

# Deep Stratospheric Gravity Waves Imaged from Satellites in Support of DEEPWAVE Science

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*we gratefully acknowledge support for this research (leveraging participation in DEEPWAVE science) by:*

**1. The Office of Naval Research (ONR)** *through NRL's base 6.1 research program*

**2. NASA**, *through a research grant under AO NH09ZDA001N-TERRAQUA: The Science of Terra and Aqua*

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- 1. Gravity-Wave Detection in Nadir Radiance Scene*
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# Satellite GW Product: Executive Summary

- Gravity waves (GWs) are an “accidental detection” in nadir radiances
- First noted ~5-7 years ago as a result of advances in nadir sounding technology, particularly:
  - Improved footprint (horizontal) resolution ( $\sim 100$  km  $\rightarrow$   $\sim 10$  km): horizontal wavelength
  - Improved precision and reduced noise in radiometric detection channels (NEDTs  $\sim 0.1$ - $0.5$  K): wave amplitude
  - Hyperspectral imagery (more channels  $\rightarrow$  height profiles)
- We have crude forward RT models of GW detection in nadir imagery
  - Partial detection only, and most GWs are not observed at all
  - Fails in the troposphere due to cloud moisture contamination
  - GW detectability changes as background winds vary, making separation of geophysical and instrumental signals tricky



# Variation of Gravity-Wave Vertical Wavelength with Winds

$$\lambda_z = \frac{2\pi |c - \bar{U} \cos(\varphi - \phi)|}{N} \propto \bar{U}$$

$\varphi$  wind vector azimuth

$\phi$  wave vector azimuth

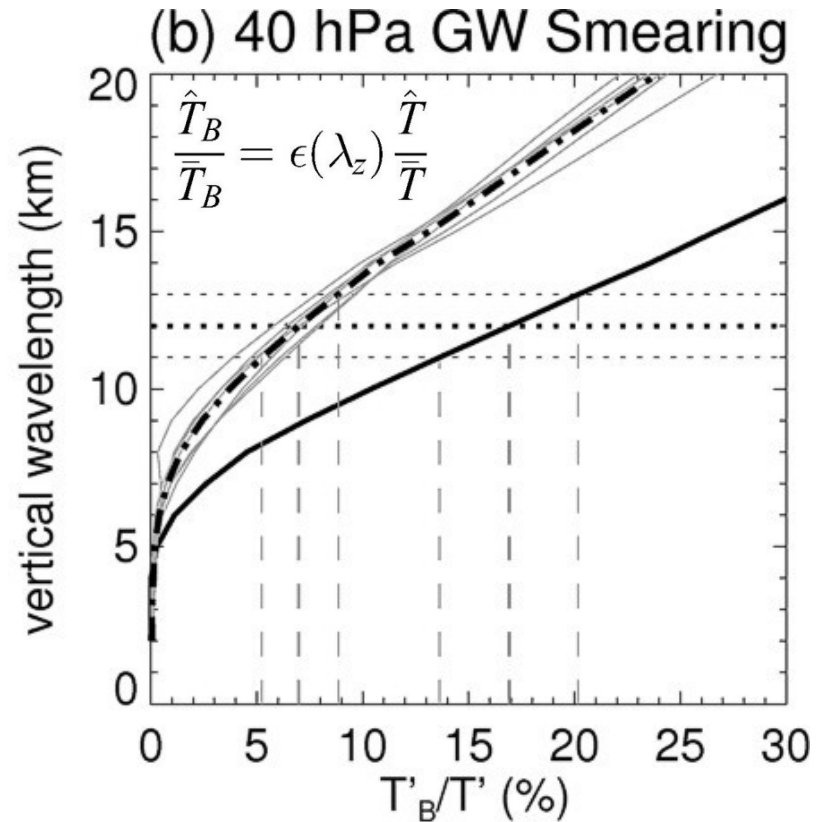
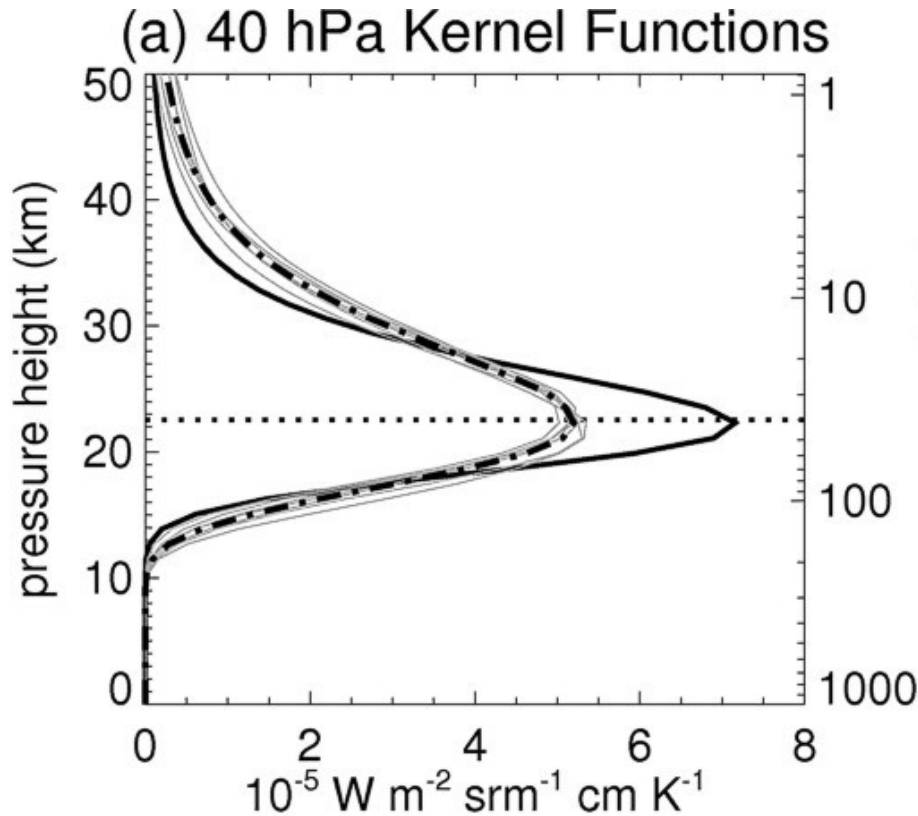
$\lambda_z$  gravity-wave vertical wavelength

$c$  gravity-wave phase velocity ( $c \approx 0$ )

$N$  background buoyancy frequency

$\bar{U}$  background wind speed

# AIRS 40 hPa Radiance Channels



AIRS channels 64, 88, 90, 94, 100, 106 & 118 ( $665.015\text{--}678.839\text{ cm}^{-1}$ )

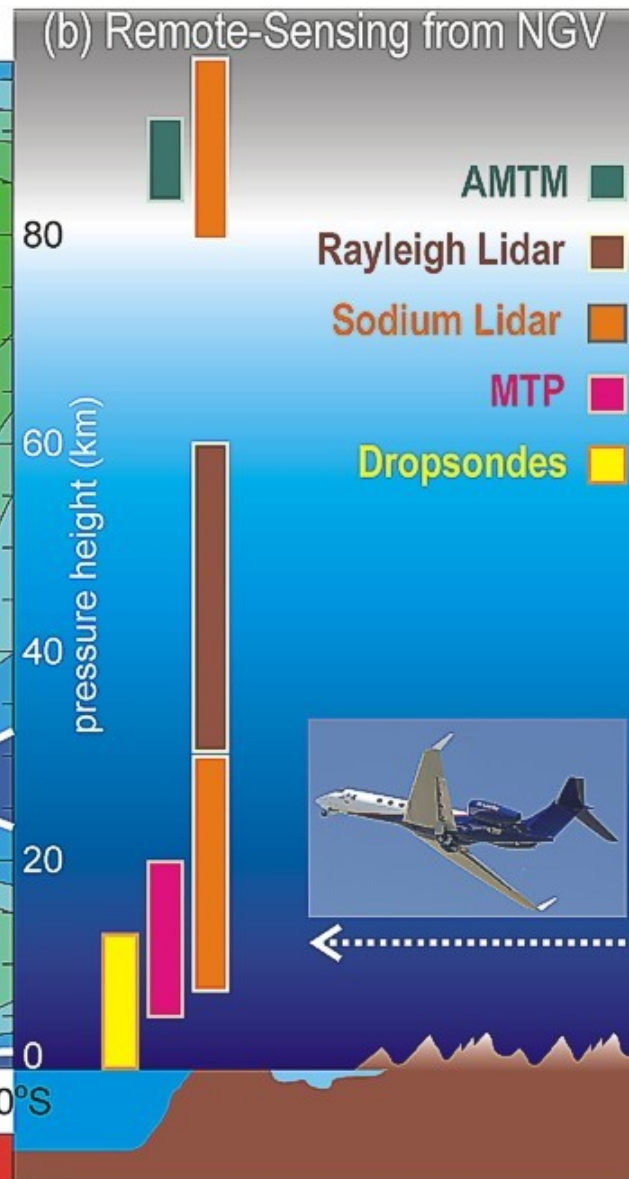
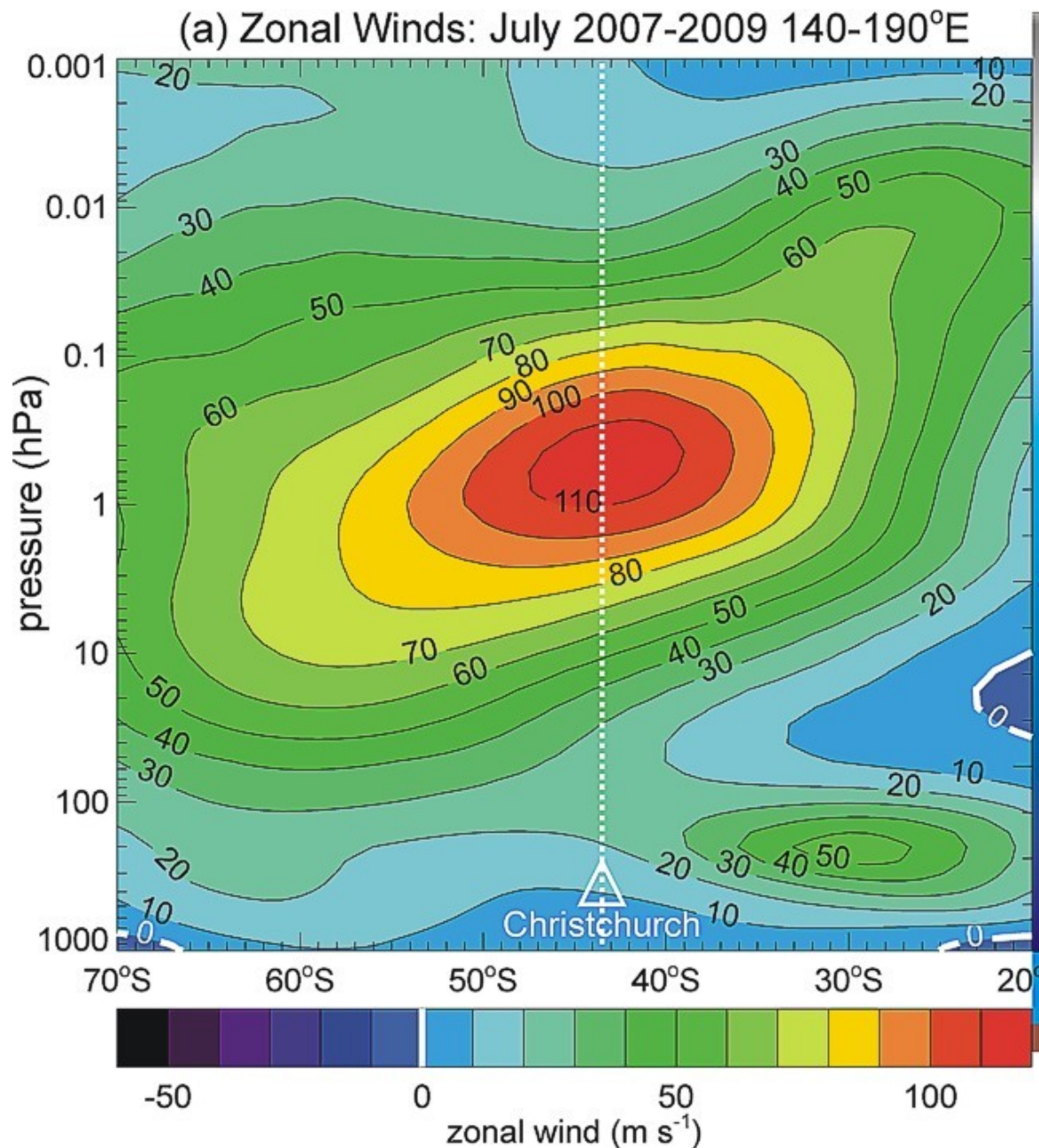
———— Individual Channel Radiances 64,...,118

- - - - - Mean Channel Radiance 64,...,118

AIRS channel 71 ( $666.773\text{ cm}^{-1}$ ).

————

see Hoffmann and Alexander (JGR, 2009)  
Eckermann et al. (GRL 2009)



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- 1. Gravity-Wave Detection in Nadir Radiance Scene*
- 2. Pre DEEPWAVE Climatologies*
- 3. Proof-of-Concept Nowcasting/Validation during DEEPWAVE Practice Field Phase*
- 4. Science Motivation and Goals*

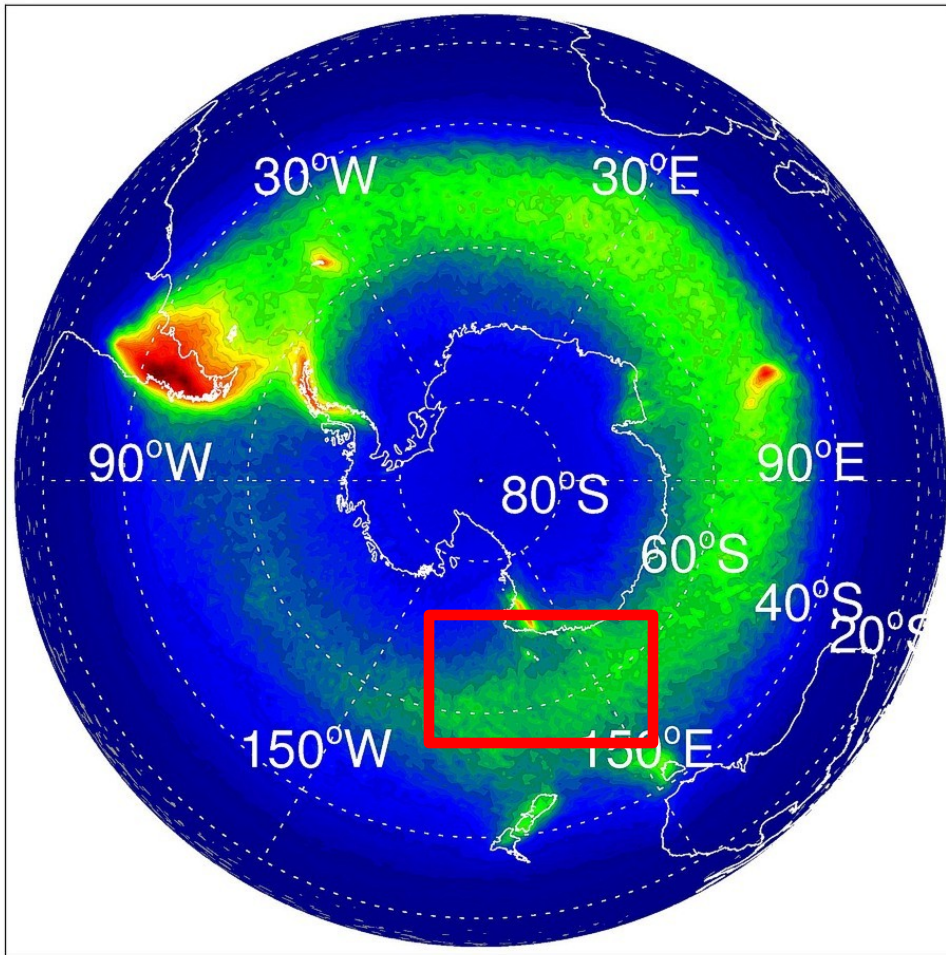
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## RMS AIRS Radiance: 7 hPa



0.135 0.237 0.340 0.442 0.545 0.647 0.750  
K

## Hemispheric Perspective

- Broad band of enhanced variance over Southern Ocean
- Clearly nonorographic sources
- Well correlated with midlatitude spiral jet

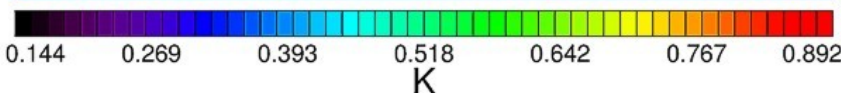
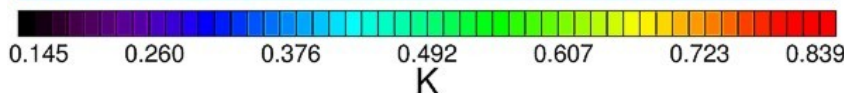
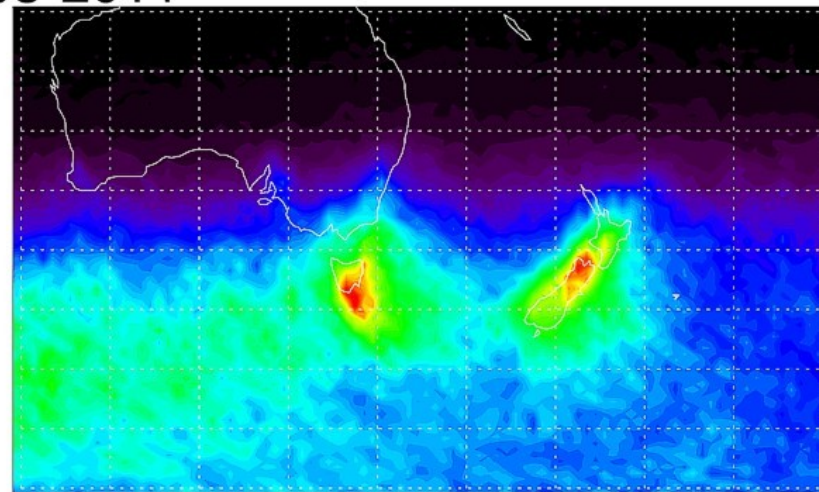
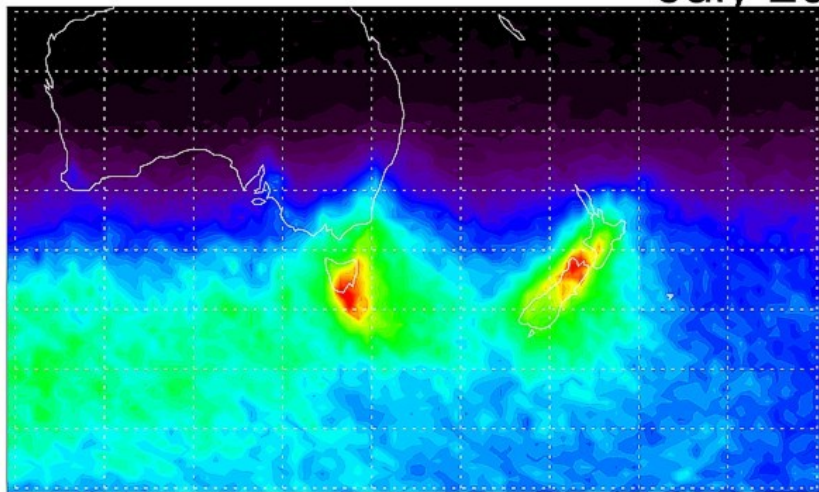
***Hendricks et al. J. Atmos. Sci., in press, 2014.***

# Greater Australia/New Zealand Region

Asc+Des 2 hPa

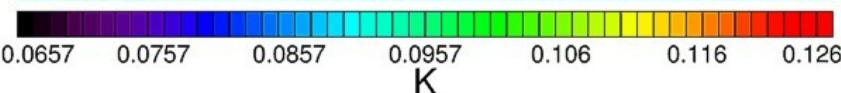
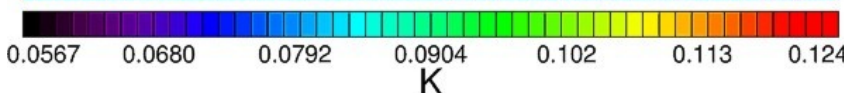
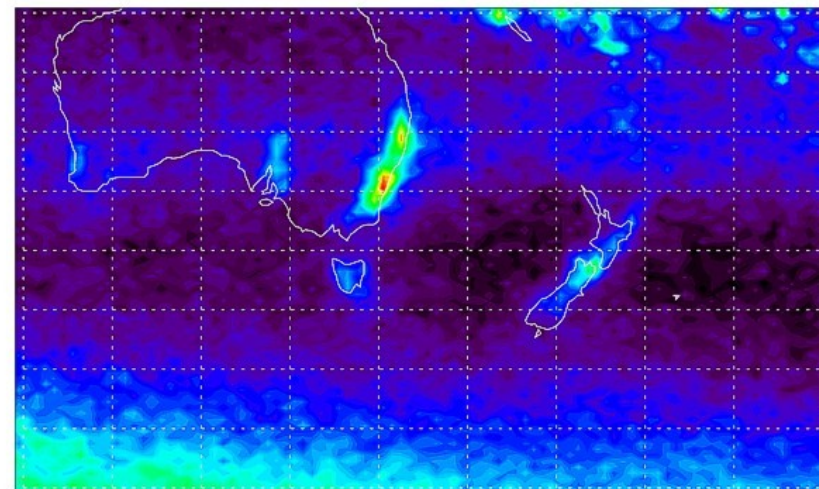
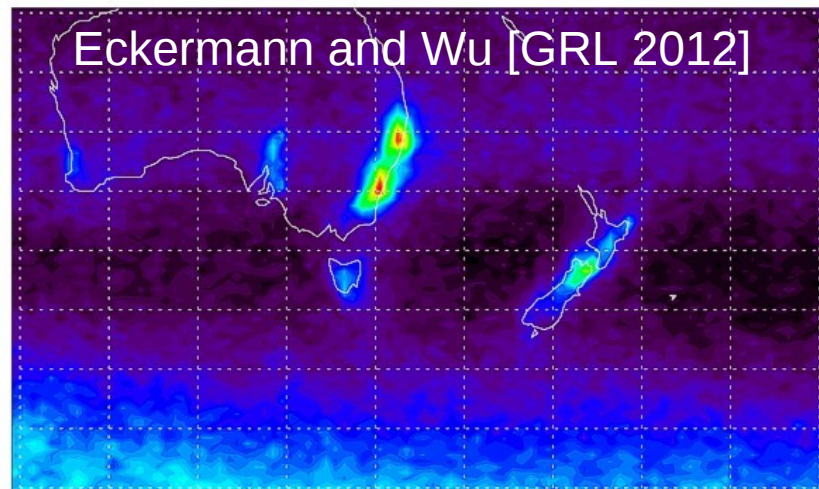
July 2003-2011

Asc+Des 2.5 hPa



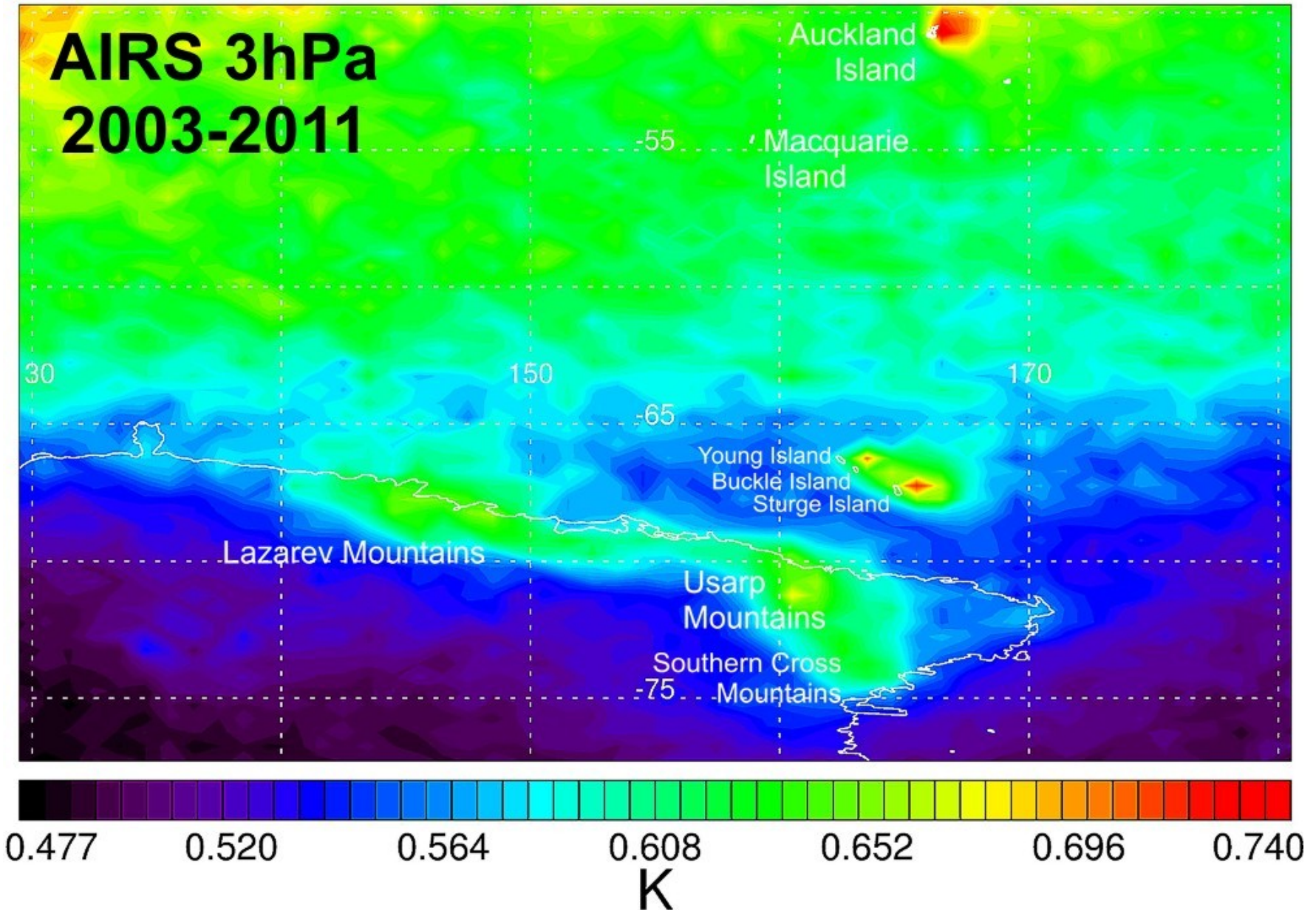
Asc+Des 80 hPa

Asc+Des 100 hPa

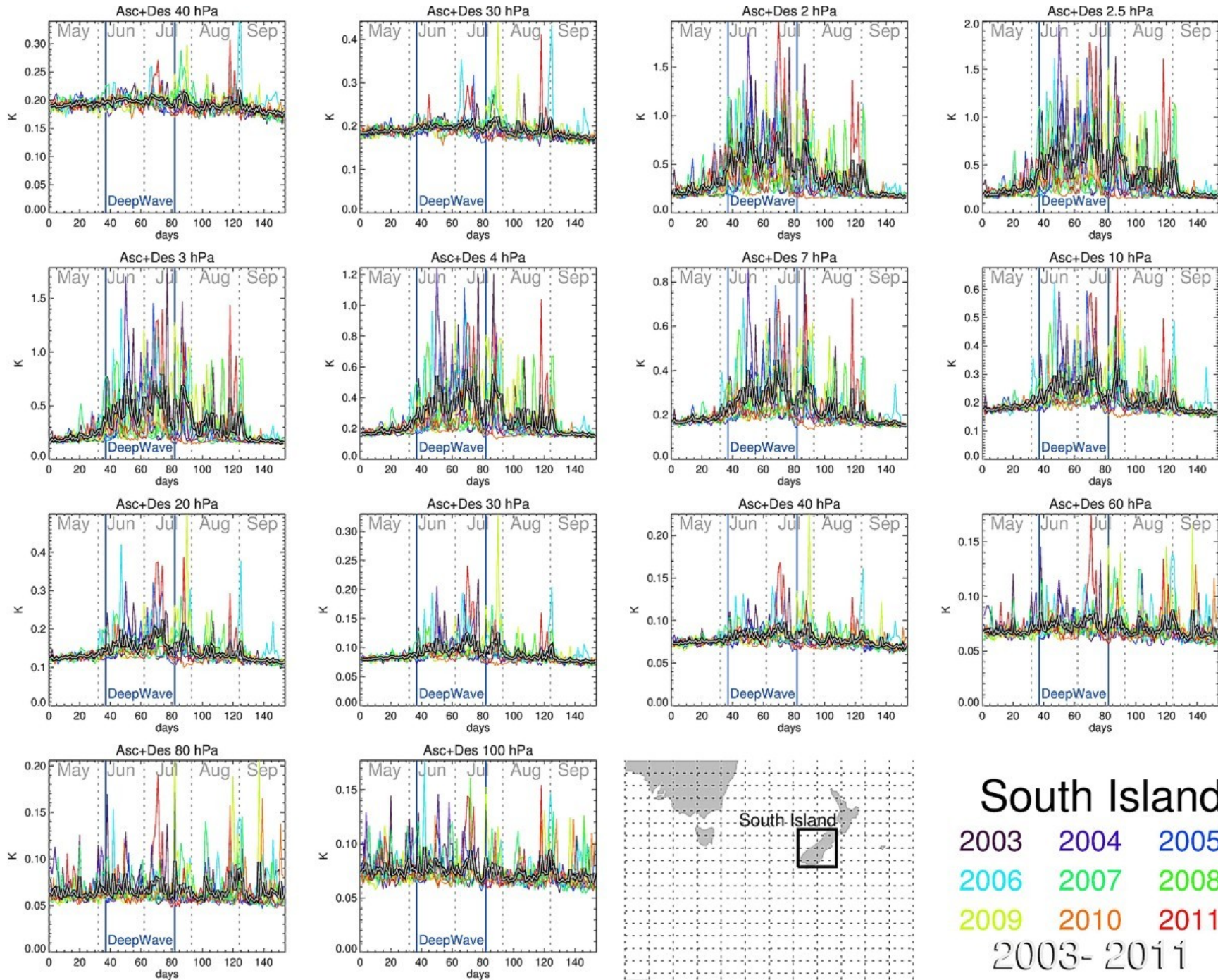




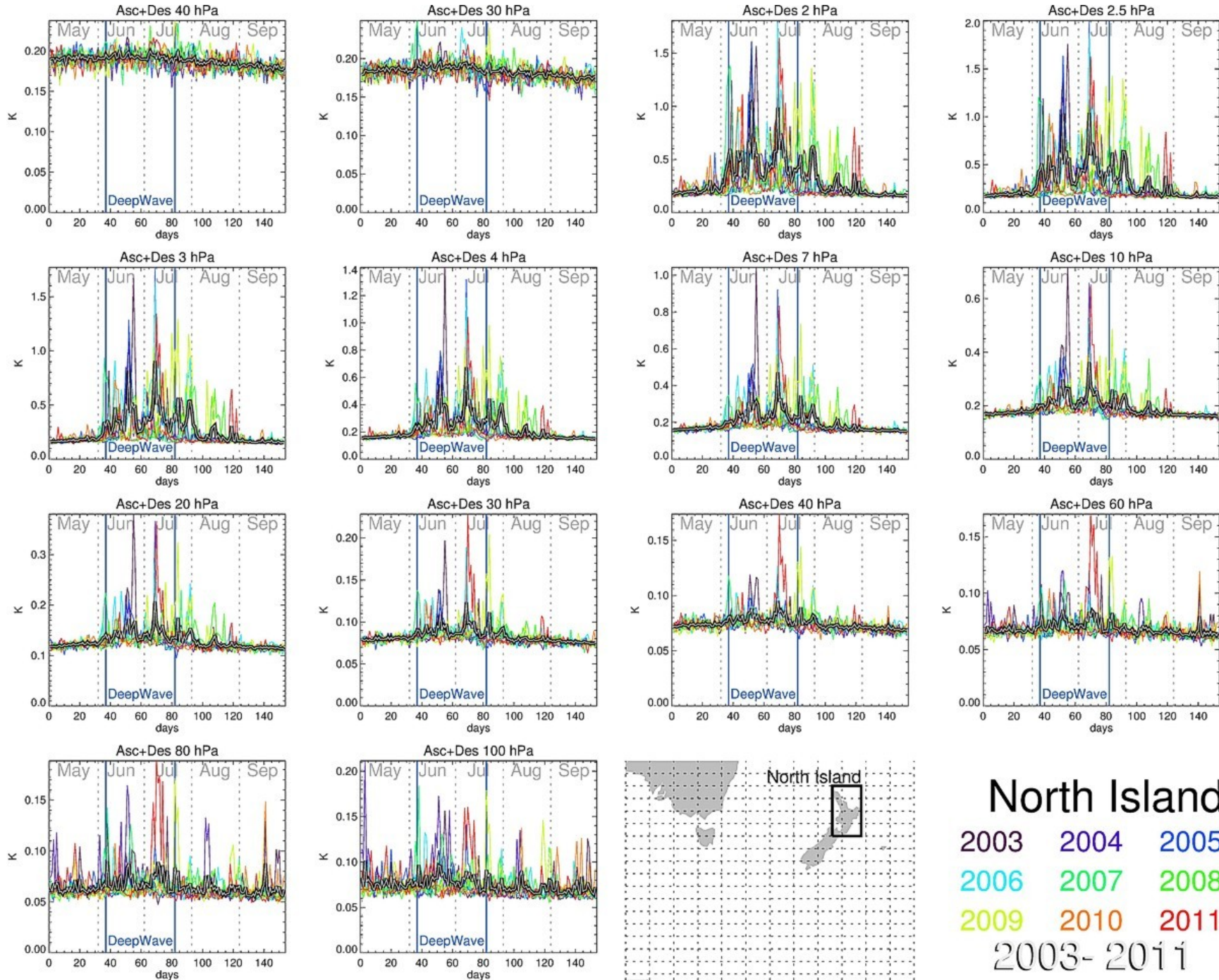
# Southern Ocean to Antarctica









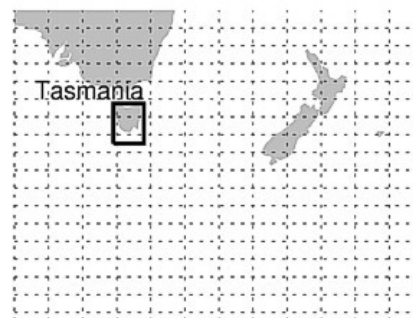
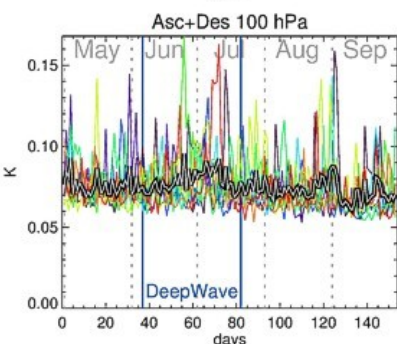
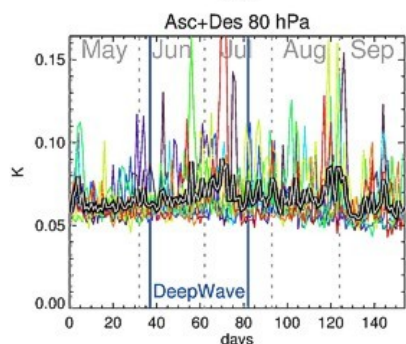
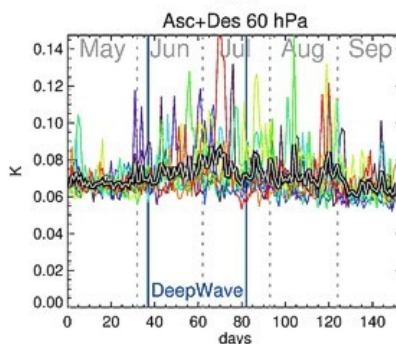
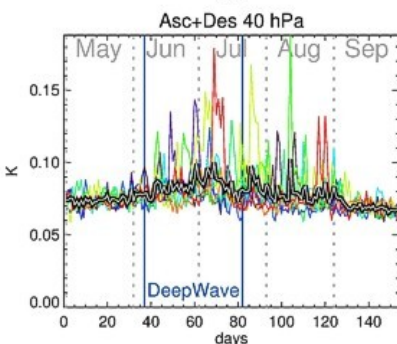
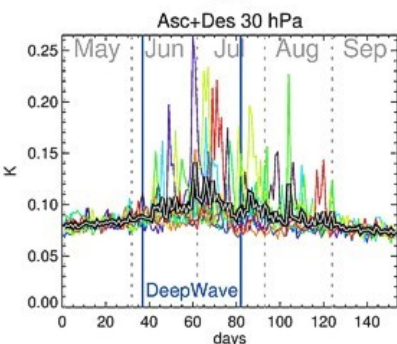
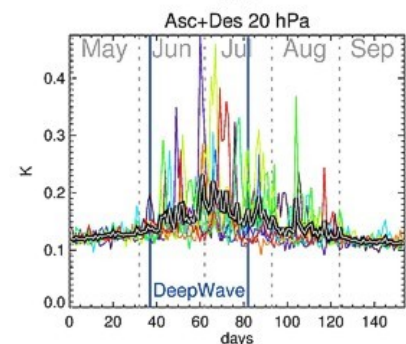
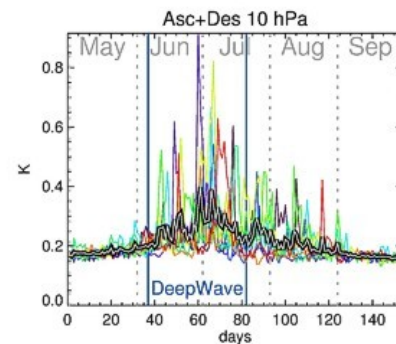
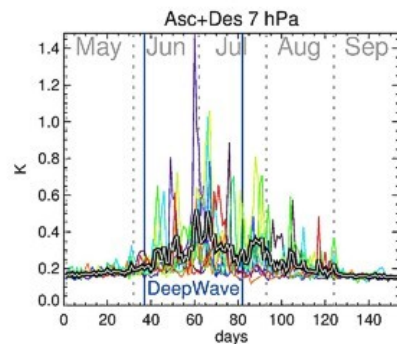
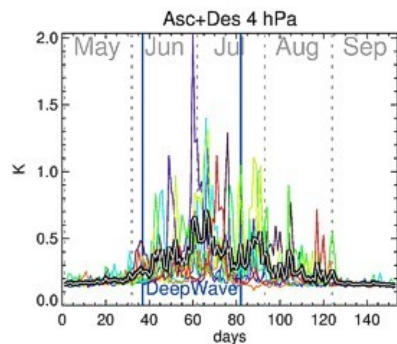
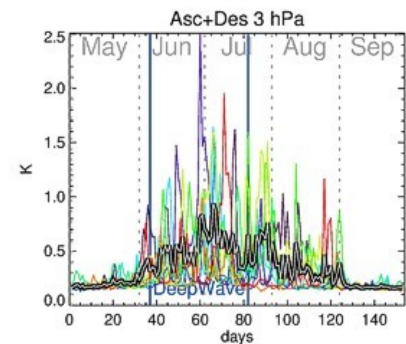
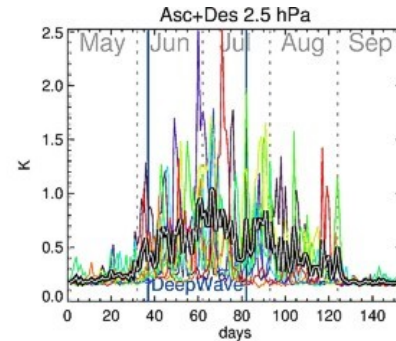
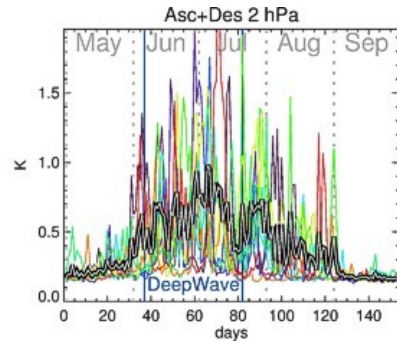
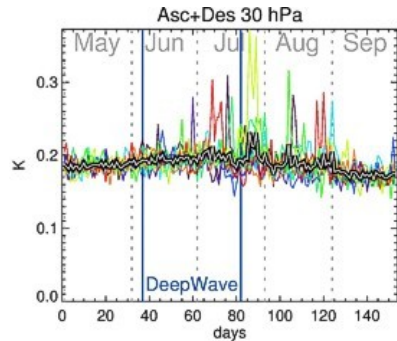
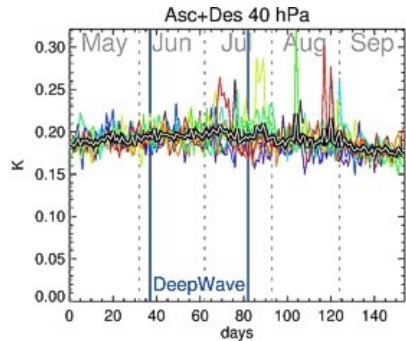


# North Island

- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011

2003- 2011



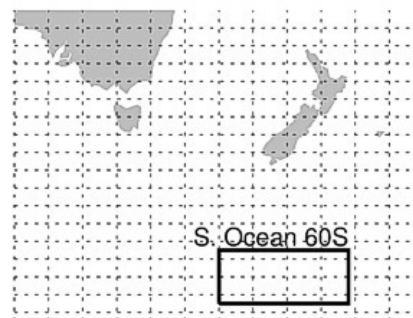
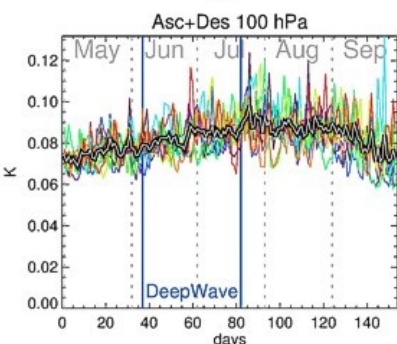
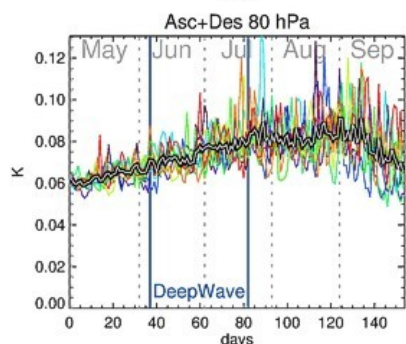
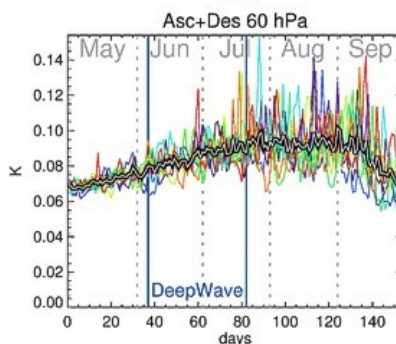
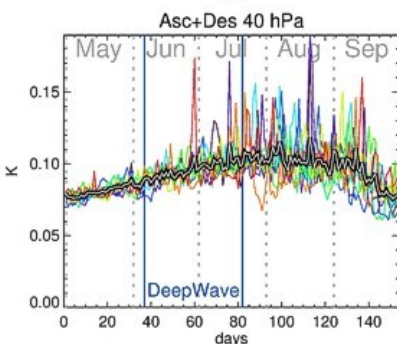
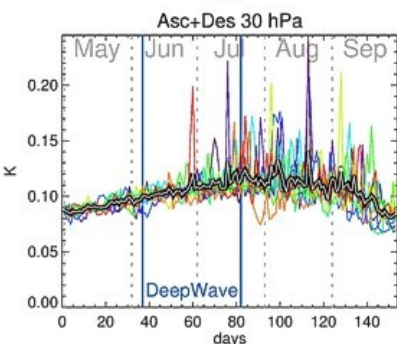
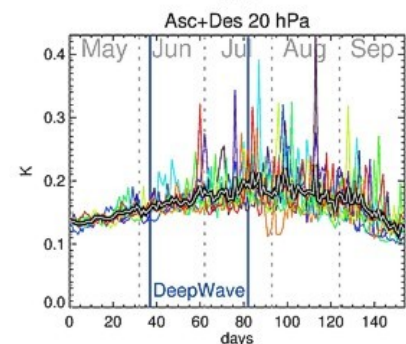
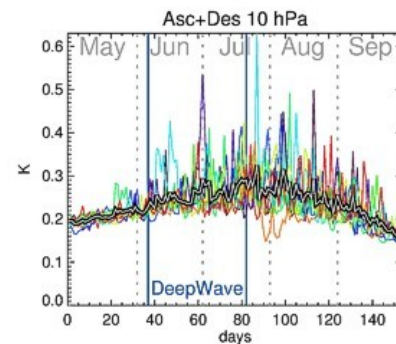
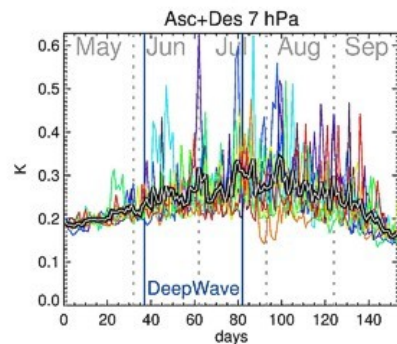
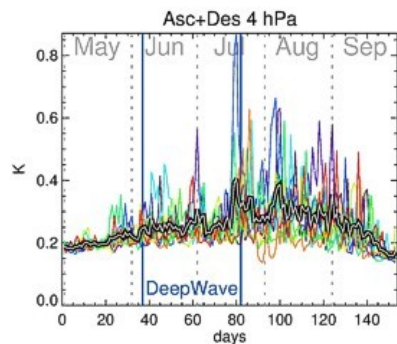
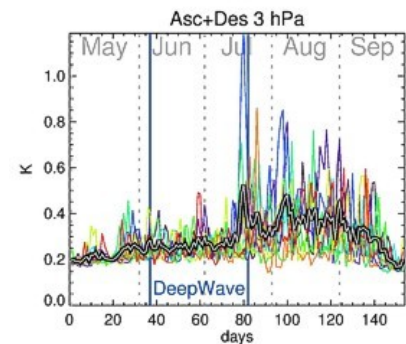
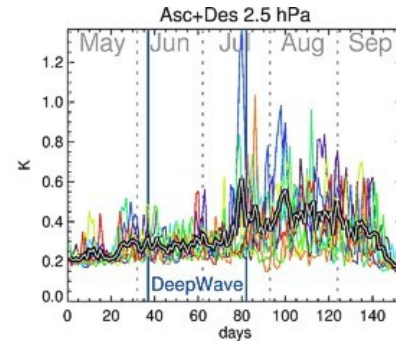
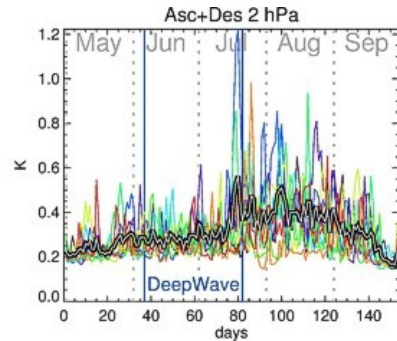
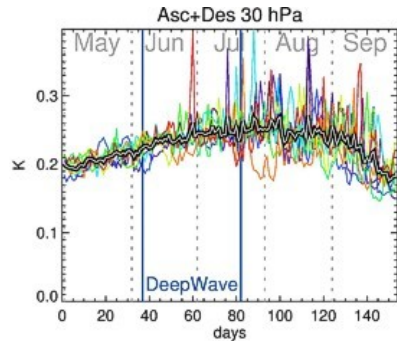
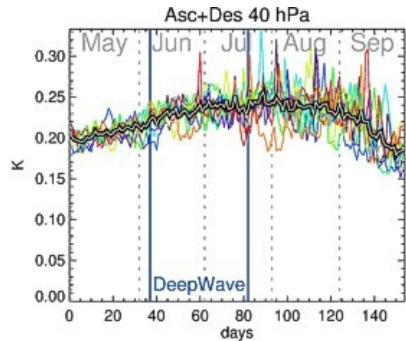


Tasmania

2003	2004	2005
2006	2007	2008
2009	2010	2011

2003-2011





# S. Ocean 60S

2003 2004 2005  
 2006 2007 2008  
 2009 2010 2011

2003-2011

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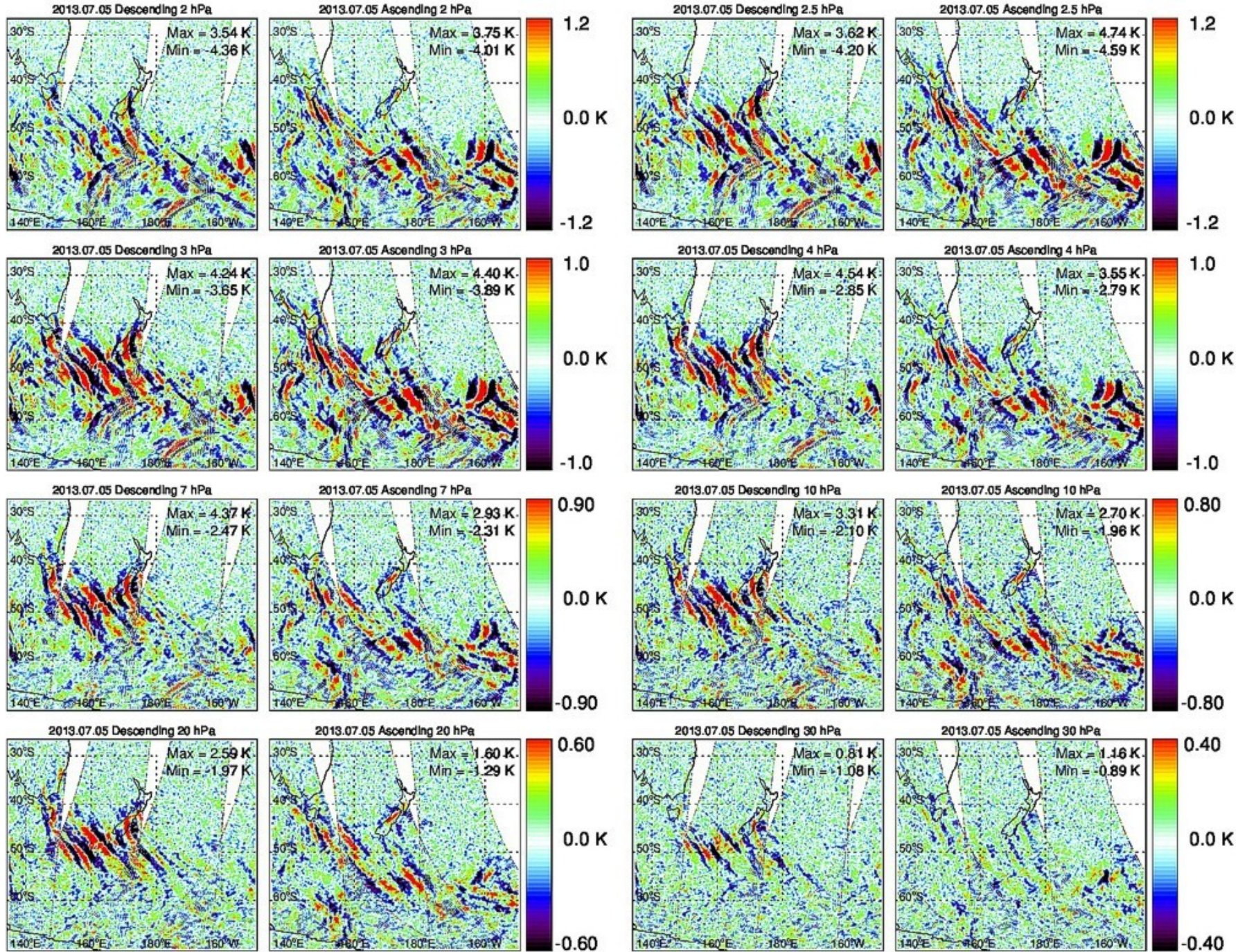
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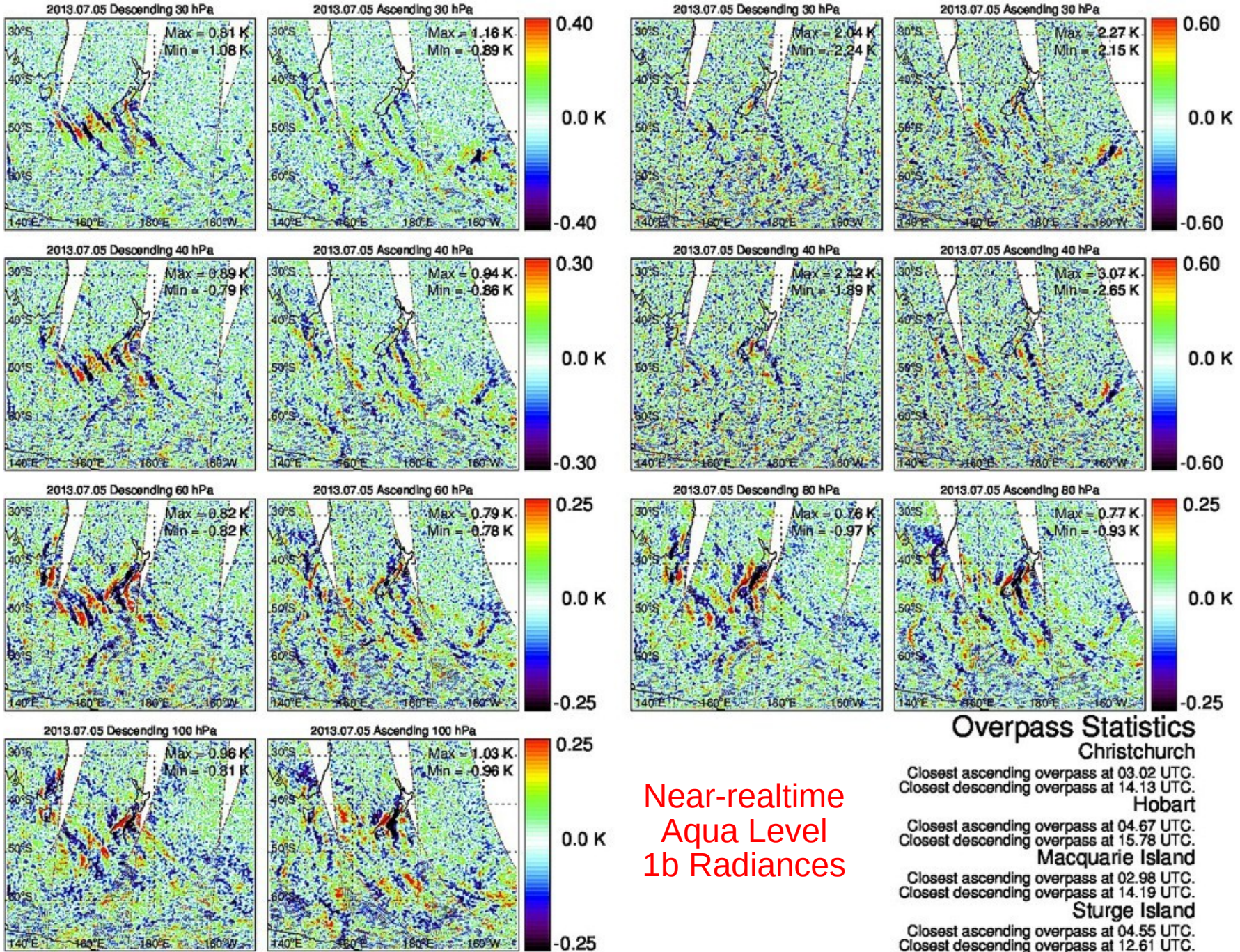
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Near-realtime  
Aqua Level  
1b Radiances

### Overpass Statistics

- Christchurch**  
Closest ascending overpass at 03.02 UTC.  
Closest descending overpass at 14.13 UTC.
- Hobart**  
Closest ascending overpass at 04.67 UTC.  
Closest descending overpass at 15.78 UTC.
- Macquarie Island**  
Closest ascending overpass at 02.98 UTC.  
Closest descending overpass at 14.19 UTC.
- Sturge Island**  
Closest ascending overpass at 04.55 UTC.  
Closest descending overpass at 12.61 UTC.



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# DEEPWAVE Field Phase Issues

## Backup Nadir Data Sources Besides AIRS

- AIRS launched 2002 (could die) + AIRS NRT data stream sometimes goes down
- **we plan to also use operational CrIS radiances from NPP** (downloads large & slow)
- **Microwave Nadir Sounders** (footprint resolution ~3 times larger)
  - **AMSU** on Aqua and NOAA-15 ... NOAA-19 (12 overpasses/day)
  - SSMIS on DMSP-15 ... 19 (up to ~90 km but Zeeman splitting complicates radiances)

## Limb Sounders

- MLS, SABER, GPS occultations (I don't plan to study/monitor these in-field)
- common volume predictions would need to monitor limb viewing geometries, yaws etc.

## Predictions of Overpass Time-Locations for NGV common volume data

- NRLDC investigating data catalogue uploaded based on getting an NRL “seat” in Satellite Toolkit to generate a time series for June-July 2014 (data might also come from NRL MRY)

## Data Uploading/Processing for Field Mission

- data volumes far too large to do in field, need scripts running back in NRLDC
- NRLDC security/access issues heavily complicate transfer imagery from/to field
- plan to have redundant versions running at other sites (e.g., CPI, NRLMRY, elsewhere?)

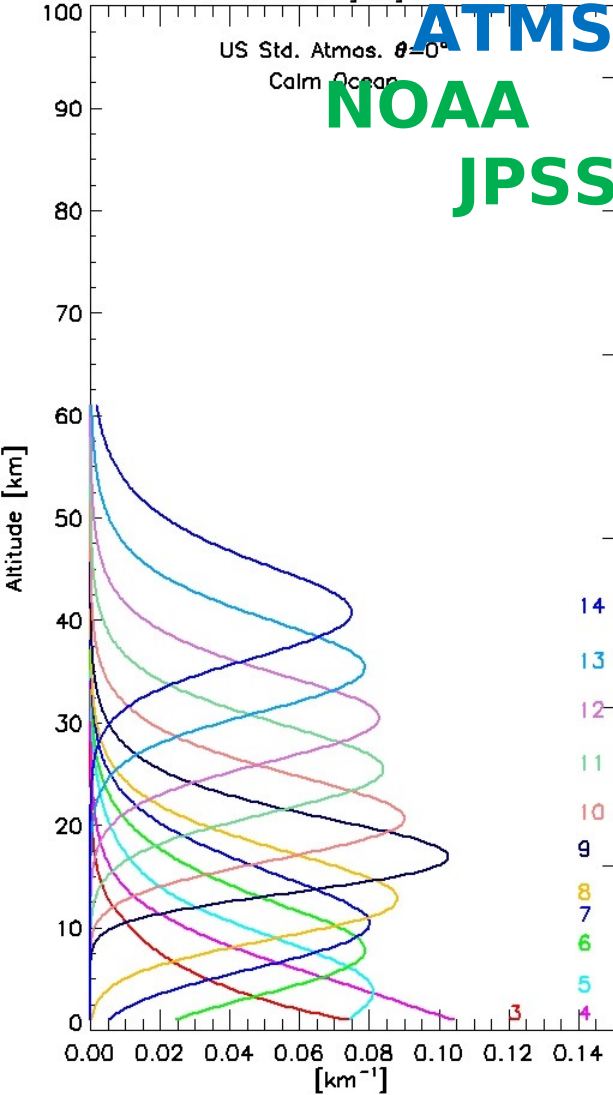


# Weighting Functions: Operational Microwave Nadir Sounders

## AMSU-A

NOAA AMSU Weighting Functions

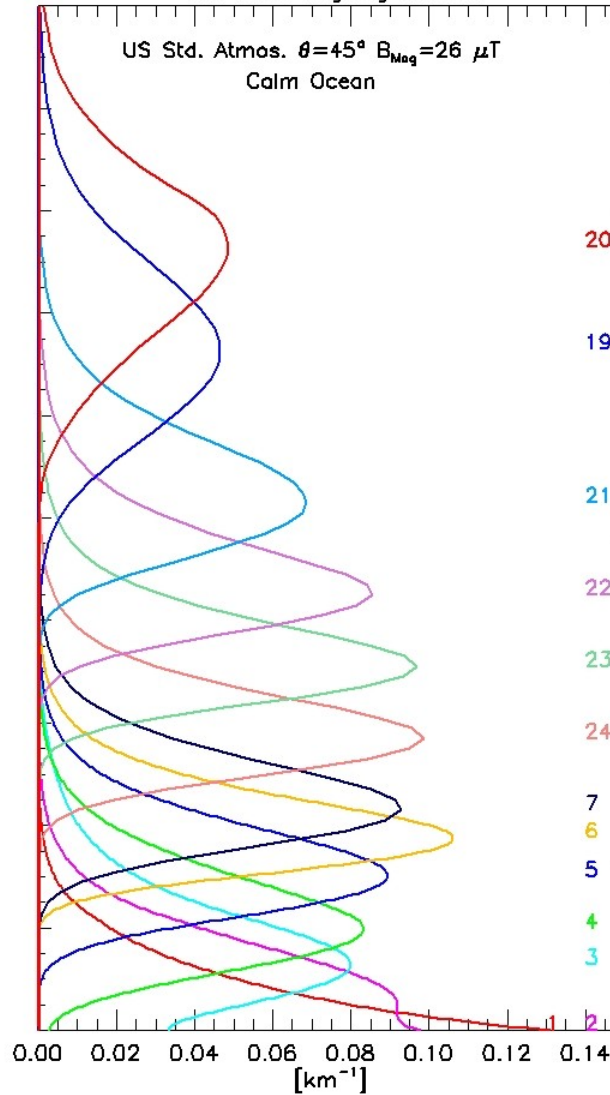
US Std. Atmos.  $\theta=0^\circ$   
Calm Ocean



## SSMIS

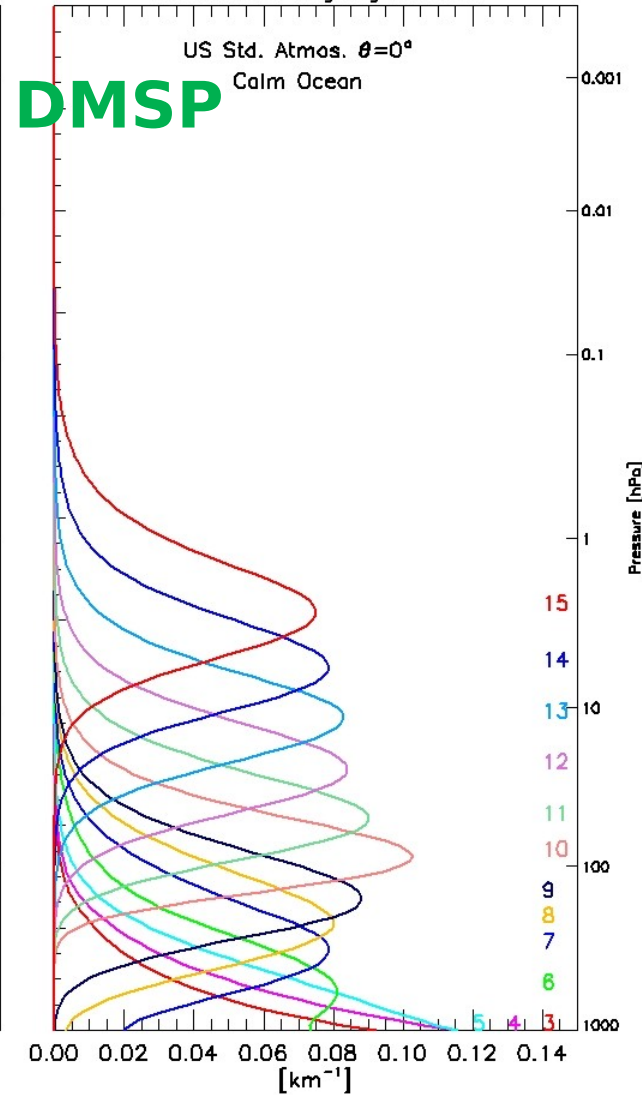
DMSP SSMIS Weighting Functions

US Std. Atmos.  $\theta=45^\circ$   $B_{Mag}=26 \mu T$   
Calm Ocean



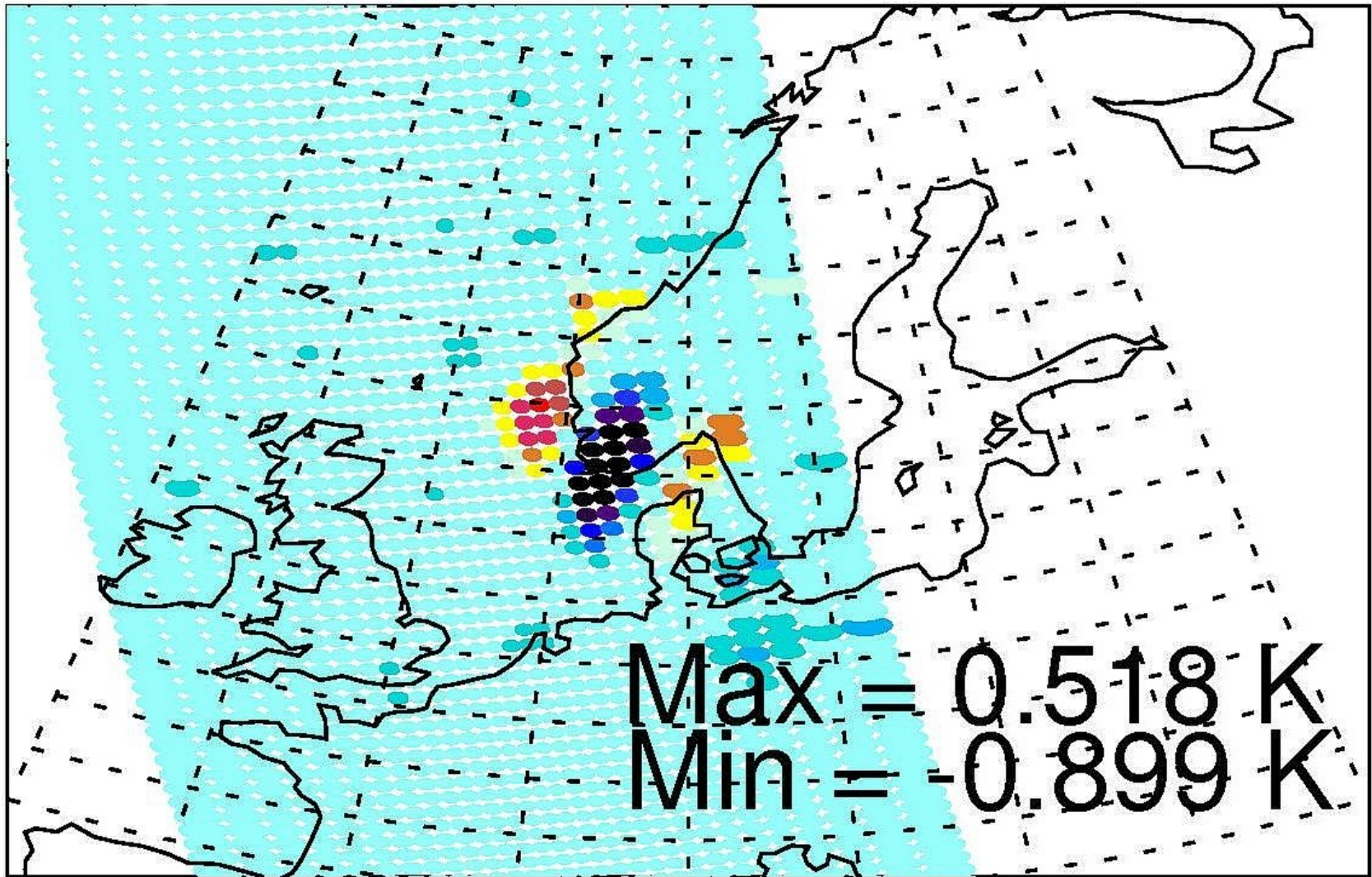
NPOESS ATMS Weighting Functions

US Std. Atmos.  $\theta=0^\circ$   
Calm Ocean



## Channel 9

AMSU-A EOS Aqua 1229 UTC





# SOLVE-II DC-8 Flight of 14 January 2003

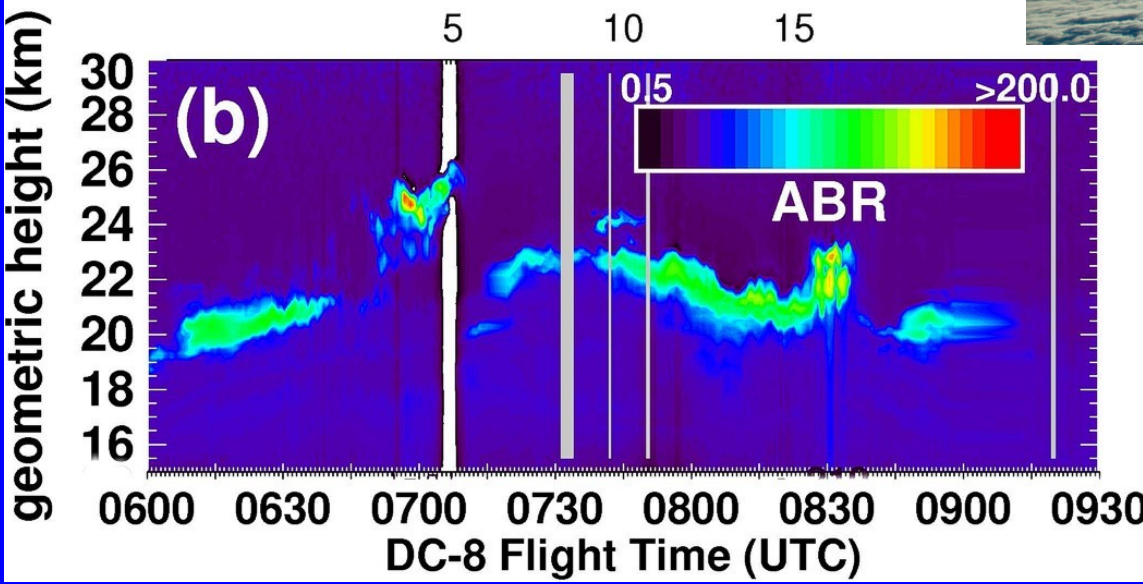
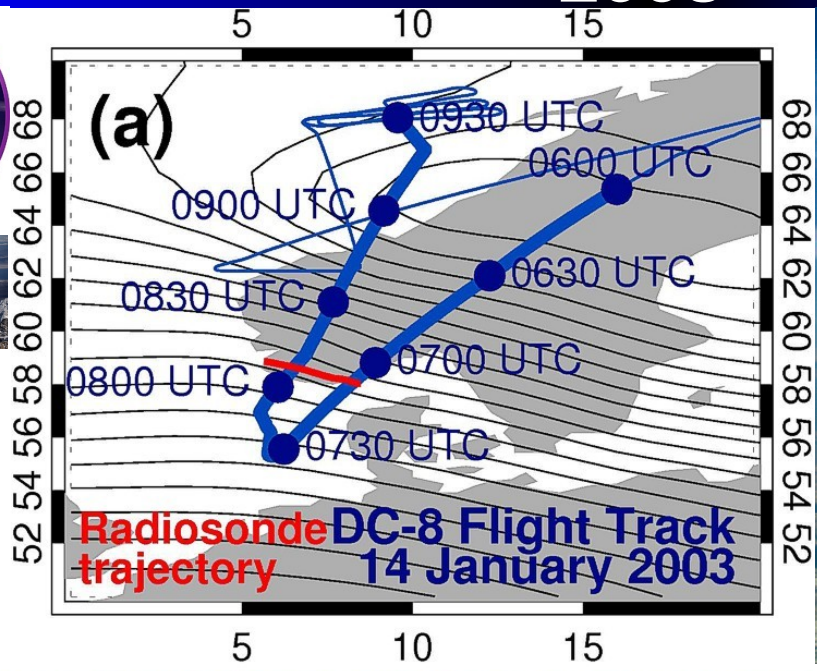


Photo from the NASA DC-8 of mountain wave PSCs over south-western Scandinavia on 14 January 2003 (courtesy Paul Newman, NASA GSFC)

## Mountain Wave PSCs

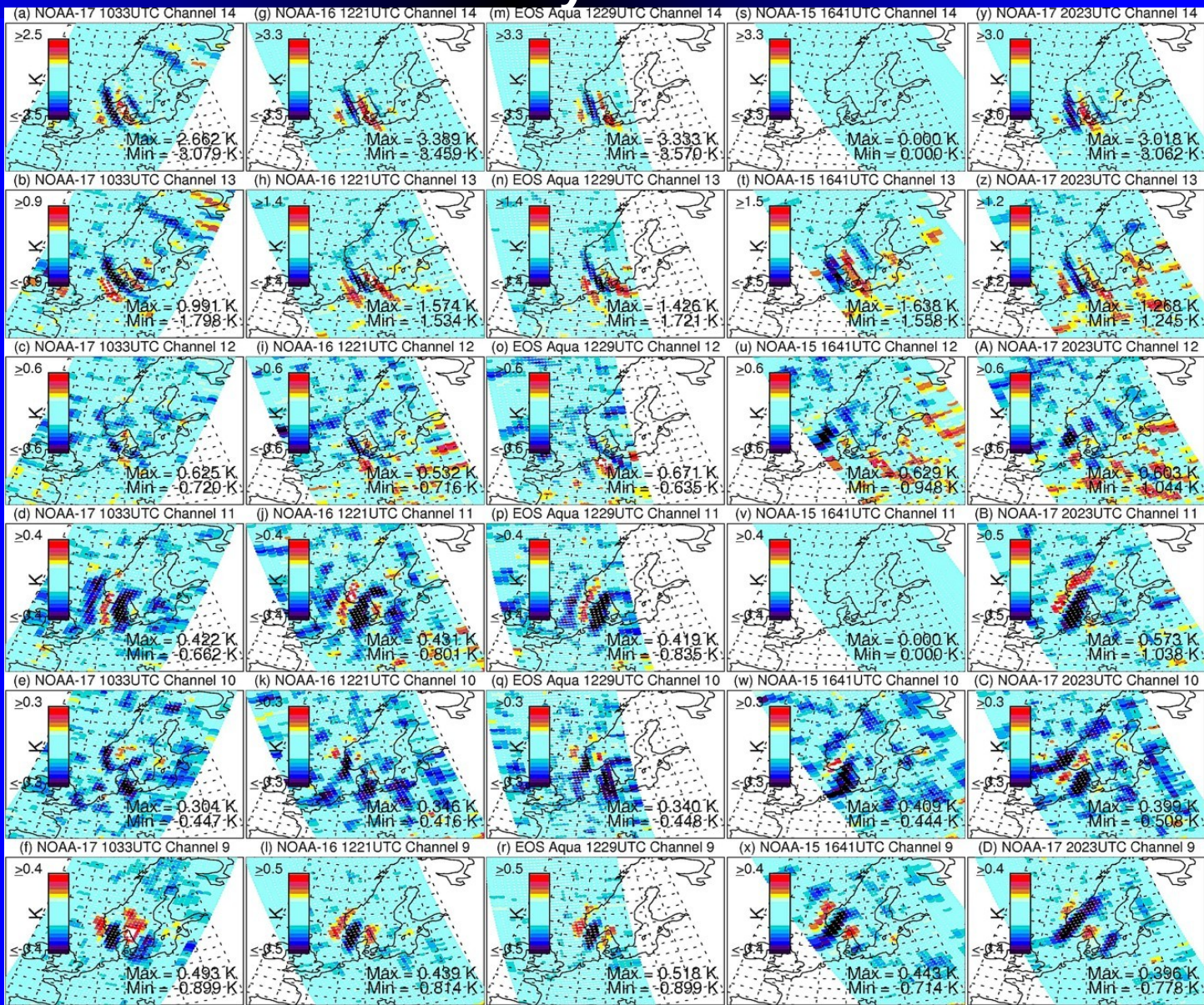
Aerosol Backscatter Coefficients (ABR) from NASA Langley Lidar on DC-8



# AMSU-A Channels 9-14 Radiances:

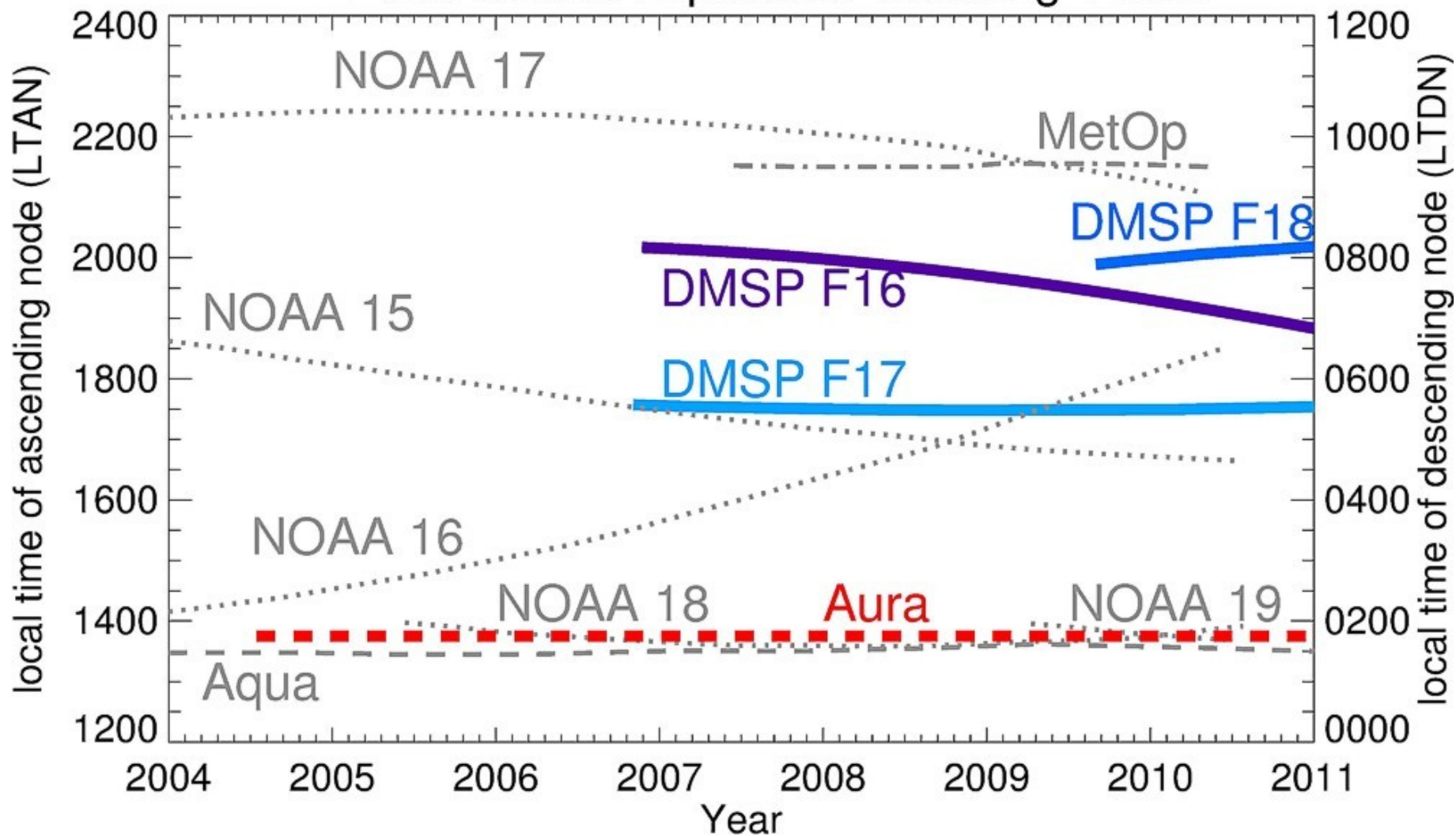
## 14 January 2003

Increasing altitude

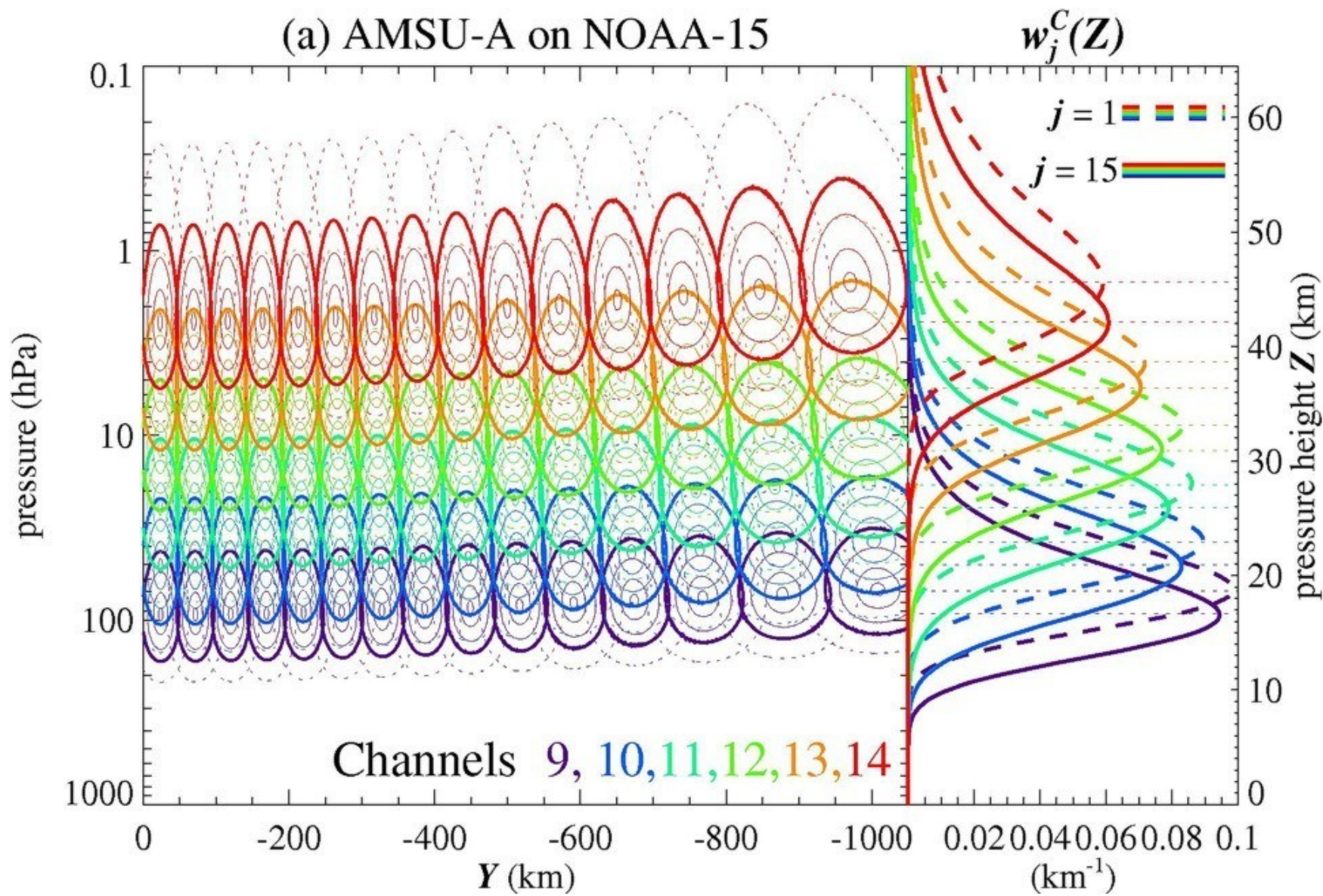




# Polar Orbiter Equatorial Crossing Times



(a) AMSU-A on NOAA-15





# Specific Science Questions for DEEPWAVE

**Question:** Which stratospheric gravity waves are and are not resolved in satellite imagery?

**Closure:** Coincident “ground truth” NGV deep GW measurements during satellite overpasses, forward modeled into satellite radiances

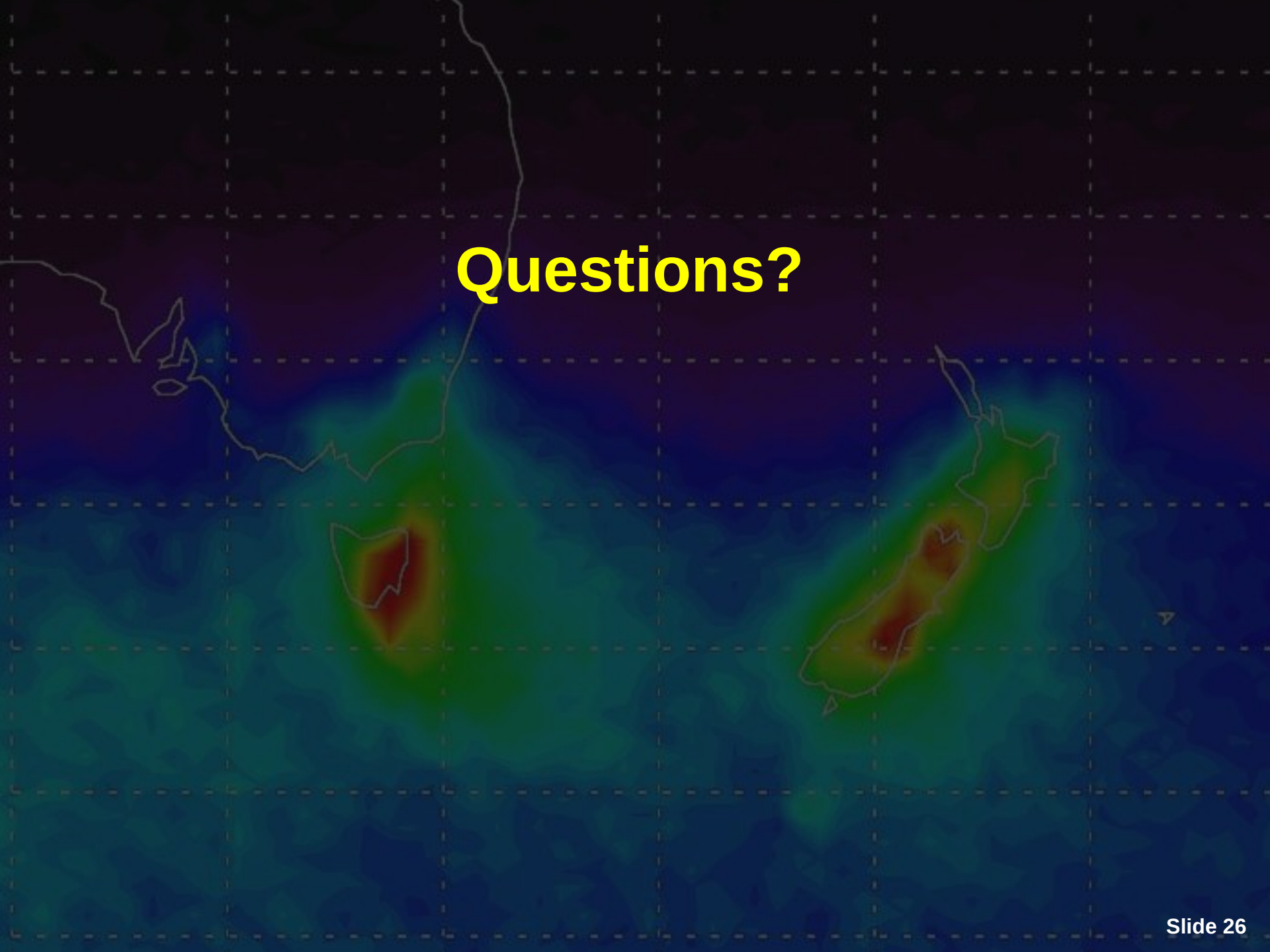
**Question:** What are the origins of rich variable 3D GW structures seen in satellite GW swath imagery in the DEEPWAVE RAO?

**Closure:** DEEPWAVE NGV measurements and detailed 3D modeling

**Questions:** What are the dominant sources of GWs in DEEPWAVE RAO?  
What are the relative flux contributions of GWs of various sources to the stratospheric circulation and climate?

**Closure:** DEEPWAVE NGV measurements, detailed 3D modeling and parameterization

**Questions?**





**Backup Slides follow....**

