

# Airborne Observations of Non-Orographic Gravity Waves over the Southern Ocean: Tropospheric or Stratospheric Wave Excitation?

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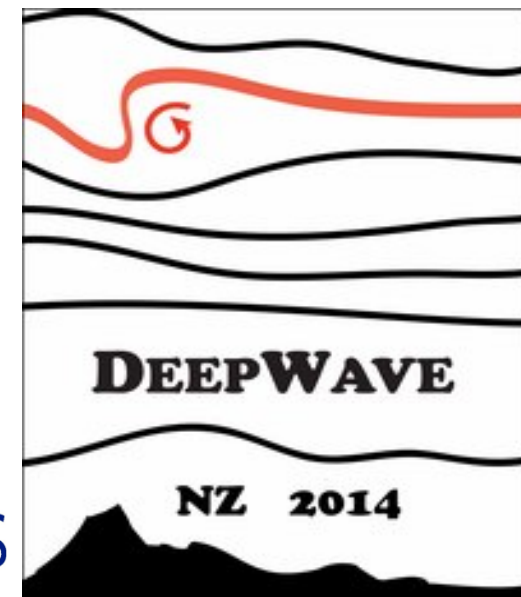
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and the **DEEPWAVE** team

**Nedjeljka Žagar and Damjan Jelić**

University of Ljubljana  
Faculty of Mathematics and Physics  
Ljubljana, Slovenia

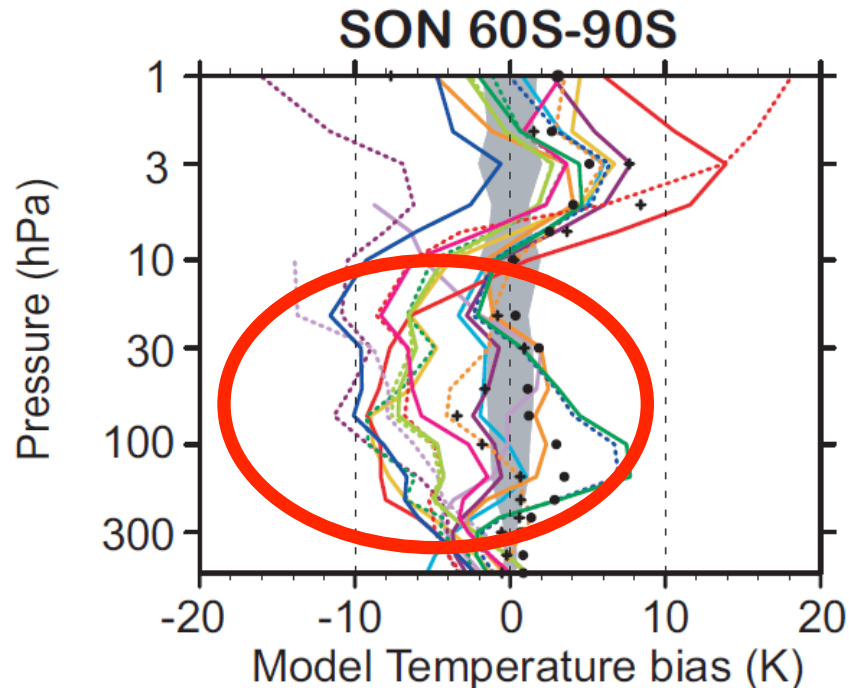
*University of Ljubljana*



# 1. Problems, Research Questions

## Executive Summary SPARC CCMVal (Stratospheric Dynamics)

„... Climatological mean polar temperature biases are generally small (< 5 K) across the model ensemble except in the southern hemisphere (SH) lower stratosphere during spring. ...”



McLandress et al., 2012:

„ ... The faulty springtime behavior of the southern hemispheric stratospheric polar vortex (cold pole bias) can be partly be remedied by an additional orographic gravity wave drag at 60°S! ...“

McLandress, C., T. G. Shepherd, S. Polavarapu, and S. R. Beagley, 2012: Is missing orographic gravity wave drag near 60°S the case of the stratospheric zonal winds biases in chemistry-climate models? *J. Atmos. Sci.*, **69**, 802–818.

Butchart, N., and Coauthors, 2011: Multimodel climate and variability of the stratosphere. *J. Geophys. Res.*, **116**, D05102, doi:10.1029/2010JD014995..

Eyring, V., T. G. Shepherd, D. W. Waugh (Eds.), 2010: SPARC Report on the Evaluation of Chemistry-Climate Models, SPARC Report No. 5, WCRP-132, WMO/TD-No. 1526, <http://www.atmosp.physics.utoronto.ca/SPARC>.

# Why Orographic Gravity Wave Drag near 60°S?



## Potential Sources

- large amplitude orographic gravity waves over 80°W–40°E from the southern Andes and Antarctic Peninsula (downwind advection and meridional refraction into the polar night jet)
- orographic gravity waves from small islands
- secondary waves generated locally in the breaking region of these primary orographic waves
- non-orographic waves from sources associated with winter storm tracks over the southern oceans
- a zonally uniform distribution of small amplitude waves from non-orographic mechanisms such as spontaneous adjustment and jet instability around the edge of the stratospheric jet

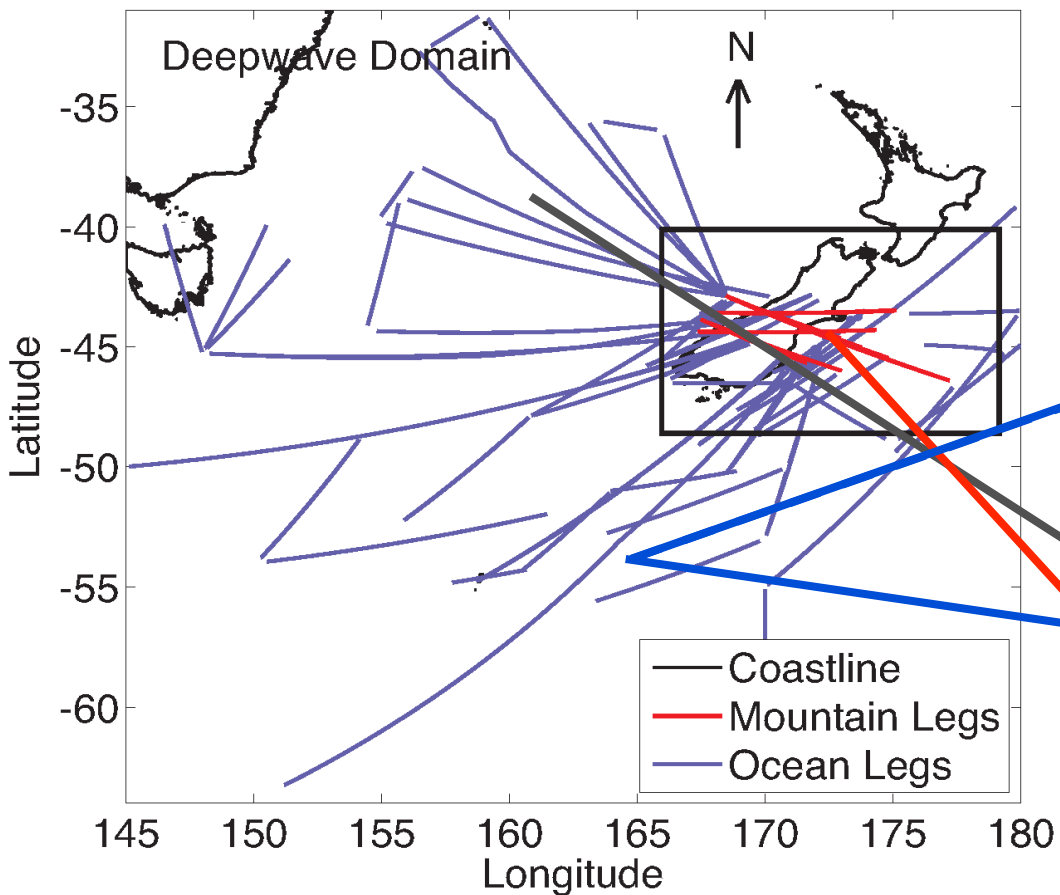
Sato et al. 2009, Sato et al., 2012, Alexander et al. 2009, Alexander and Grimsdell 2013, Hendricks et al., 2014, Hindley et al 2015,.....

# Research Questions:

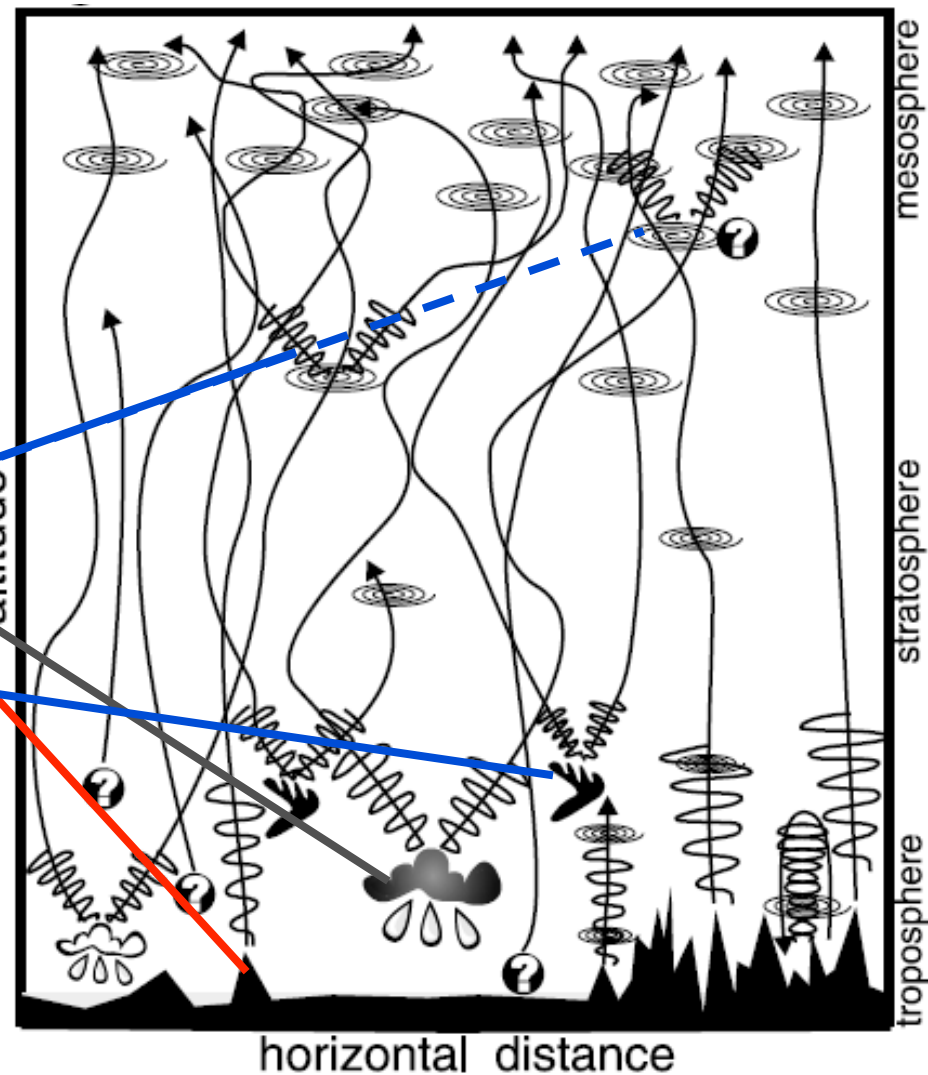
- Do DEEPWAVE observations provide further evidence of non-orographic wave sources in the middle to upper stratosphere over the southern ocean?
- How do ECMWF analyses represent the observed phenomena in the stratosphere?

# 2. DEEPWAVE Flights

## GV Flights June -July 2014

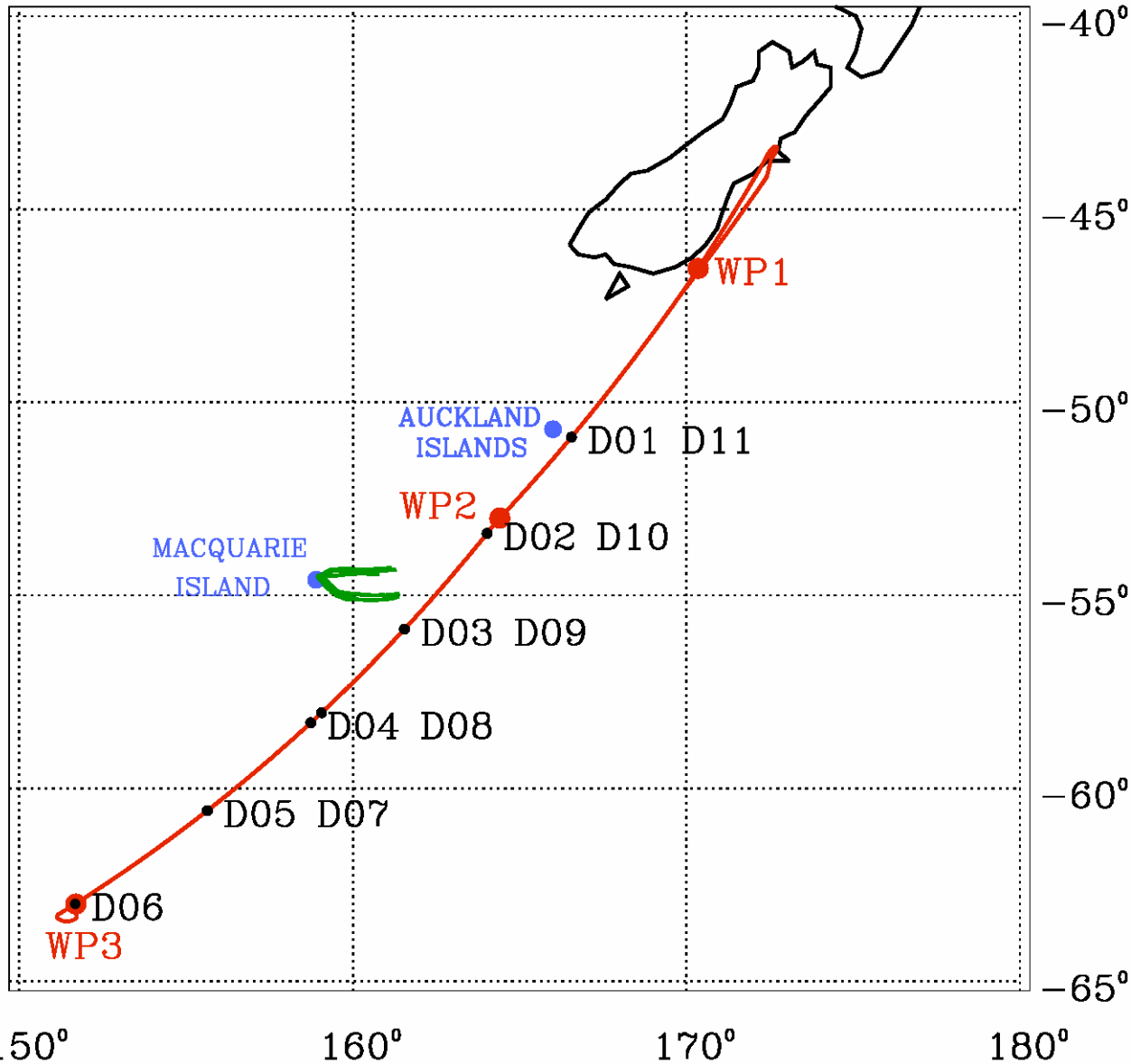


Smith et al., 2016



Kim et al., 2003

# 3. NSF/NCAR GV Research Flight 25



## Take-off

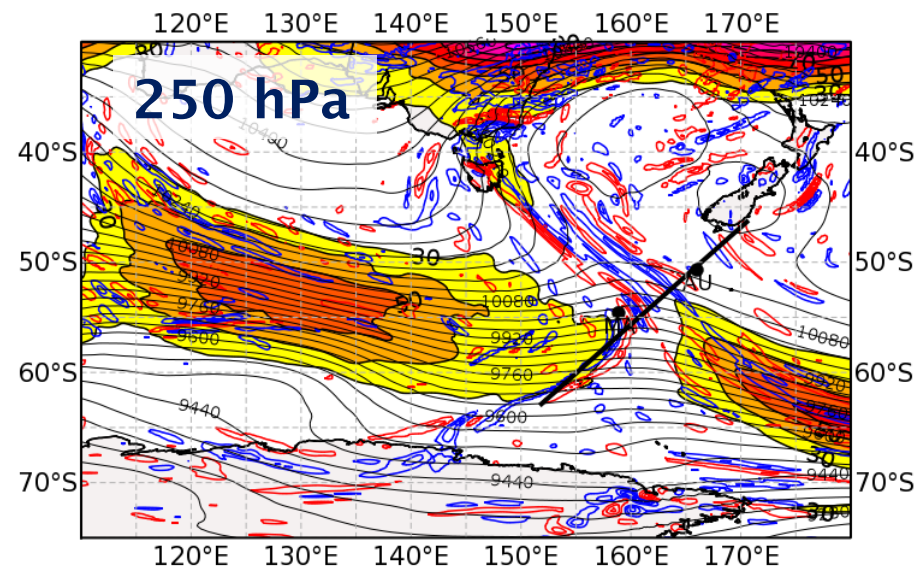
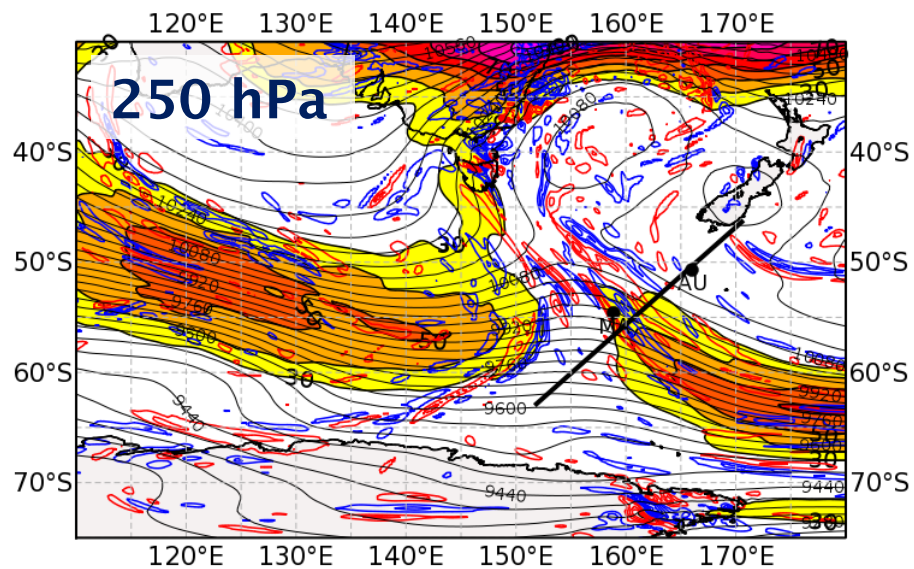
18 July 2014 ~0552 UTC

## Landing

18 July 2014 ~1225 UTC

- two long legs (~2300 km)
- 11 dropsondes

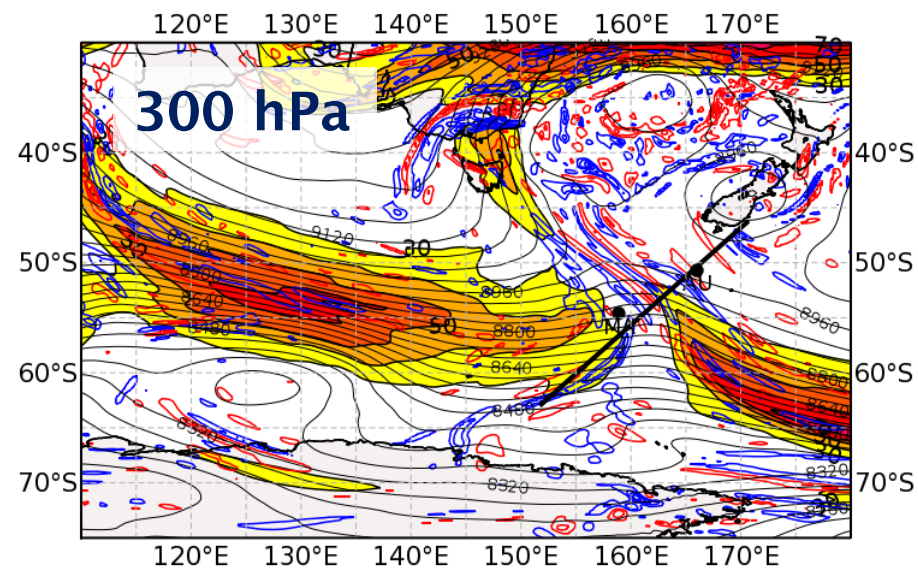
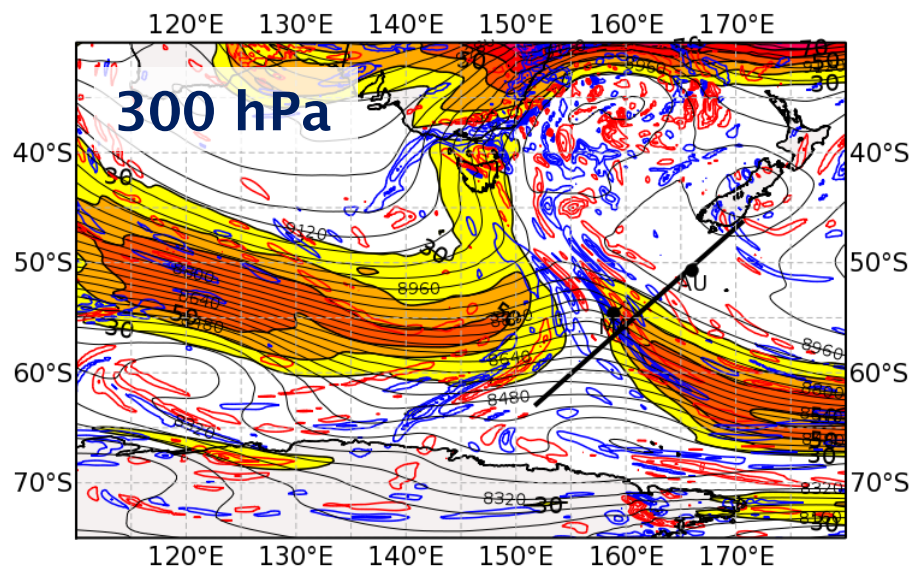
7 radiosondes from Macquarie Island

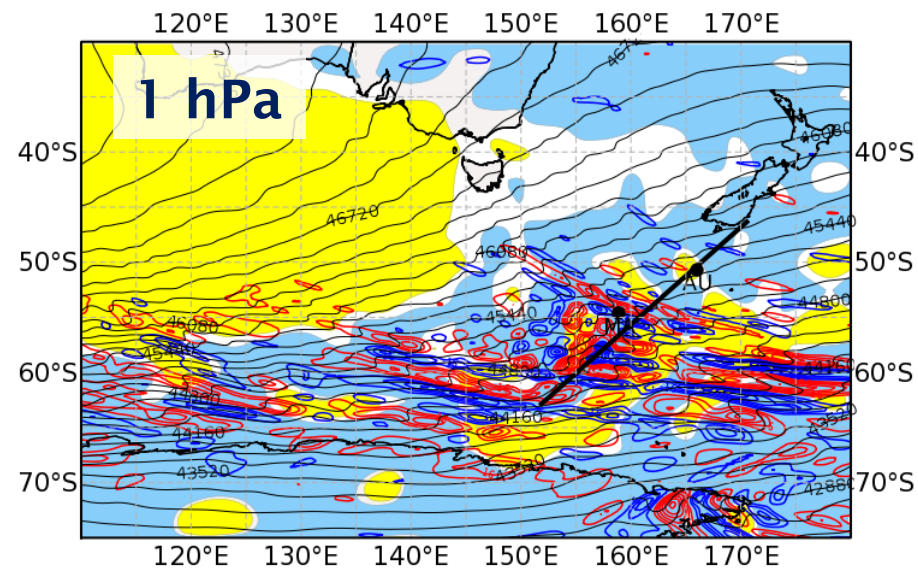
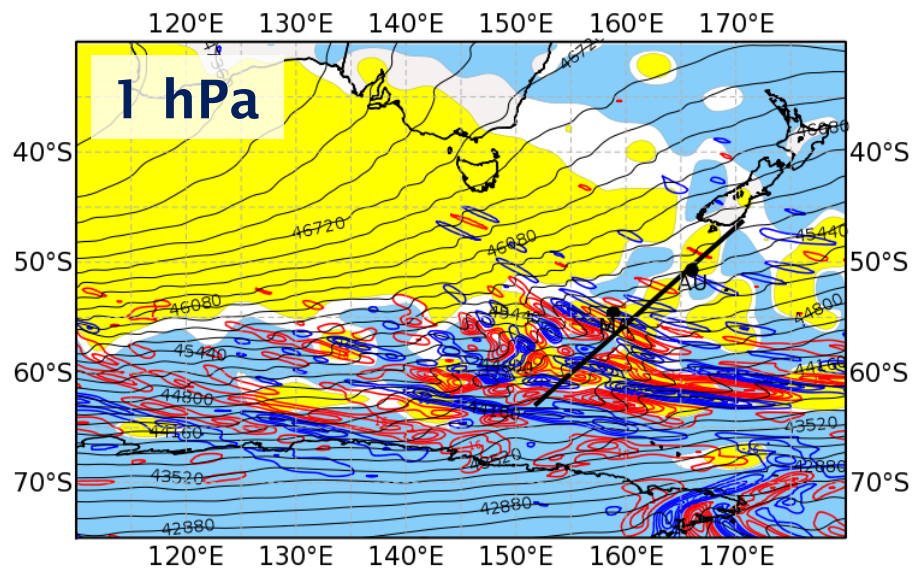


06 UTC

18 July 2014

12 UTC

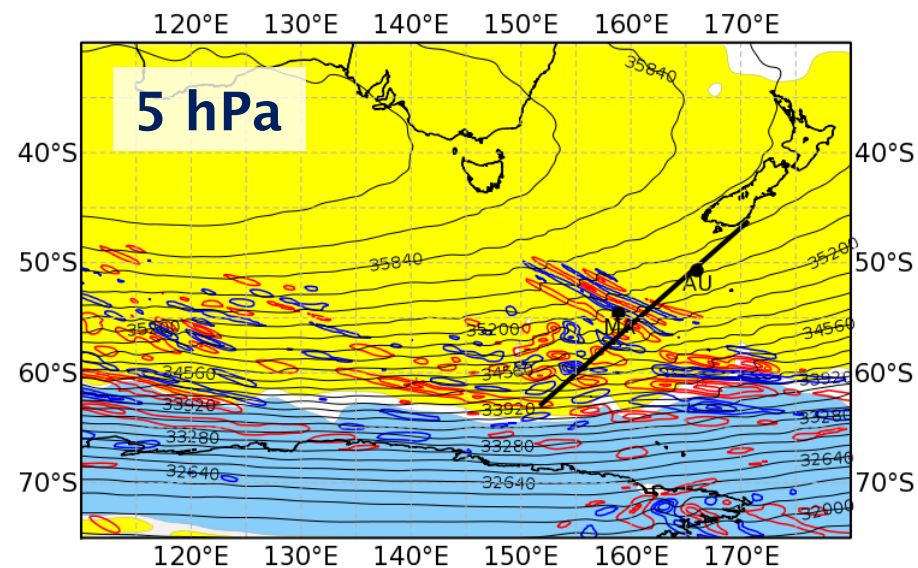
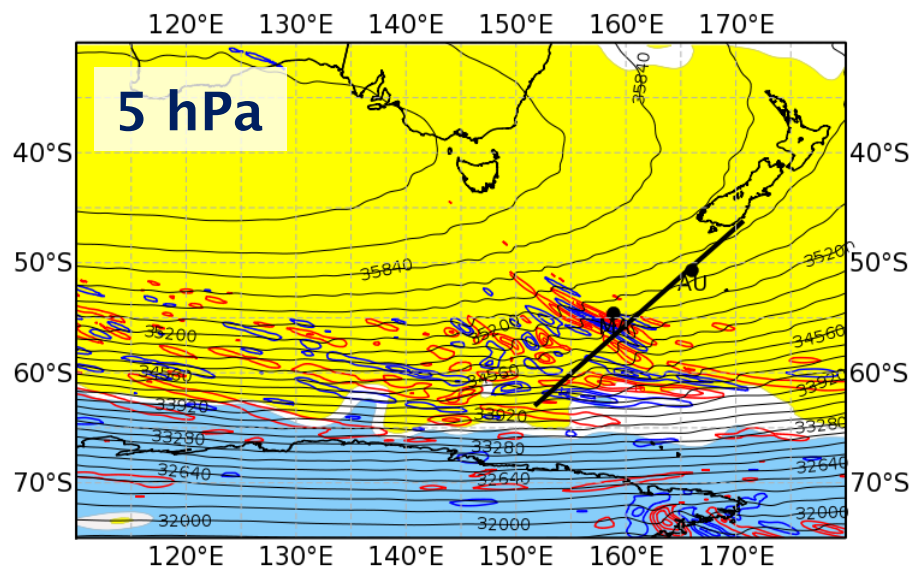




**06 UTC**

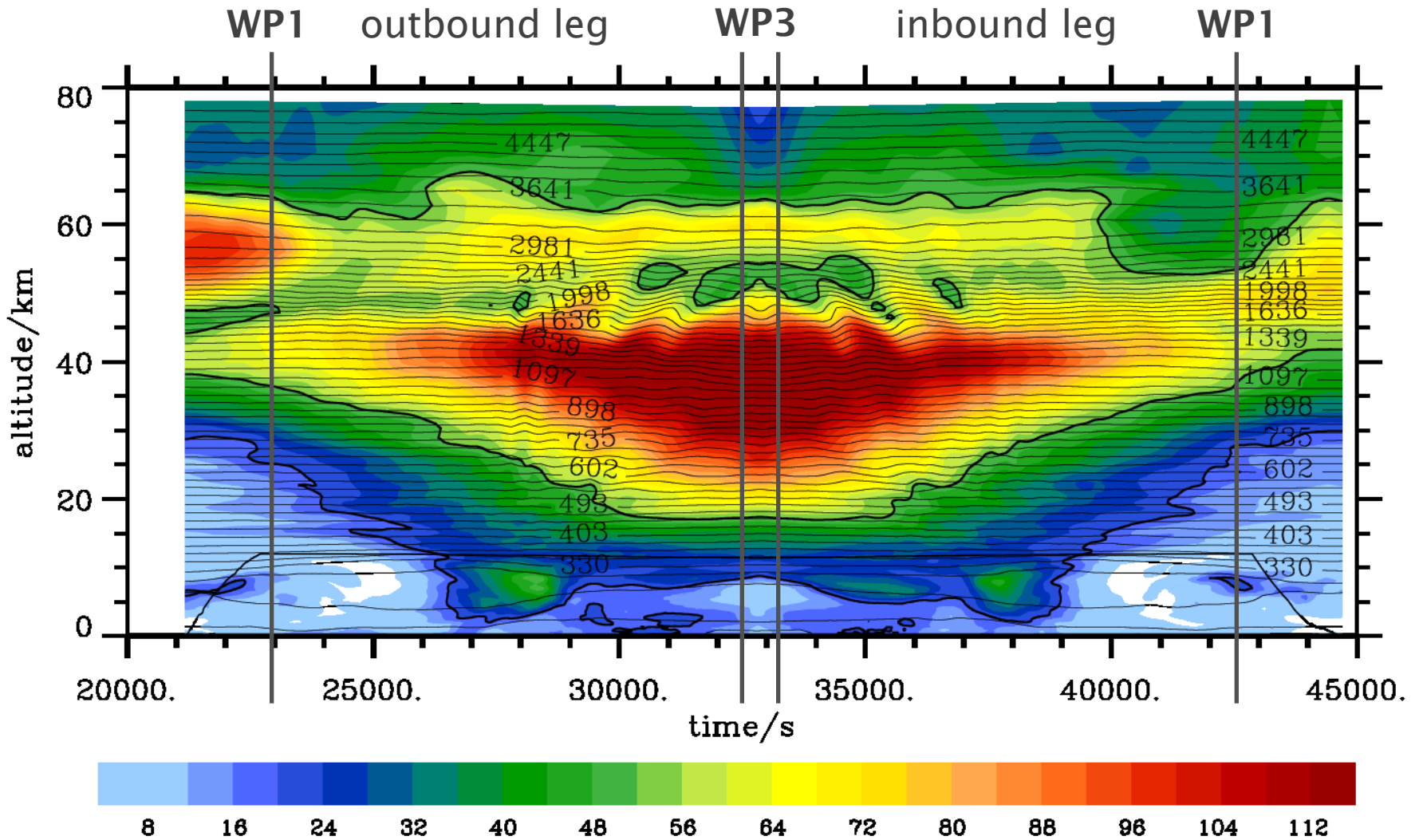
**18 July 2014**

**12 UTC**



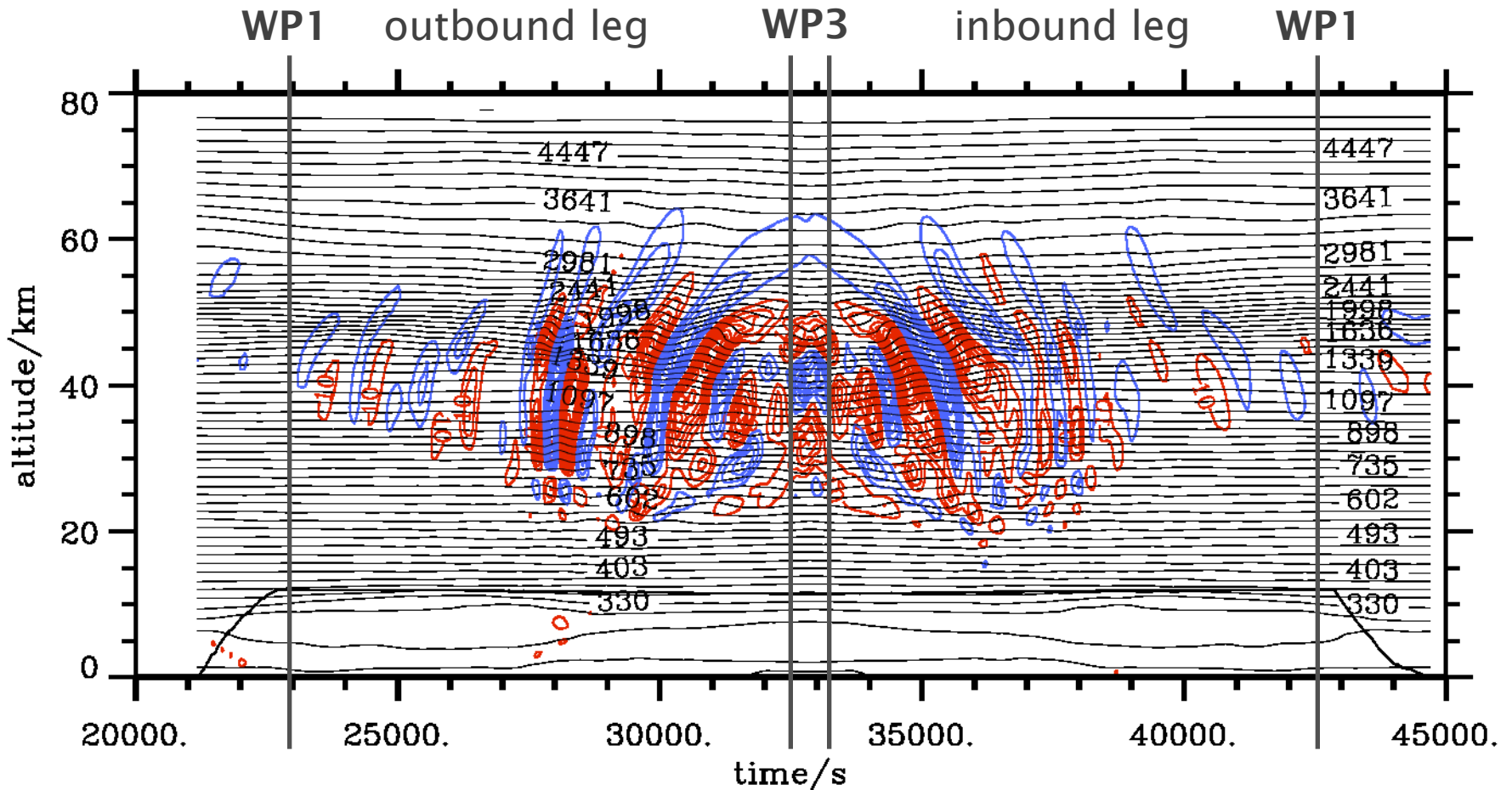


# Horizontal Wind (m/s) along RF25



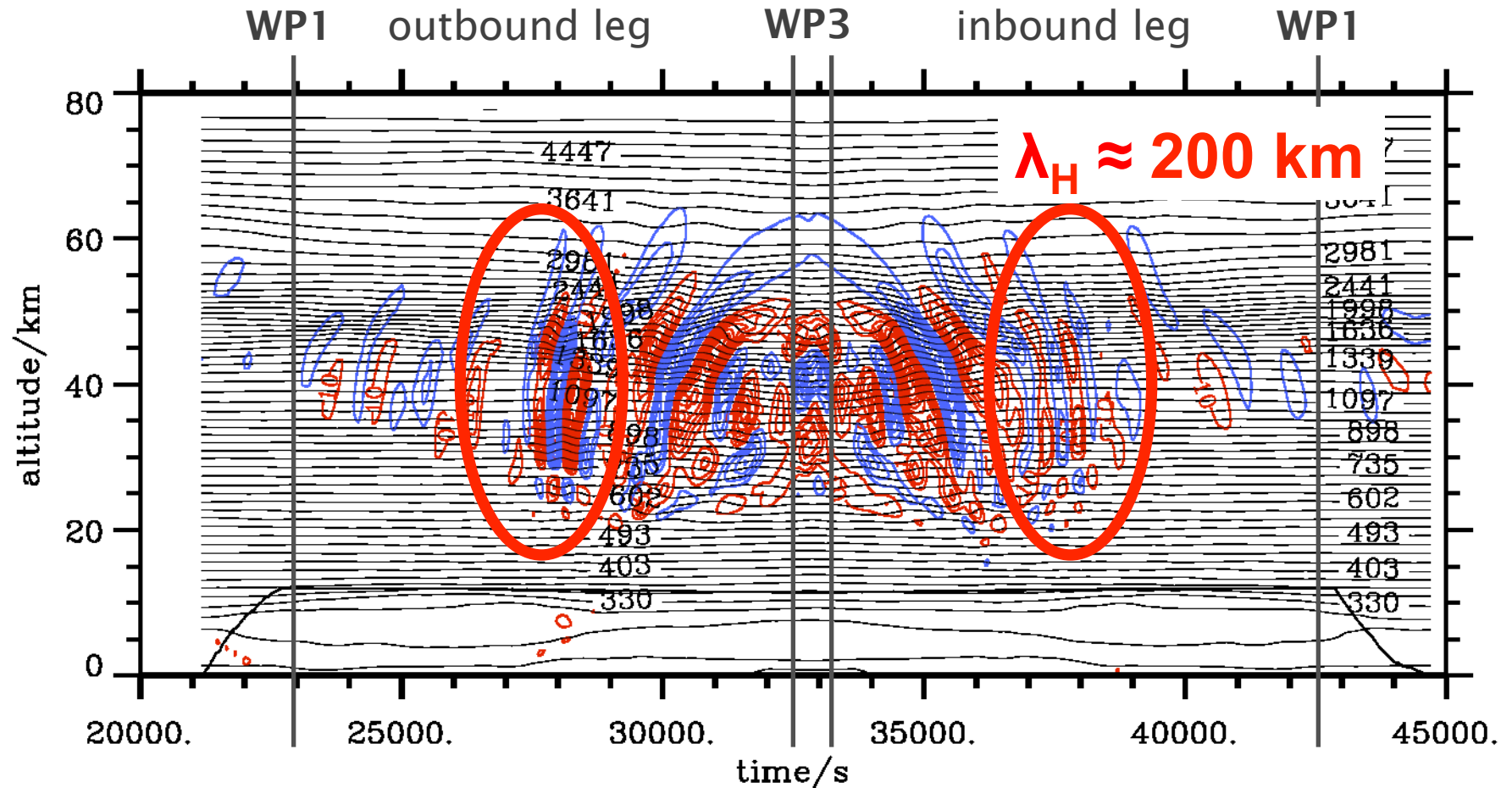
ECMWF T1279/L137 operational analyses (6 h) and 1 hourly high-resolution IFS predictions

# Vertical Wind (m/s) along RF25



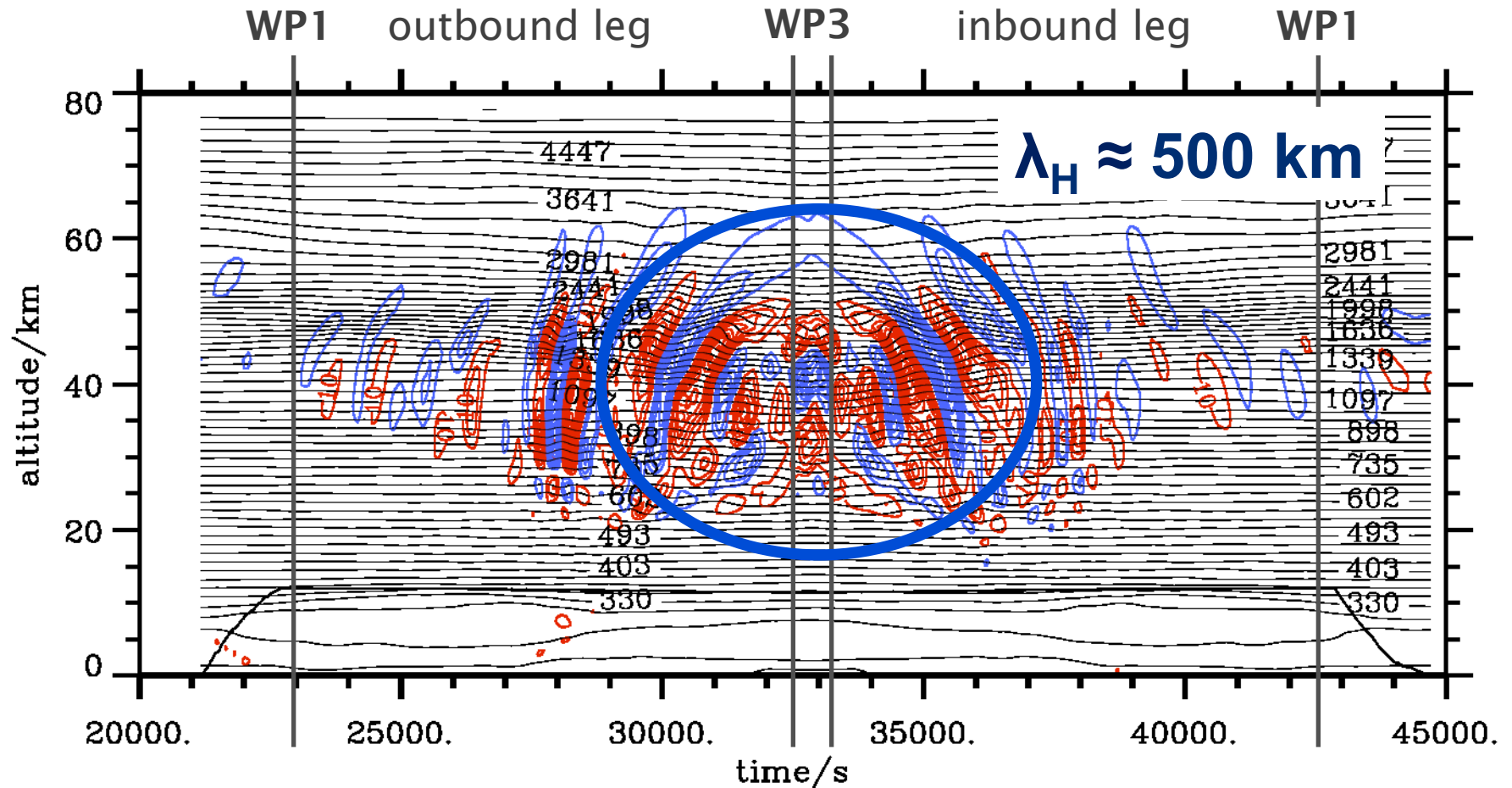
min/max w (z > 15 km):  $-85.9 \text{ cms}^{-1}$ ,  $105.2 \text{ cms}^{-1}$

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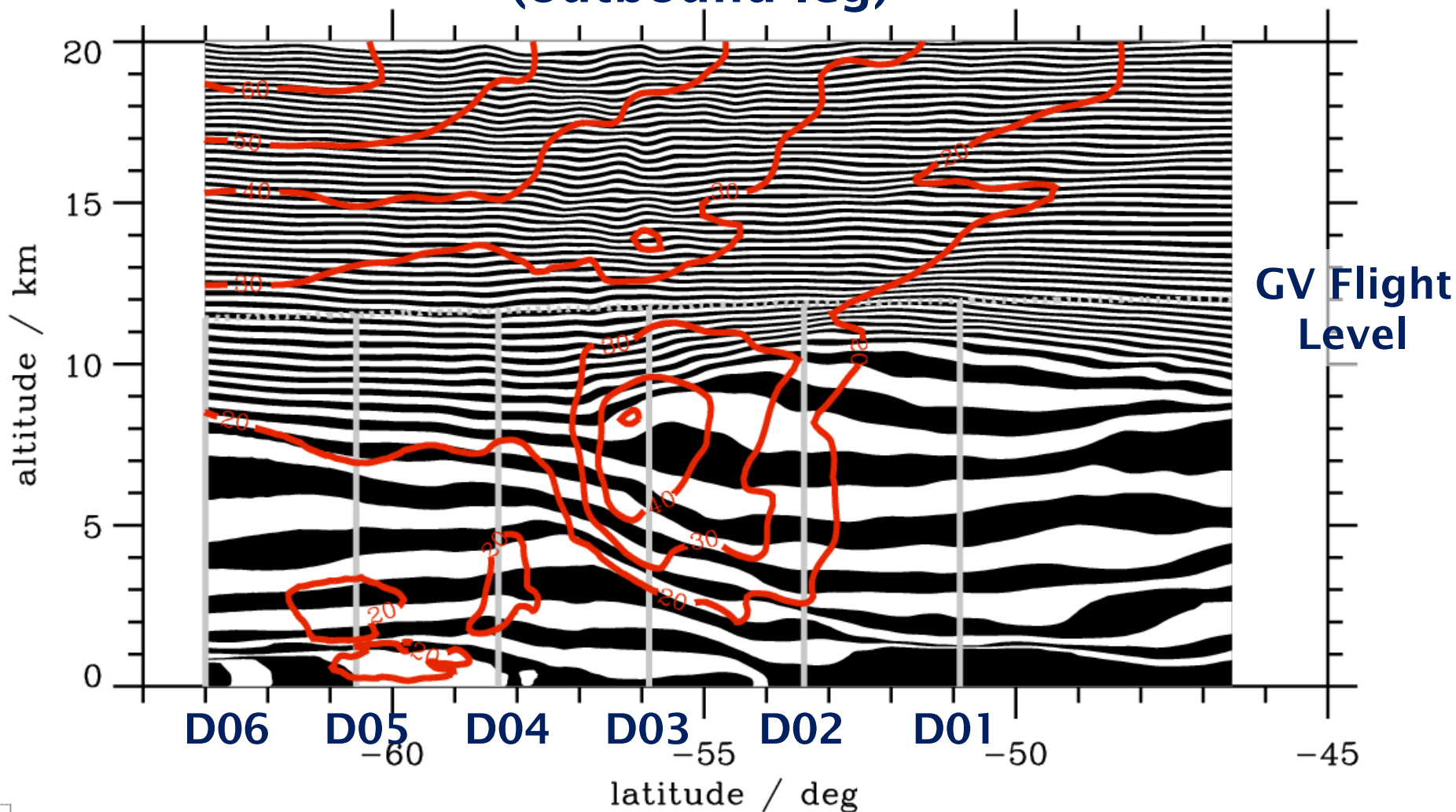


min/max w (z > 15 km):  $-85.9 \text{ cms}^{-1}$ ,  $105.2 \text{ cms}^{-1}$

# Potential Temperature (K, $\Delta\Theta = 2.5$ K) Horizontal Wind ( $\text{m s}^{-1}$ ) (ECMWF IFS) (outbound leg)

SOUTH

NORTH



# Absolute Temperature (K)

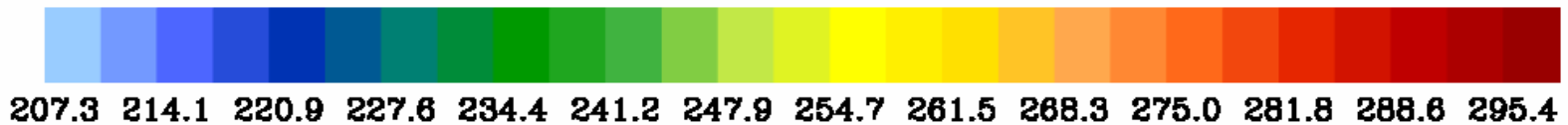
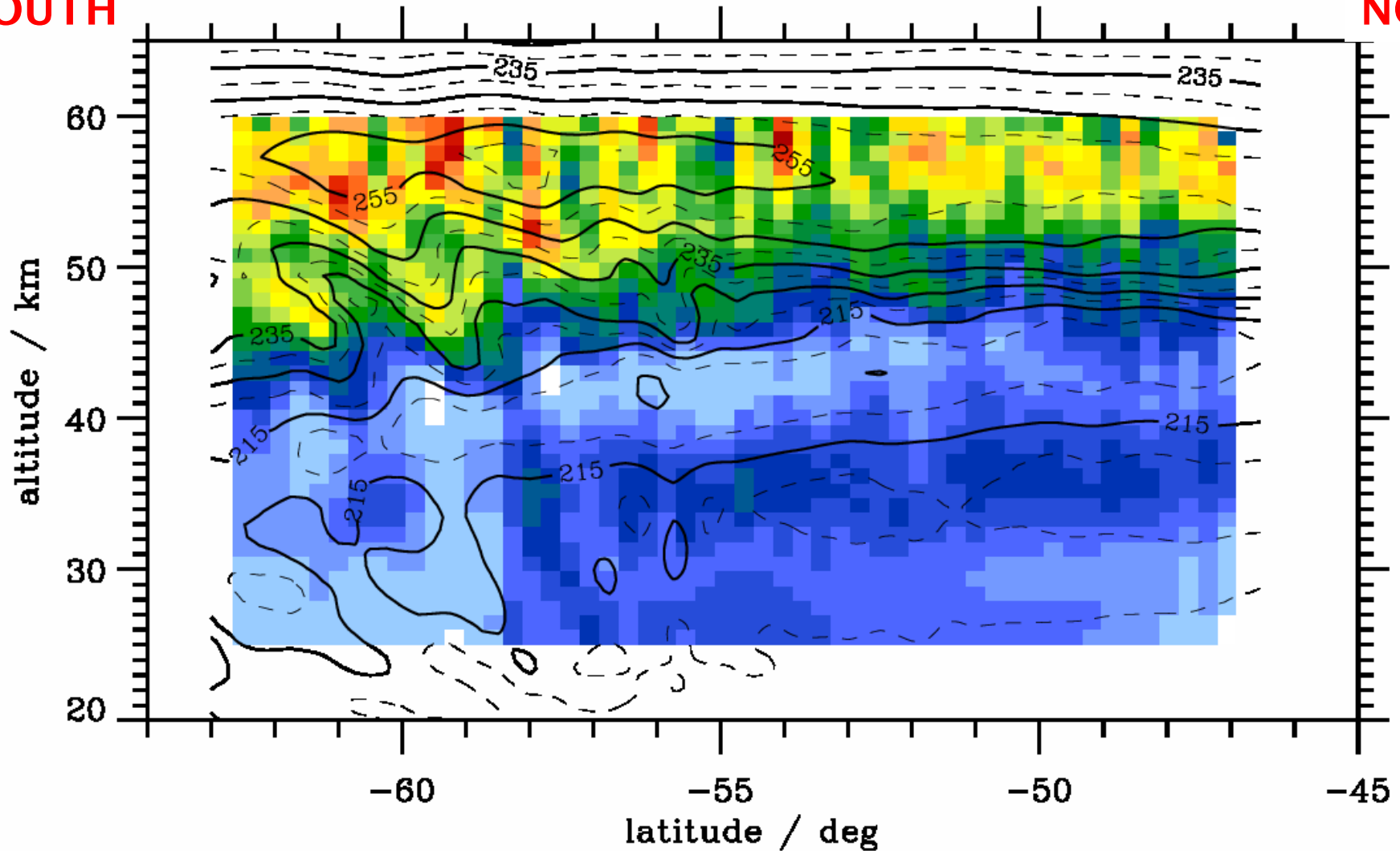
(GV Rayleigh Lidar and ECMWF)

# Outbound Leg

(06:23 - 09:03 UTC)

**SOUTH**

**NORTH**

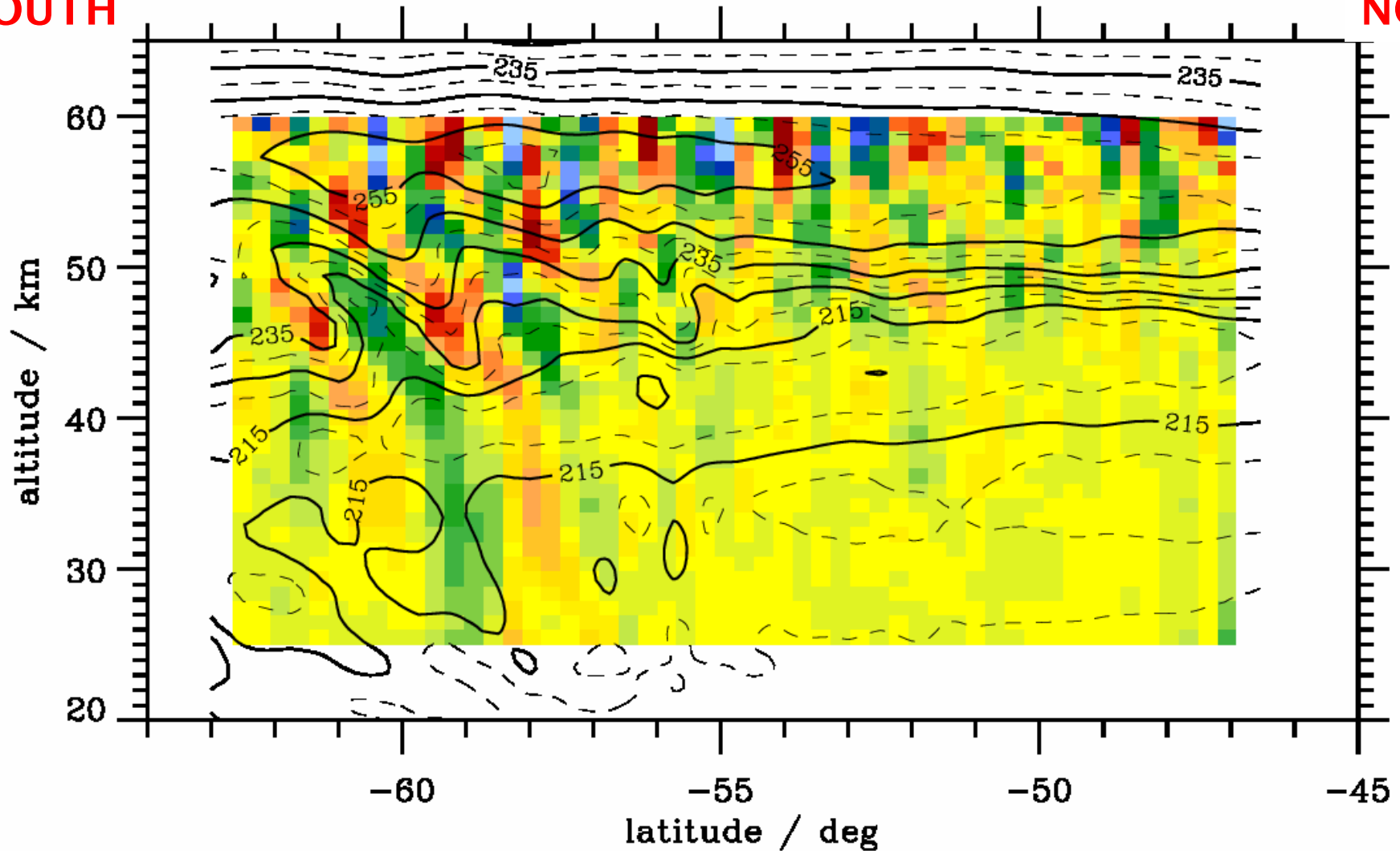


# Temperature Perturbation (Lidar) Outbound Leg

(Temperature: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



-22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26

# Temperature Perturbations (K)

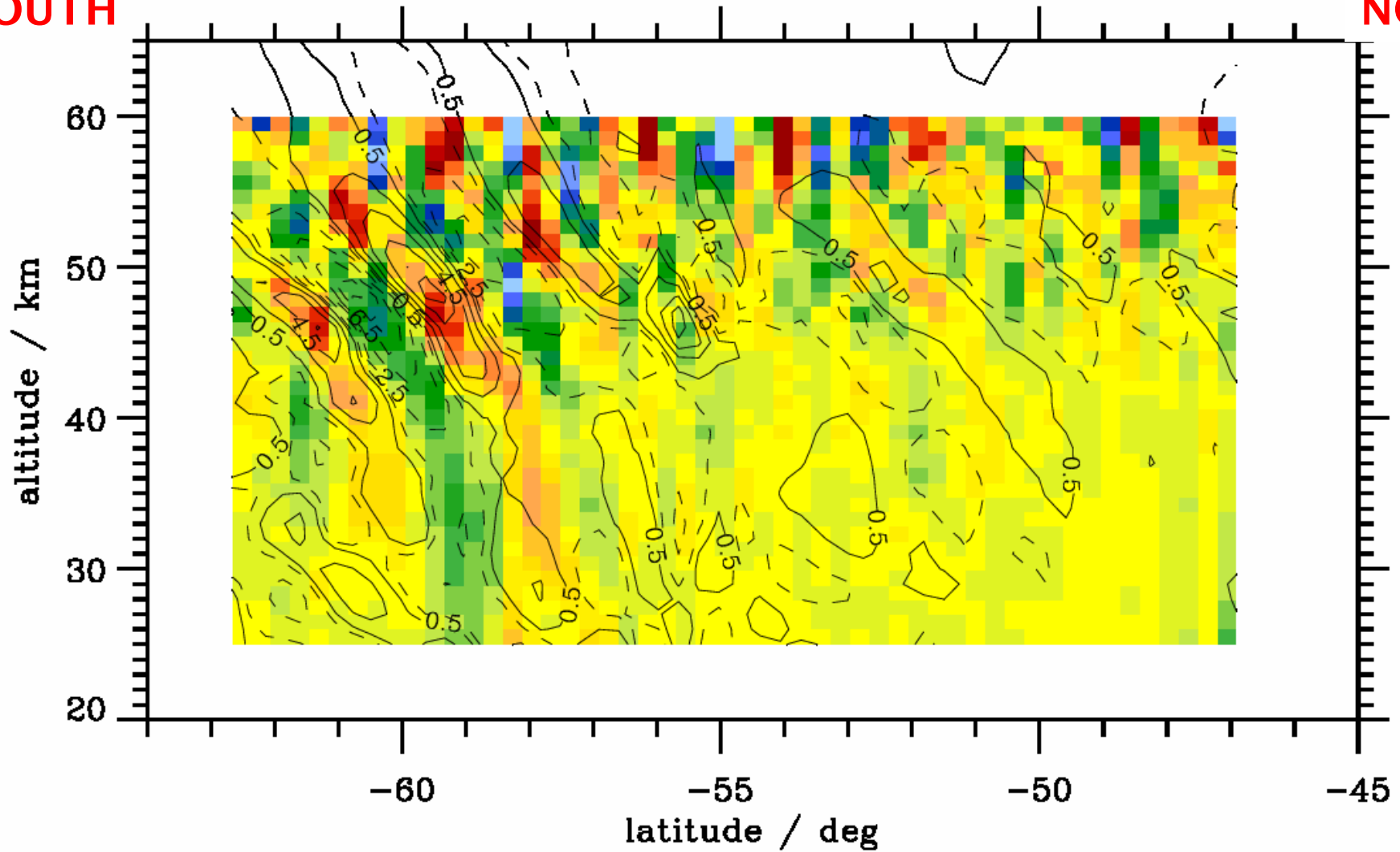
(Rayleigh Lidar and ECMWF)

## Outbound Leg

(06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



-22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26

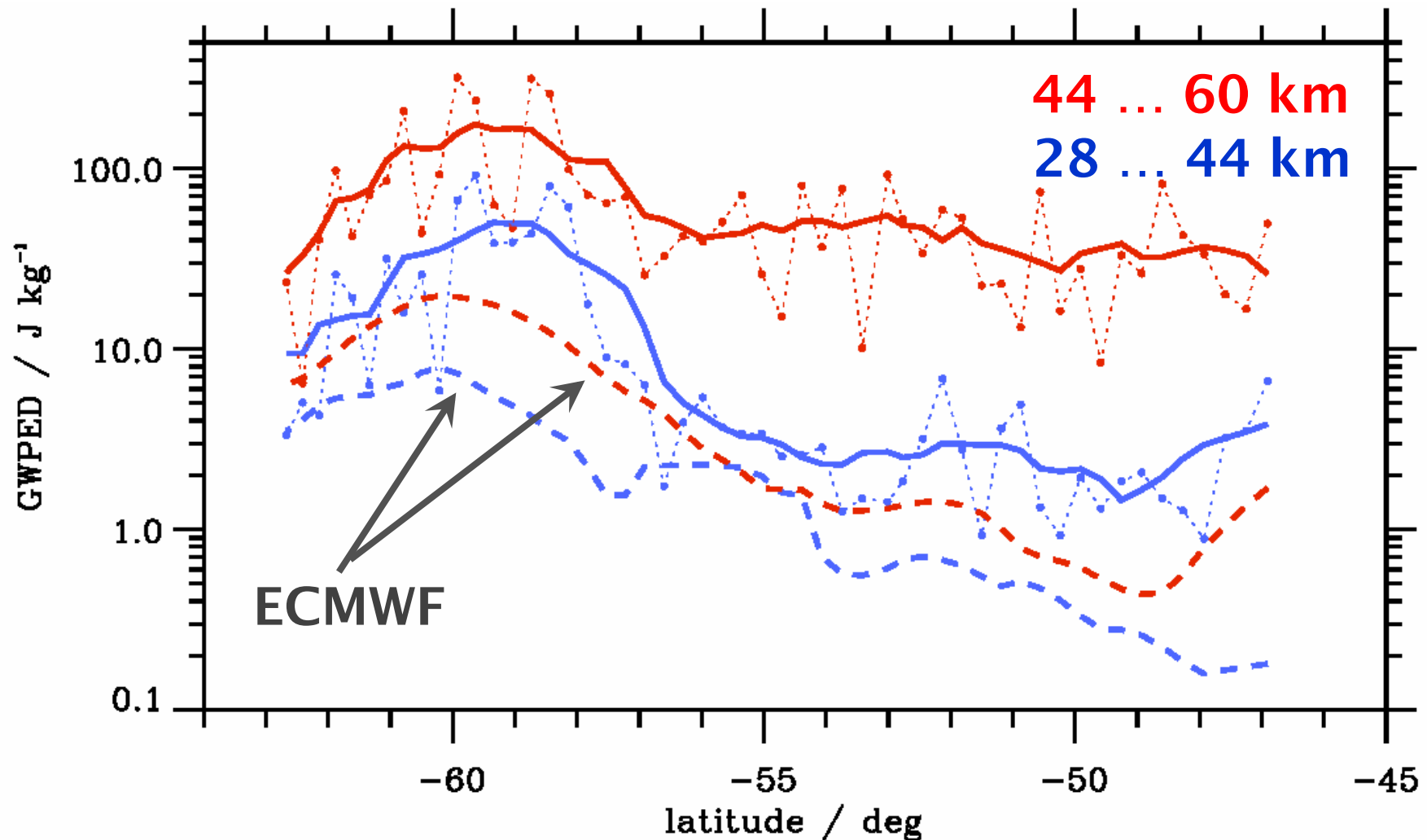




# Gravity Wave Potential Energy GV Rayleigh Lidar & ECMWF (outbound leg)

SOUTH

NORTH

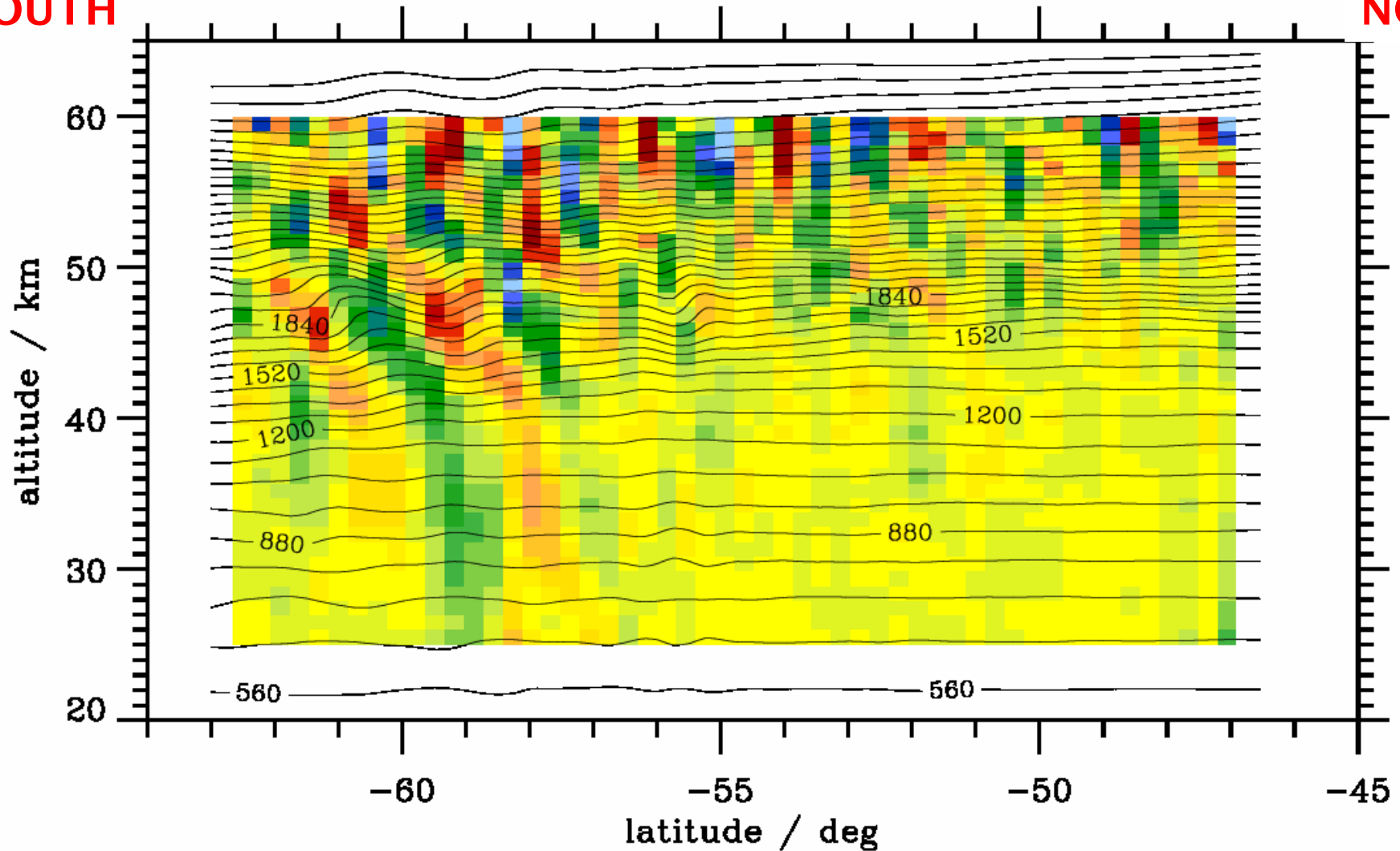


# Temperature Perturbation (Lidar) Outbound Leg

(Potential Temperature: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



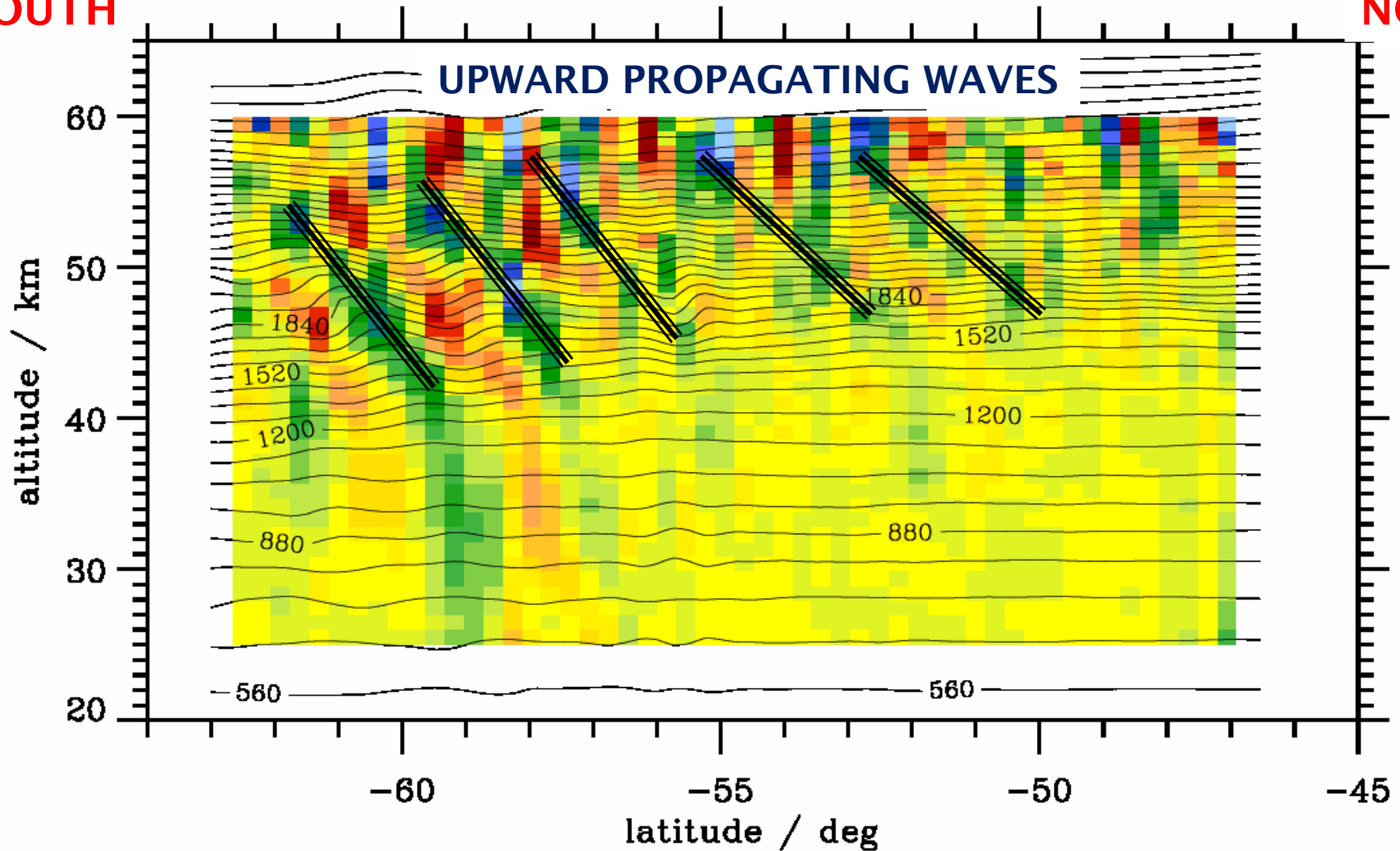
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(Potential Temperature: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



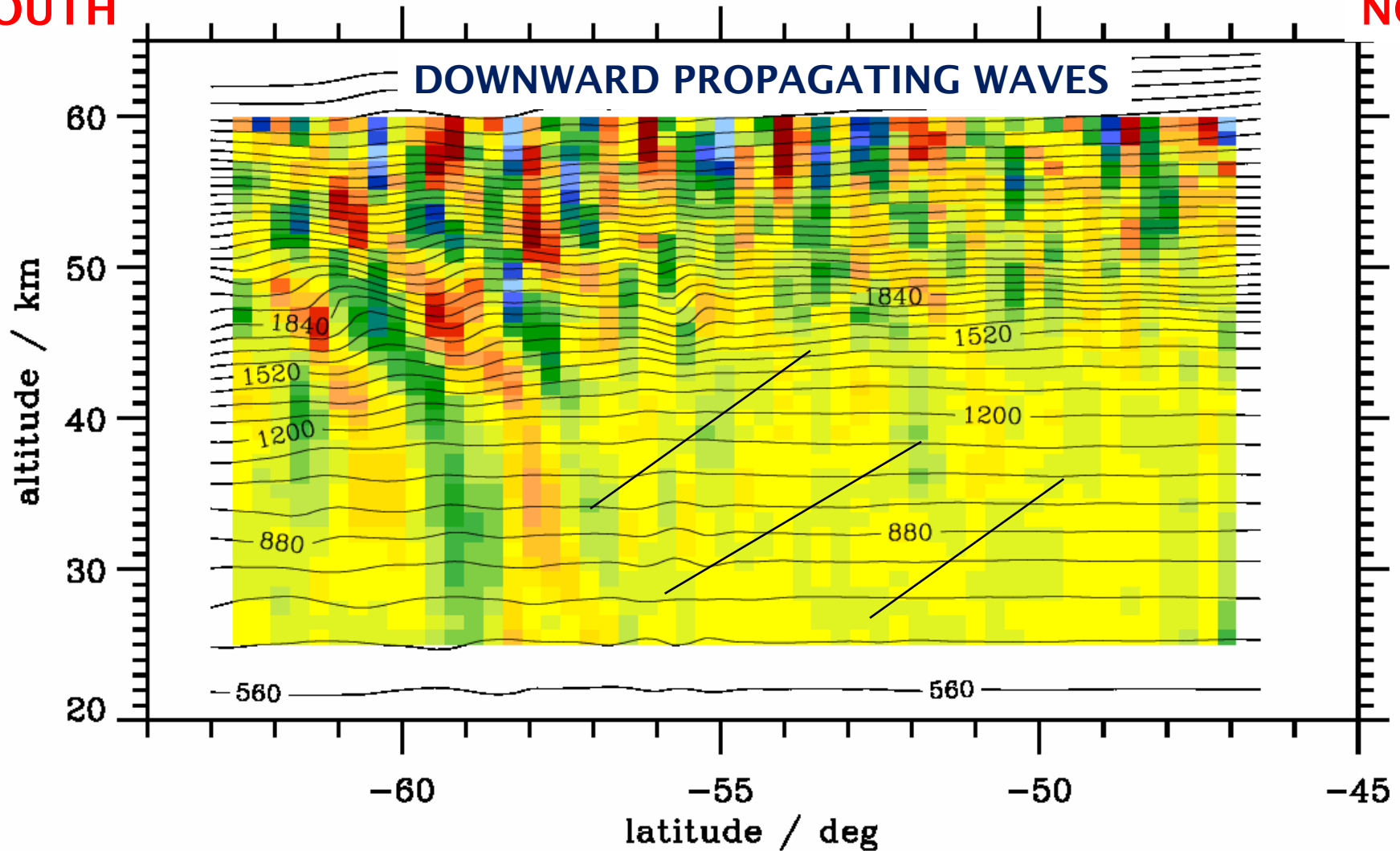
-22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26

# Temperature Perturbation (Lidar) Outbound Leg

(Potential Temperature: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



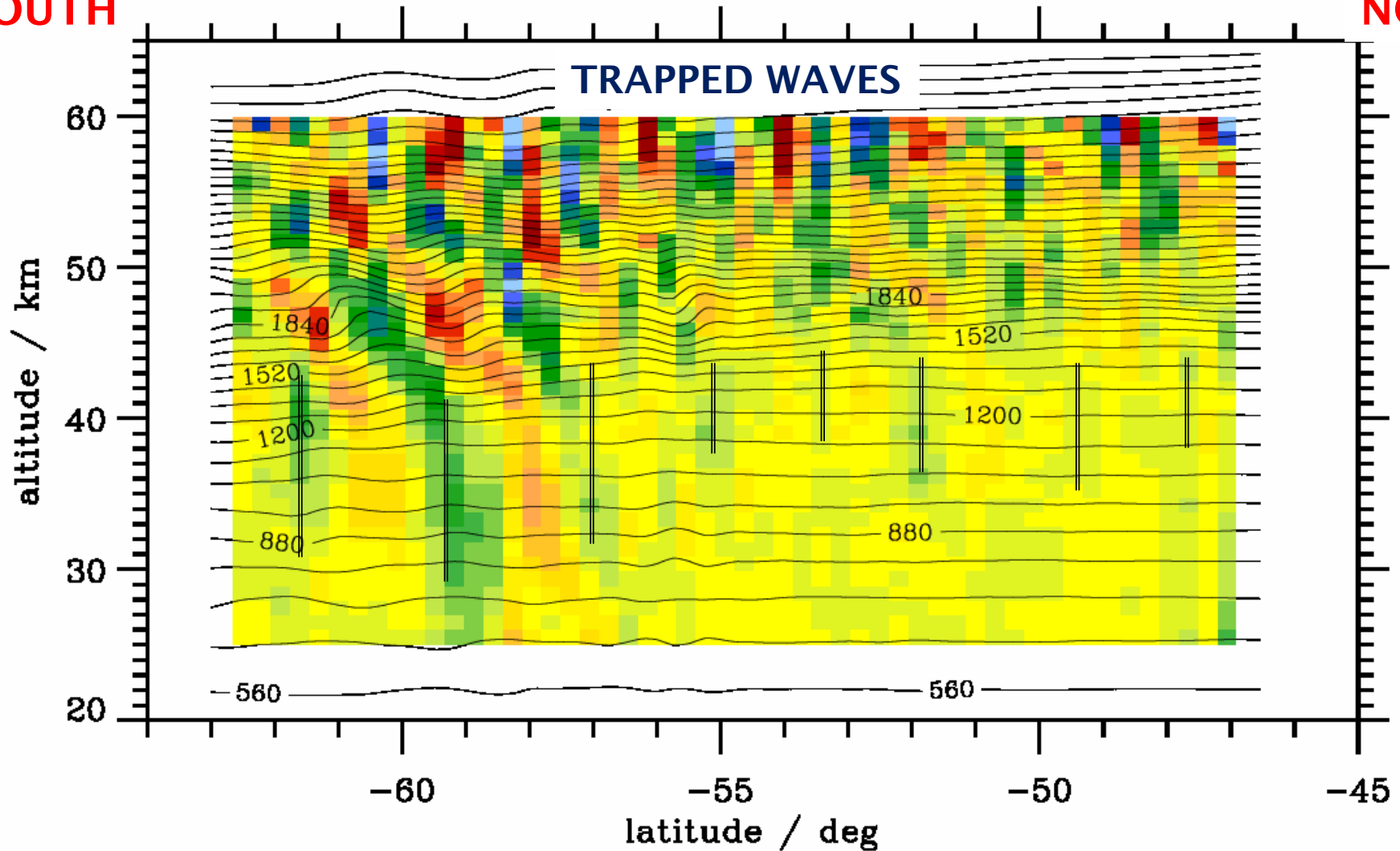
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# Temperature Perturbation (Lidar) Outbound Leg

(Potential Temperature: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



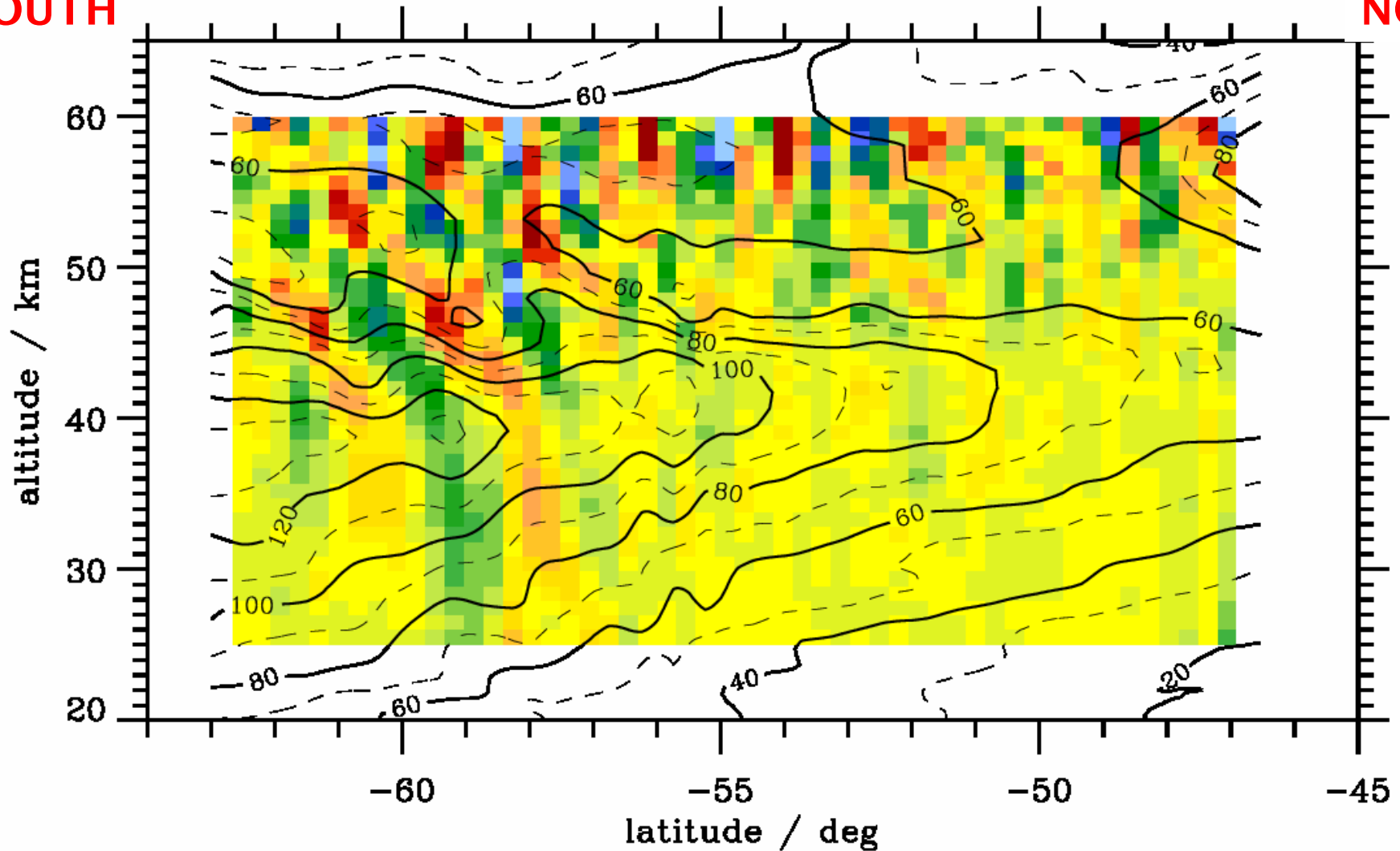
-22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26

# Temperature Perturbation (Lidar) Outbound Leg

(Horizontal Wind: ECMWF) (06:23 - 09:03 UTC)

**SOUTH**

**NORTH**



-22 -18 -14 -10 -6 -2 2 6 10 14 18 22 26

# 4. Inertia-Gravity Waves from PNJ

**MODES:** Normal-mode function representation of global 3-D data sets

-visualize the **balanced** and the **inertia-gravity wave circulations** of the ECMWF operational analyses (6 hourly operational analyses with about  $0.45^\circ \times 0.45^\circ$  resolution on 137 vertical hybrid levels)

-so far: only horizontal wind interpolated on selected pressure levels

## References

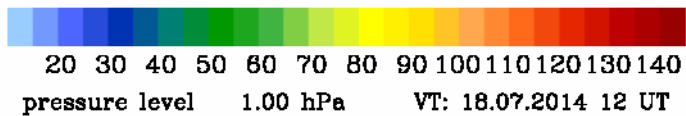
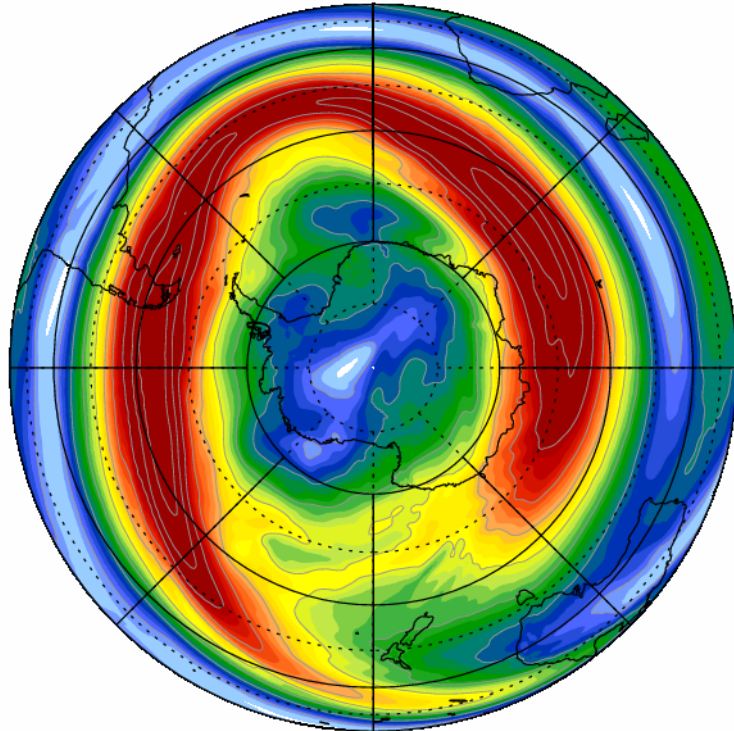
Žagar, N., Kasahara, A., Terasaki, K., Tribbia, J., and Tanaka, H.: Normal-mode function representation of global 3-D data sets: open-access software for the atmospheric research community, *Geosci. Model Dev.*, **8**, 1169-1195, doi:10.5194/gmd-8-1169-2015, 2015.



# 18 July 2014 12 UTC

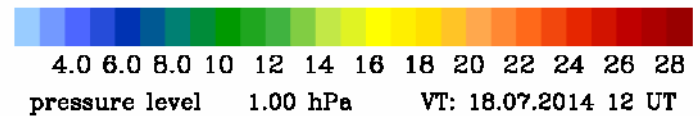
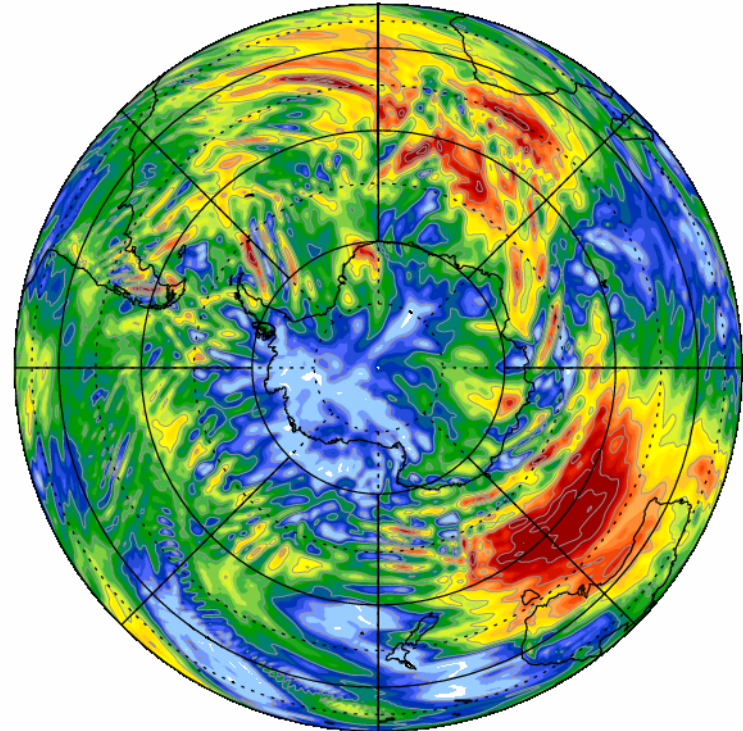
# 1 hPa

Horizontal Wind /  $\text{m s}^{-1}$



## balanced

Horizontal Wind /  $\text{m s}^{-1}$

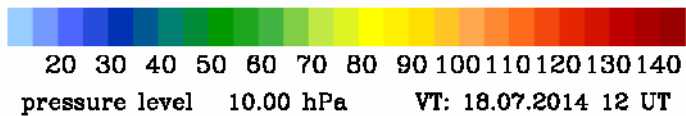
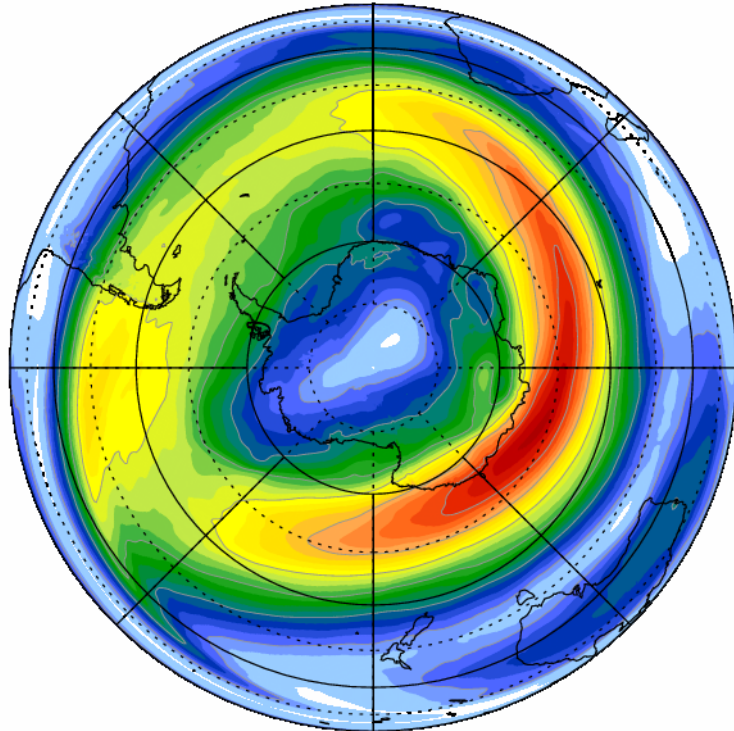


## IGW circulations

# 18 July 2014 12 UTC

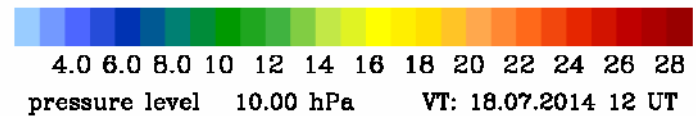
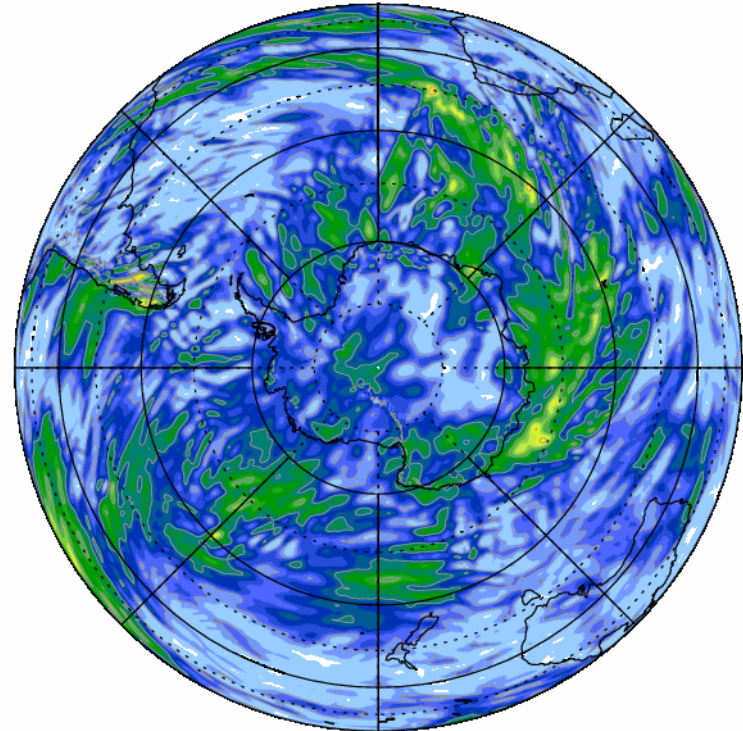
# 10 hPa

Horizontal Wind /  $\text{m s}^{-1}$



## balanced

Horizontal Wind /  $\text{m s}^{-1}$



## IGW circulations

# 5. Conclusions

- observational evidence of a non-orographic stratospheric wave source in the vicinity of the polar night jet  $\rightarrow$  potential contribution to missing gravity wave drag near  $60^\circ\text{N}$ !
- complicated stratospheric gravity wave pattern impacted by tropospheric and dynamics and by stratospheric planetary wave activity
- ECMWF analysis agree reasonably well with observations and MODES proves observed gravity waves are inertia-gravity waves



**Thank you !**