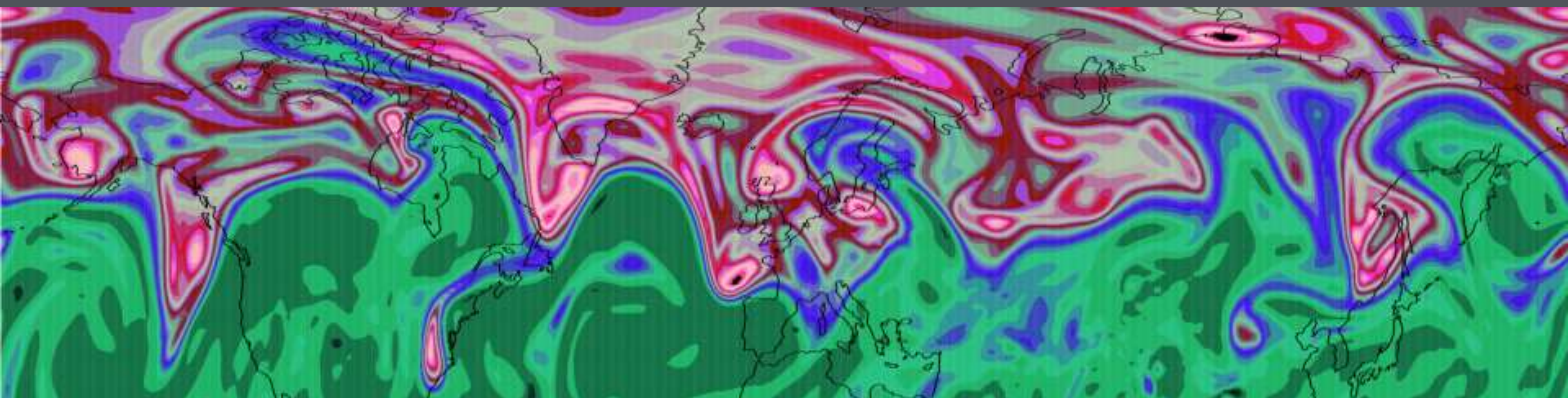
Department of Meteorology

Ramifications of observed tropopause errors (learning from NAWDEX)



John Methven, Ben Harvey, Leo Saffin and Sue Gray

Department of Meteorology, University of Reading

Andreas Schäfler, DLR

Claudio Sanchez, Met Office

Talk Outline

University of Reading

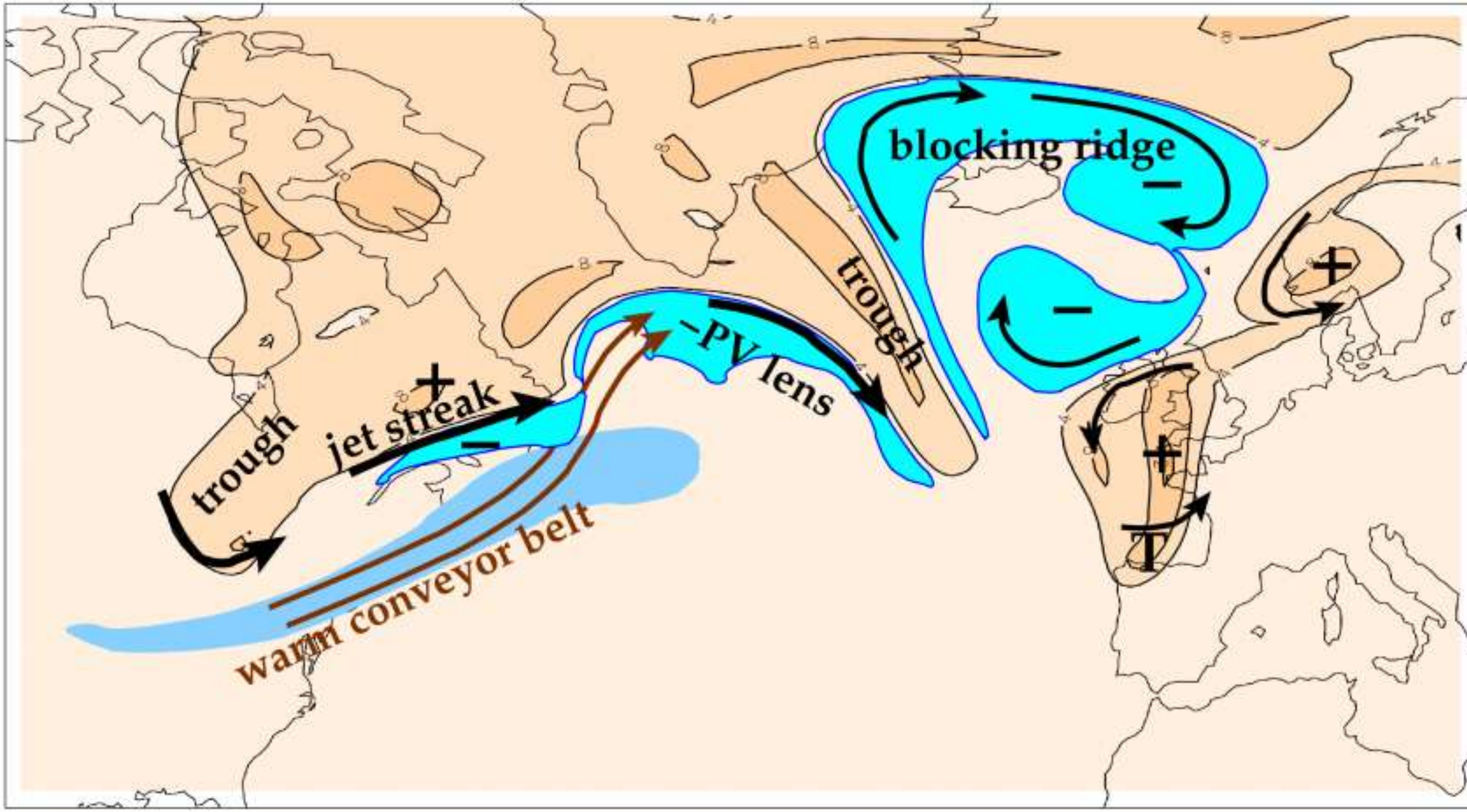
1. Purpose of NAWDEX (North Atlantic Waveguide and Downstream Impacts Experiment)

2. Initial characterization of systematic tropopause level analysis and forecast errors

3. Ramifications for nature of model error in forecasts

4. Further plans utilising NAWDEX observations and suggestions for wider involvement

Overarching scientific aim of NAWDEX:
to quantify the effects of diabatic processes on disturbances to the jet stream near North America, their influence on downstream propagation across the North Atlantic, and consequences for high-impact weather in Europe.



Features related to the meandering tropopause and jet stream
(orange is stratospheric air; cyan marks upper tropospheric PV anomalies).

NAWDEX Research Plans

How sharp is the jet stream and what are the ramifications for Rossby wave propagation?

How much do cloud and radiative processes influence jet stream disturbances and downstream predictability?

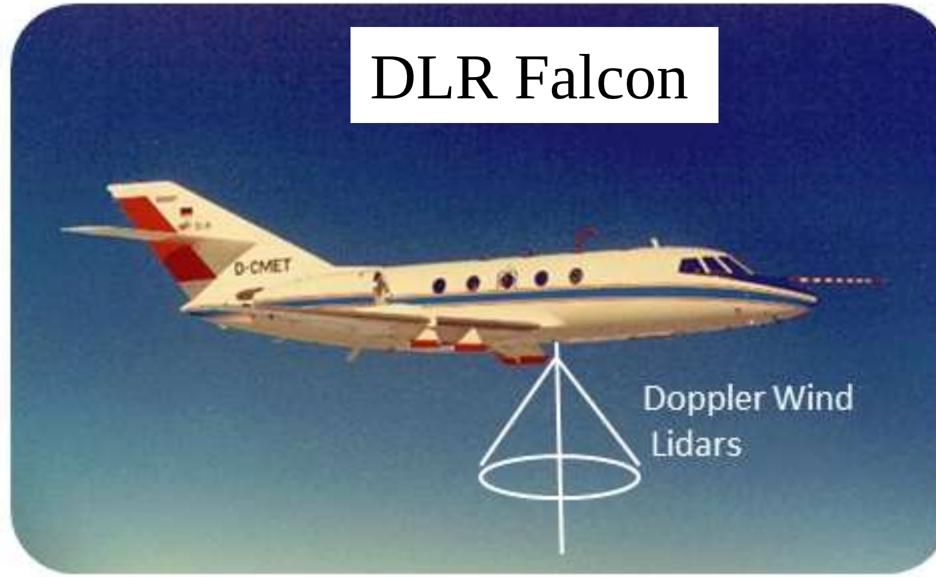
What are the situations with lowest predictability for Europe, and why?

Collaborators

Germany (Waves 2 Weather, DFG)
Switzerland (ETH, Bern)
UK (Reading, Manchester, Met Office)
France (Meteo France, LMD, CNRS)
Canada (ECCC)
USA (NRL)
Norway (Met Norway)

NAWDEX: 16/9/16-18/10/16

North Atlantic Waveguide and Downstream Impacts Expt



Meteorological variables measured:

- wind components

- humidity

- liquid/ice water paths

- nature of hydrometeors

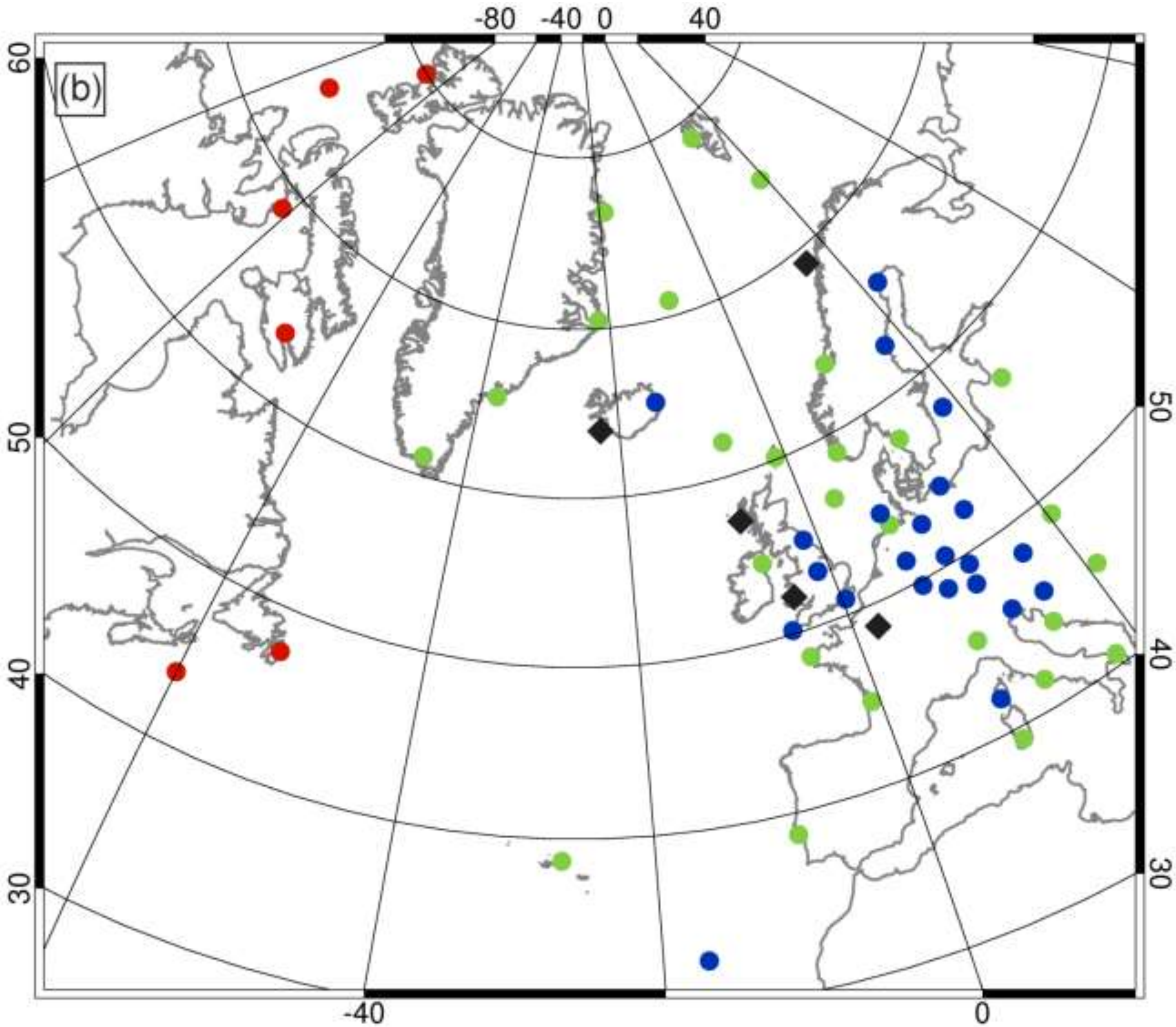
- radiative fluxes

SAFIRE Falcon

In-situ sondes Radar-Lidar Dropsondes

Schäfler *et al* (2018), BAMS

Sonde profiles during NAWDEX



16/9/16-18/10/16.

289 dropsondes

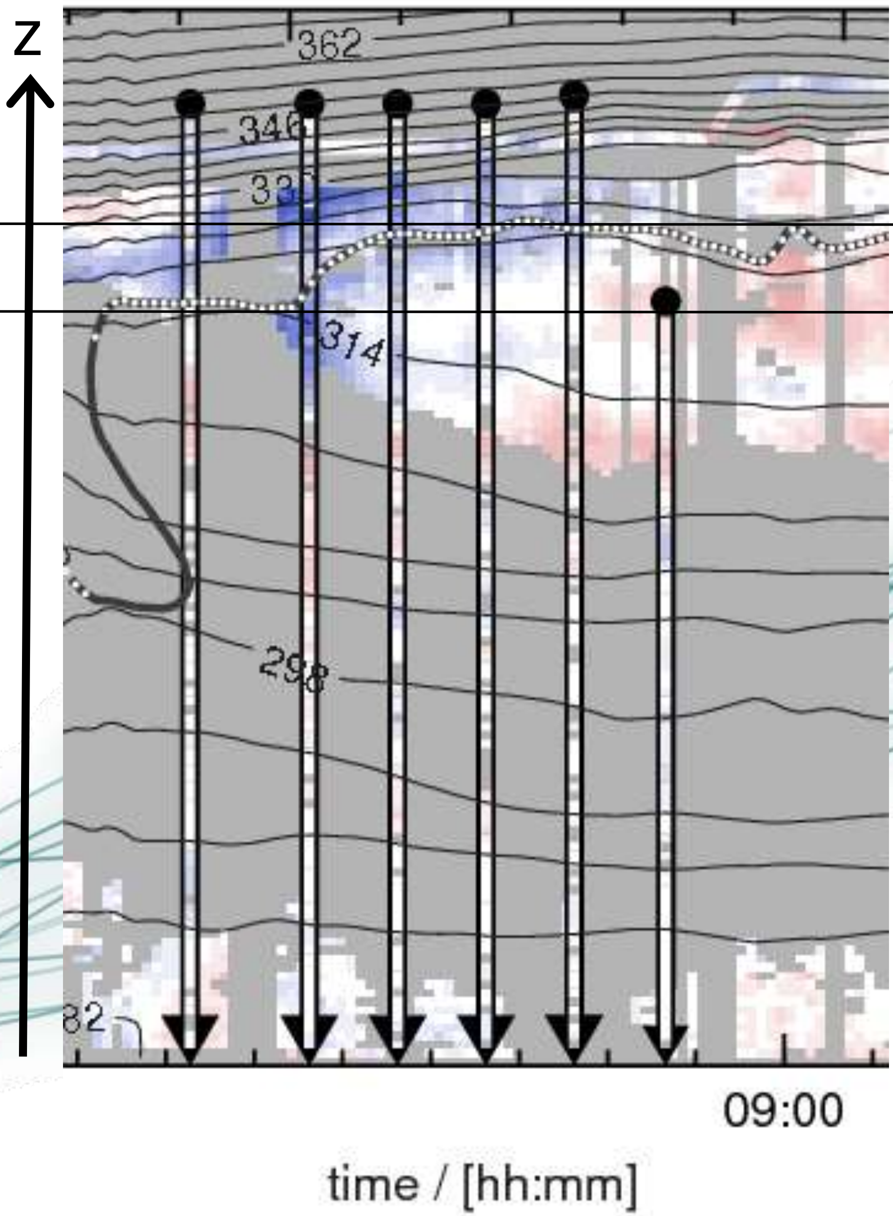
589 additional balloon launches from 14 countries

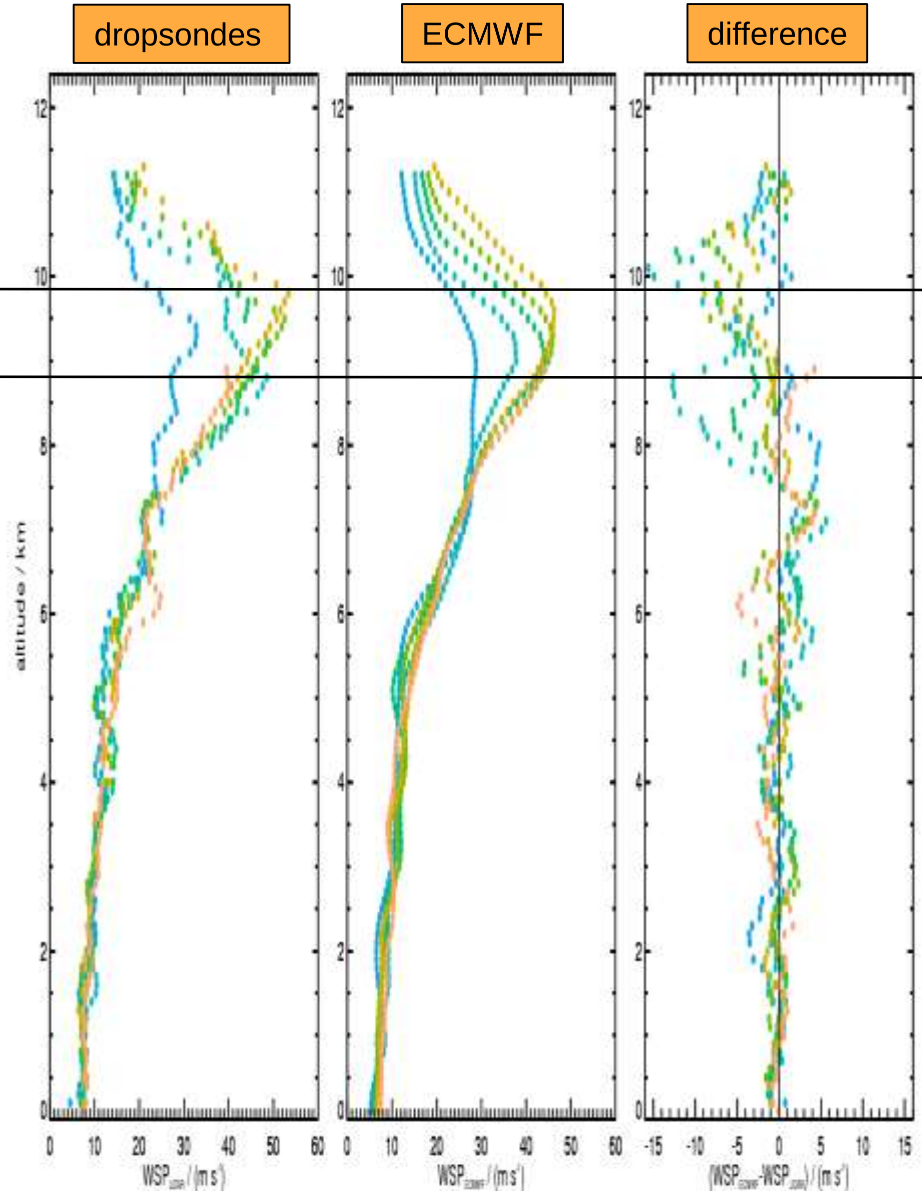
4 wind profilers across tropopause

Falling during 13 IOPs related to downstream development of weather and its impacts on Europe.

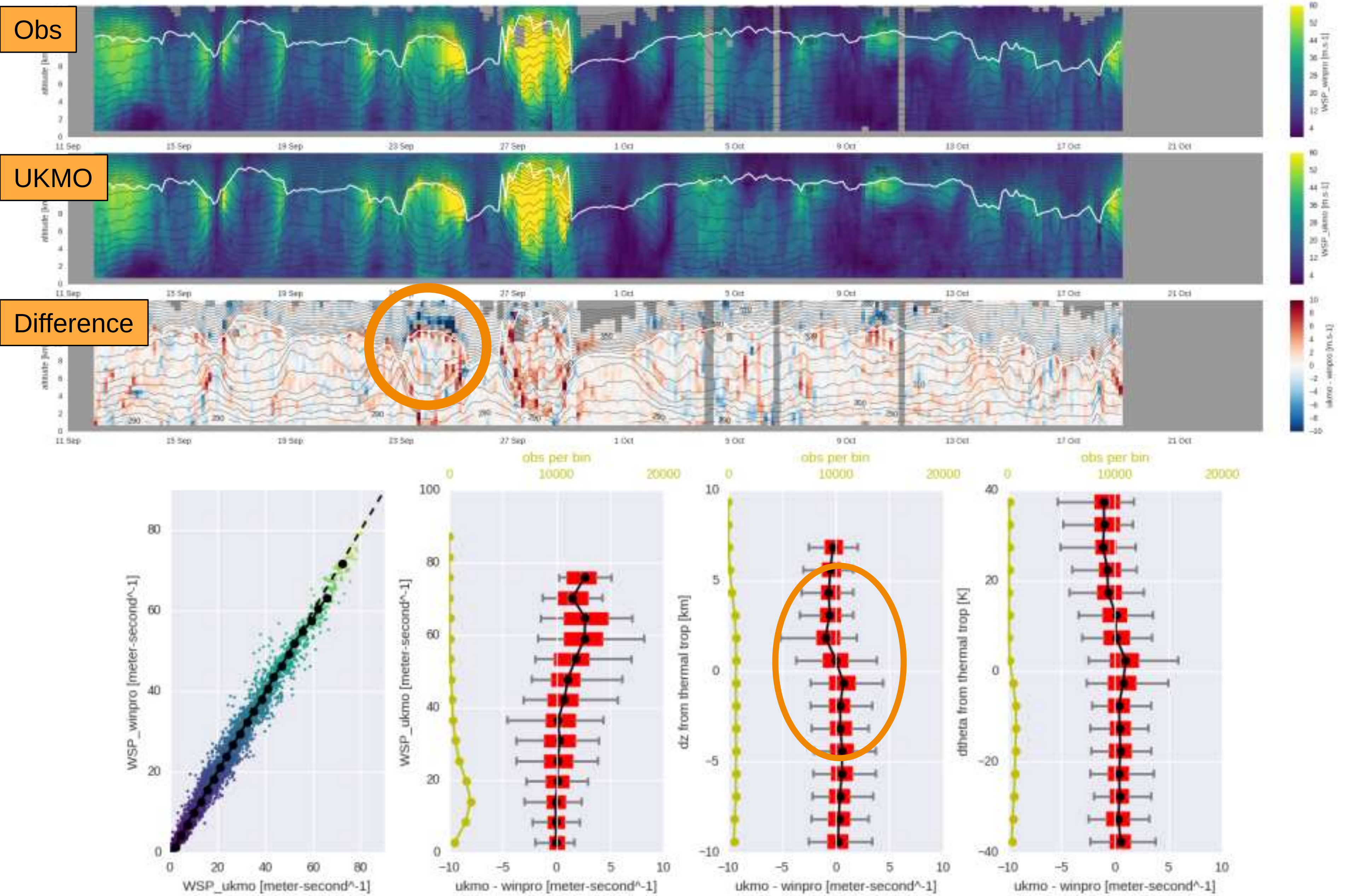
RF04: 23/9/16 (**DLR wind lidar**)
analysis - obs wind speed

Systematic error identified

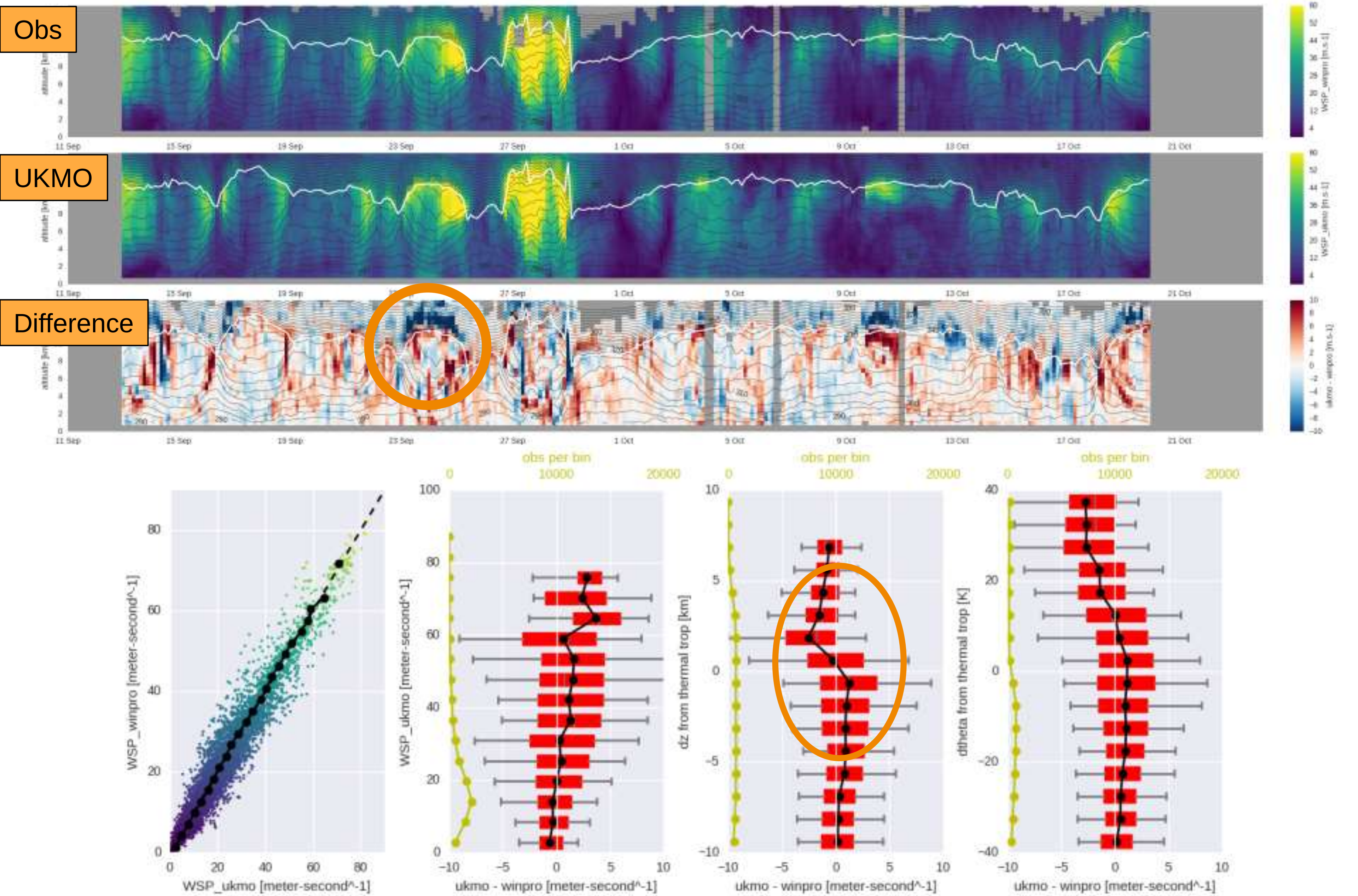




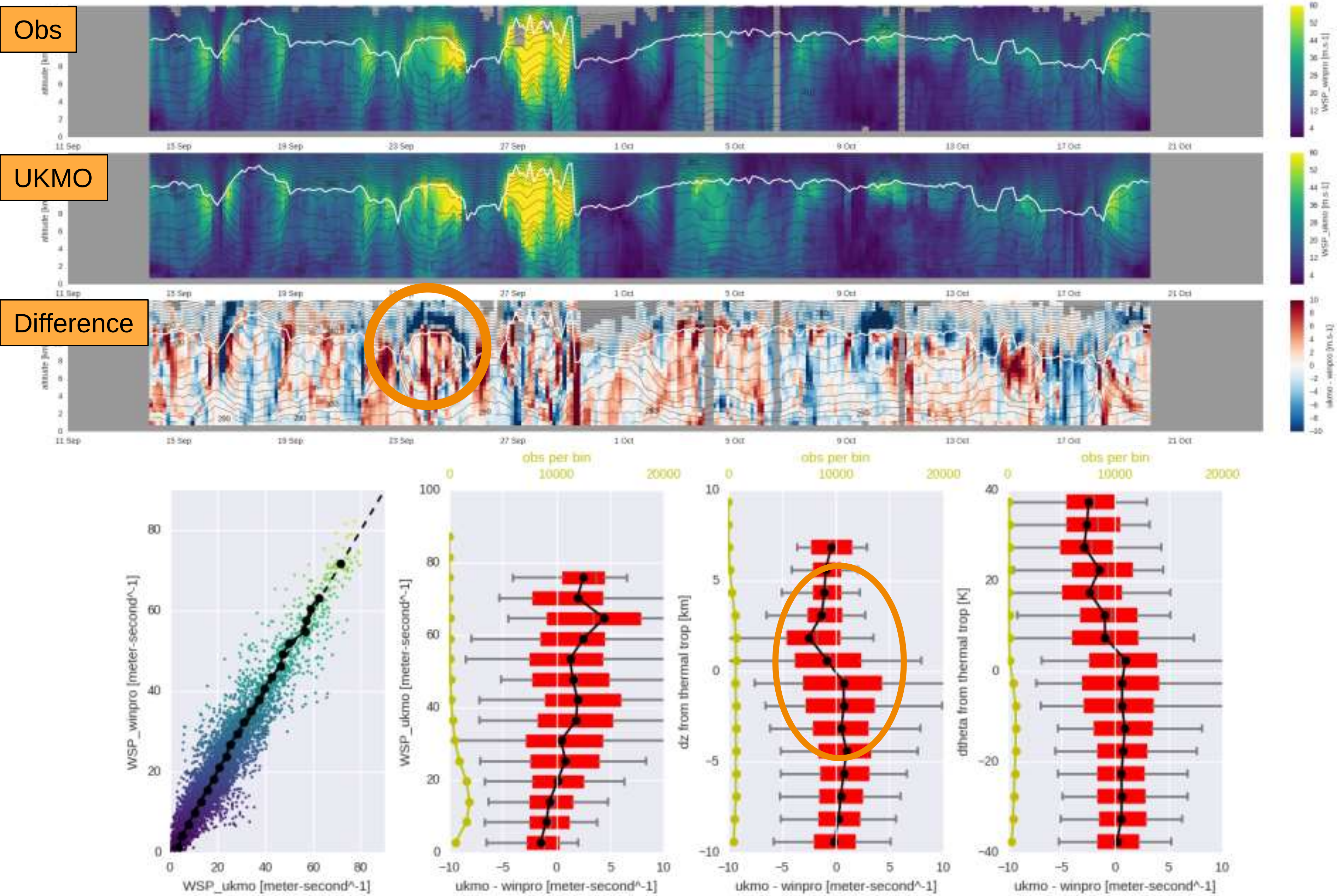
Analysis - Obs (Uist ST wind profiler)



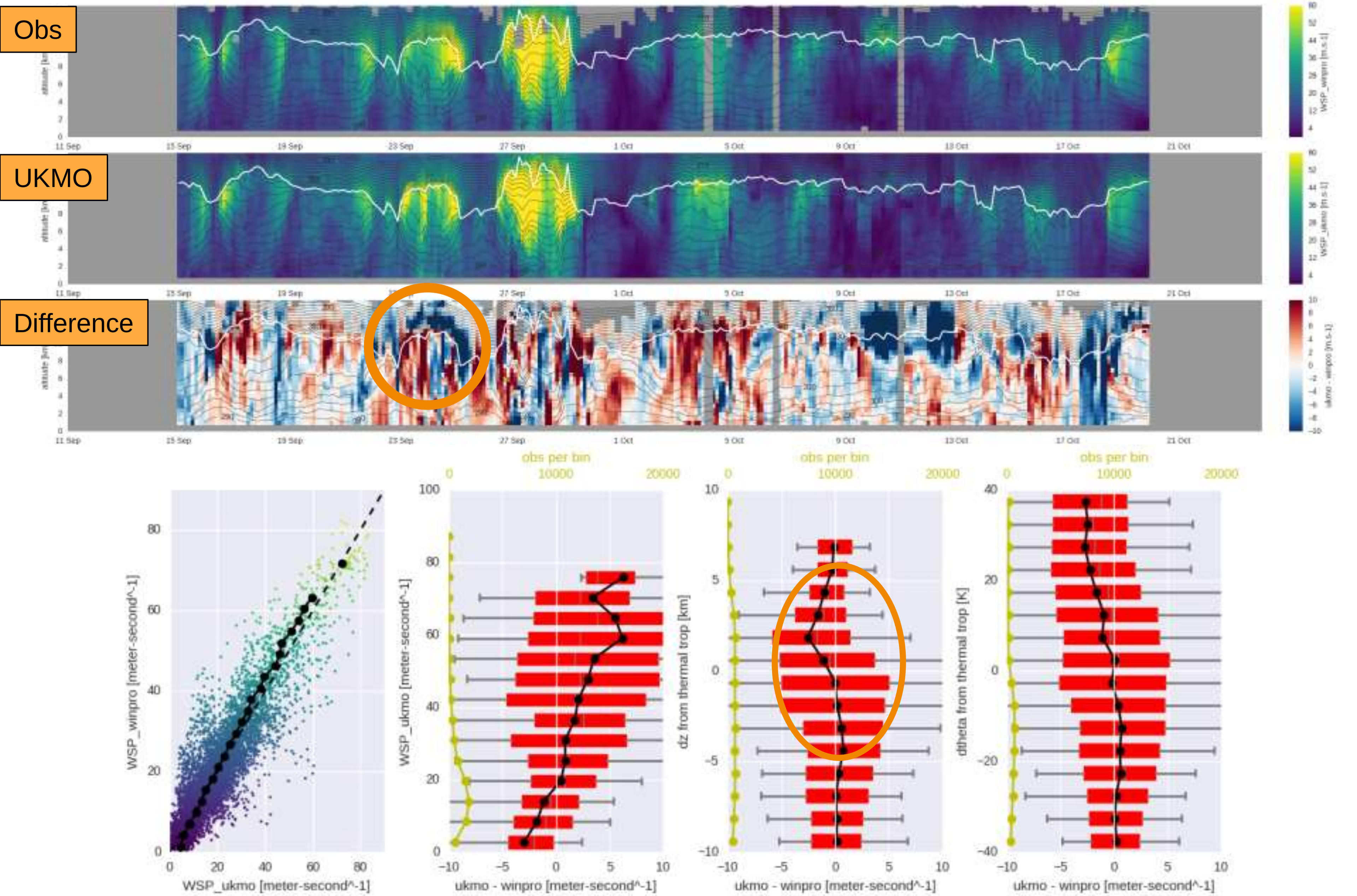
Forecast - Obs (Uist ST wind profiler) at T+24



Forecast - Obs (Uist ST wind profiler) at T+48

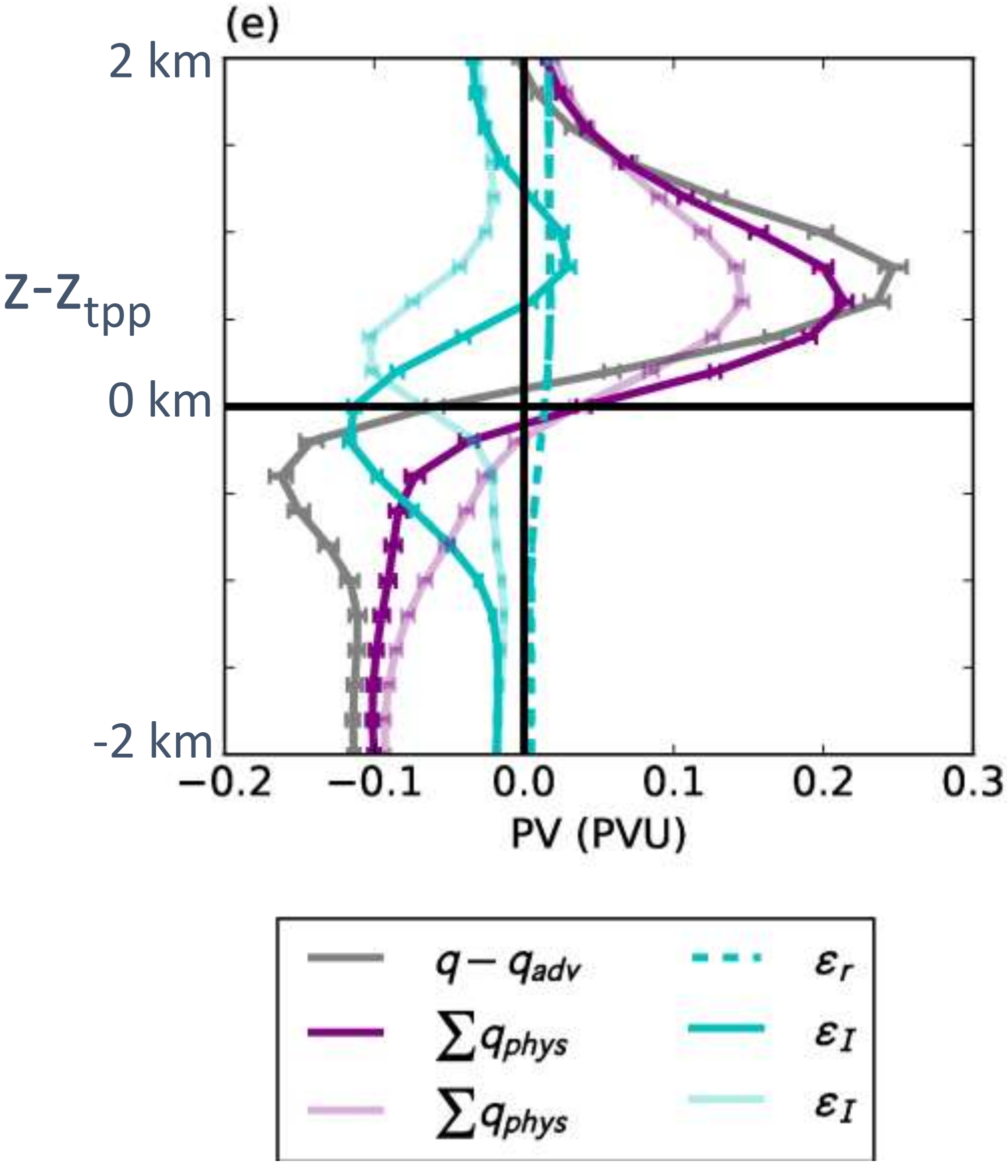


Forecast - Obs (Uist ST wind profiler) at T+72



Composite of 92 winter forecasts

"Diabatic PV" relative to the tropopause in troughs



Troughs defined by locations where

$$\theta'(\lambda, \phi, PV2, t) < 0$$

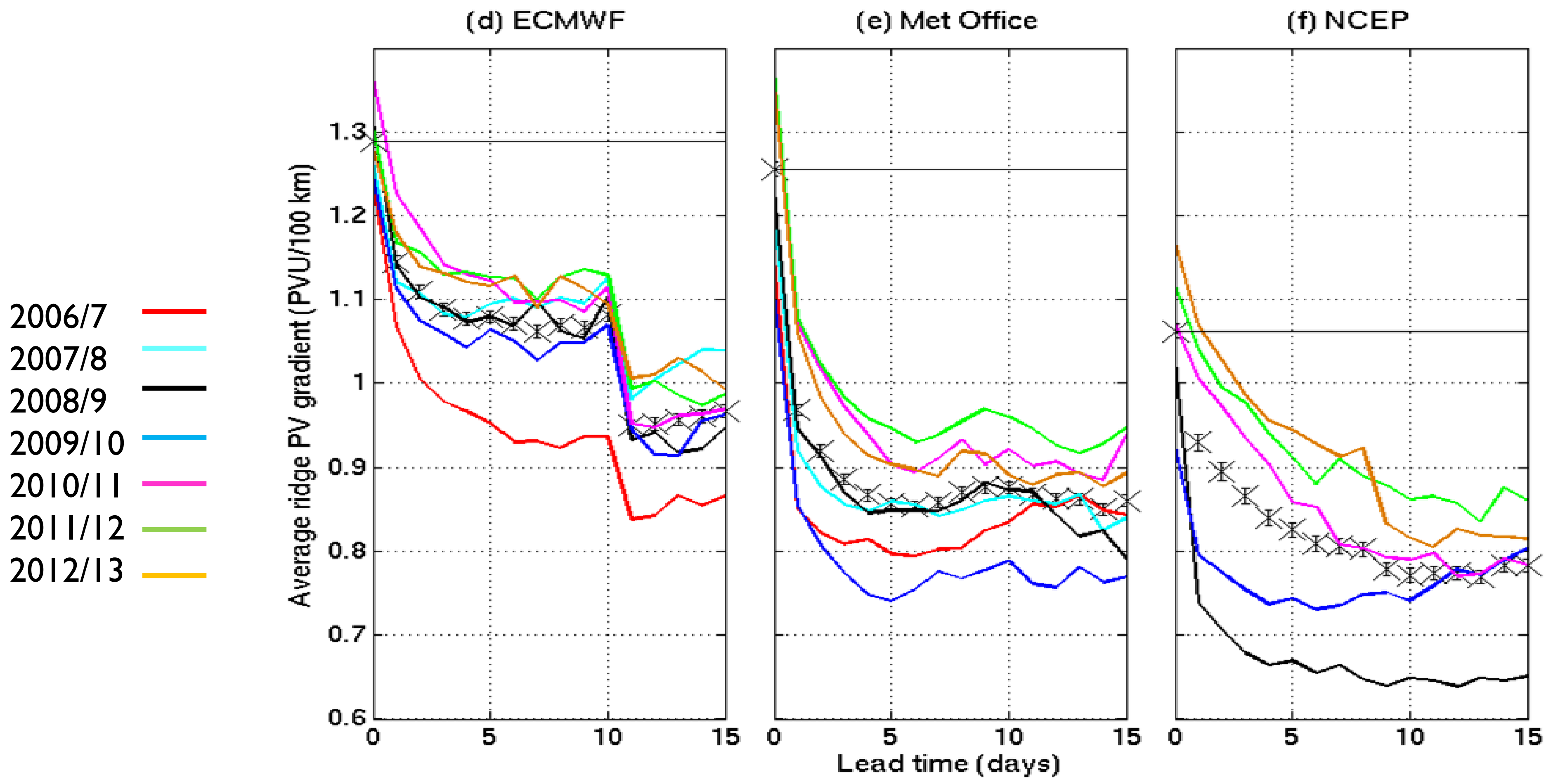
Average on set of levels defined by vertical distance from the tropopause

Physics parameterisations reduce PV below tropopause (and increase it above)

Dynamical core of Met Office model reduces PV at tropopause

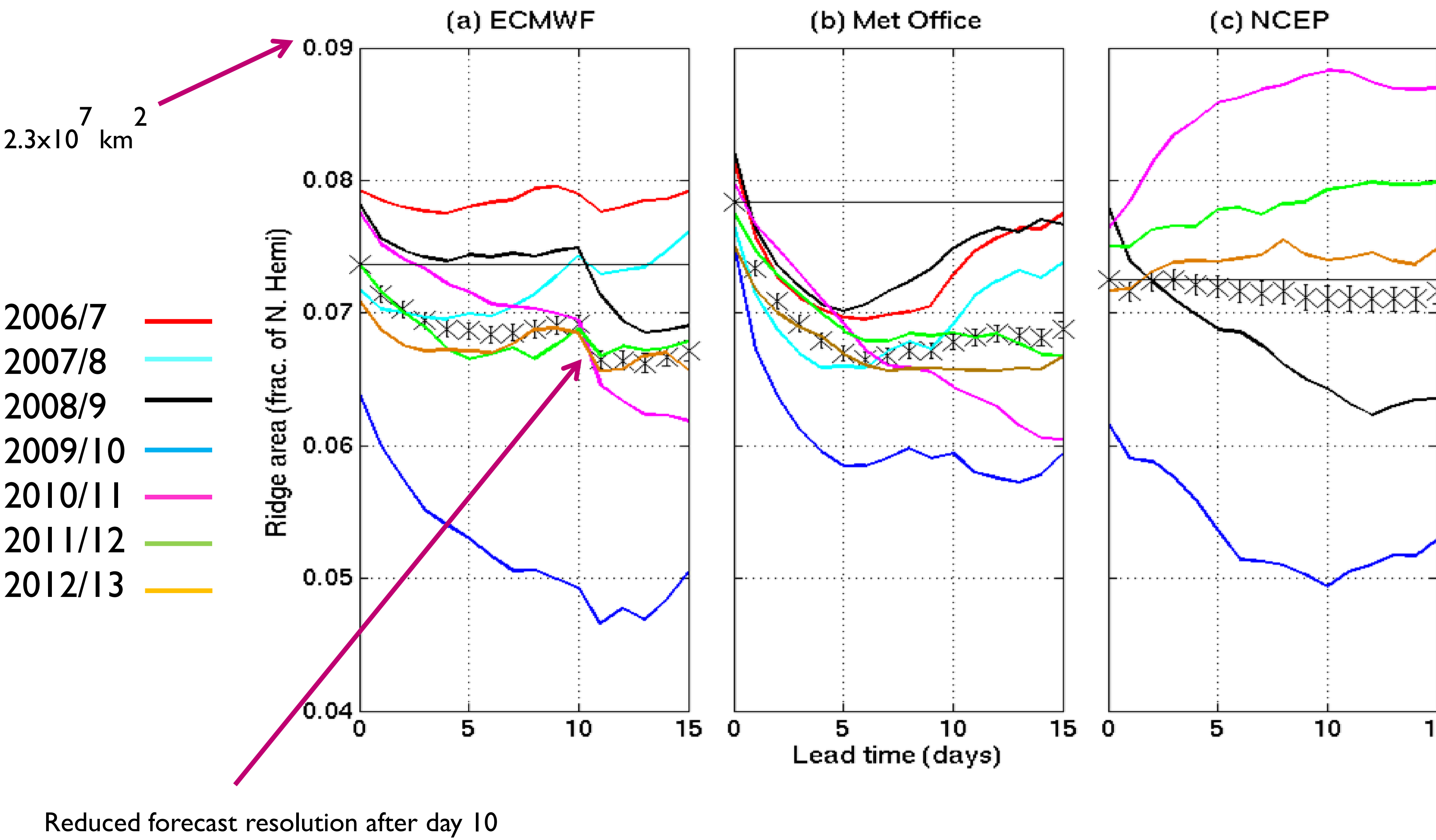
Saffin *et al* (2017), JGR

Forecast in horizontal PV gradient across the tropopause (from TIGGE)



Gray, Dunning, Methven, Masato and Chagnon (2014), *GRL*

Forecasts of ridge area in Rossby waves

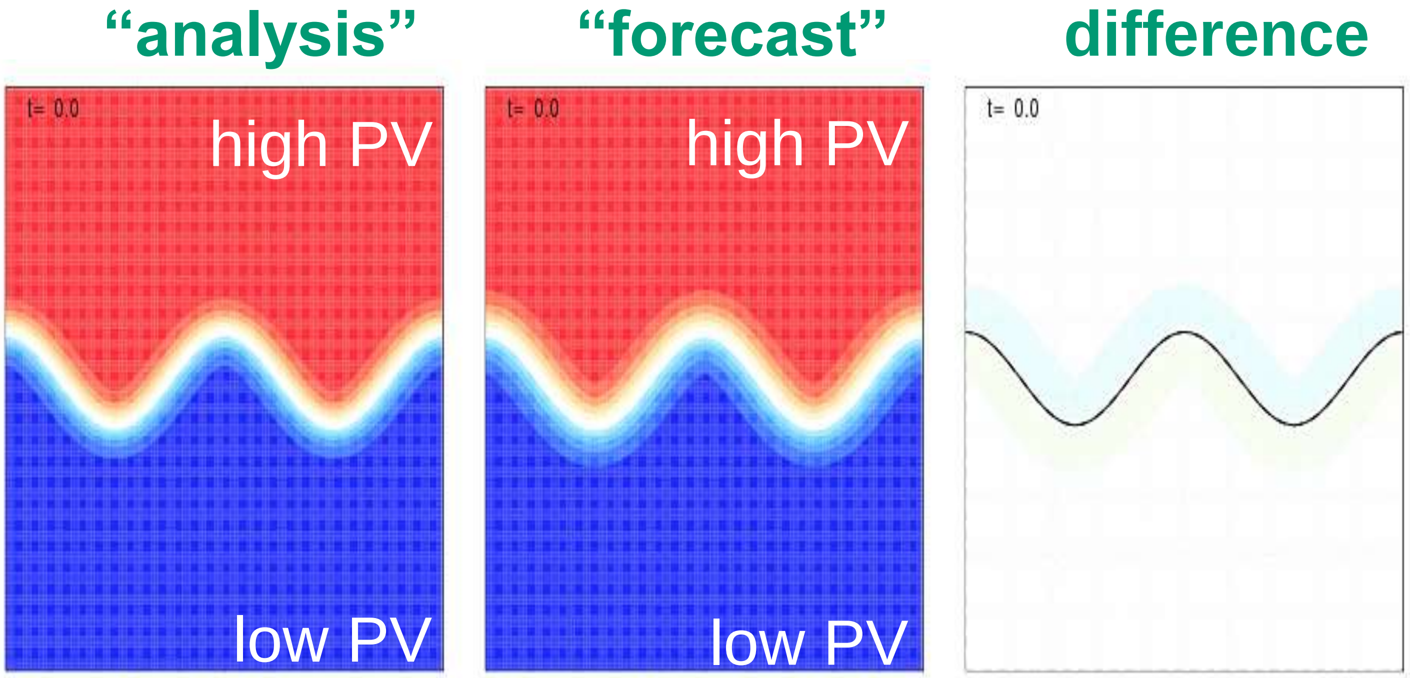


Gray, Dunning, Methven, Masato and Chagnon (2014), *GRL*

Does PV gradient sharpness matter?

- QG shallow water ("equivalent barotropic") equations:

$$\frac{DP}{Dt} = 0 \qquad\qquad P = f_0 + \nabla^2\psi - \psi/L_R^2$$



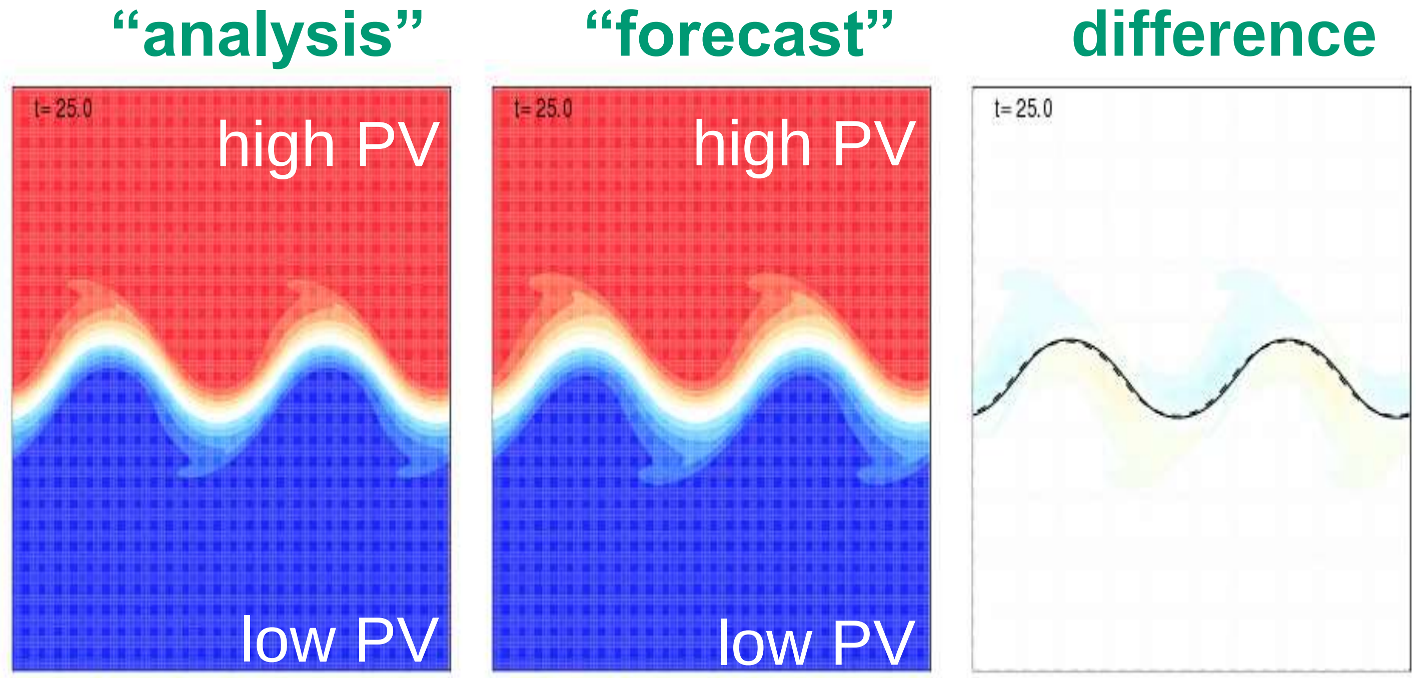
$r_0 \approx 308\ km$ $\qquad$ $r_0 \approx 381\ km$

Use: $L_R = 700\ km$

A simple simulation

- QG shallow water ("equivalent barotropic") equations:

$$\frac{DP}{Dt} = 0 \qquad P = f_0 + \nabla^2\psi - \psi/L_R^2$$



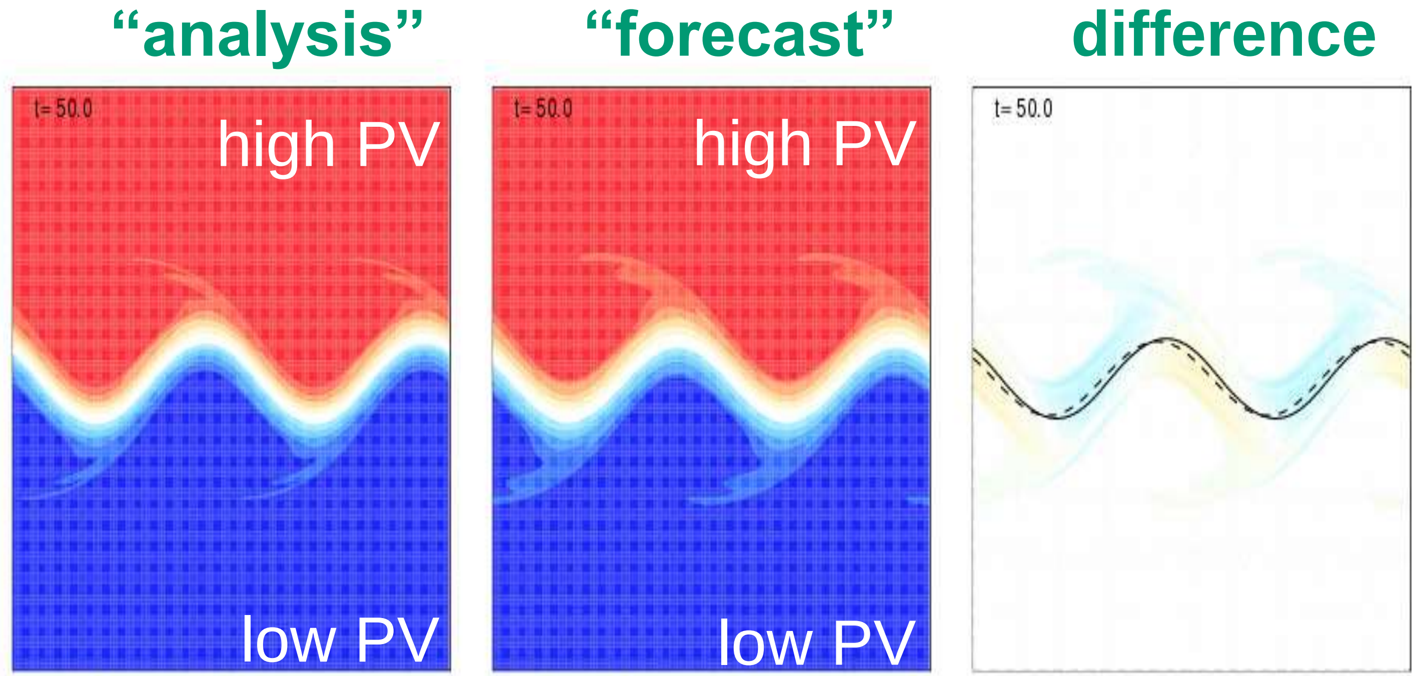
$r_0 \approx 308\ km$ $\qquad$ $r_0 \approx 381\ km$

Use: $L_R = 700\ km$

A simple simulation

- QG shallow water ("equivalent barotropic") equations:

$$\frac{DP}{Dt} = 0 \qquad\qquad P = f_0 + \nabla^2\psi - \psi/L_R^2$$



$r_0 \approx 308\ km$ $\qquad$ $r_0 \approx 381\ km$

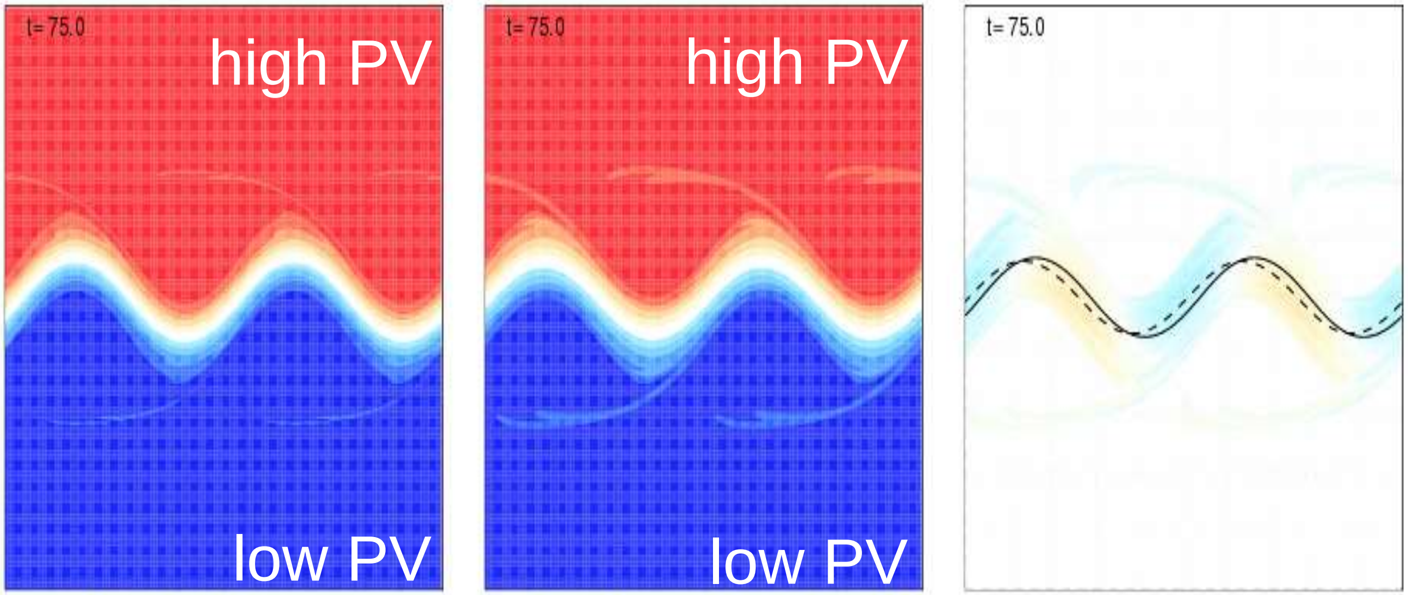
Use: $L_R = 700\ km$

A simple simulation

- QG shallow water ("equivalent barotropic") equations:

$$\frac{DP}{Dt} = 0 \qquad P = f_0 + \nabla^2\psi - \psi/L_R^2$$

"analysis" **"forecast"** **difference**



$r_0 \approx 308\ km$ $r_0 \approx 381\ km$

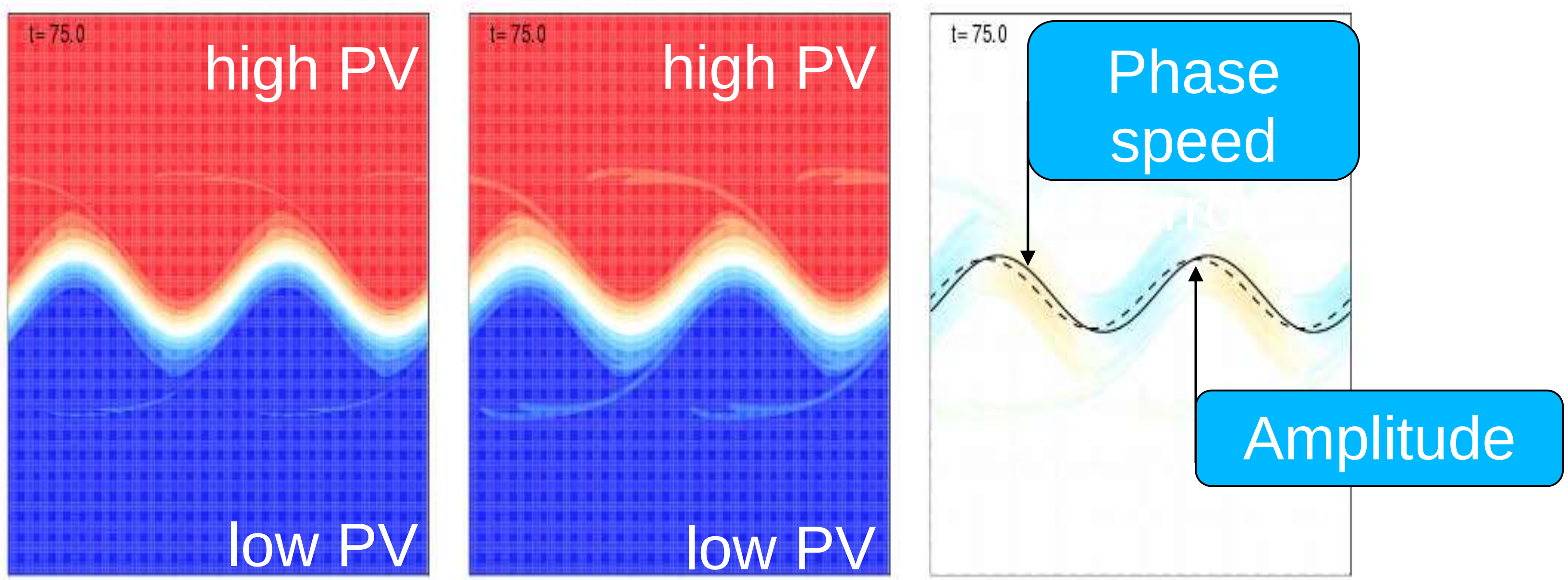
Use: $L_R = 700\ km$

A simple simulation

- QG shallow water ("equivalent barotropic") equations:

$$\frac{DP}{Dt} = 0 \qquad\qquad P = f_0 + \nabla^2\psi - \psi/L_R^2$$

"analysis" "forecast" difference



$r_0 \approx 308\ km$ $\qquad$ $r_0 \approx 381\ km$

Use: $L_R = 700\ km$

RW propagation on smooth PV step

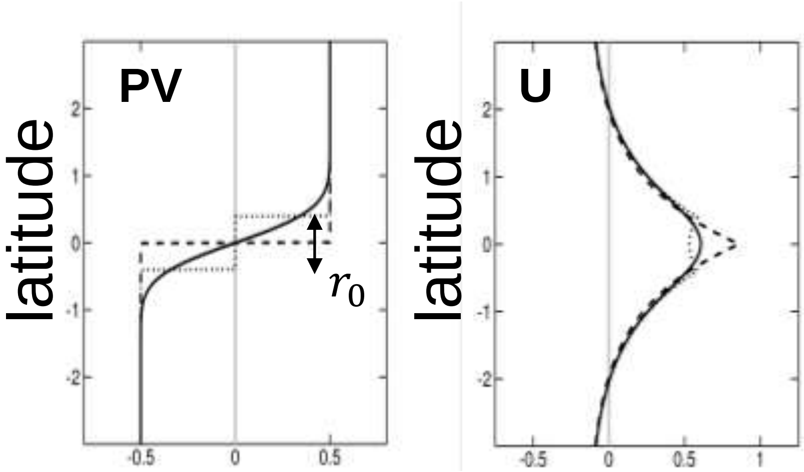
Single step in PV is smoothed by convolution with a weight.

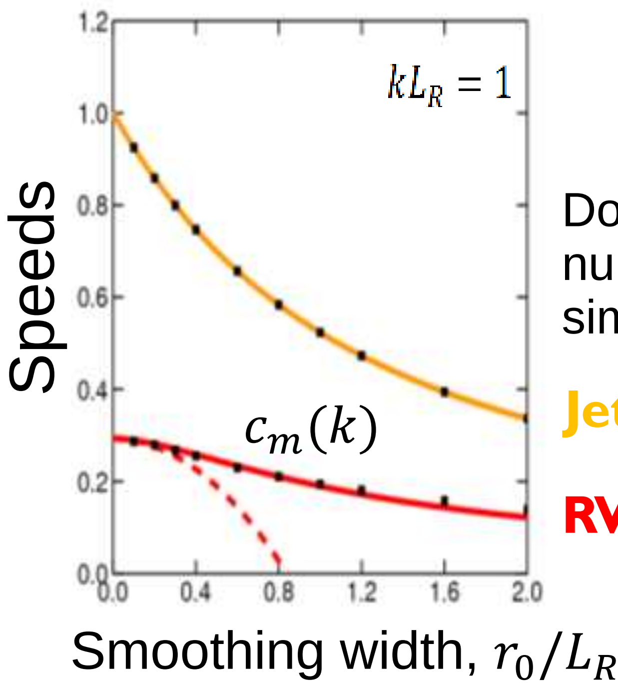
Solution obtained in limit where tropopause width is narrow compared with wavelength ($kr_0 \ll 1$)

General conclusion: smoothing PV gradient reduces both jet maximum and counter-propagation rate … but jet decrease is greater

$\Rightarrow$ phase speed reduces

$\Rightarrow$ affects shorter waves more, increasing dispersion





Dots = numerical simulation

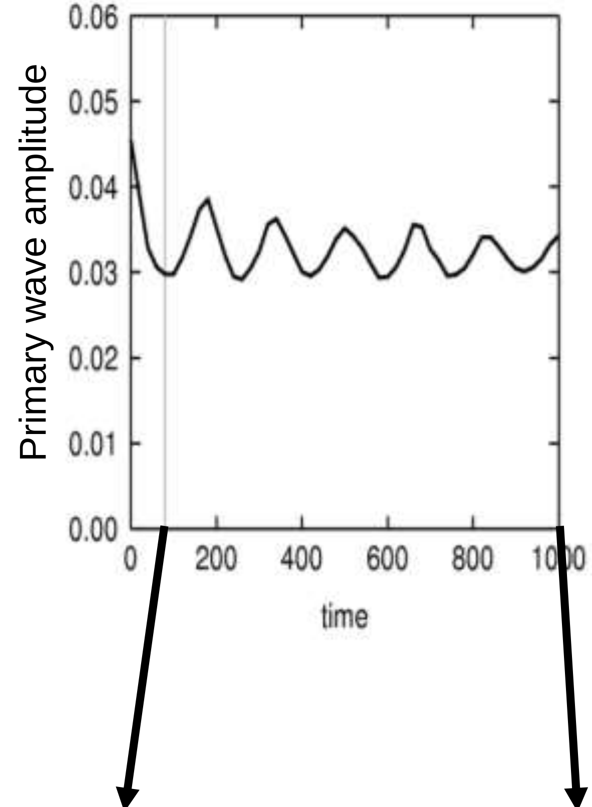
Jet speed

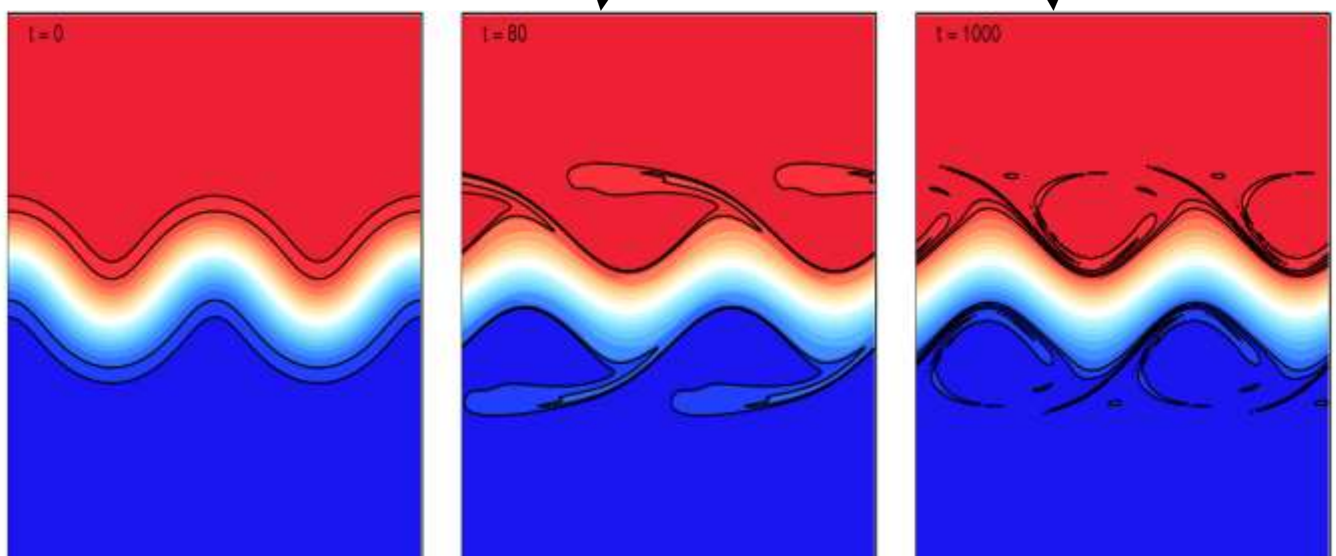
RW speed

Harvey, *J. F. Mech.* (2016)

Evolution of wave amplitude

- Fast oscillation:
  advection of PV filaments around the critical layer
- Gradual decrease:
  mixing of PV within the critical layer

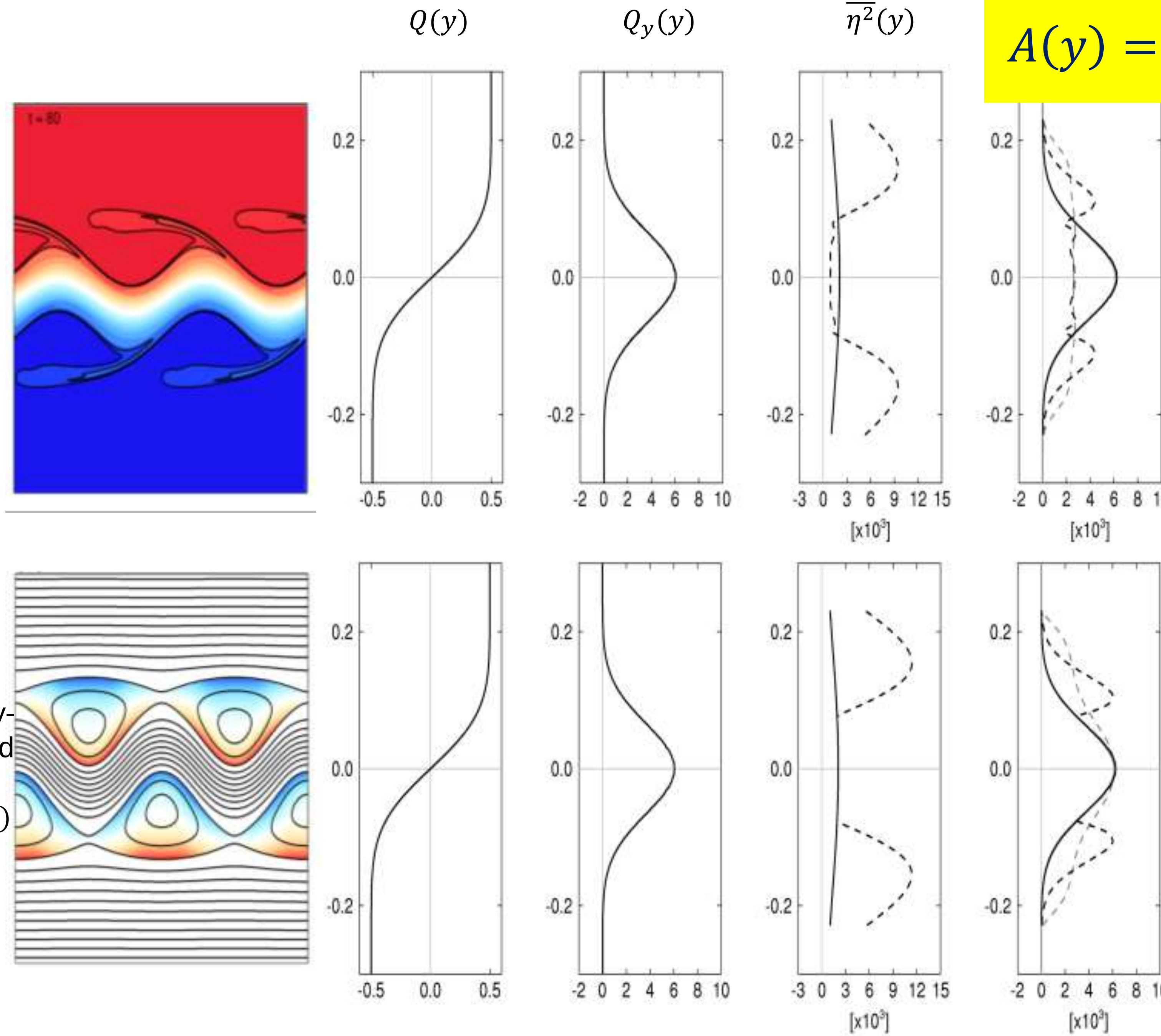




$$A(y) = \frac{1}{2} Q_y \overline{\eta^2}$$

Full model PV

Artificially-generated PV - $q(t = 0)$



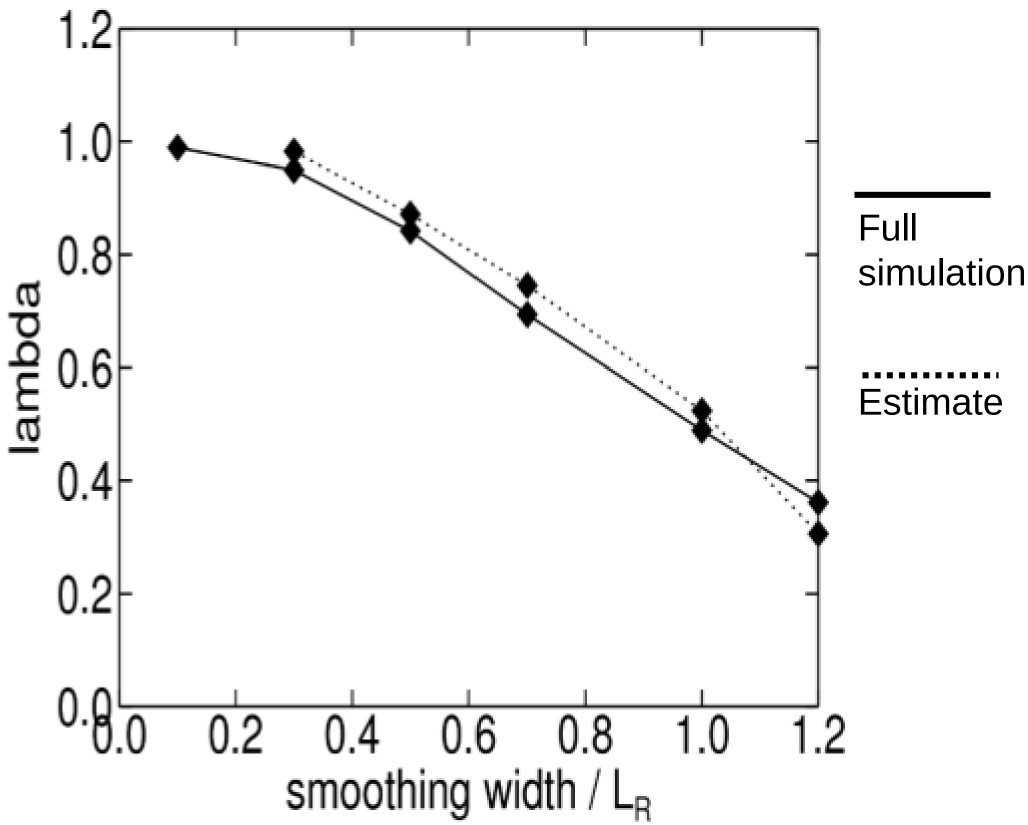
$\Delta M = 0.0$

Integral wave activity conserved

$\Delta M = -6.0$

Primary wave amplitude reduction predicted from wave activity conservation

$$\lambda = \frac{\eta_{final}(y=0)}{\eta_{initial}(y=0)}$$



Putting some numbers in…

Timescale – advection around ridges

Magnitude

$$r = \frac{\Delta PV}{\max PV_y} \approx \begin{cases} 308\ km\ (analysis) \\ 381\ km\ (forecast) \end{cases}$$

•Also use: $L_R = 700\ km\ , \Delta PV = 4PVU$

•Gives: $\frac{\Delta\lambda}{\lambda} \approx 10\%$

Ramifications

1. Sharpness of tropopause (PV gradient) is important to Rossby wave phase speed and amplitude in models

2. Very high resolution required to represent observed sharpness (and maintain it in forecasts)

3. Representation of gradients has surprisingly large impacts on large scale waves (although well-resolved)

4. Example where "sub-grid scales" have an effect but cannot be treated as a stochastic process

Next steps in NAWDEX science

University of Reading

- Small groups working on 6 Golden Cases

- Integrating themes include:
    - observed mesoscale wind structure of the jet stream
    - warm conveyor belt moisture transport and latent heating
    - identifying signature of diabatic influence on jet from obs data
    - origins of predictability barriers

- Influence of sonde observations during NAWDEX on analyses (ongoing)

- "NAWDEX-AMIP" – climate models run for NAWDEX cases in "NWP mode"
    - Led by Gwendal Rivière, LMD, Paris

- **Next NAWDEX workshop**, Toulouse, 26-28 March 2019

NAWDEX-AMIP specification

University of Reading

"NAWDEX-AMIP" – climate models run for NAWDEX cases in "NWP mode"

- Led by Gwendal Rivière, LMD, Paris

Model runs (10 days)

IPSL, CNRM – low resolution CMIP6 config + higher resolution 50km runs

ICON with DWD NWP physics and ICON with MPI climate physics
Run by Aiko Voigt: ICON-NWP (40km), ICON-Clim (160 and 40km)

Met Office Unified Model: NWP oper and climate config (tbd)
Run by Claudio Sanchez

Priority initial dates 00UT 20, 22, 29 Sep 2016 and 00UT 2, 13 Oct 2016
But probably daily from 16 Sep – 18 Oct 2016

Two initial states: ECMWF and Meteo-France operational analyses
SSTs from ECMWF analyses

Thankyou for your attention

Mechanisms for diabatic PV modification

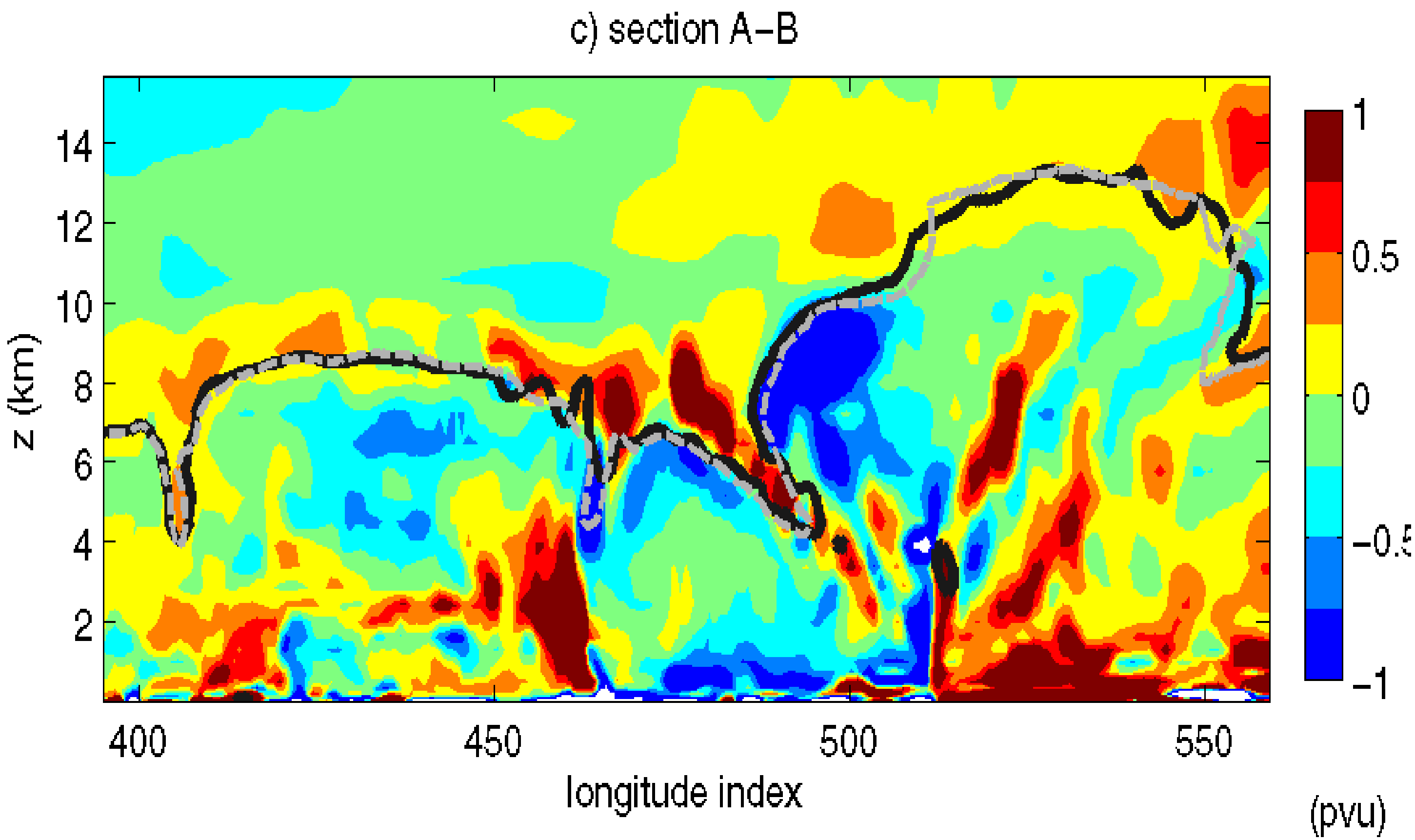
NAWDEX focuses on the diabatic influences on Rossby waves at tropopause level (*wave guide disturbances*).

1. Maintenance of PV contrast across the tropopause

2. Influence of latent heating on level of warm conveyor belt outflow and advection of tropopause by divergent flow

3. Sharpening of jet stream PV gradient and max winds by non-advective PV flux (heating in shear)

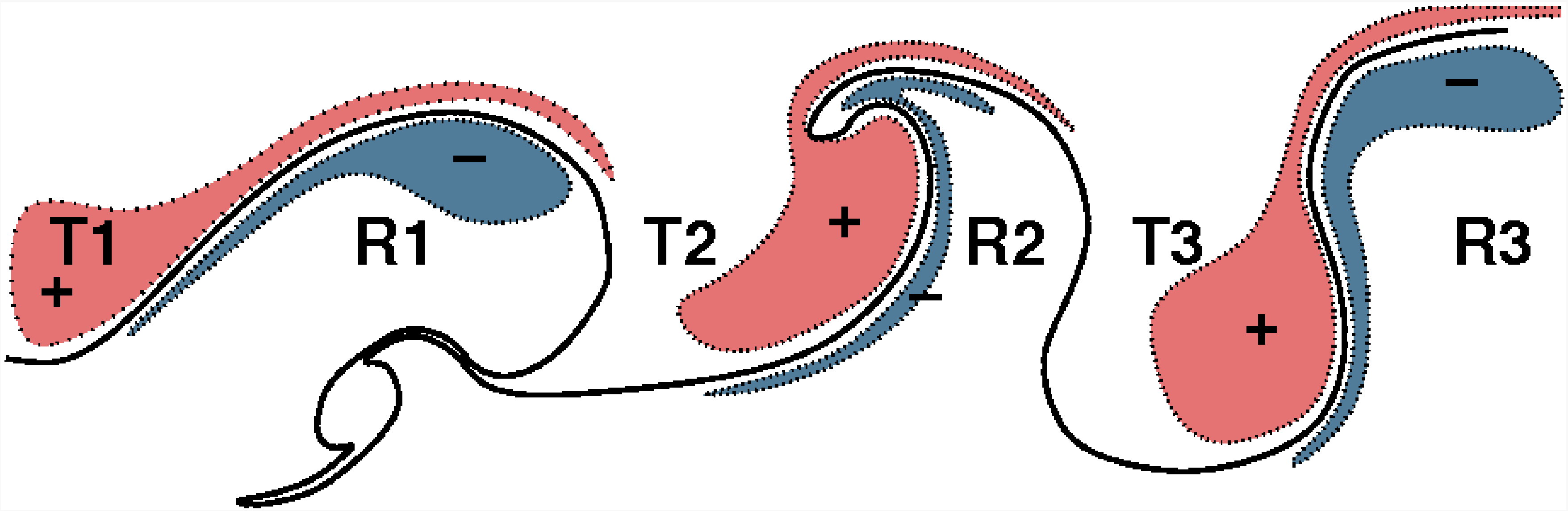
Total diabatic PV in section across tropopause fold



- Positive *diabatic PV* above (on strat side) of tropopause
- Negative *diabatic PV* beneath (on trop side) of tropopause
- Tropopause elevation not significantly altered by **direct diabatic PV modification**

Chagnon, Gray and Methven (2013), *Q J R Met S*

Diabatic influence on Rossby waves



1. LW cooling max at tropopause (humidity step)
   ⇒ "diabatic PV dipole" but ***little direct PV change*** at tropopause
   ⇒ enhances tropopause PV gradient
   ⇒ would be influenced by cirrus just under tropopause
2. Diabatic PV enhances PV anomaly pattern of Rossby wave
   ⇒ greater westward propagation and enhanced baroclinic interaction
   ⇒ But, also stronger jet associated with greater PV contrast

Chagnon, Gray and Methven (2013), QJRMetS