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

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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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Satellite GW Product: Executive Summary

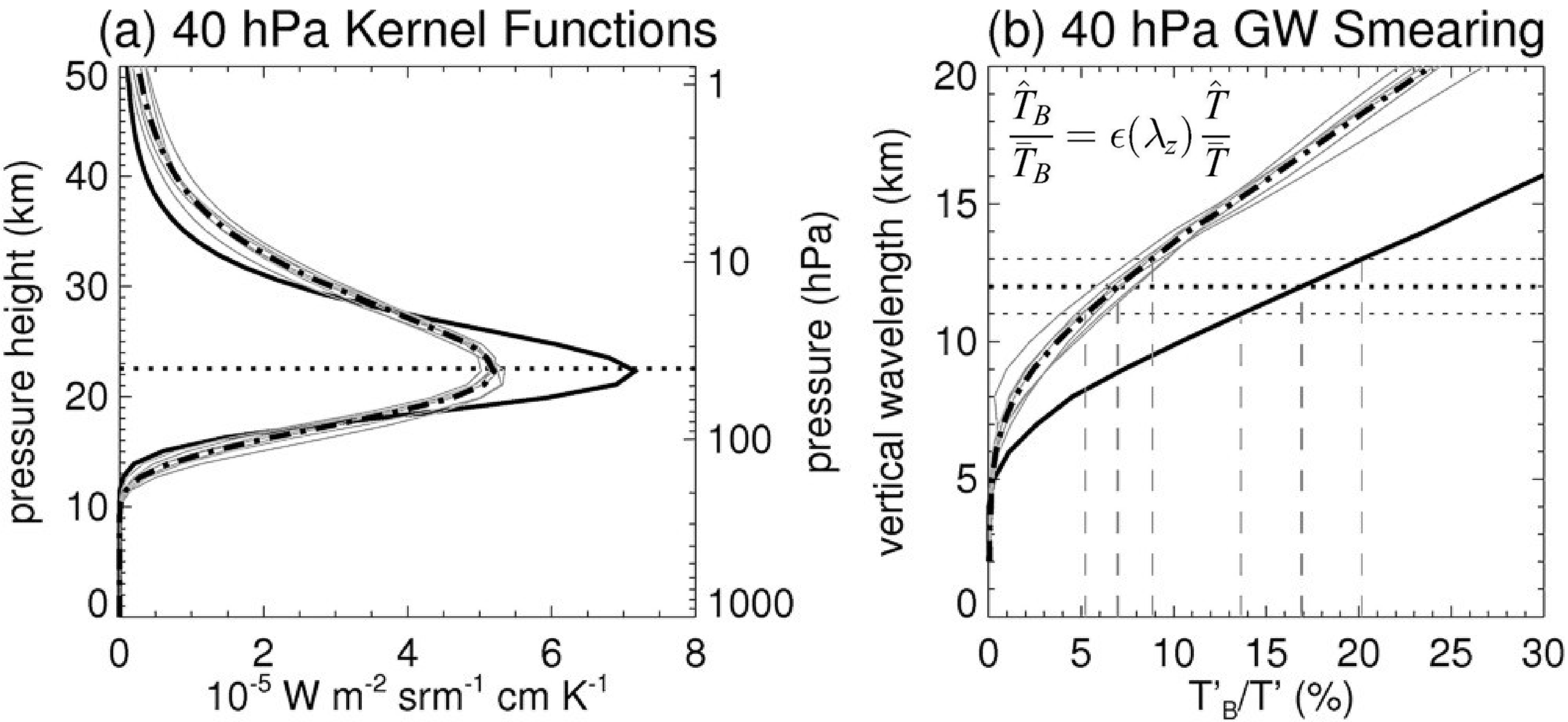
- Gravity waves (GWs) are an "accidental detection" in nadir radiances
- First noted ~5-7 years ago as a result of advances in nadir sounding technology, particularly:
  - Improved footprint (horizontal) resolution (~100 km → ~10 km): horizontal wavelength
  - Improved precision and reduced noise in radiometric detection channels (NEDTs ~ 0.1-0.5 K): wave amplitude
  - Hyperspectral imagery (more channels → 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

$$z \qquad \frac{2 \left| c \quad \bar{U}\cos \right|}{N} \qquad \bar{U}$$

φ	wind vector azimuth
	wave vector azimuth
λ_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 (665.015–678.839 cm^{-1})

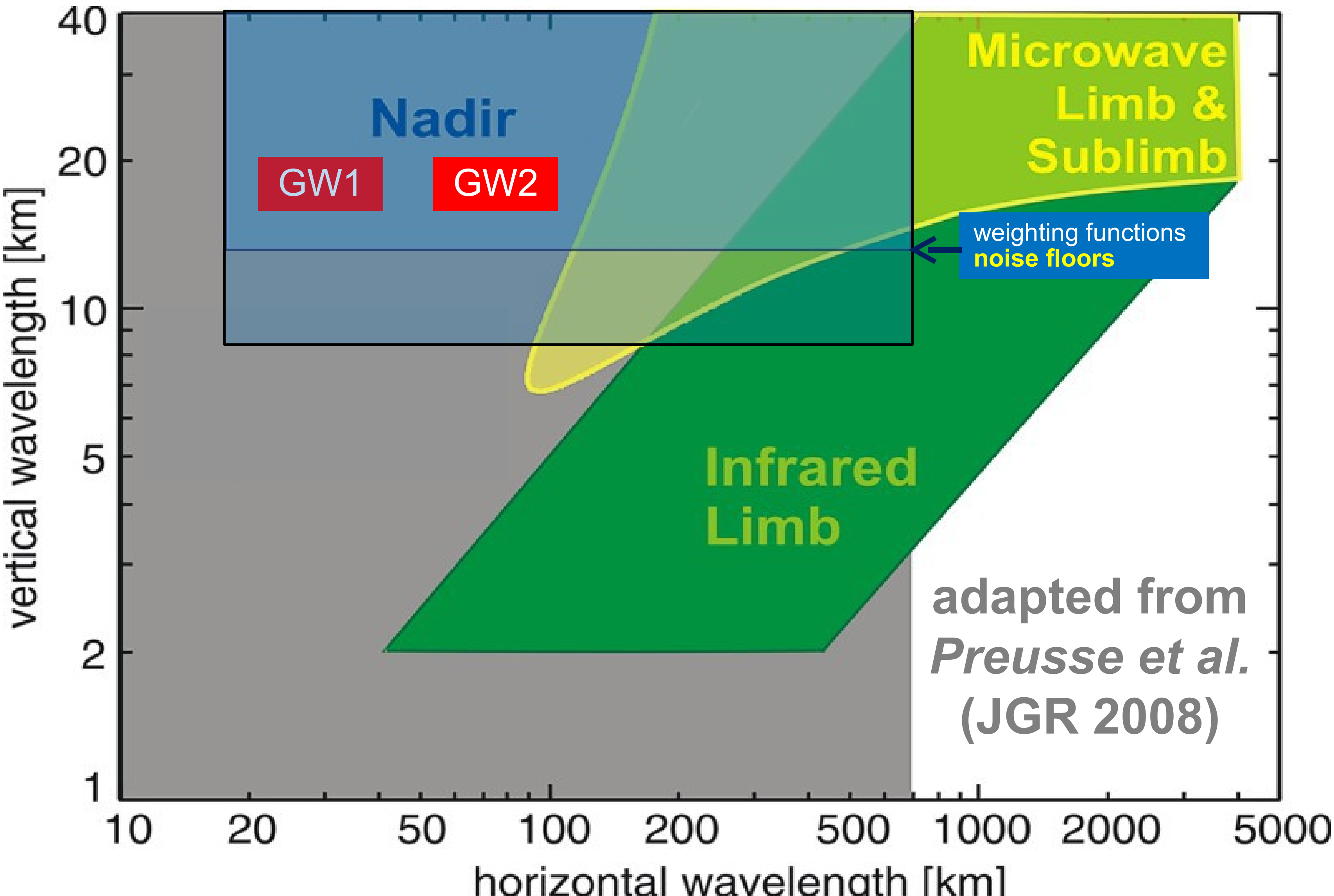
Individual Channel Radiances 64,…,118

Mean Channel Radiance 64,..,118

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

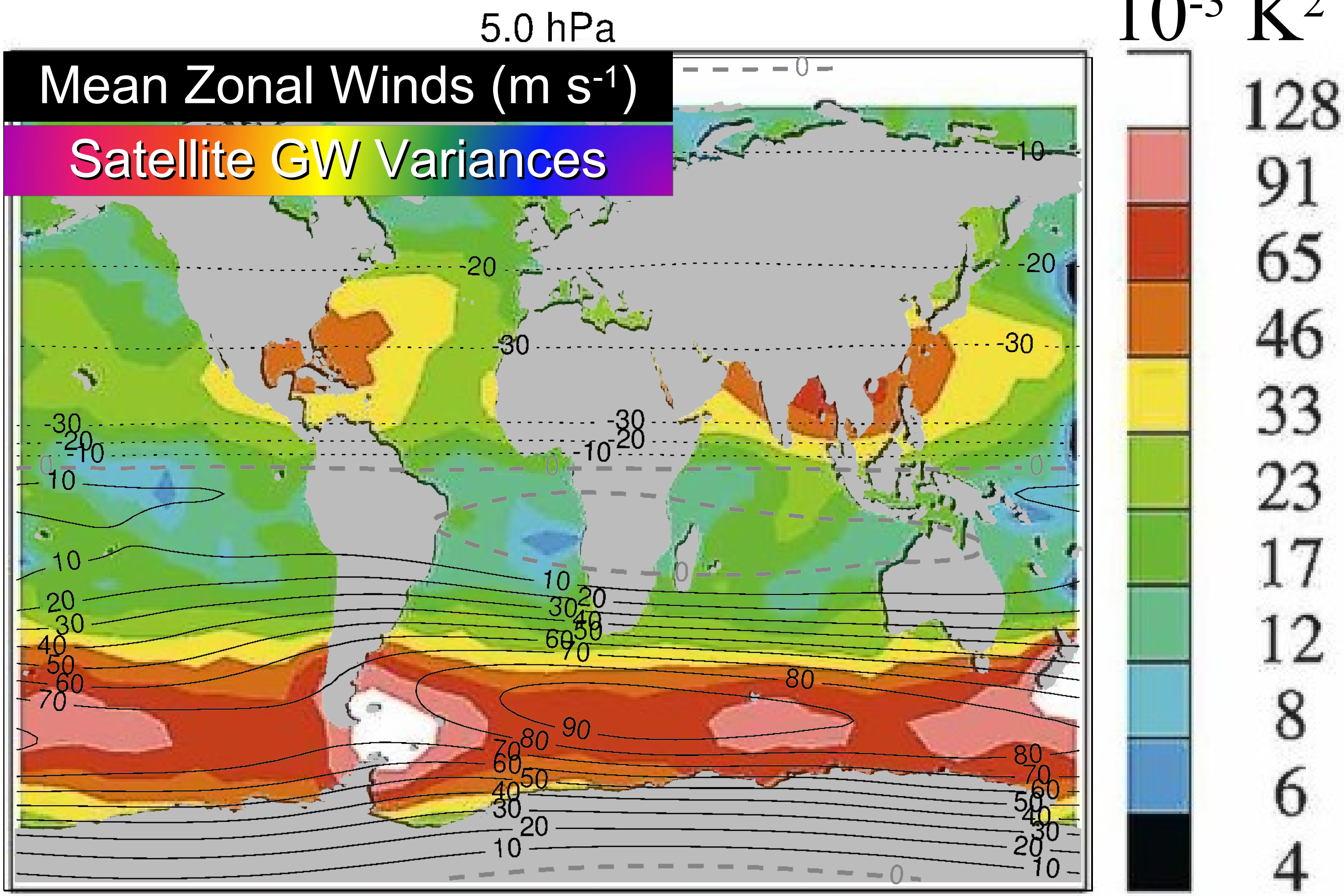
see Hoffmann and Alexander (JGR, 2009)
Eckermann et al. (GRL 2009)

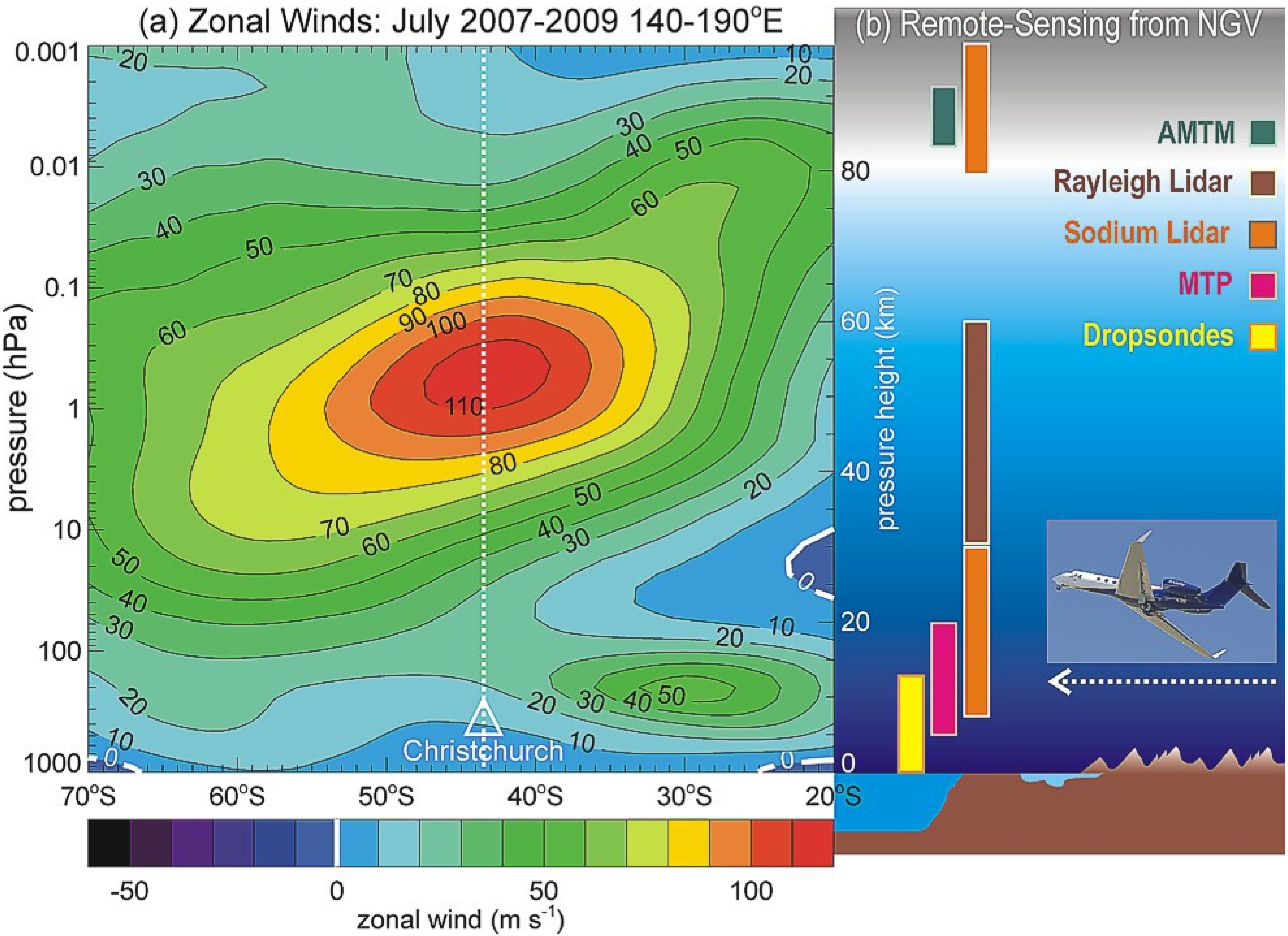
Wavelength Phase Space for Satellite GW Detection



Previous Satellite Studies: Aura MLS July 2005

Wu and Eckermann (JAS 2005)





(a) Zonal Winds: July 2007-2009 140-190°E
pressure (hPa)
0.001
0.01
0.1
1
10
100
1000
70°S
60°S
50°S
40°S
30°S
20°S
Christchurch
-50
0
50
100
zonal wind (m s^{-1})
(b) Remote-Sensing from NGV
AMTM
Rayleigh Lidar
Sodium Lidar
MTP
Dropsondes
pressure height (km)
80
60
40
20
0

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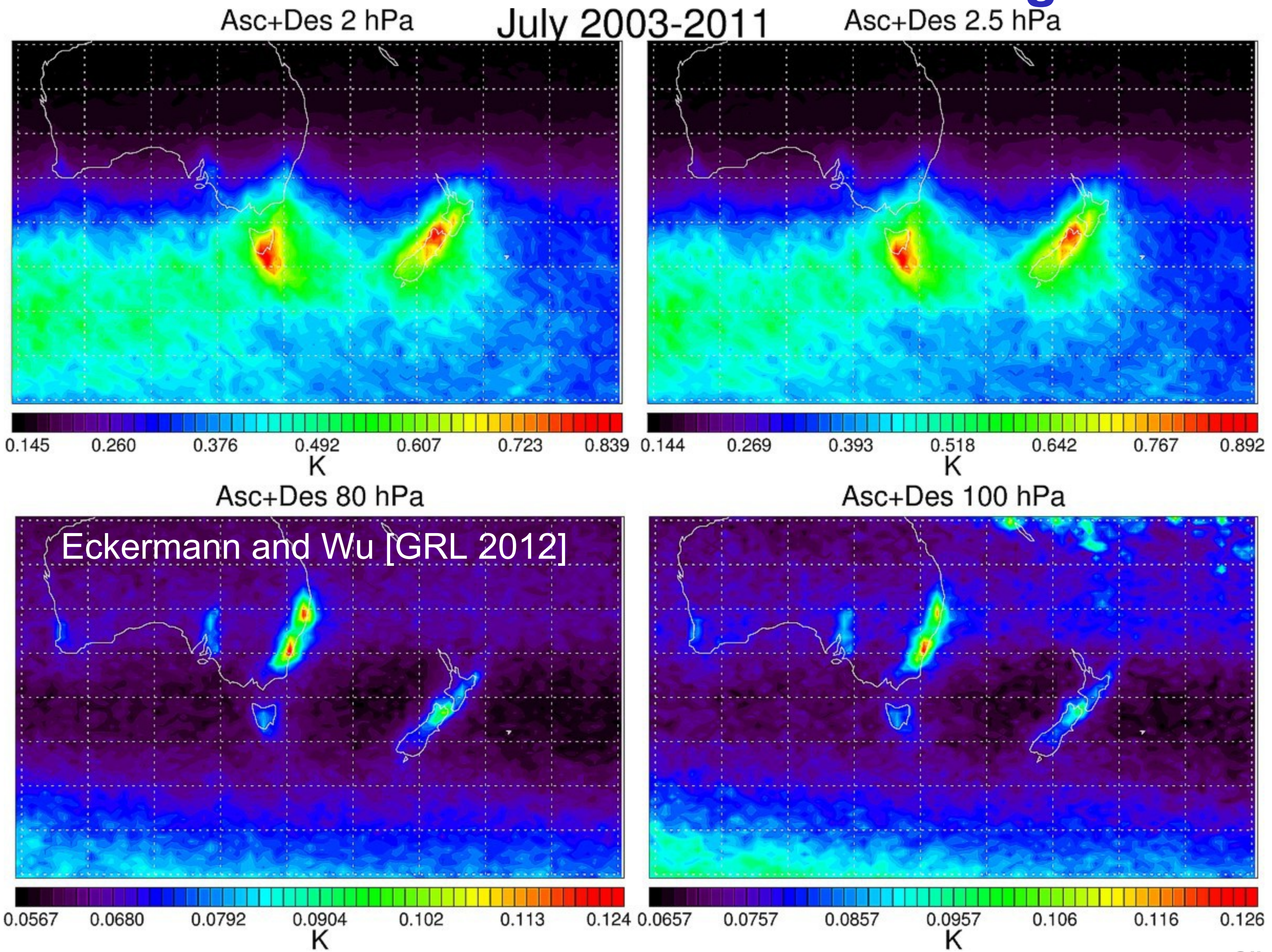
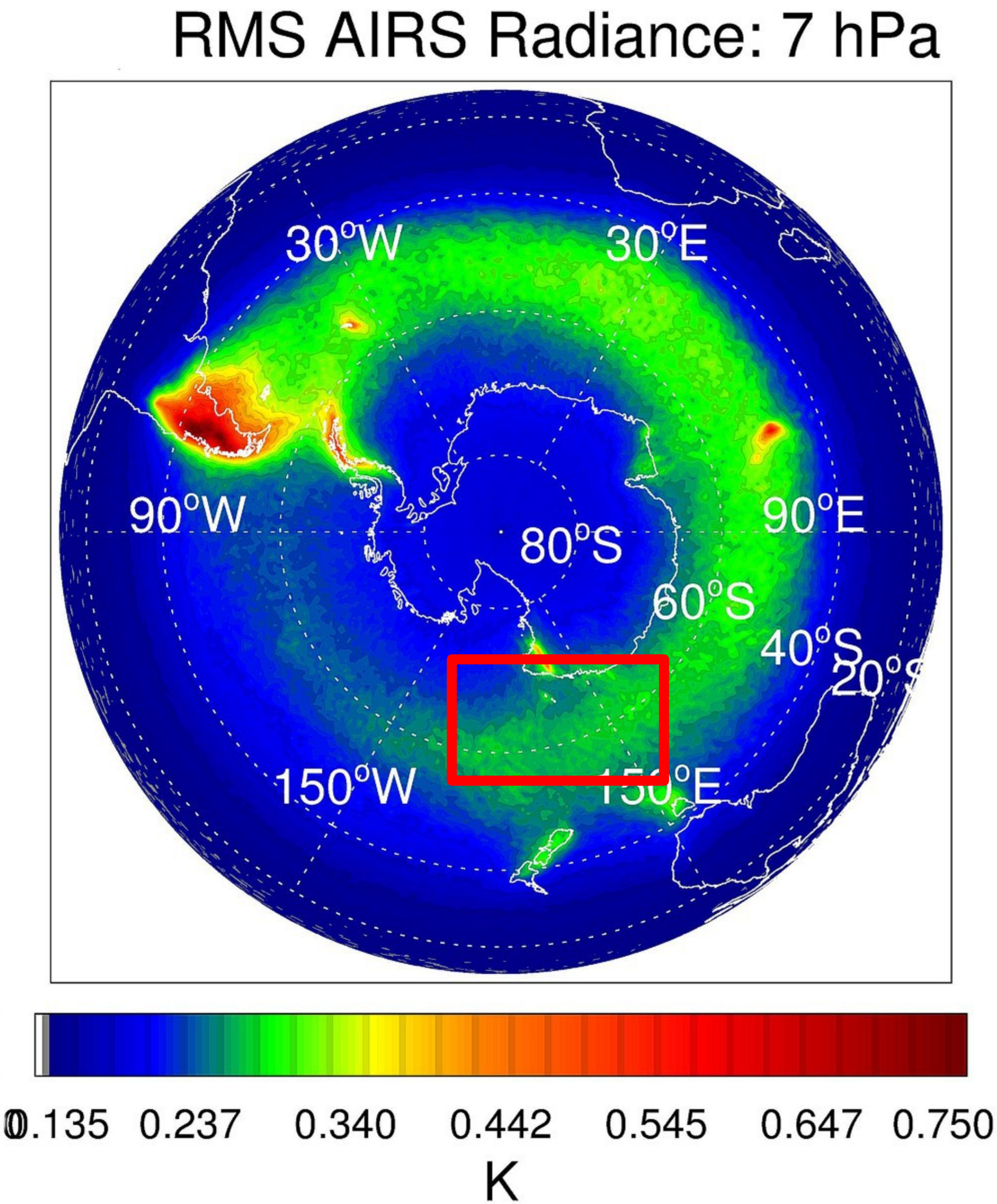
Greater Australia/New Zealand Region



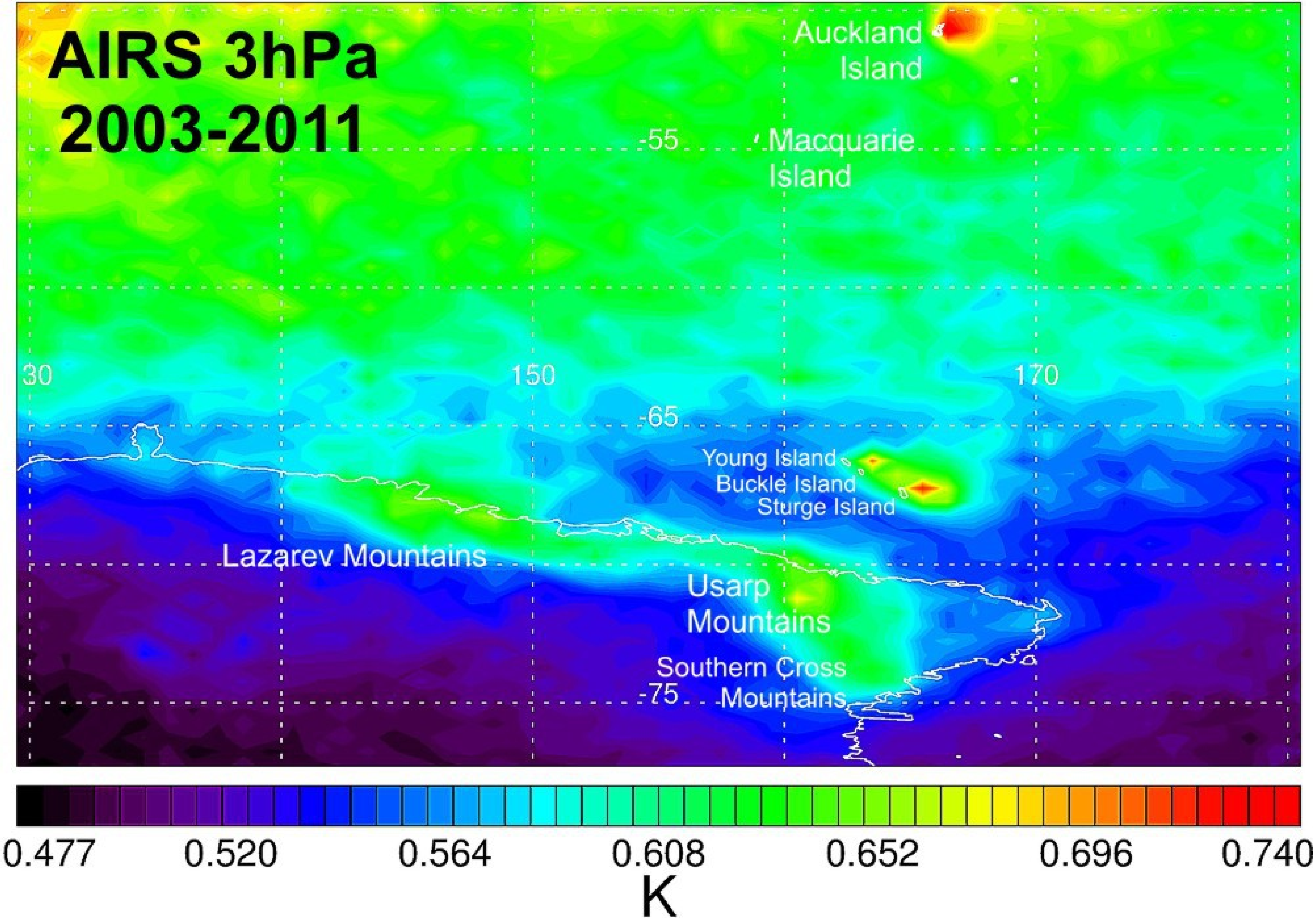


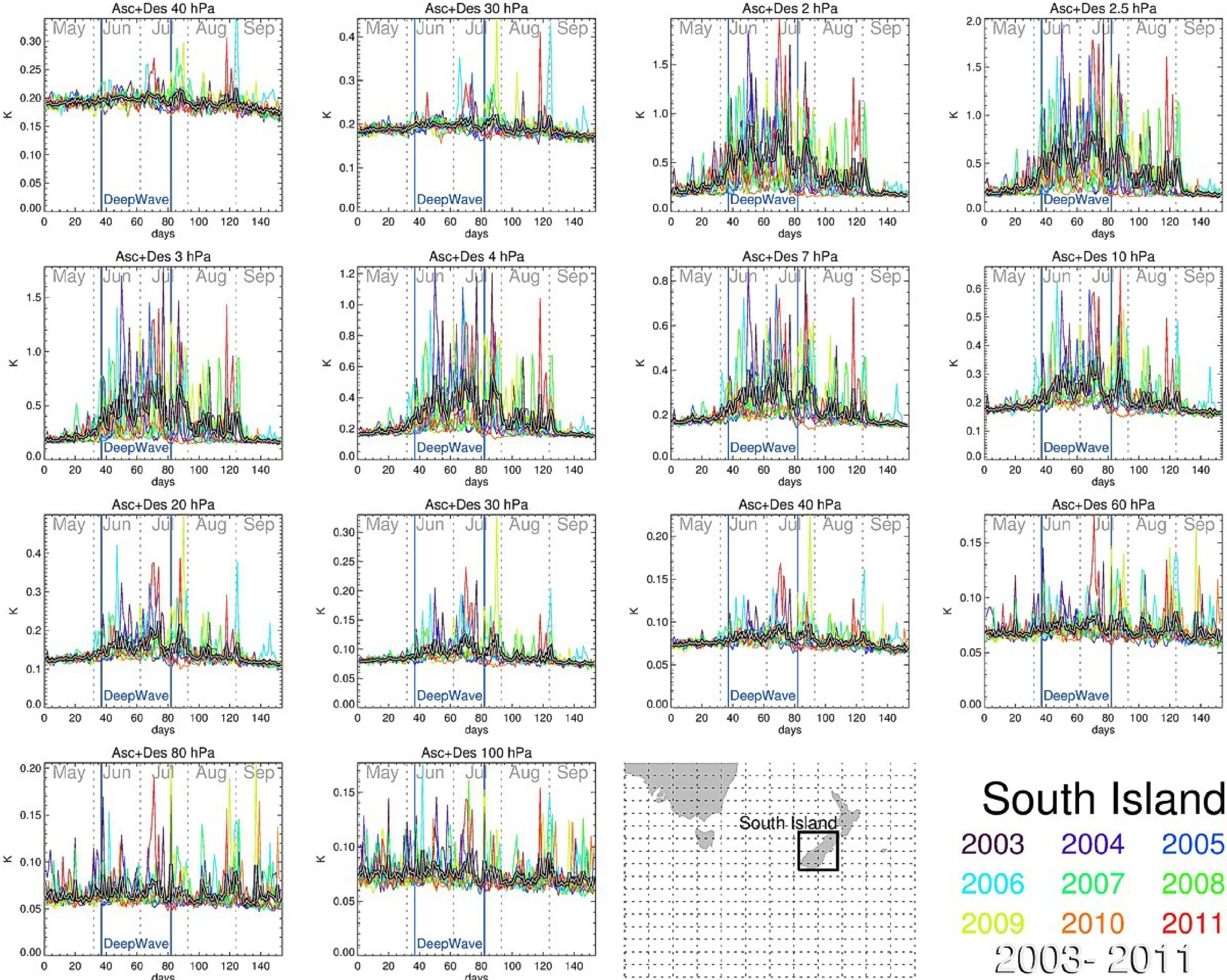
Hemispheric Perspective

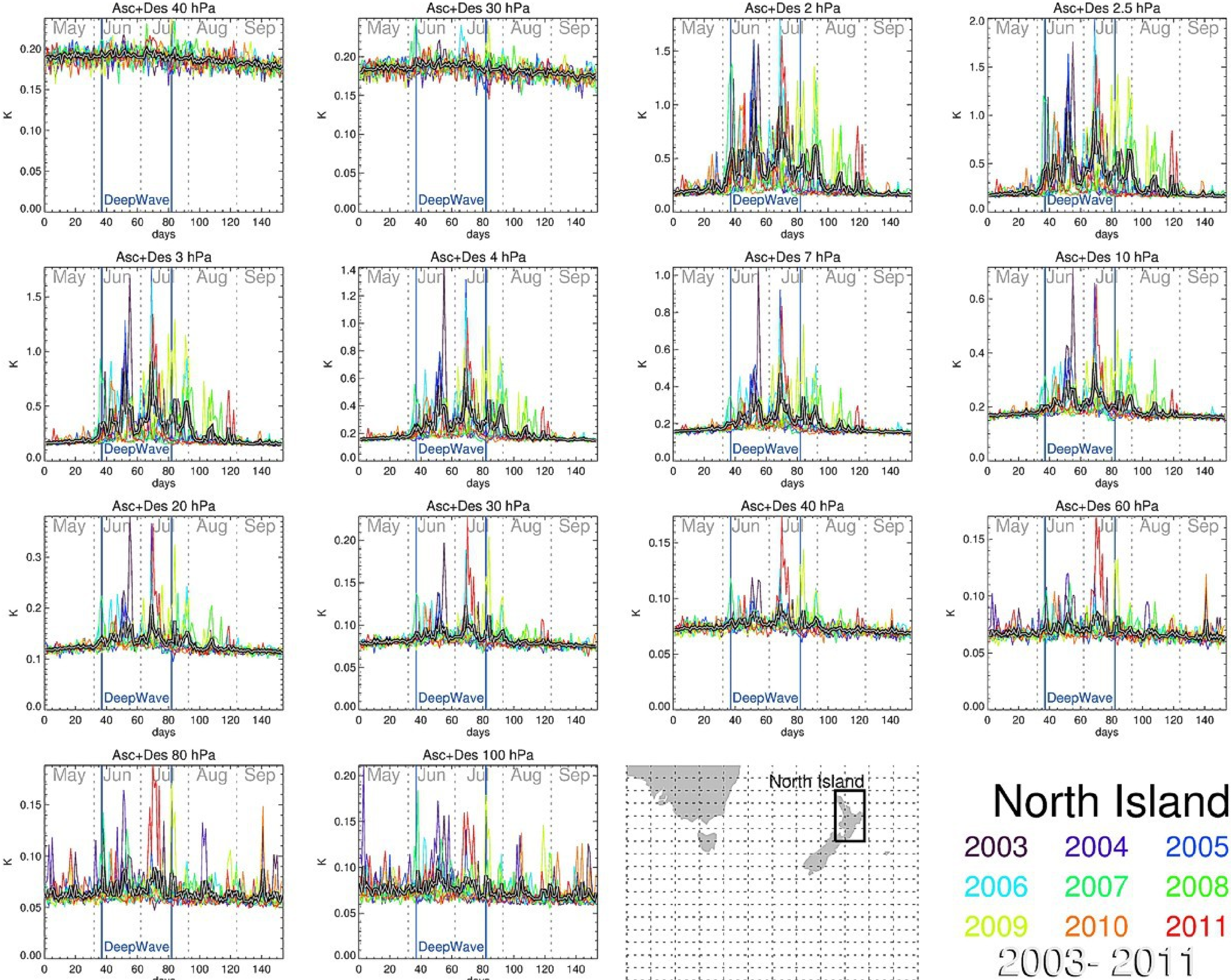
- Broad band of enhanced variance over Southern Ocean
- Clearly nonorographic sources
- Well correlated with midlatitude spiral jet

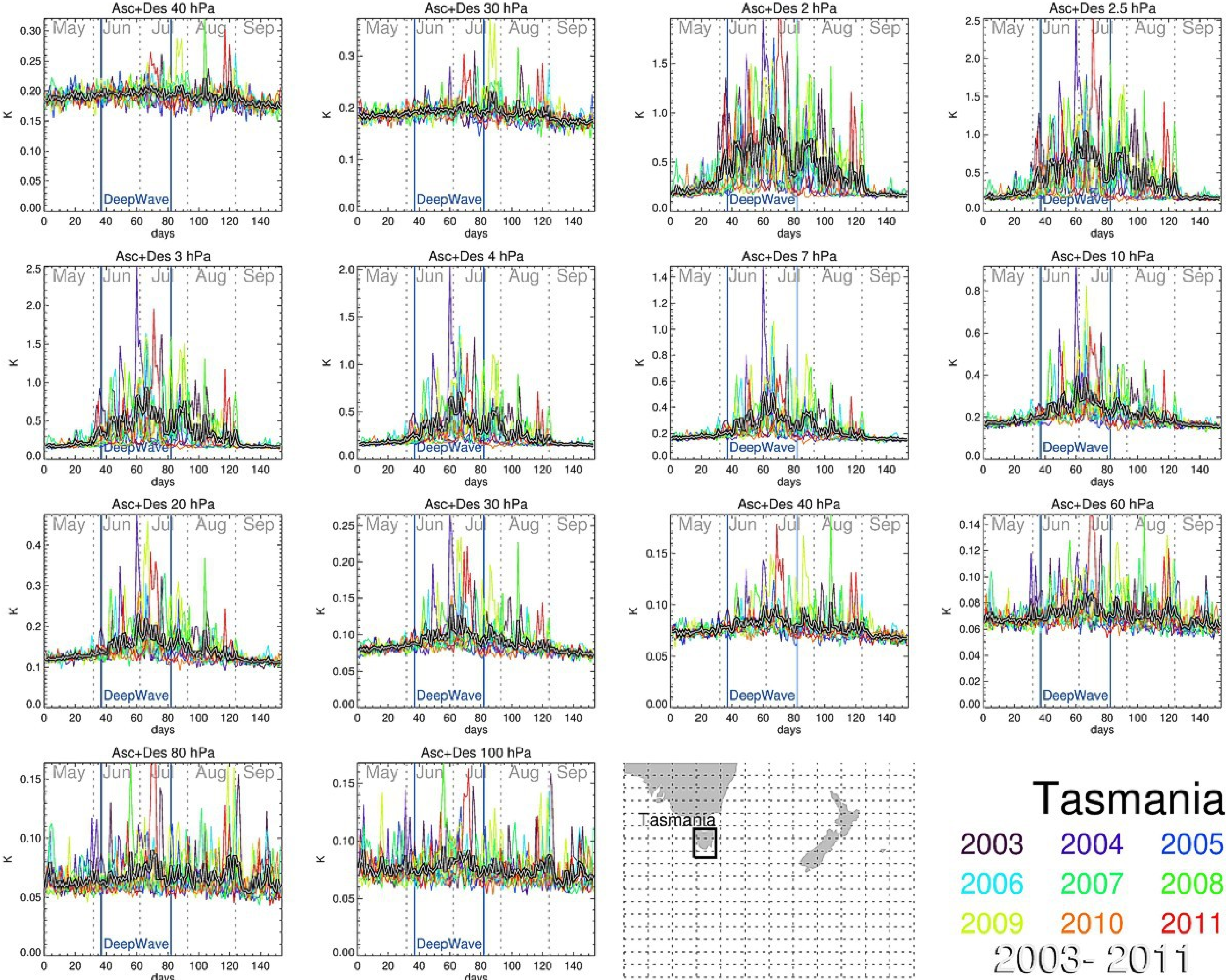
Hendricks et al. J. Atmos. Sci., in press, 2014.

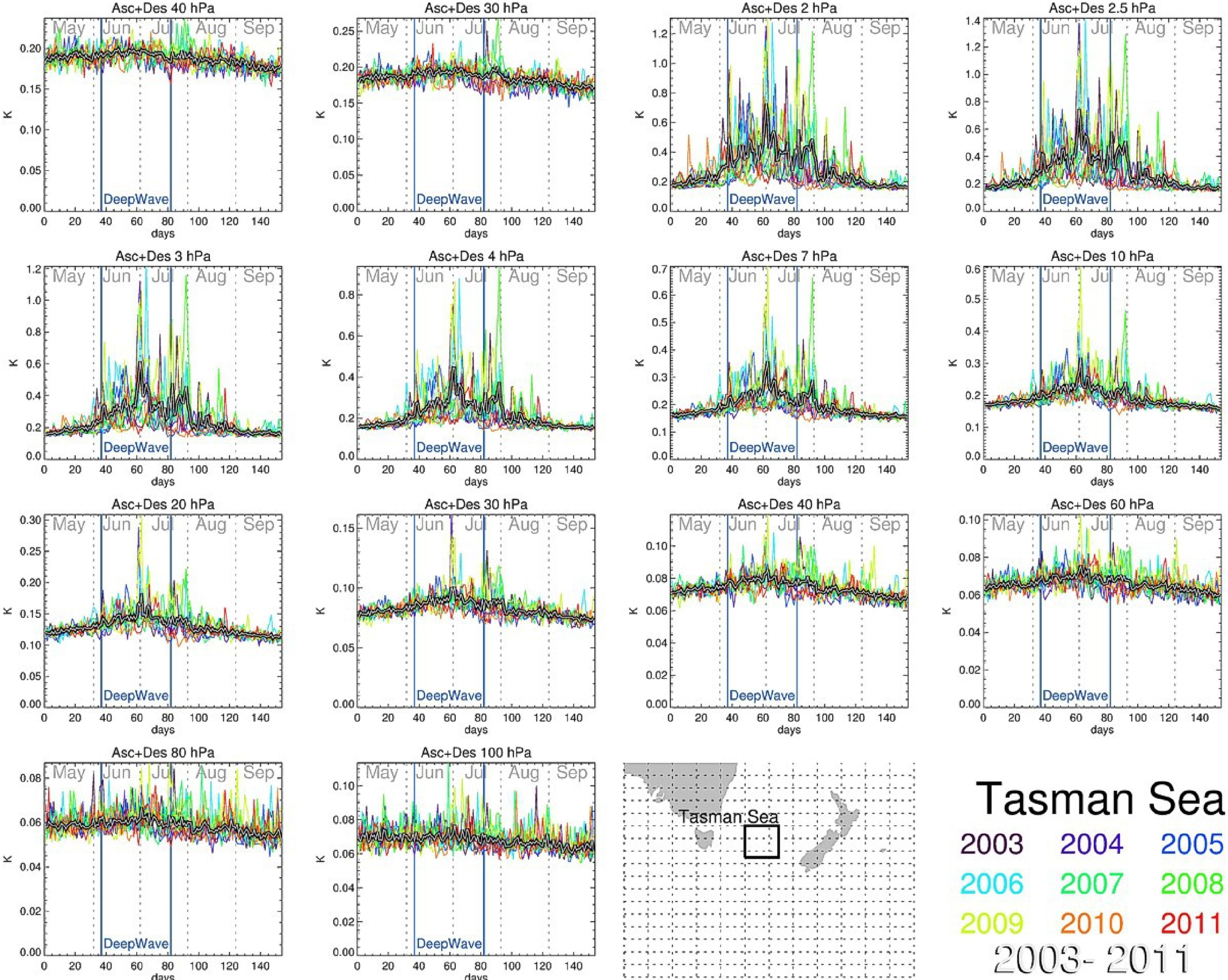
Southern Ocean to Antarctica

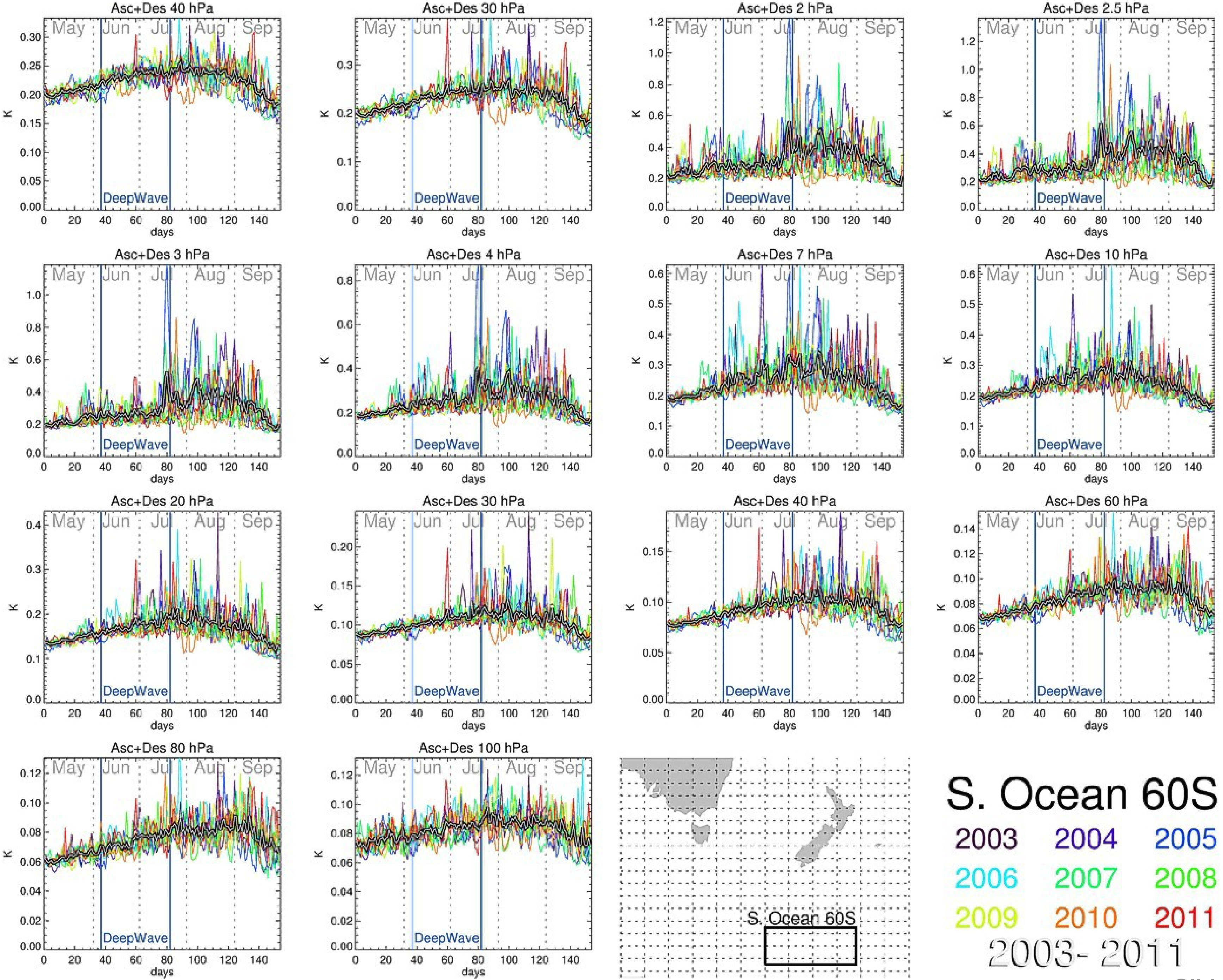



Asc+Des 40 hPa
Asc+Des 30 hPa
Asc+Des 2 hPa
Asc+Des 2.5 hPa
Asc+Des 3 hPa
Asc+Des 4 hPa
Asc+Des 7 hPa
Asc+Des 10 hPa
Asc+Des 20 hPa
Asc+Des 30 hPa
Asc+Des 40 hPa
Asc+Des 60 hPa
Asc+Des 80 hPa
Asc+Des 100 hPa
May
Jun
Jul
Aug
Sep
DeepWave
K
days
South Island
South Island
2003
2004
2005
2006
2007
2008
2009
2010
2011
2003- 2011


Asc+Des 40 hPa
Asc+Des 30 hPa
Asc+Des 2 hPa
Asc+Des 2.5 hPa
Asc+Des 3 hPa
Asc+Des 4 hPa
Asc+Des 7 hPa
Asc+Des 10 hPa
Asc+Des 20 hPa
Asc+Des 30 hPa
Asc+Des 40 hPa
Asc+Des 60 hPa
Asc+Des 80 hPa
Asc+Des 100 hPa
May
Jun
Jul
Aug
Sep
DeepWave
K
days
North Island
North Island
2003
2004
2005
2006
2007
2008
2009
2010
2011
2003- 2011


Asc+Des 40 hPa
Asc+Des 30 hPa
Asc+Des 2 hPa
Asc+Des 2.5 hPa
Asc+Des 3 hPa
Asc+Des 4 hPa
Asc+Des 7 hPa
Asc+Des 10 hPa
Asc+Des 20 hPa
Asc+Des 30 hPa
Asc+Des 40 hPa
Asc+Des 60 hPa
Asc+Des 80 hPa
Asc+Des 100 hPa
May Jun Jul Aug Sep
DeepWave
K
days
Tasmania
Tasmania
2003 2004 2005
2006 2007 2008
2009 2010 2011
2003- 2011


Asc+Des 40 hPa
Asc+Des 30 hPa
Asc+Des 2 hPa
Asc+Des 2.5 hPa
Asc+Des 3 hPa
Asc+Des 4 hPa
Asc+Des 7 hPa
Asc+Des 10 hPa
Asc+Des 20 hPa
Asc+Des 30 hPa
Asc+Des 40 hPa
Asc+Des 60 hPa
Asc+Des 80 hPa
Asc+Des 100 hPa
May Jun Jul Aug Sep
DeepWave
K
days
Tasman Sea
Tasman Sea
2003 2004 2005
2006 2007 2008
2009 2010 2011
2003- 2011


Asc+Des 40 hPa
Asc+Des 30 hPa
Asc+Des 2 hPa
Asc+Des 2.5 hPa
Asc+Des 3 hPa
Asc+Des 4 hPa
Asc+Des 7 hPa
Asc+Des 10 hPa
Asc+Des 20 hPa
Asc+Des 30 hPa
Asc+Des 40 hPa
Asc+Des 60 hPa
Asc+Des 80 hPa
Asc+Des 100 hPa
May
Jun
Jul
Aug
Sep
DeepWave
K
days
S. Ocean 60S
S. Ocean 60S
2003
2004
2005
2006
2007
2008
2009
2010
2011
2003- 2011

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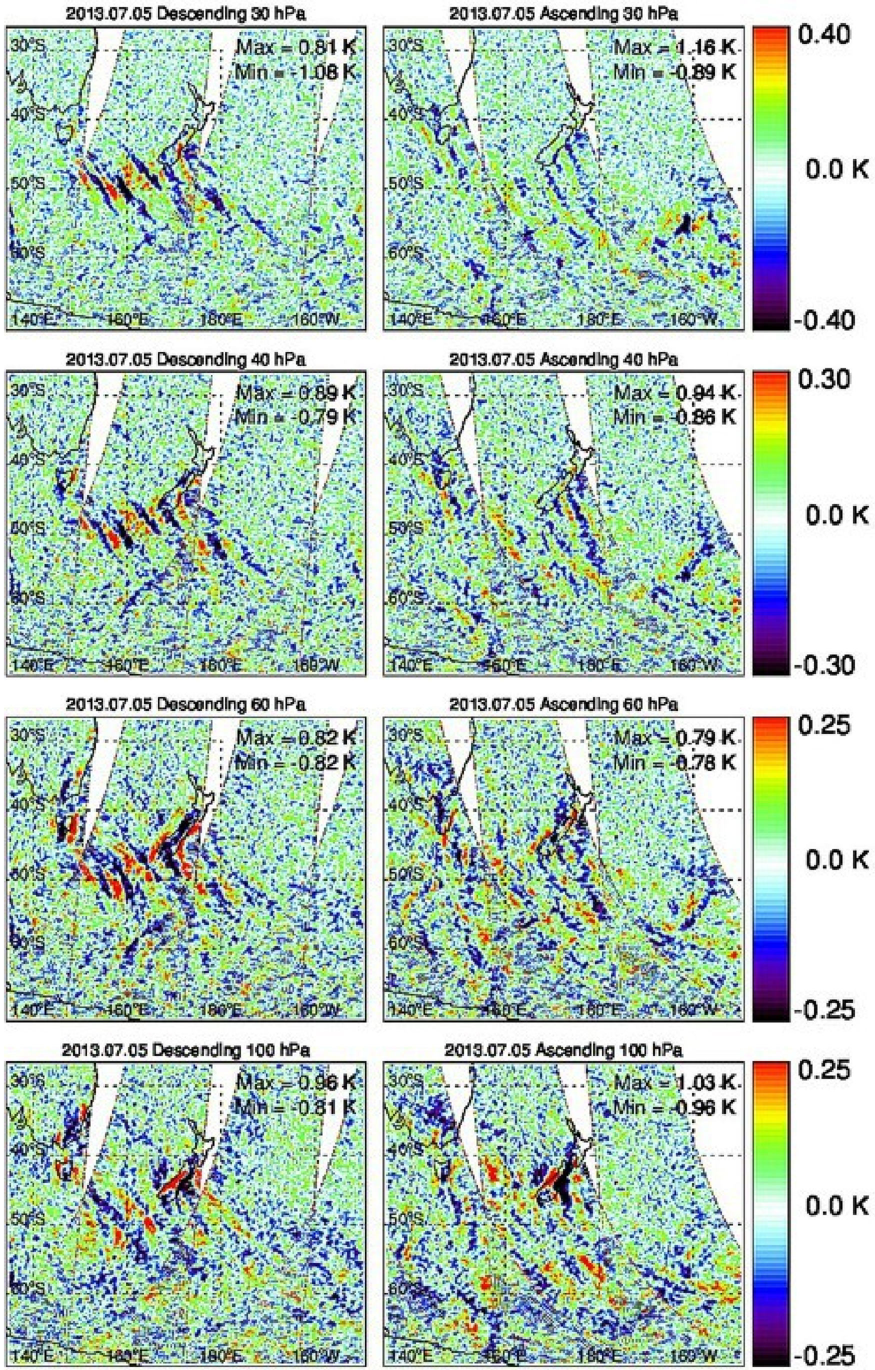
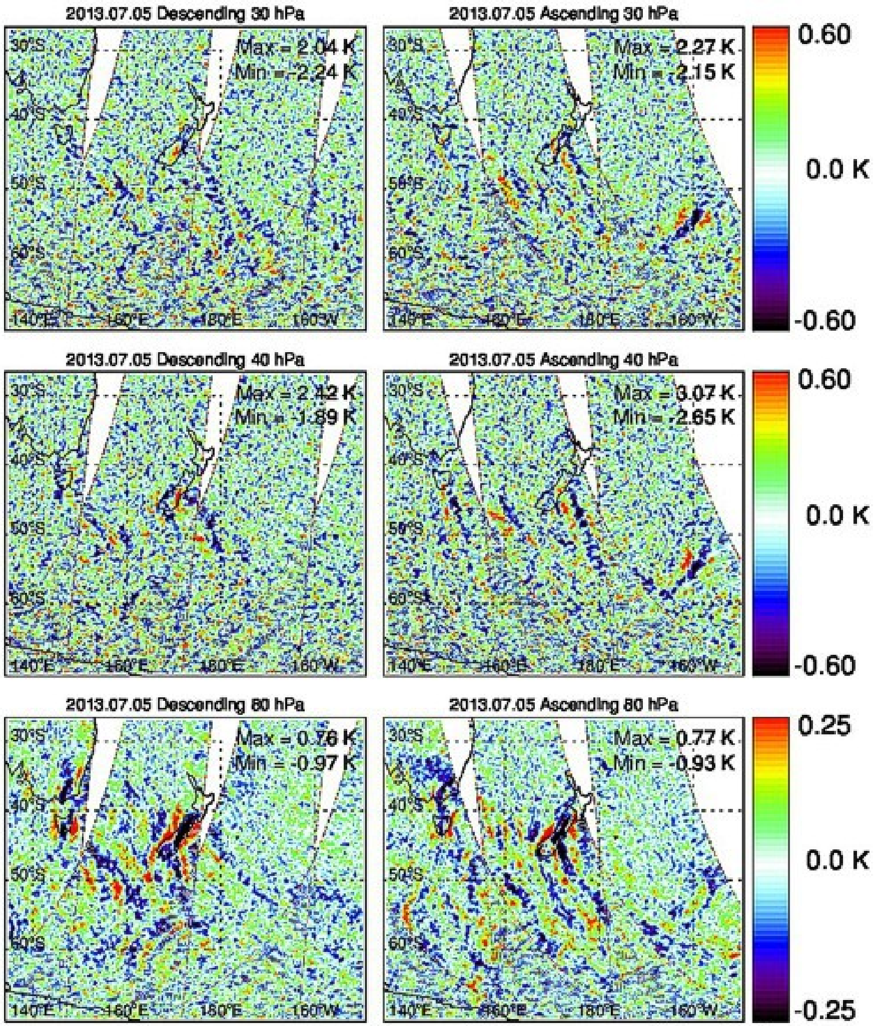




Near-realtime Aqua Level 1b Radiances

Overpass Statistics

Christchurch

Closest ascending overpass at 03.02 UTC.
Closest descending overpass at 14.13 UTC.

Hobart

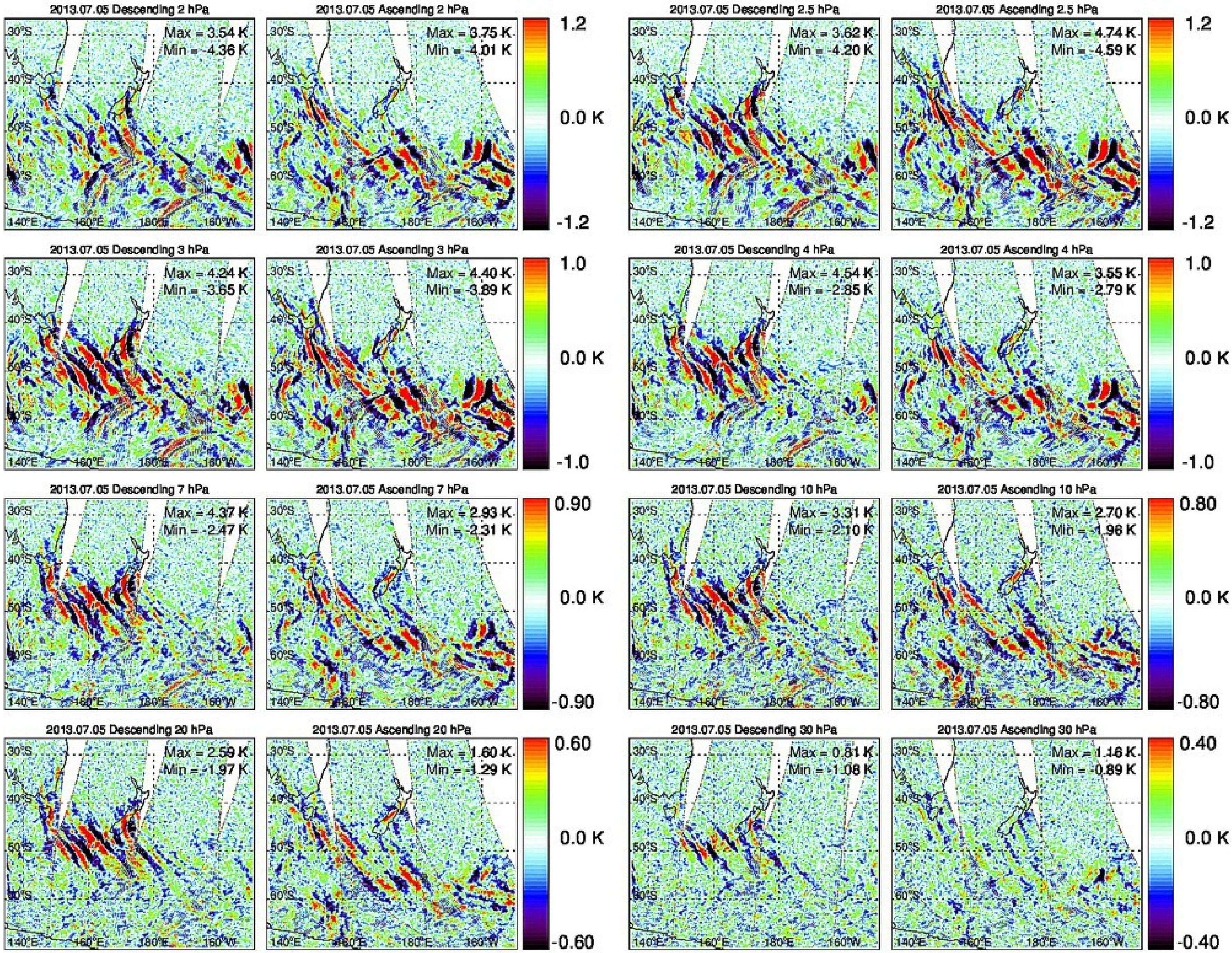
Closest ascending overpass at 04.67 UTC.
Closest descending overpass at 15.78 UTC.

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.



2013.07.05 Descending 2 hPa
Max = 3.54 K
Min = -4.36 K
2013.07.05 Ascending 2 hPa
Max = 3.75 K
Min = -4.01 K
1.2
0.0 K
-1.2
2013.07.05 Descending 2.5 hPa
Max = 3.62 K
Min = -4.20 K
2013.07.05 Ascending 2.5 hPa
Max = 4.74 K
Min = -4.59 K
1.2
0.0 K
-1.2
2013.07.05 Descending 3 hPa
Max = 4.24 K
Min = -3.65 K
2013.07.05 Ascending 3 hPa
Max = 4.40 K
Min = -3.89 K
1.0
0.0 K
-1.0
2013.07.05 Descending 4 hPa
Max = 4.54 K
Min = -2.85 K
2013.07.05 Ascending 4 hPa
Max = 3.55 K
Min = -2.79 K
1.0
0.0 K
-1.0
2013.07.05 Descending 7 hPa
Max = 4.37 K
Min = -2.47 K
2013.07.05 Ascending 7 hPa
Max = 2.93 K
Min = -2.31 K
0.90
0.0 K
-0.90
2013.07.05 Descending 10 hPa
Max = 3.31 K
Min = -2.10 K
2013.07.05 Ascending 10 hPa
Max = 2.70 K
Min = -1.96 K
0.80
0.0 K
-0.80
2013.07.05 Descending 20 hPa
Max = 2.59 K
Min = -1.97 K
2013.07.05 Ascending 20 hPa
Max = 1.60 K
Min = -1.29 K
0.60
0.0 K
-0.60
2013.07.05 Descending 30 hPa
Max = 0.81 K
Min = -1.08 K
2013.07.05 Ascending 30 hPa
Max = 1.16 K
Min = -0.89 K
0.40
0.0 K
-0.40
30°S
40°S
50°S
60°S
140°E
160°E
180°E
160°W

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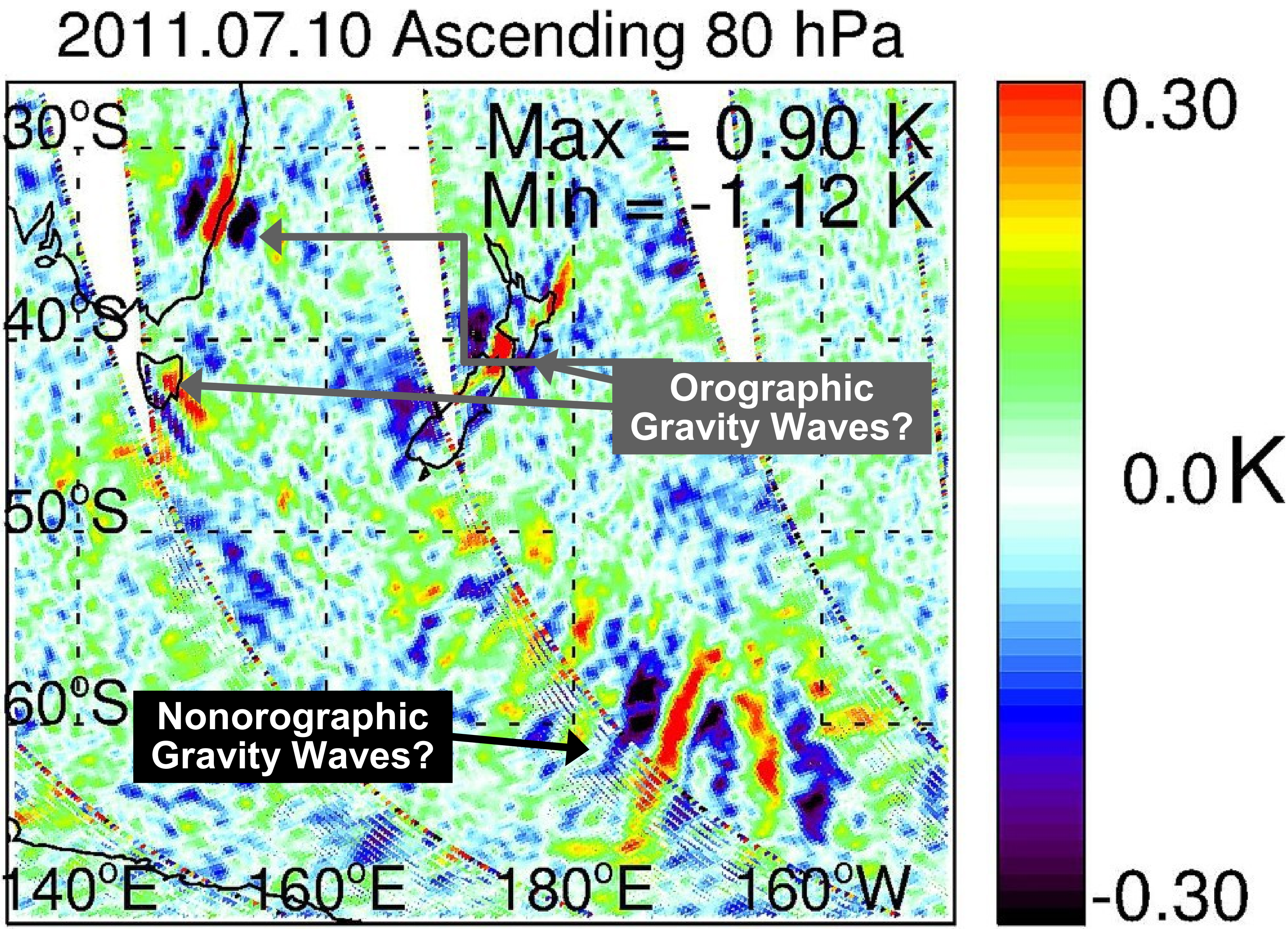
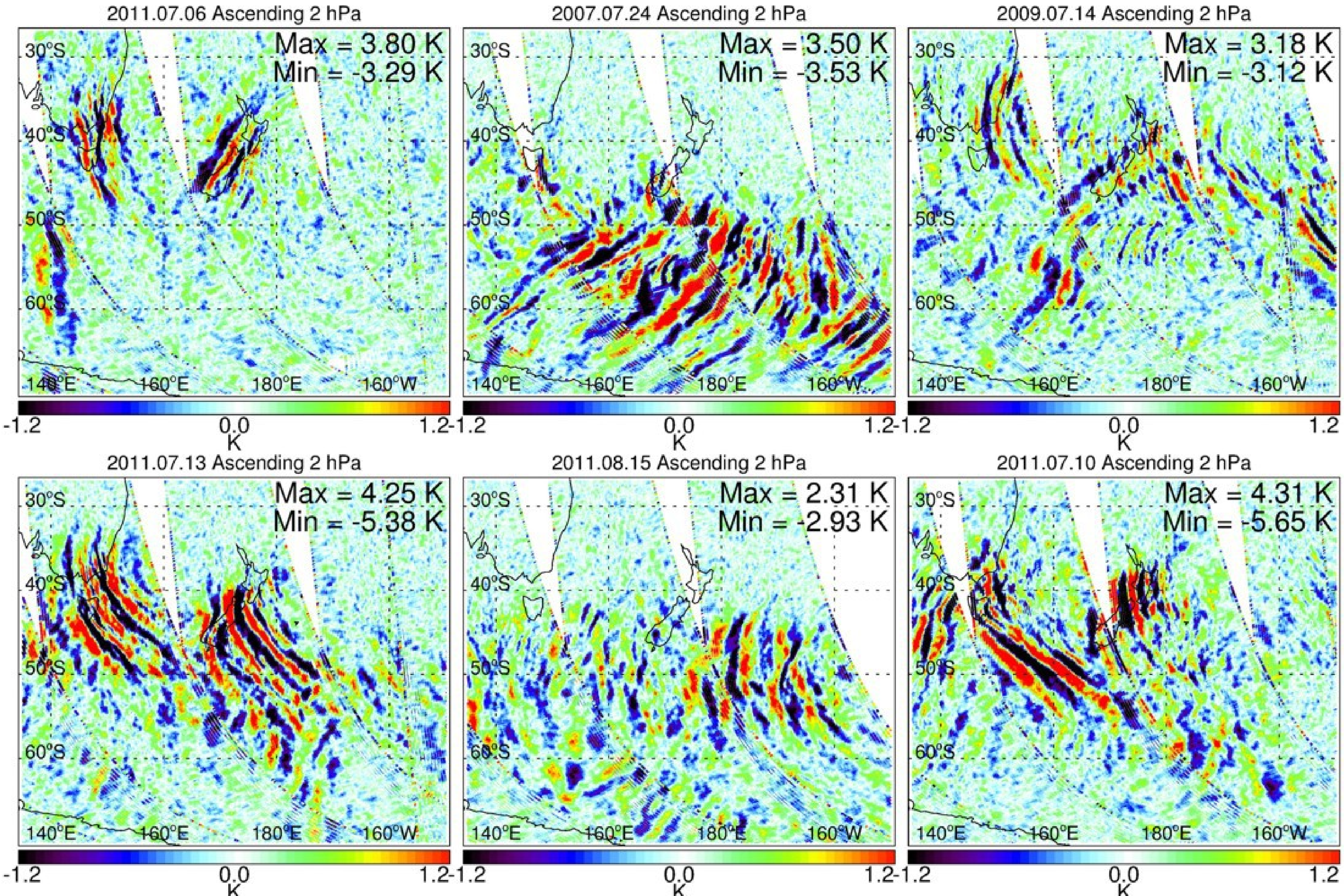

2011.07.10 Ascending 80 hPa
Max = 0.90 K
Min = -1.12 K
30°S
40°S
50°S
60°S
140°E
160°E
180°E
160°W
Orographic Gravity Waves?
Nonorographic Gravity Waves?
0.30
0.0K
-0.30

Rich Variable Wave Structure: Not Understood



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

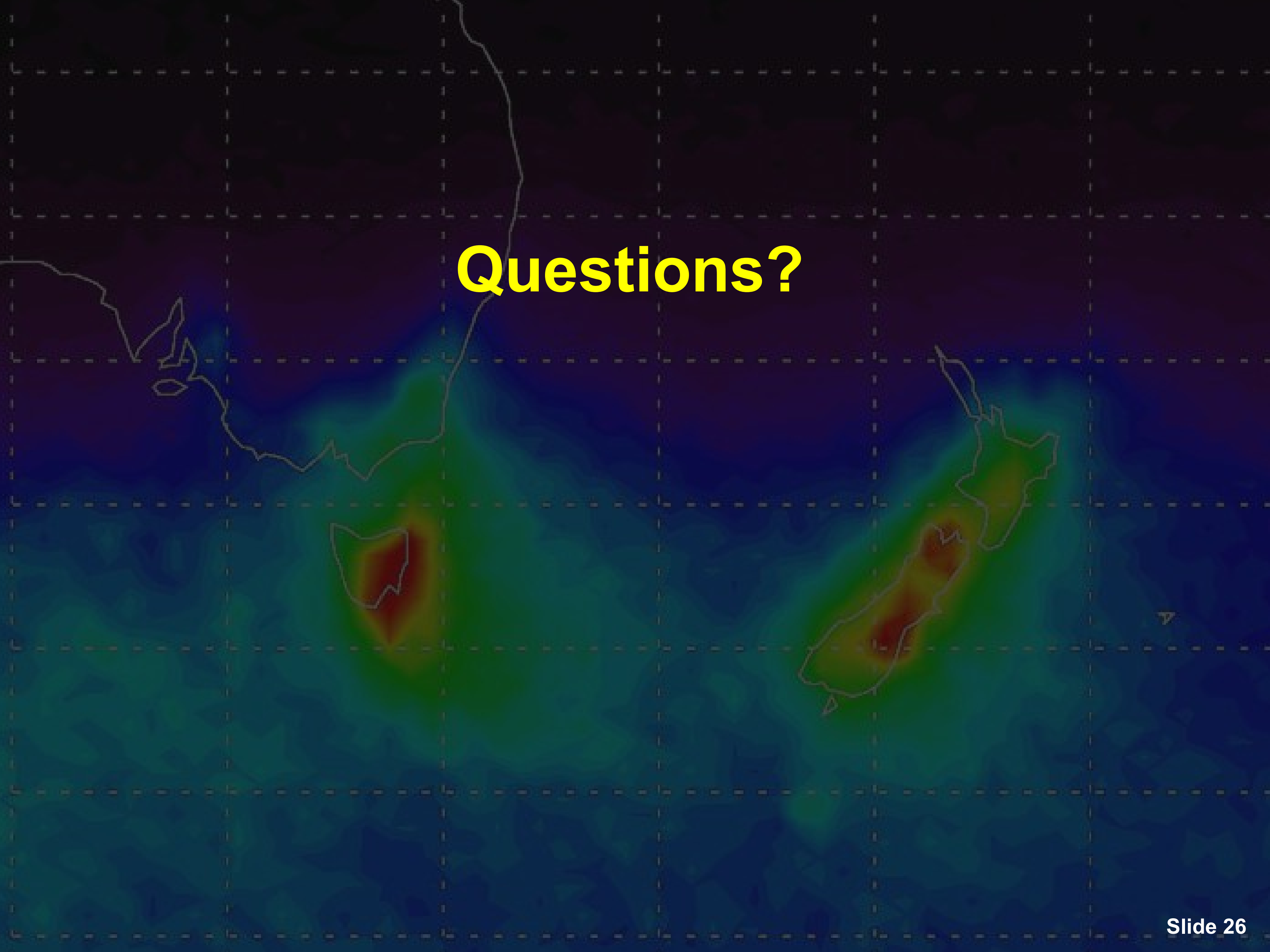
Question: What are the origins of rich variable 3D GW structures seen in satellite GW swath imagery in the DEEPWAVE RAO?

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?

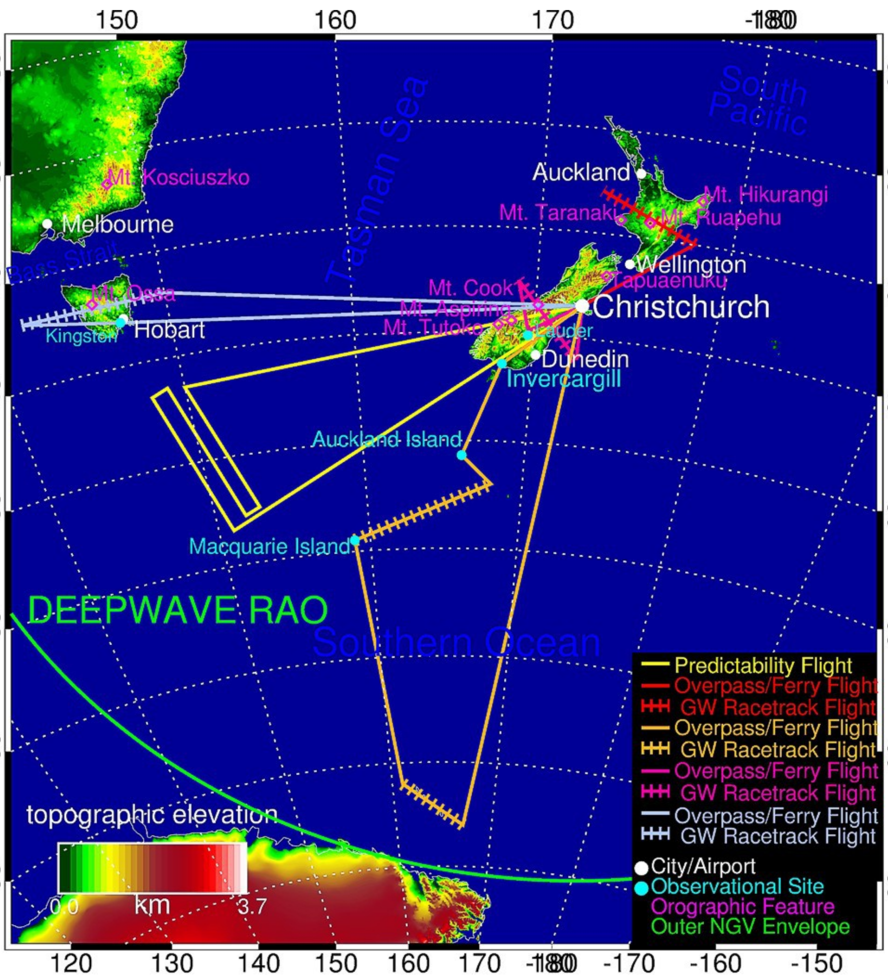
Closure: DEEPWAVE NGV measurements, detailed 3D modeling and parameterization

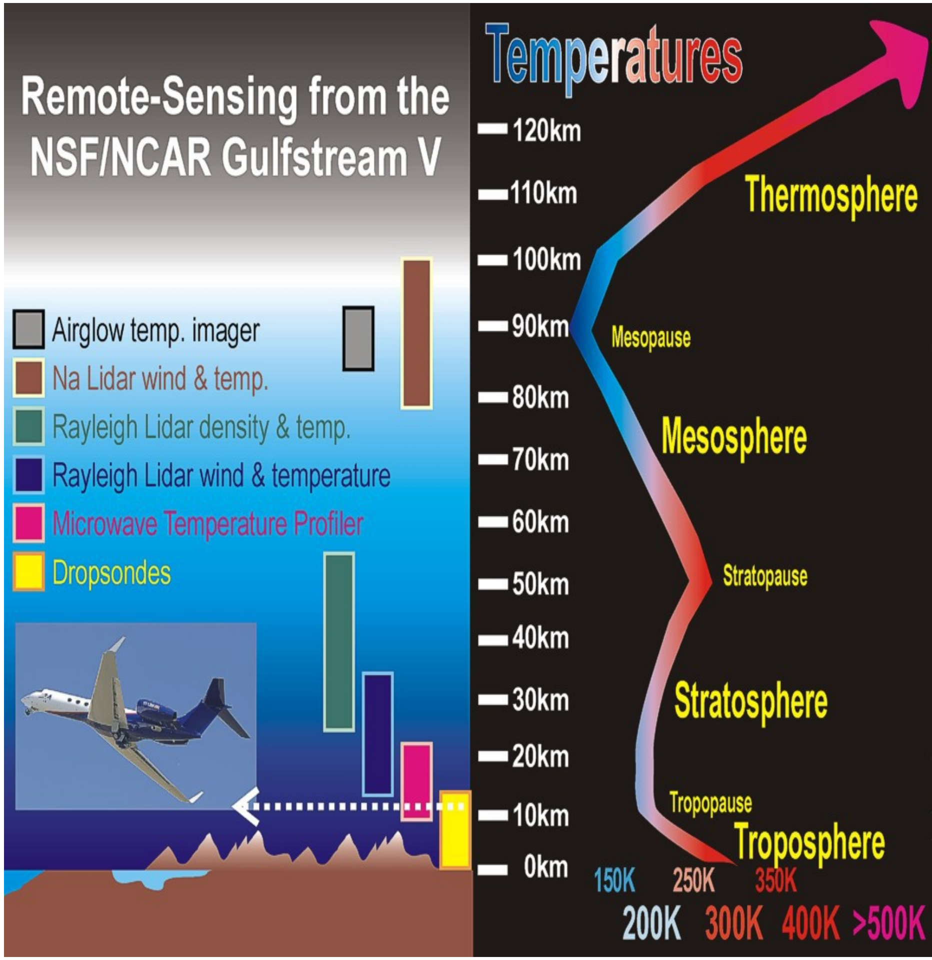
Questions?



Backup Slides follow….

NSF DEEPWAVE Mission: June-July 2014





Channel Averaging: 100-2 hPa

50 raw channel radiances → 12 net channel radiances

Gong Wu & Eckermann (Atmos. Chem. Phys., 12, 1701-1720, 2012)

Pressure (hPa)	Channel numbers	Noise (K^2)	NEdT (K^2)	Min. detectable GW var. ($\times 10^{-3}$ K^2) Zonal mean	Map
2	74	0.149	0.165	3.78	26.64
2.5	75	0.147	0.166	3.72	26.22
3	76	0.143	0.161	3.63	25.55
4	77	0.145	0.160	3.66	25.80
7	**78**	0.153	0.162	3.88	27.34
10	**79**	0.182	0.172	4.62	32.53
20	81, 82	0.084	0.078	2.14	15.05
30	**102**, **108**, **114**, **120**, 125, 126	0.039	0.029	0.98	6.88
40	64, 88, 90, **94**, **100**, 106, 118	0.033	0.028	0.83	5.86
60	66, 68, 70, 86, 87, 91, 93, **97**, 130	0.026	0.018	0.66	4.68
80	92, 98, 104, 105, 110, 111, **116**, 117, 122, 123, 128, 129, 134, 140	0.020	0.011	0.50	3.54
100	132, 133, 138, 139, 149, 152	0.026	0.014	0.67	4.73

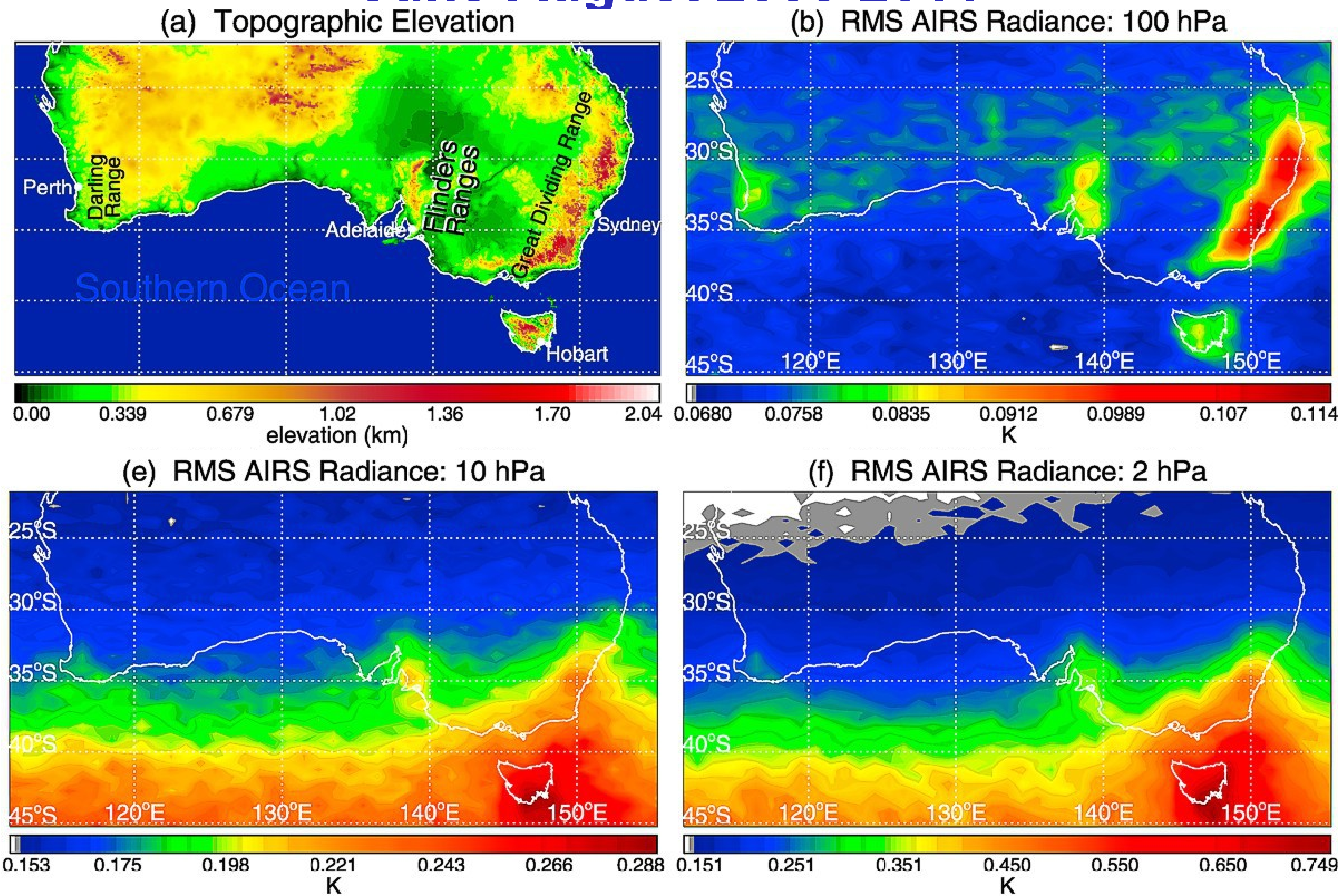
Isolating Small-Scale Gravity-Wave Perturbations from AIRS Level 1b Swath Radiance Imagery

Fit large-scale radiance structure in swath imagery:

- Smooth raw radiances along track using a 33-point running average (660 km)
- Fit every cross-track scan (90 points) of these smoothed radiances using a sixth-order polynomial (to capture both geophysical cross-track gradients as well as limb effects)
- Smooth fitted fields further using 15-point along-track running average

Subtract these fits of large-scale structure from raw radiances to isolate small-scale perturbation structure in the swath imagery.

AIRS RMS Brightness Temperatures June-August 2003-2011



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