC





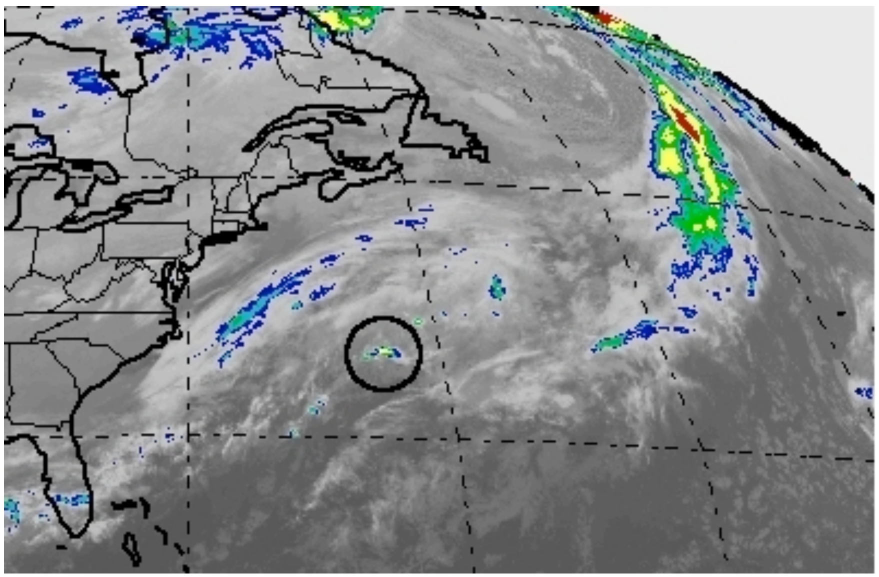
GOES IR satellite image

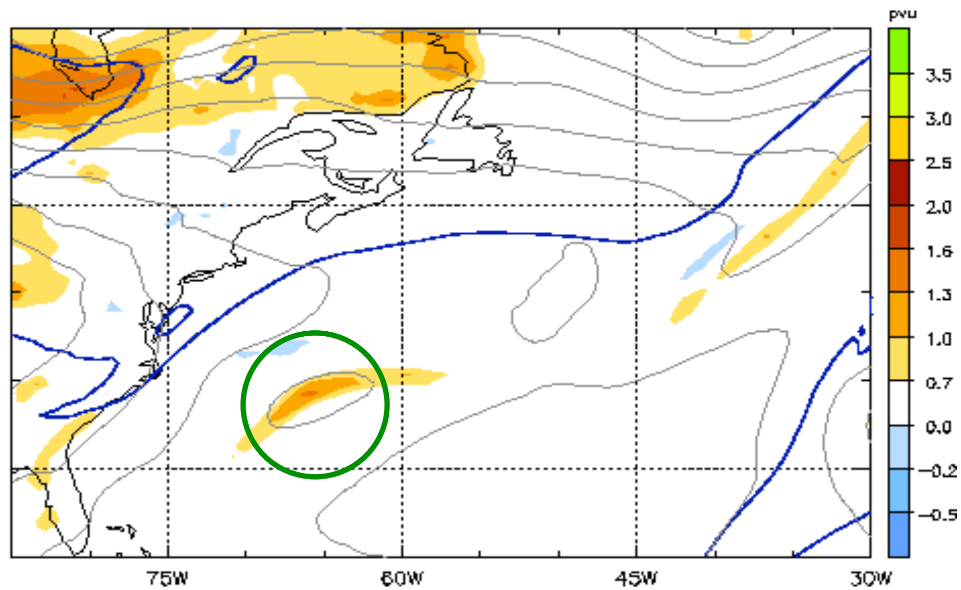
ECMWF analysis:
PV mean 975-800hPa (colors)
SLP contours

Böttcher and Wernli
(MWR, submitted)

DRW case study Dec 2005

19 Dec 2005 12 UTC



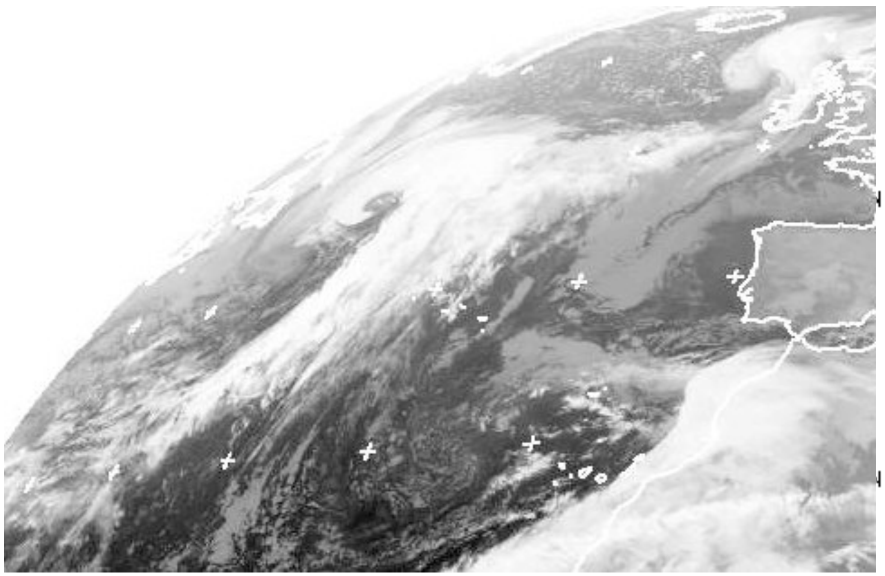


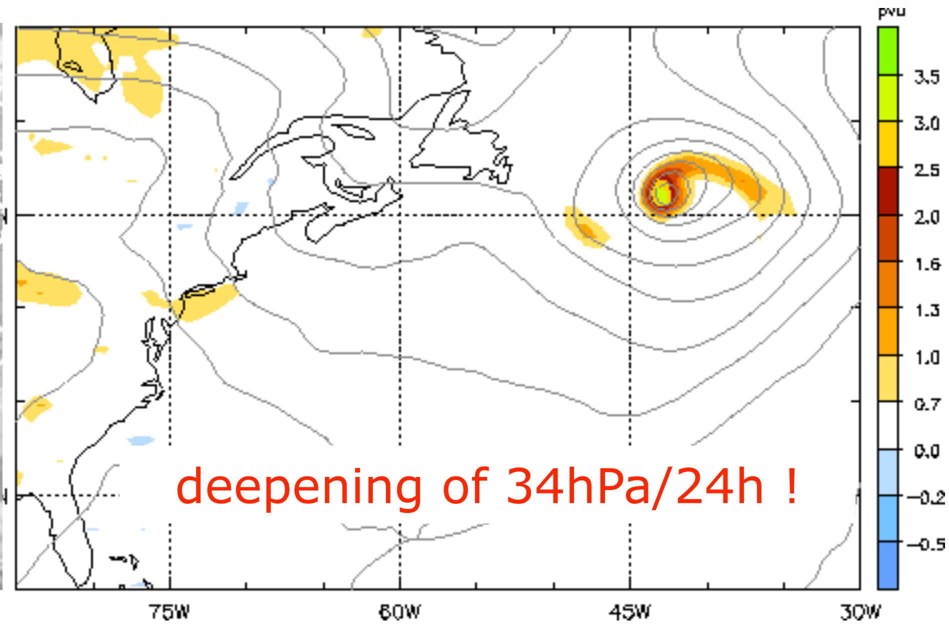
ECMWF analysis:
PV mean 975-800hPa (colors)
SLP contours

Böttcher and Wernli
(MWR, submitted)

DRW case study Dec 2005

20 Dec 2005 12 UTC

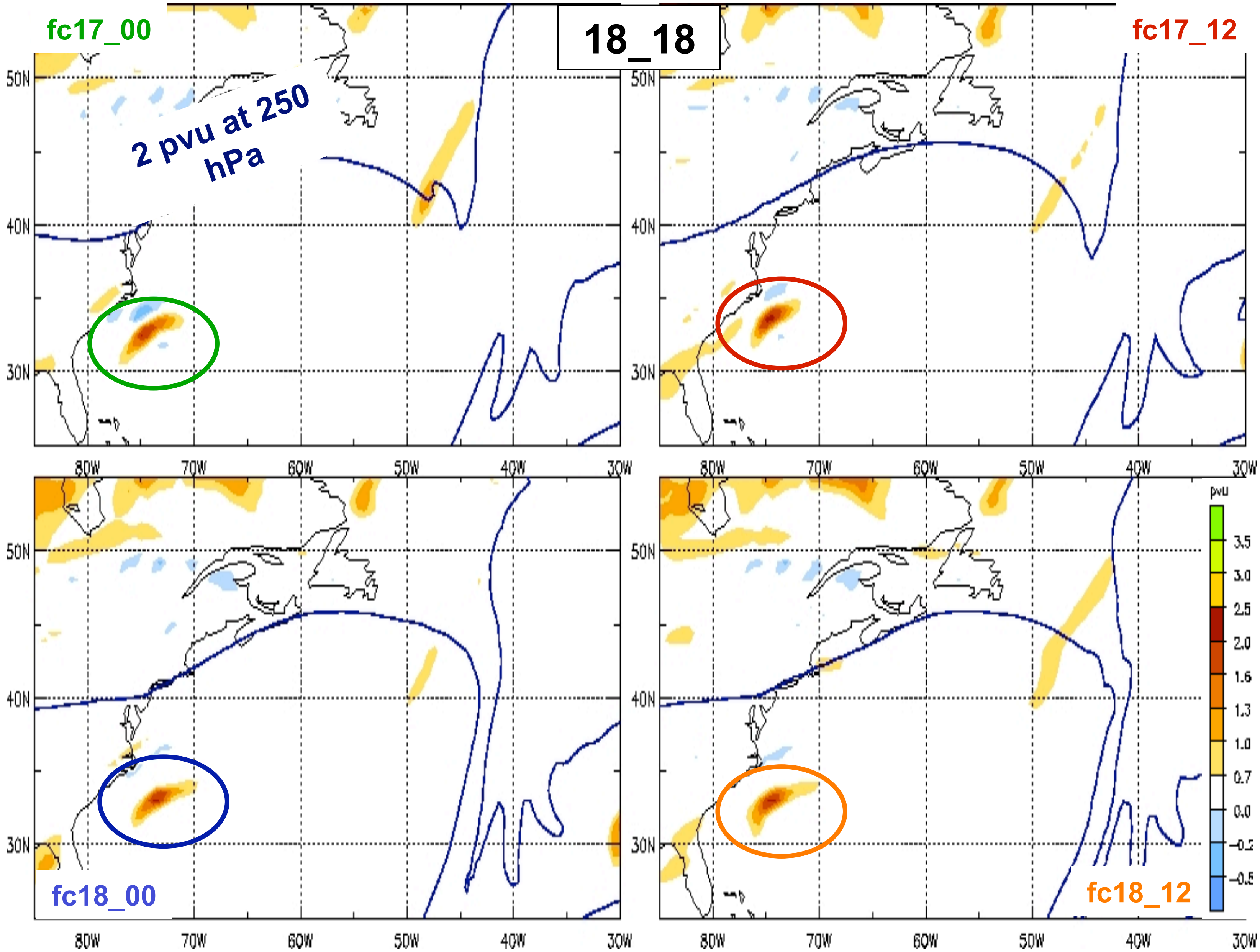




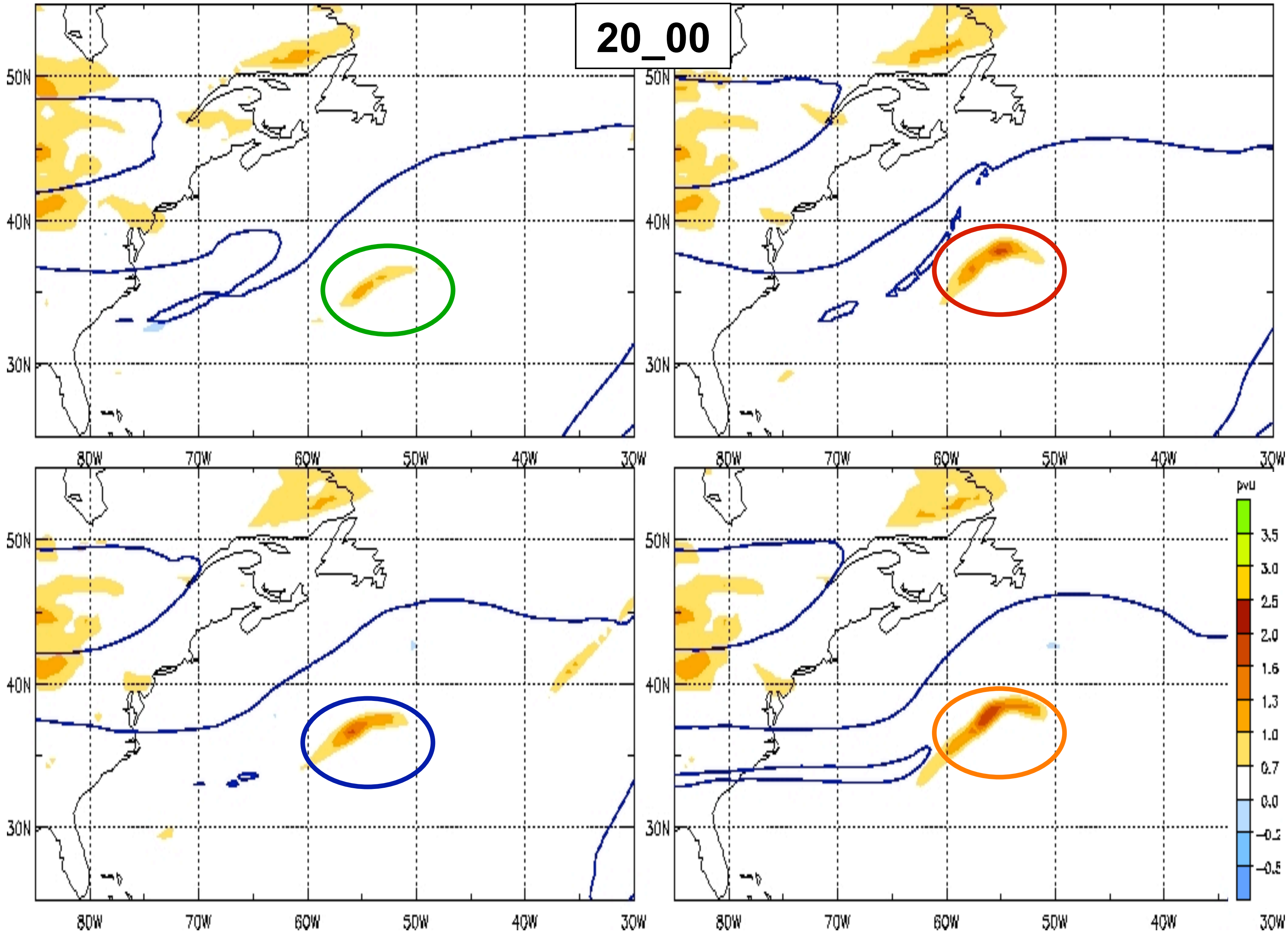
ECMWF analysis:
PV mean 975-800hPa (colors)
SLP contours

Böttcher and Wernli
(MWR, submitted)

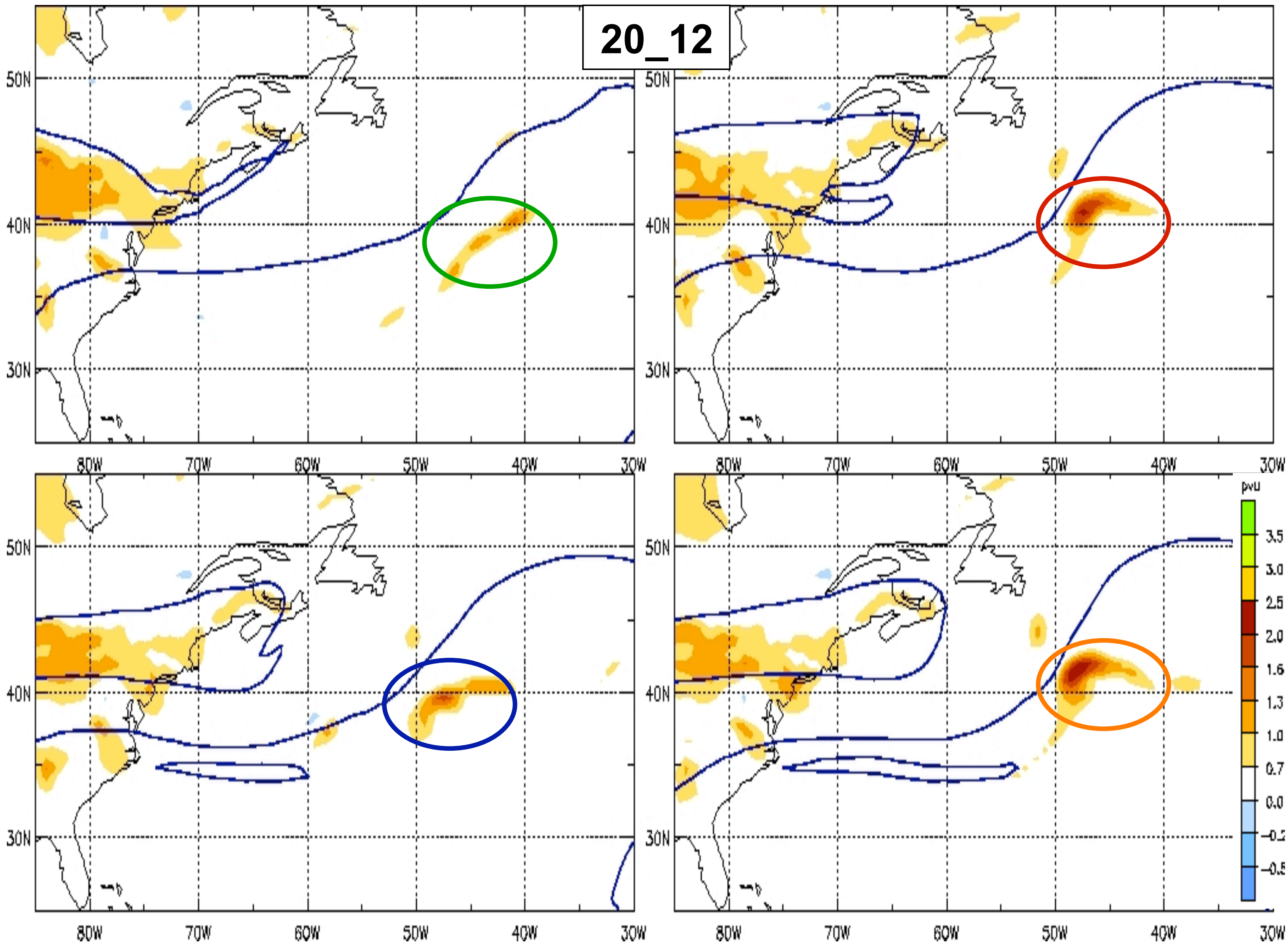
DRW case study: significant medium-range fc errors



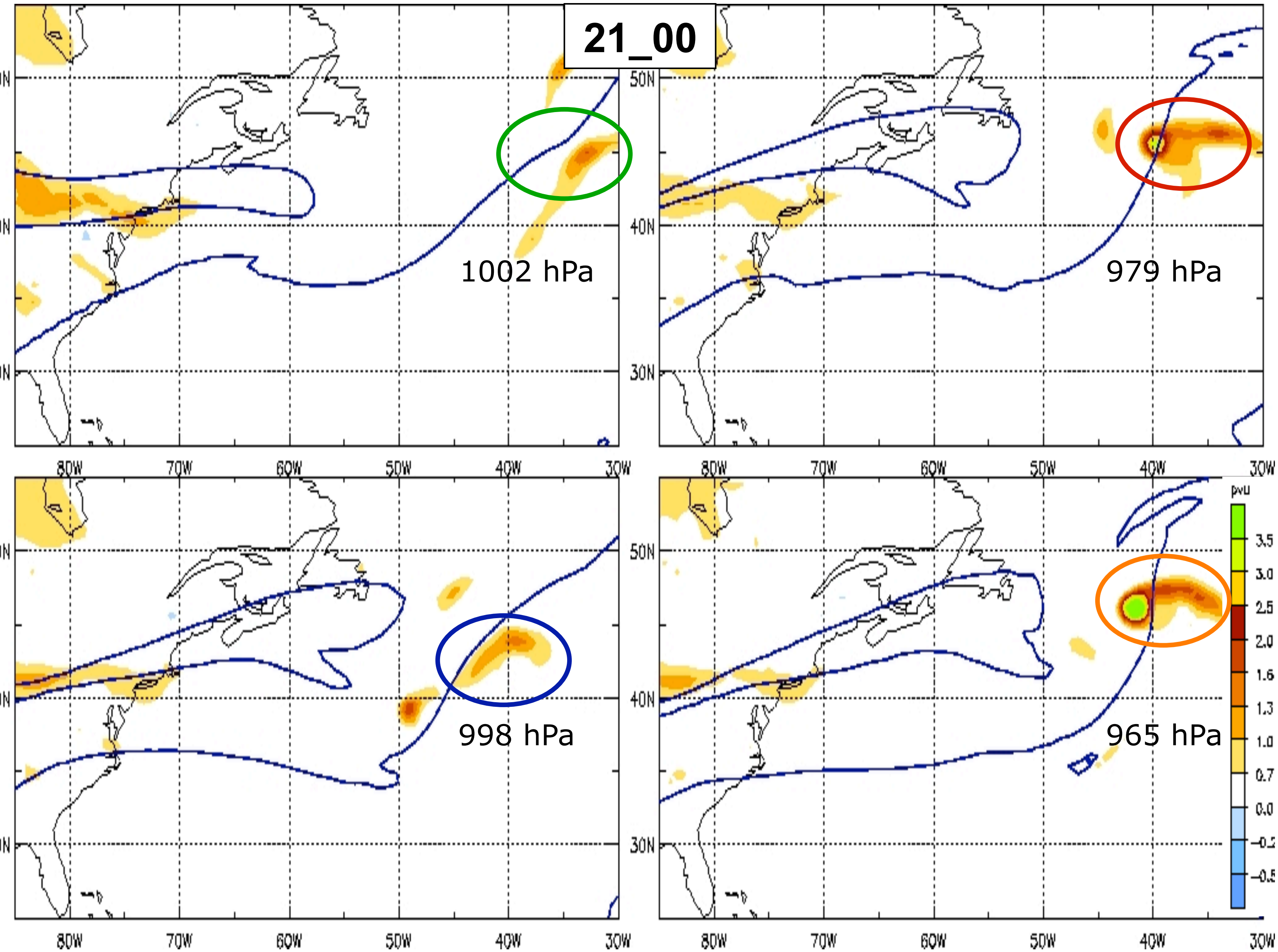
DRW case study: significant medium-range fc errors



DRW case study: significant medium-range fc errors



DRW case study: significant medium-range fc errors



Questions for future research

Relative importance of different types of waveguide disturbances?

Fundamental processes associated with generation of disturbances and their downstream evolution?

Representation of waveguide and evolving disturbances in NWP analysis and forecasts?

Reasons for potential analysis and forecast errors?

THORPEX

Suggestions for the way forward

Combined theoretical / diagnostic / modeling & experimental research initiatives on national and international level, e.g.,

- research based upon existing datasets (T-PARC, YOTC, TIGGE, …)

- T-NAWDEX initiative (2010-2015) with field experiment(s) in 2012/2013(?) and strong diagnostic / modeling components in the pre- and post-field phase

- close collaboration between NWP community (e.g., WGNE) and dynamics community (e.g., THORPEX PDP Working Group)

WMO
OMM

T-NAWDEX

THORPEX – North Atlantic Waveguide and Downstream Impact Experiment

Proposed at European THORPEX meeting by PDP Working Group in 2006

Strong interest from UK, France, Germany, Switzerland, Norway, Canada, USA, ...

Science focus on diabatic effects on North Atlantic weather systems (dynamics and predictive skill)

Funding (so far) mainly on national level:
- UK: project DIAMET (Vaughan, Methven, Parker, Renfrew et al.)
- Germany: HALO THORPEX demo mission (Dörnbrack et al.)
- Germany: PANDOWAE research group (Jones et al.)
- Switzerland: ETH contribution (Wernli et al.)

T-NAWDEX pilot flights from the UK

NERC has funded 20 flight hours in late 2009, for investigating:

1. Warm conveyor belt of system approaching UK over ocean
   - Transect with dropsondes, then stepping downwards through region of heating, moving towards inflow of WCB.
   - Aiming to **infer latent heating rates** using Lagrangian analysis of detailed temperature + water (all phases) observations.
2. Diabatic development of low level cyclone (under jet exit or DRW)
   - Transects between cold & warm sector within boundary layer measuring turbulent fluxes.
   - Aiming to **infer moisture budget** across low level domain.
3. Mixing at fronts by turbulence and slantwise convection
   - Regions with strong diabatic activity (e.g., bent-back warm fronts)
   - Aiming to **sample variability in mixing** phenomena.

HALO - High Altitude and Long Range Research Aircraft

Oberpfaffenhofen, Germany, 24 January 2009

Key specifications:

- max. altitude more than 15 km
- range well above 10000 km or more than 10 flight hours
- maximum payload of 3 tons

Demo-Mission HALO-THORPEX as nucleus for
T-NAWDEX field phase

Summary

Weather systems in the North Atlantic / European sector develop along upper-level PV waveguide

Waveguide can be disturbed, e.g., by

- stratospheric PV anomalies
- diabatic PV modifications associated with WCBs
- inter-level interactions with low-level PV anomalies (e.g., DRWs)

In some cases: significant forecast errors associated with diabatic PV modifications (WCBs, DRWs, …)

T-NAWDEX will address key questions related to diabatic effects on evolution of North Atlantic weather systems and their representation in models

Contributions to T-NAWDEX are welcome!
(Theoretical / diagnostic studies, field experiment)

Thank you for your attention !