# Gravity wave properties and propagation in the middle atmosphere

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Acknowledgments:

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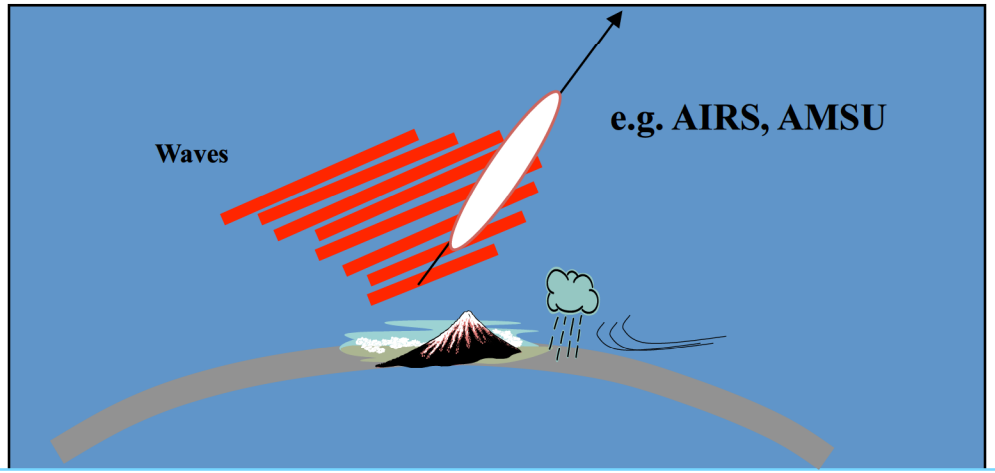
# Outline

- Gravity wave (GW) observations with temperature sounding channels
  - Microwave Limb Sounder (MLS)
  - Advanced Microwave Sounding Unit-A (AMSU-A)
  - New results from Atmosphere Infrared Sounder (AIRS)
- Gravity waves in ECMWF analysis
- Coupling between GWs and planetary wave in the polar middle atmosphere
  - Aura MLS study
- Thoughts for future GW research topics with satellite observations

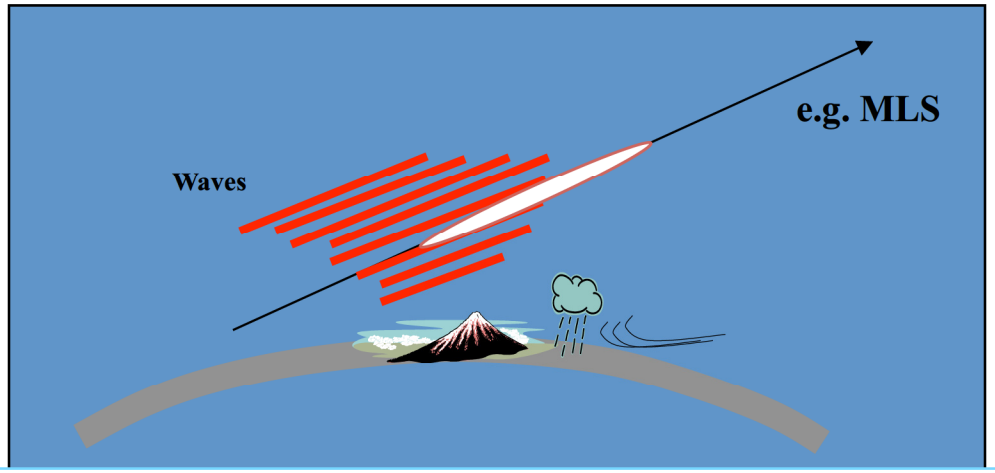
## Nadir or Slant Path

- good horizontal resolution
- limited vertical resolution
- $\lambda_z/\lambda_h \sim 1$
- e.g., AMSU-A, AIRS, SSMIS



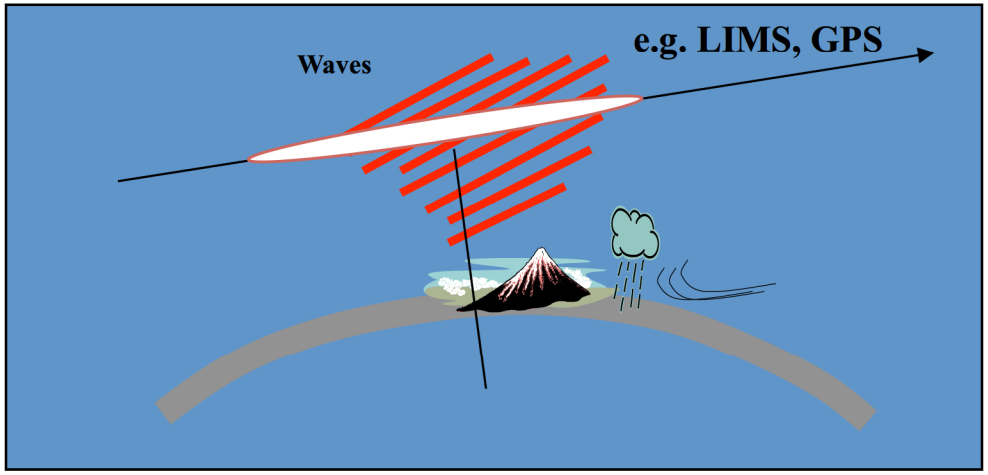

## Limb with Opaque Path

- good horizontal resolution
- limited vertical resolution
- $\lambda_z/\lambda_h \sim 0.1$
- e.g., MLS, HIRDLS



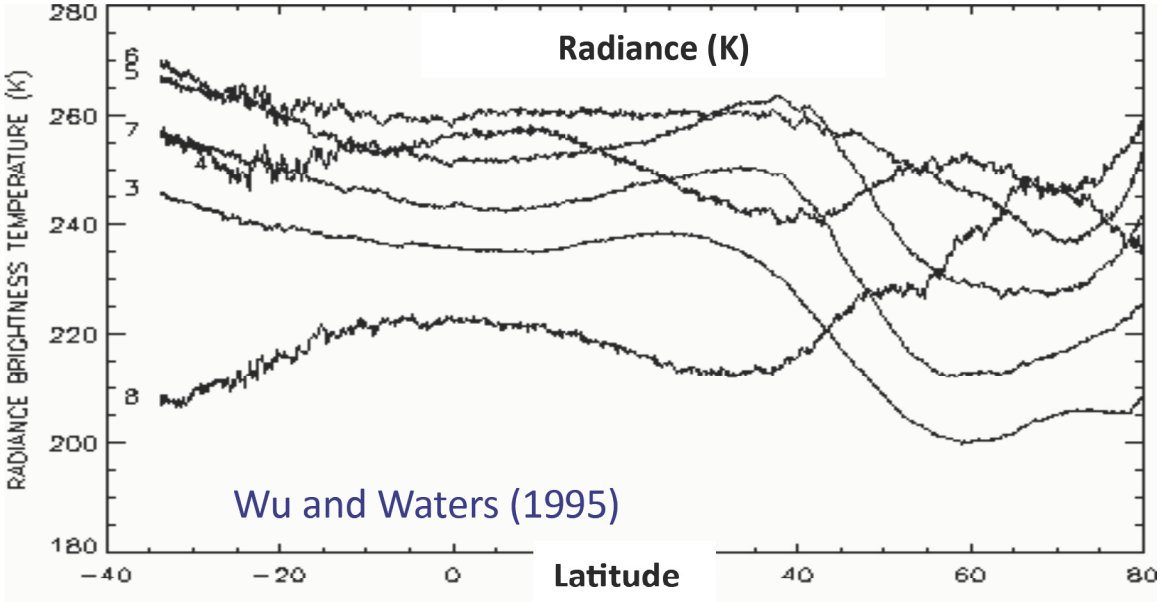

## Limb with Transparent Path

- good vertical resolution
- limited horizontal resolution
- $\lambda_z/\lambda_h < 0.1$
- e.g., LIMS, CRISTA, GPS, HIRDLS

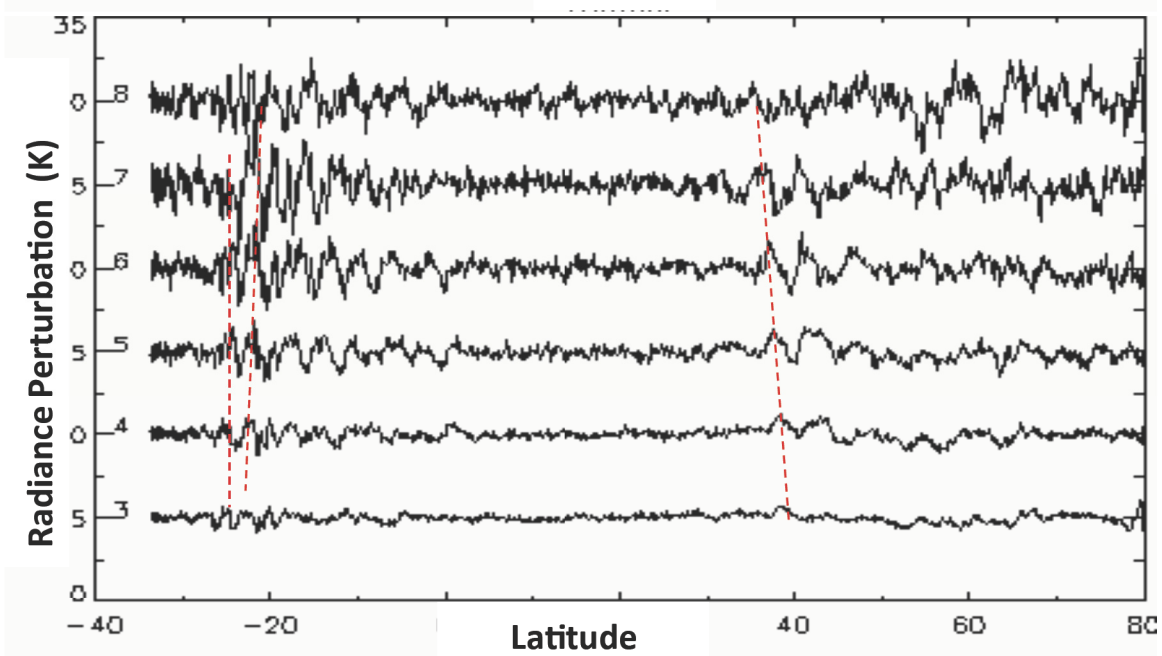


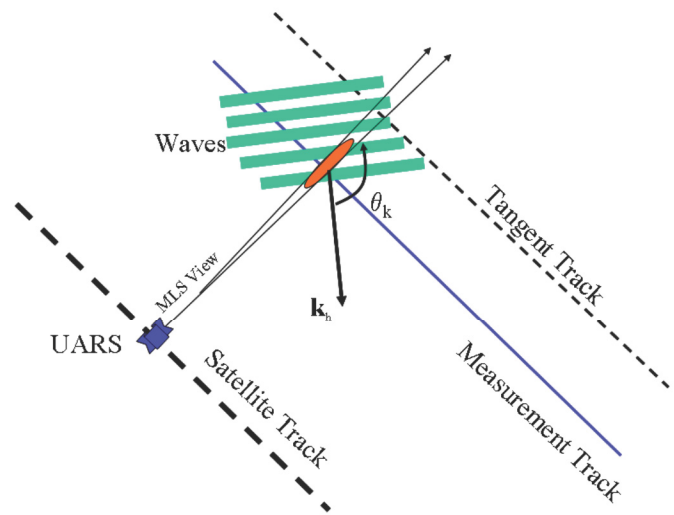

Wu et al. (2006)

# UARS MLS: Limb-Tracking Measurements

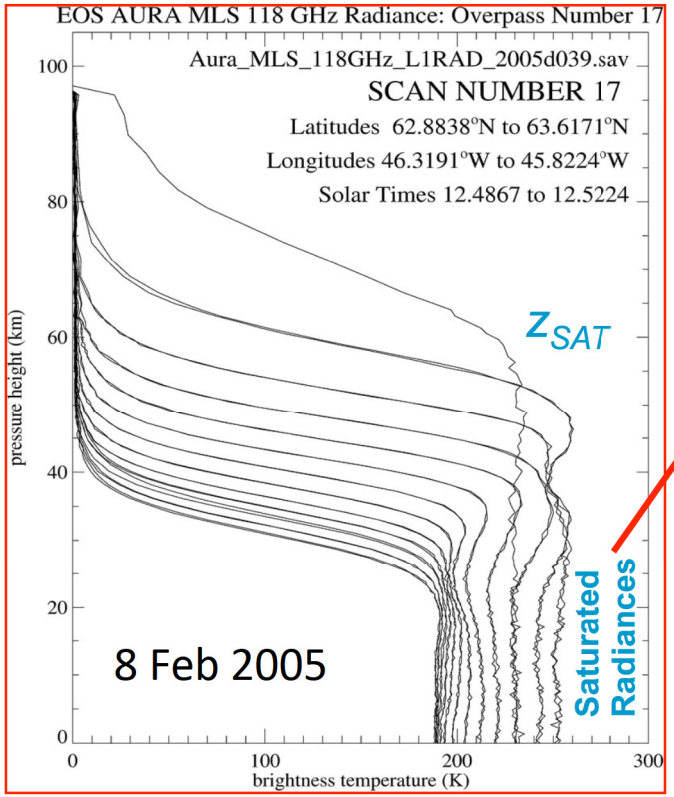


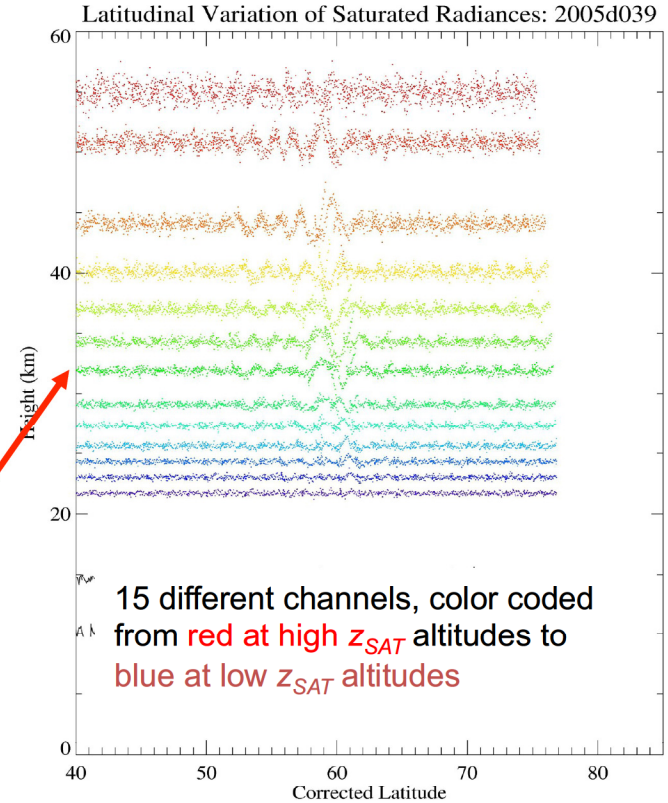

- Horizontal resolution: ~15 km
- Amp growth with height: < 5K
- Coherent perturbations among different heights
- Tilted wave structures
- Horizontal wavelengths: 30 – >1000 km
- Vertical wavelengths: > 15km

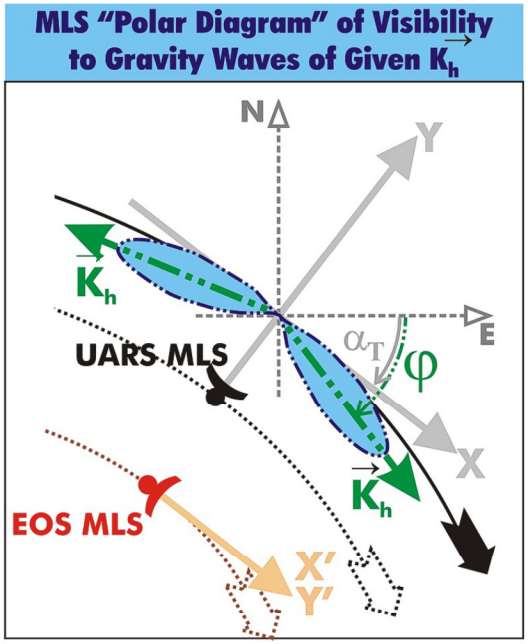


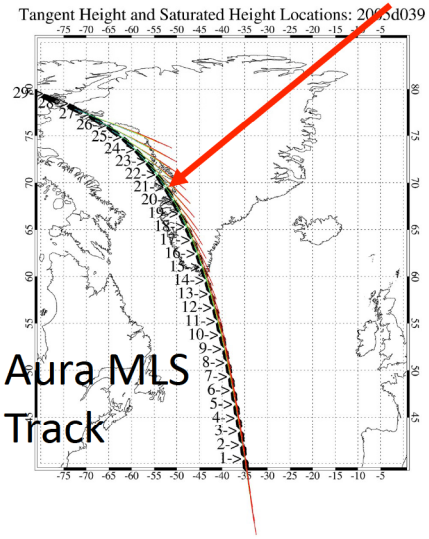



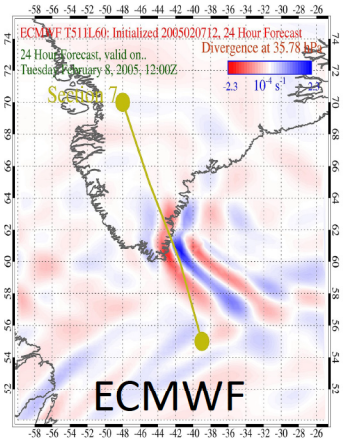
# Large fluctuations in Aura MLS radiances over southern Greenland



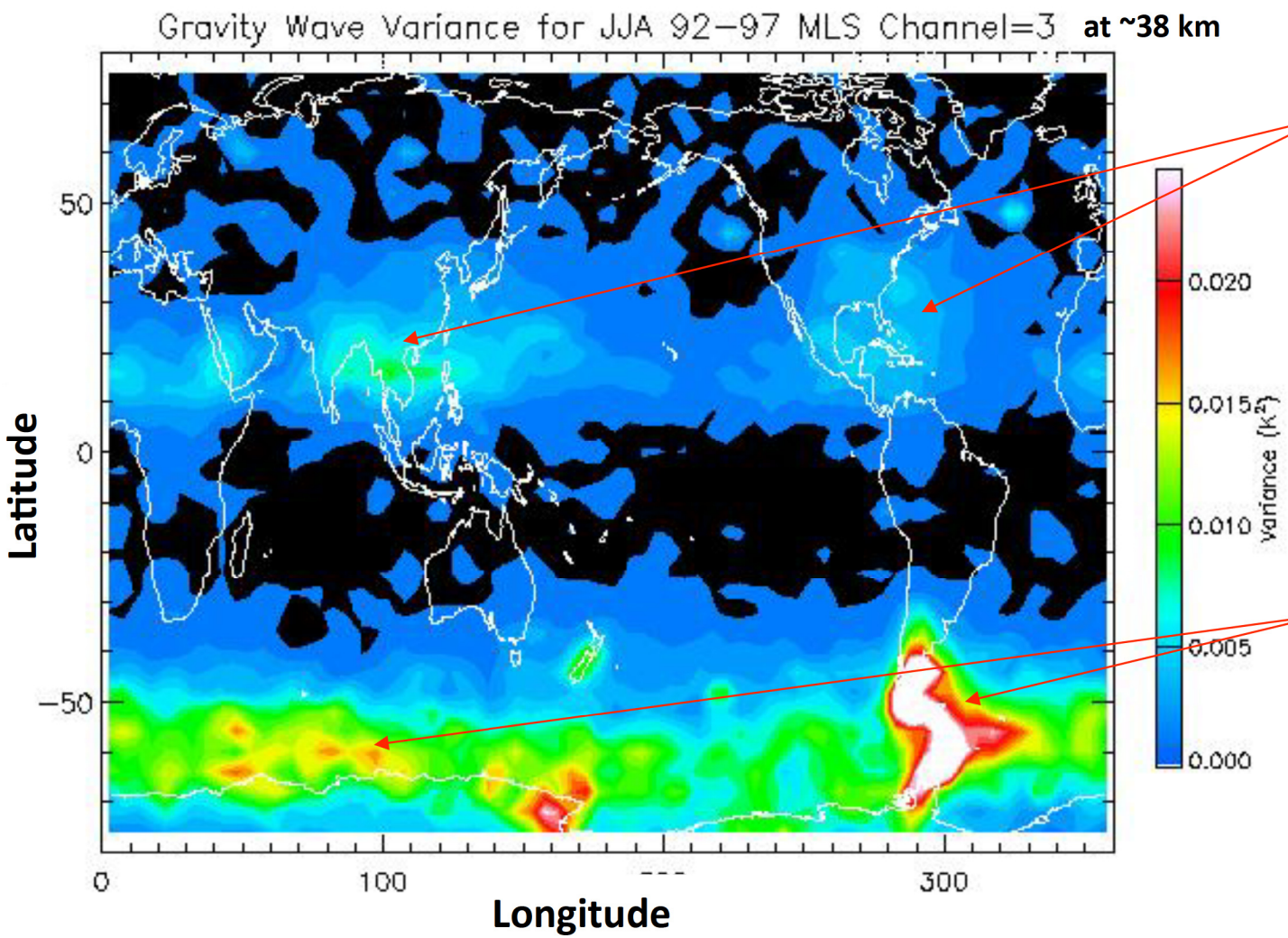




Eckermann et al. (Aura Sci Mtg, 2005)

# UARS MLS: Gravity Wave Variance Map

## (wave sources)



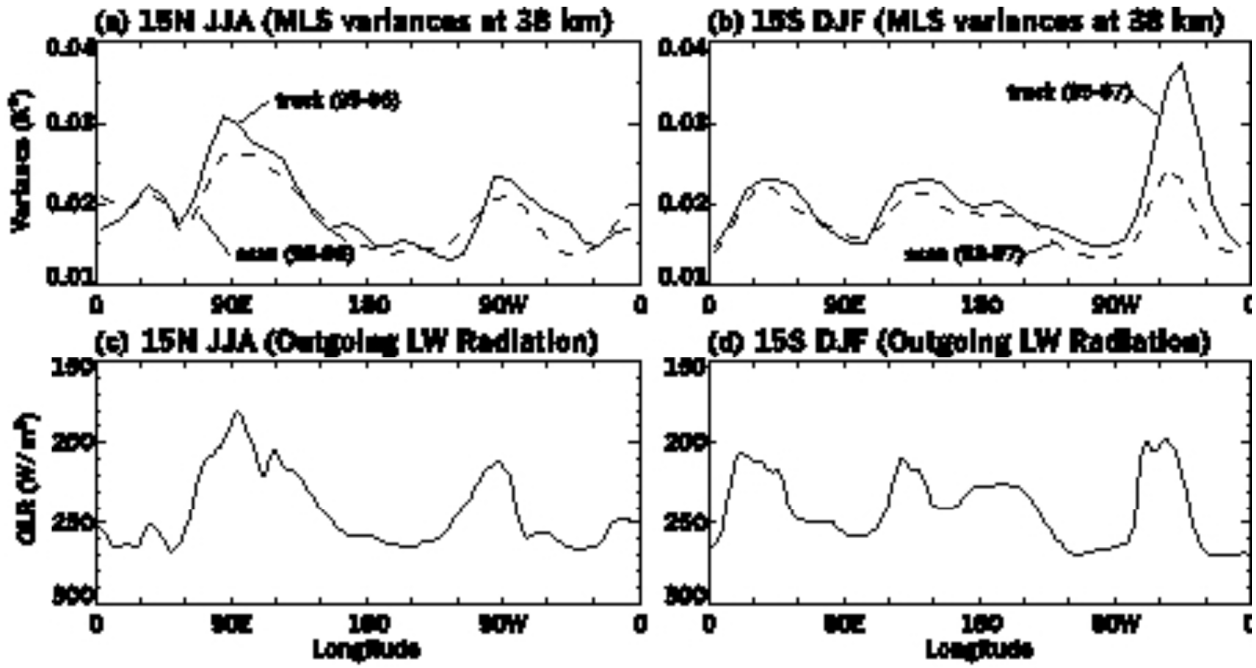

Weak but significant activity associated with convection in the northern subtropics

Strong wave activity in the SH near the southern Andes and some along the stratospheric jet

# UARS MLS: Gravity Waves from Deep Convection

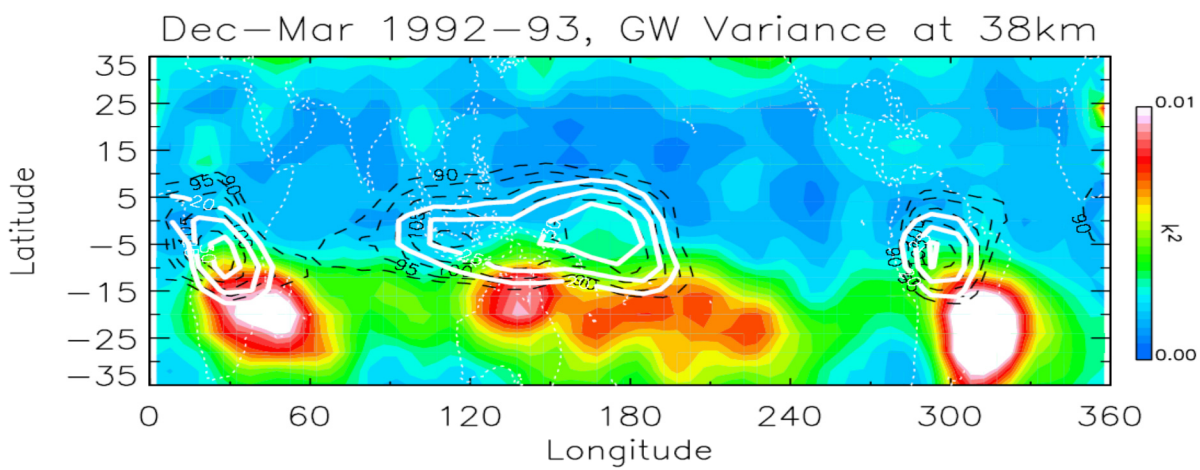
Good correlation between MLS variance and OLR in the summer subtropics

(McLandress et al., 2000)




Shifted patterns between upper-trop deep convection and lower-stratospheric GW variances

(Jiang et al., 2004)



UARS MLS
Ch 3 (~38km)

AMSU-A
FOV Group 6

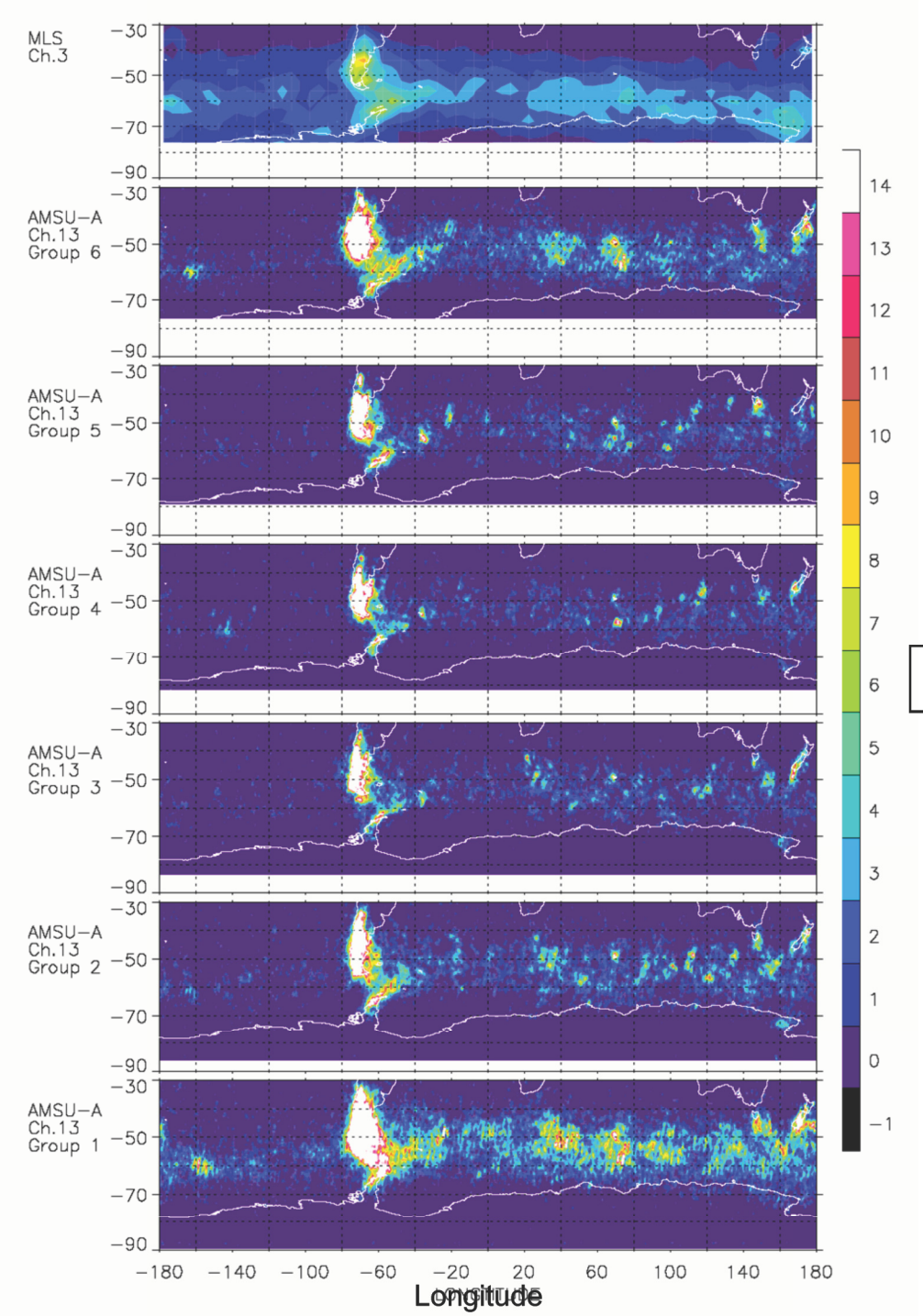
AMSU-A
FOV Group 5

AMSU-A
FOV Group 4

AMSU-A
FOV Group 3

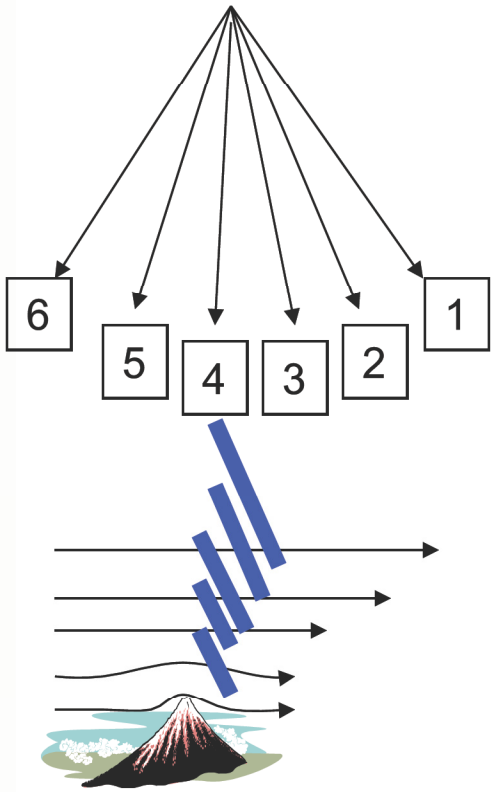
AMSU-A
FOV Group 2

AMSU-A
FOV Group 1



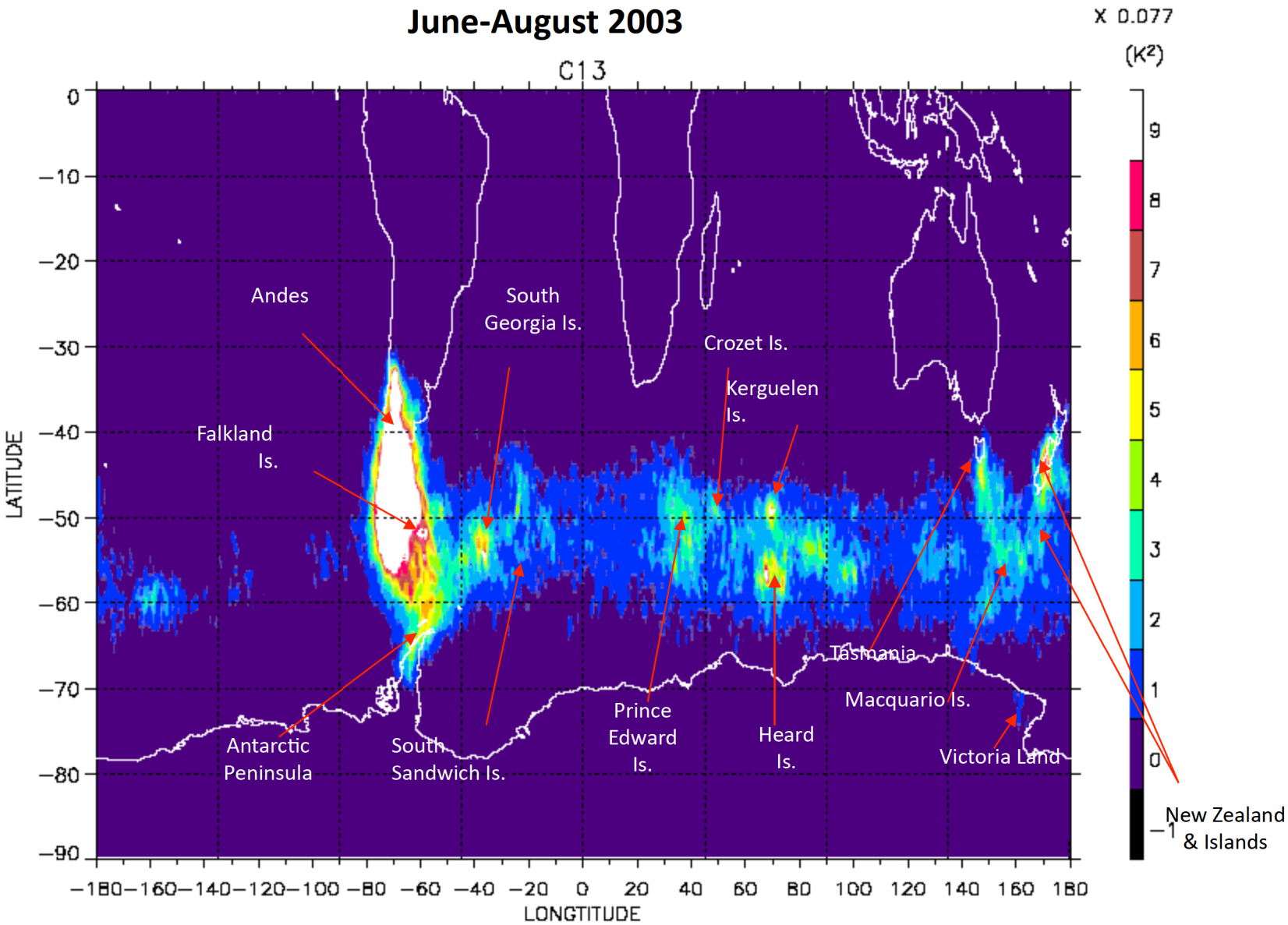

JJA Period

AMSU-A
Descending
Orbits




(Wu, GRL, 2004)

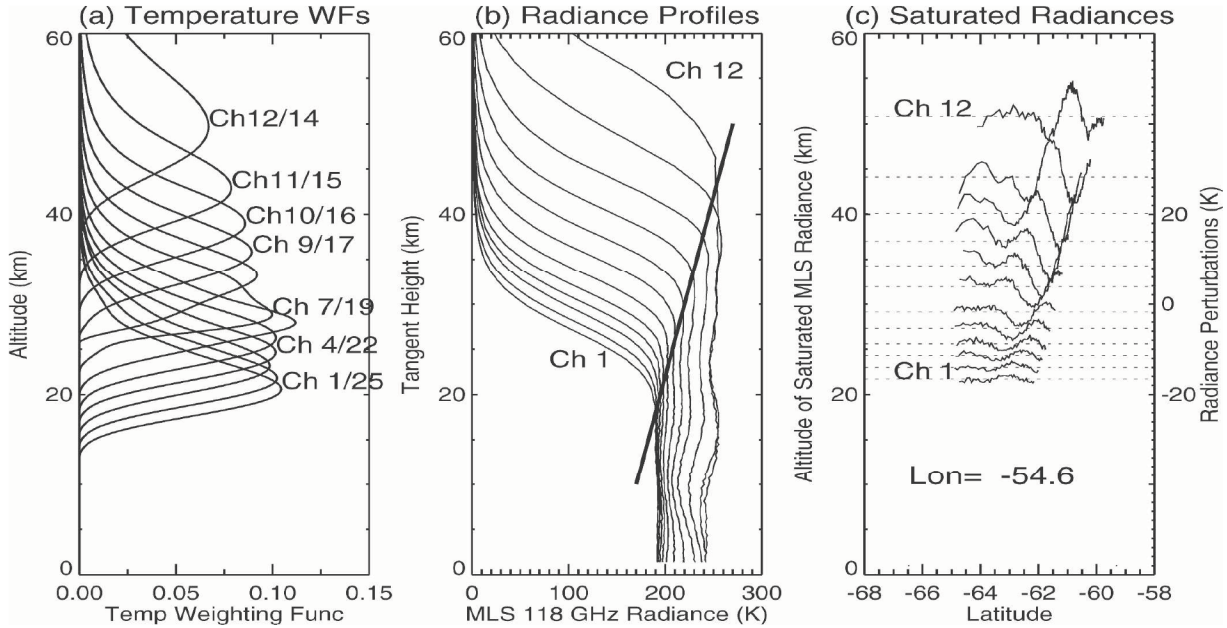
# AMSU-A: GW Variances from NOAA 15, 16, 17

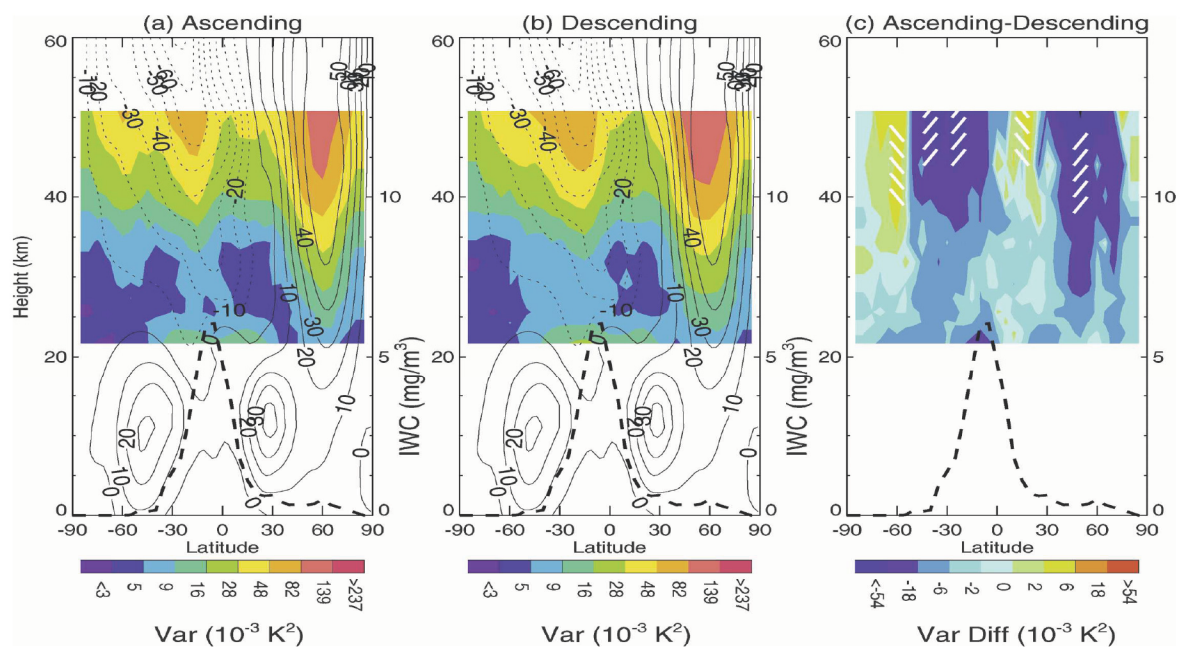


# Aura MLS

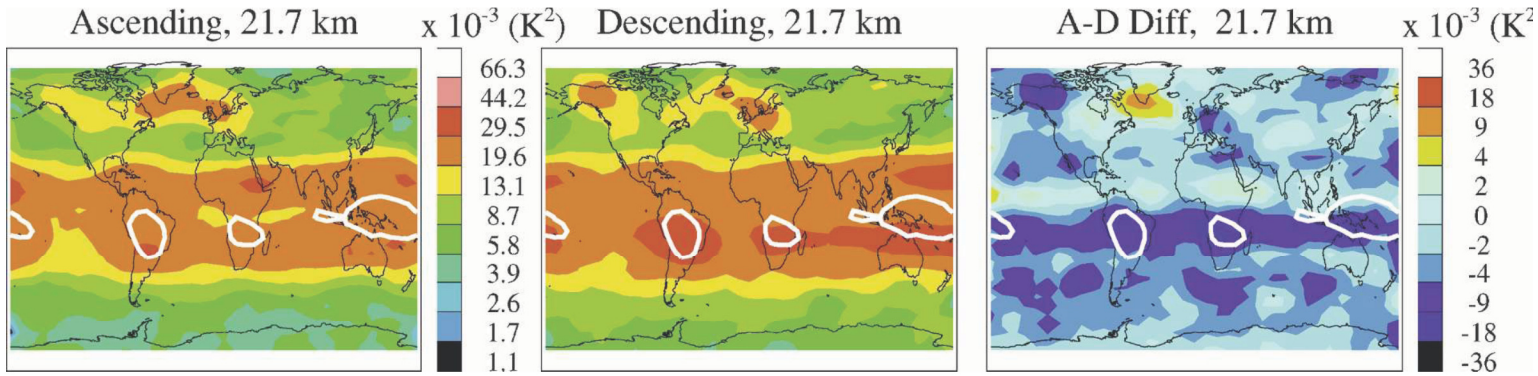
Wu and Eckermann (2008)

- Aura and UARS MLS GW variances reveal similar climatology;
- Aura MLS is sensitive to GWs propagating in the meridional direction;
- Aura MLS is more sensitive to GWs with short $\lambda_z$ than UARS MLS, and thus to inertia GWs in the lower stratosphere.

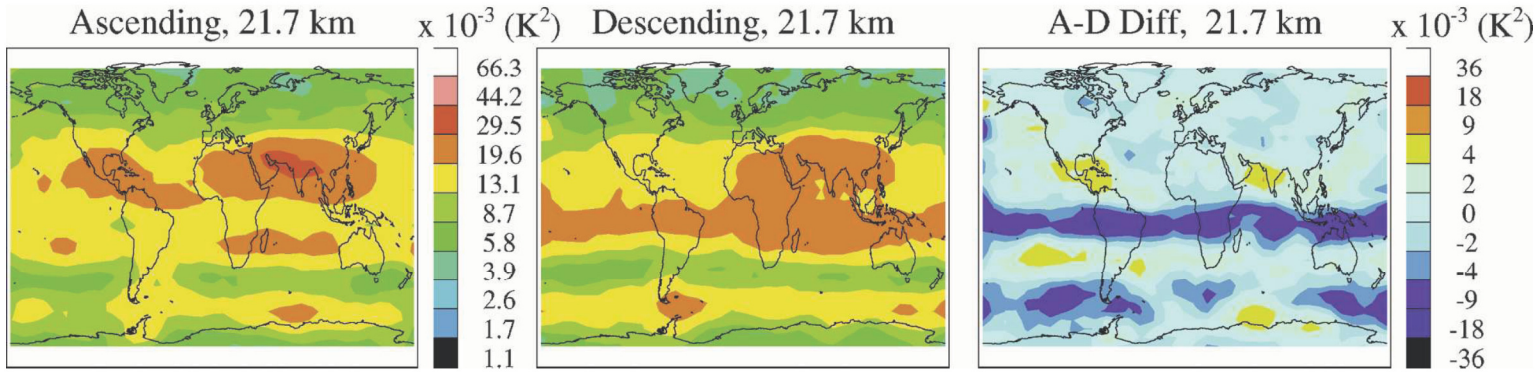


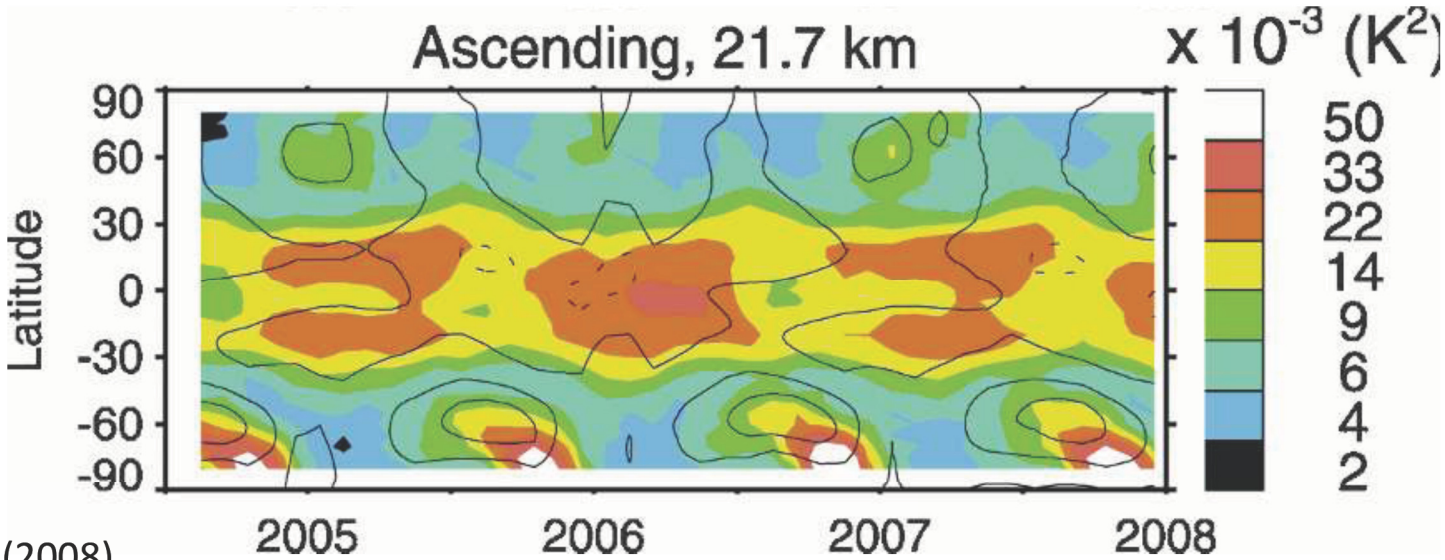



January 2005




July 2005




Wu and Eckermann (2008)

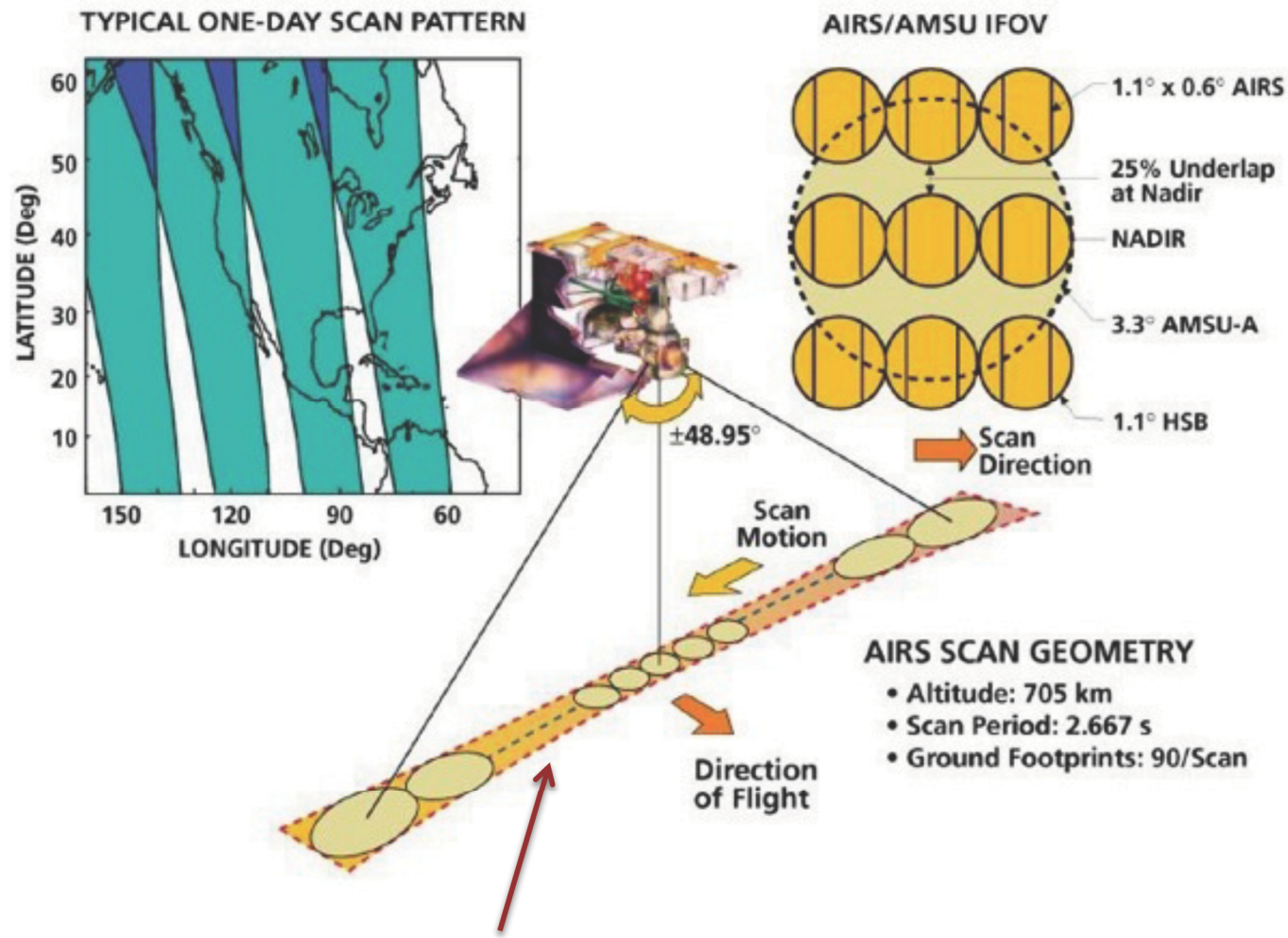
# AIRS (Atmospheric Infrared Sounder) on NASA Aqua

**Footprint: 1.1° x 0.6° (13.5 km x 7.4 km)**

**Scan range: ±48.95°**

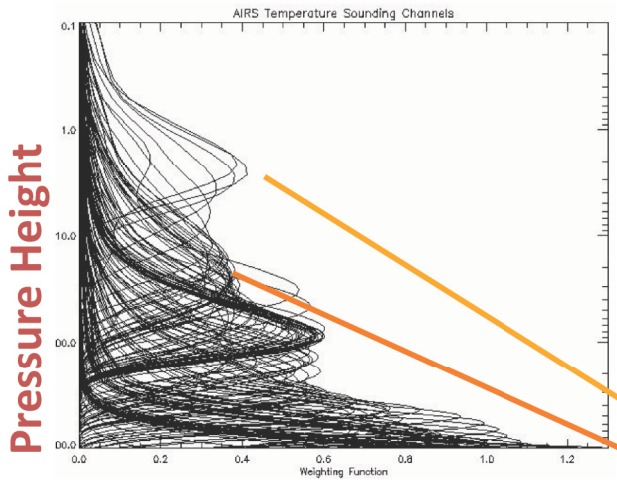
**Compared to AMSU-A, the detectable frequency range increases**

$$\frac{\lambda_z}{\lambda_h} \approx \frac{\omega}{N}$$

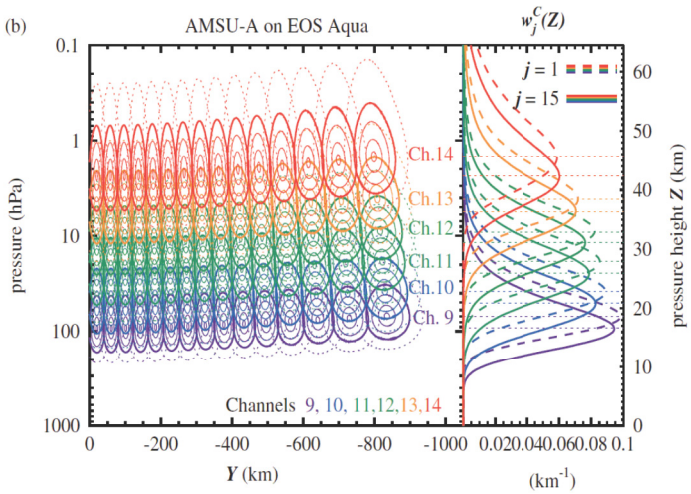



90 AIRS field-of-view (FOV) in each cross-track scan

# AIRS Radiance Subset and Analysis




- AIRS Weighting function

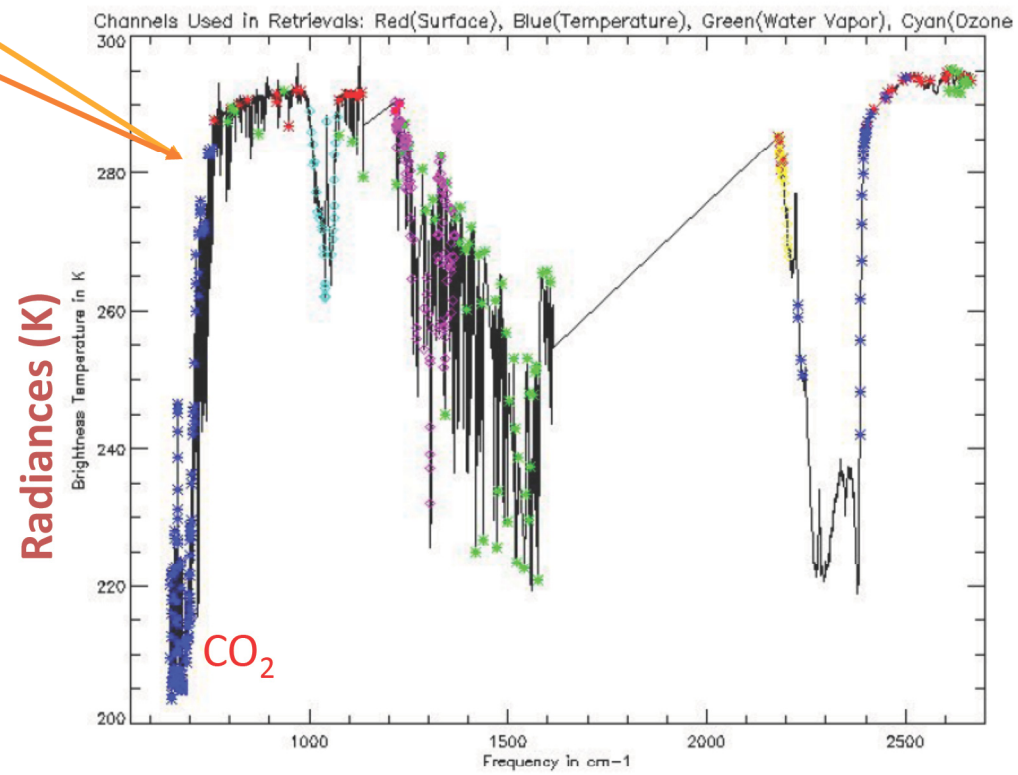



AMSU-A Weighting function

(Eckermann et al., 2007)

A subset of AIRS channels selected at pressures (hPa):

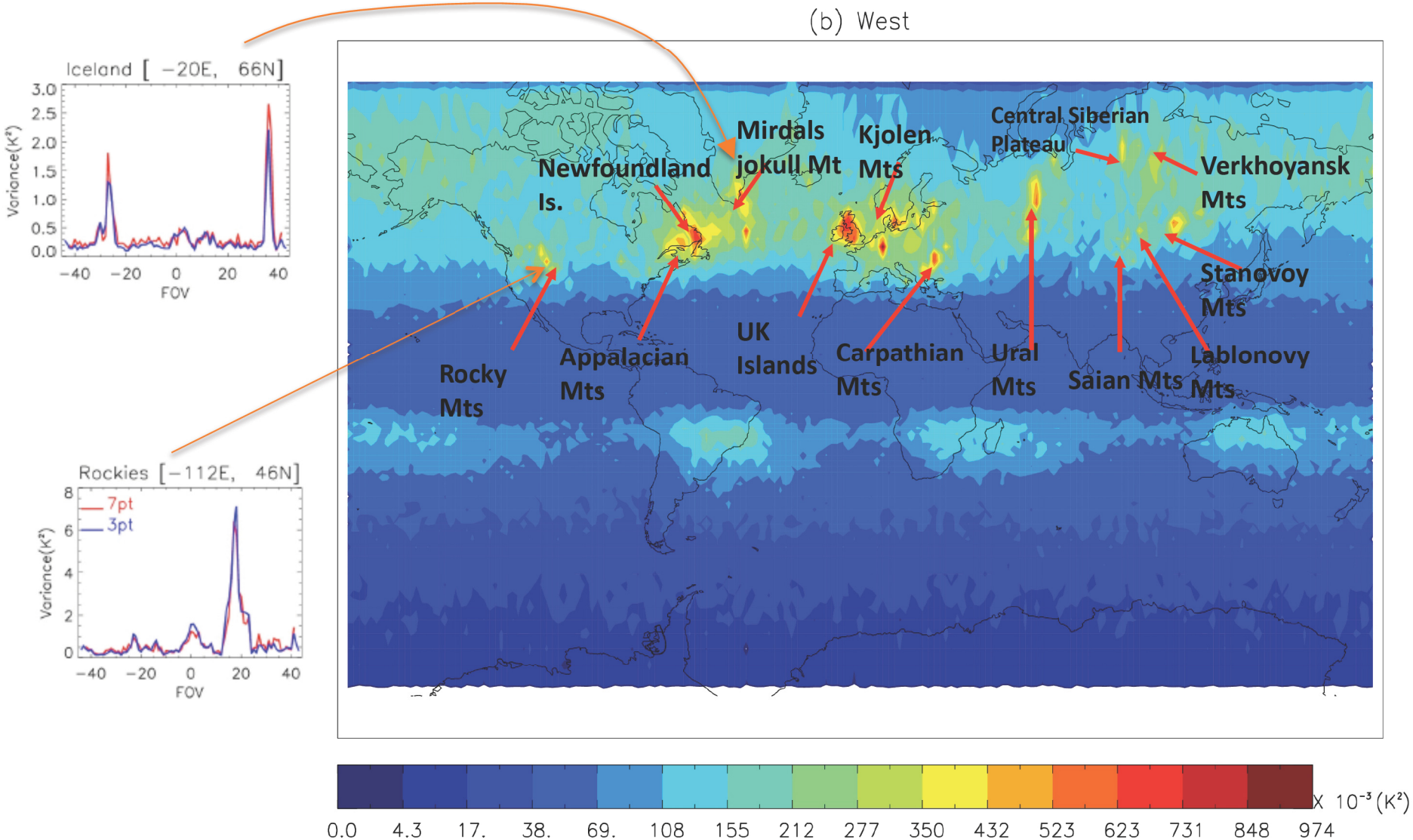
2, 2.5, 3, 4, 7, 10, 20, 30, 40, 60, 80, 100, 200, 400, 800, 1000



# Spatial distribution: Major contribution from orographic GWs

2.5 hpa, January (2002 - 2009 mean), west view

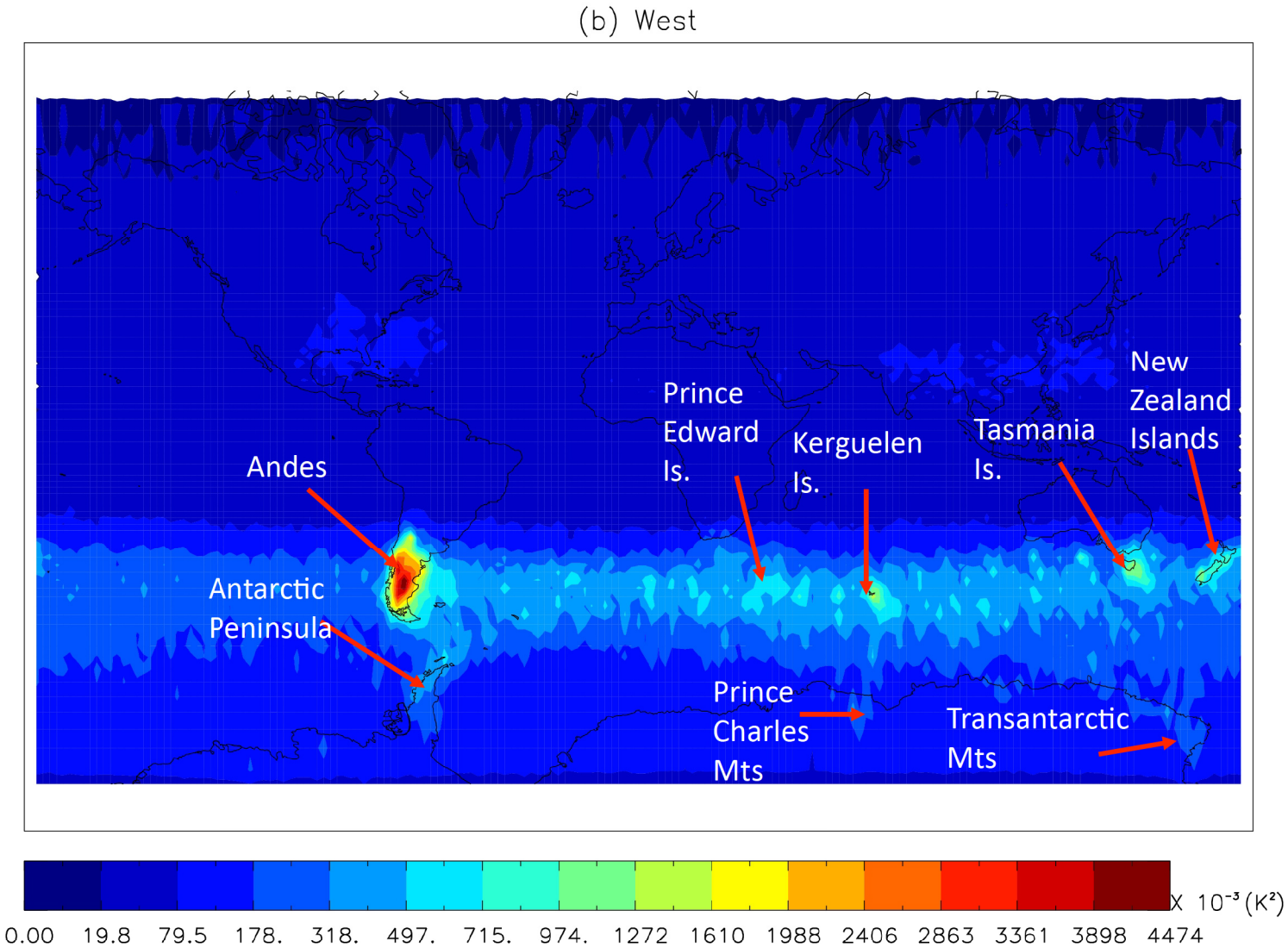
NH



# Spatial distribution: Major contribution from orographic GWs

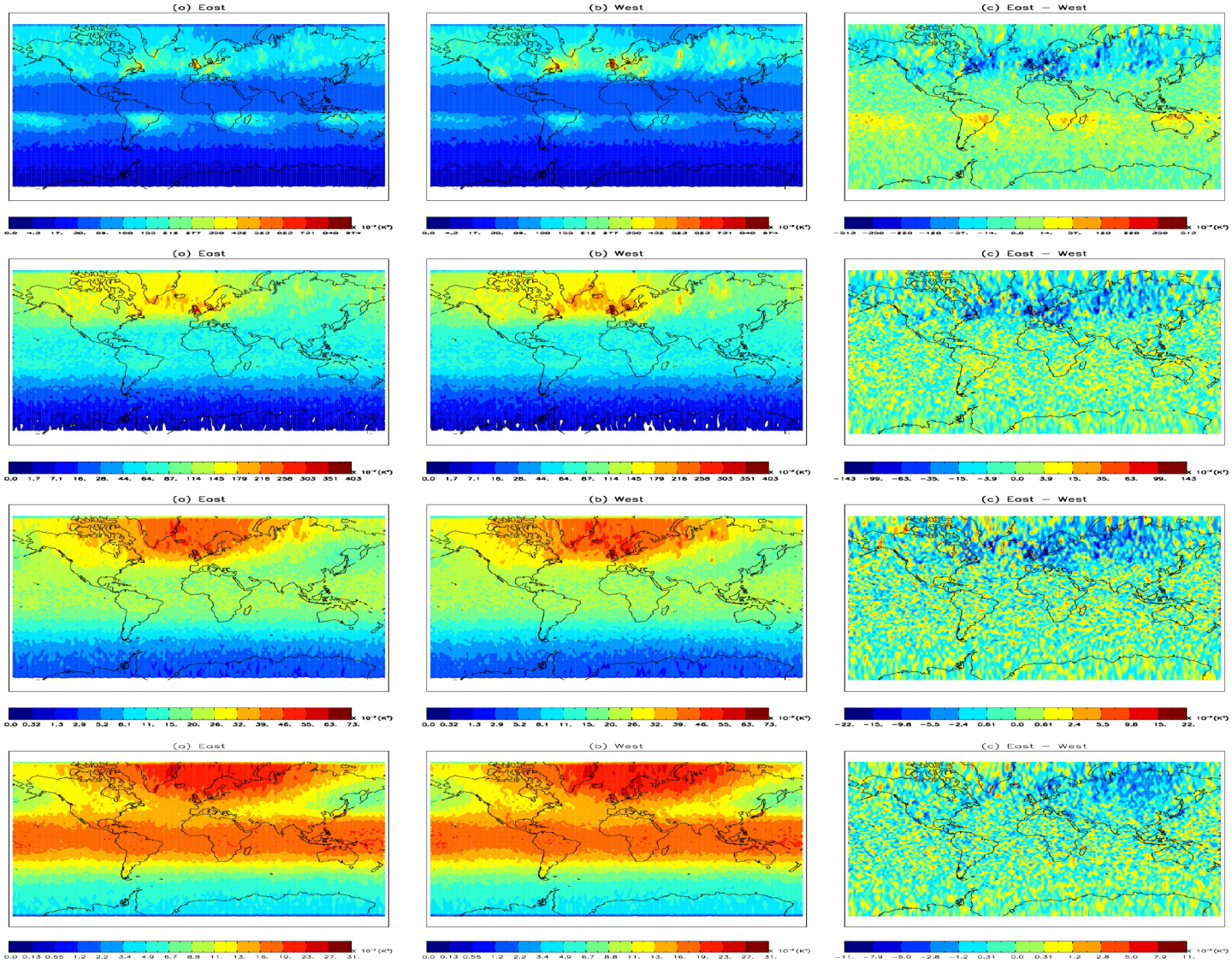
2.5 hPa, July (2002 - 2009 mean), west view

SH



# Spatial Distribution (January 2002 - 2009)

**East** | **West** | **East-West**



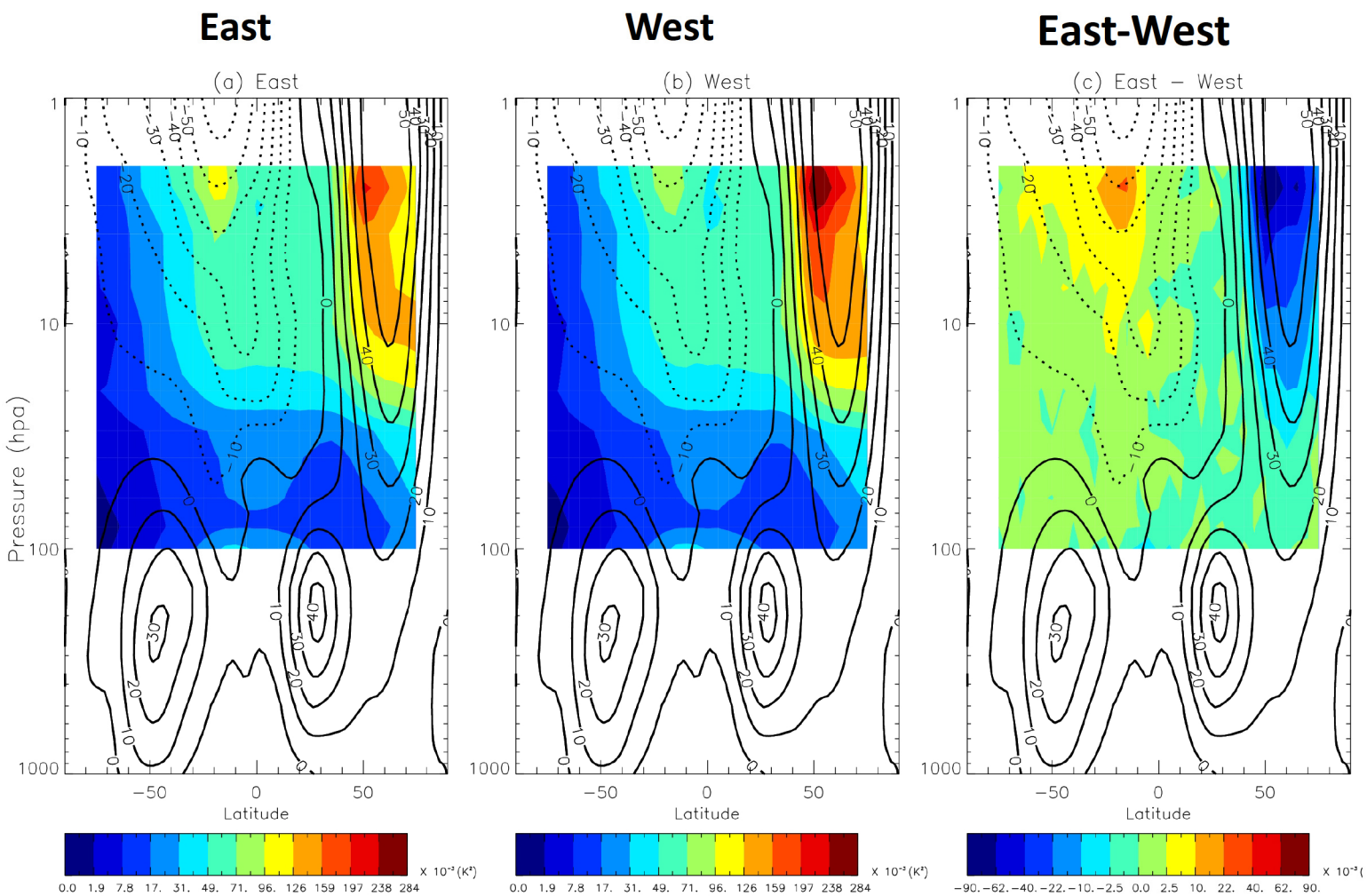

2.5 hpa (~45km)

10 hpa (~35km)

30 hpa (~25km)

80 hpa (~20km)

# January 2005



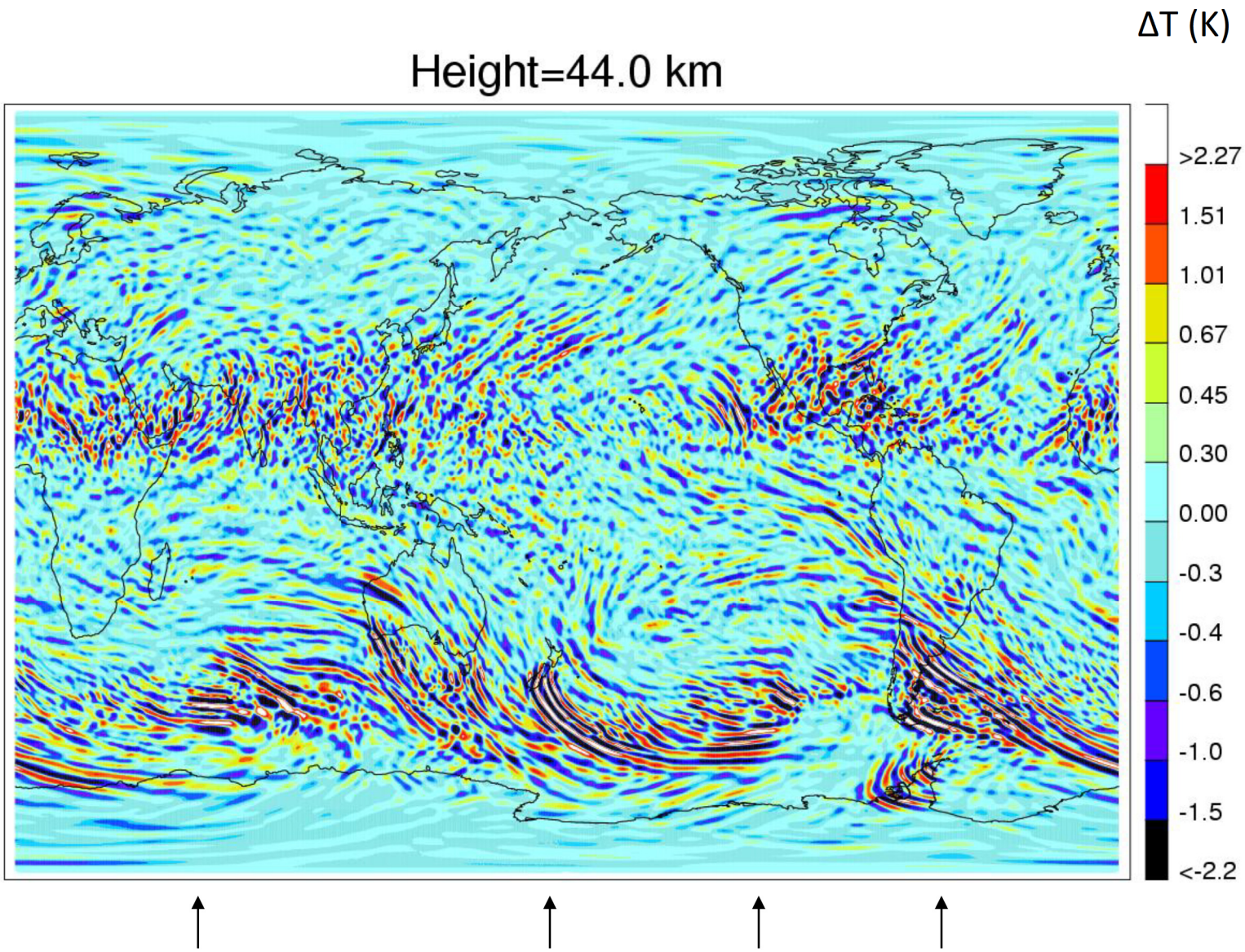

-ve: westward

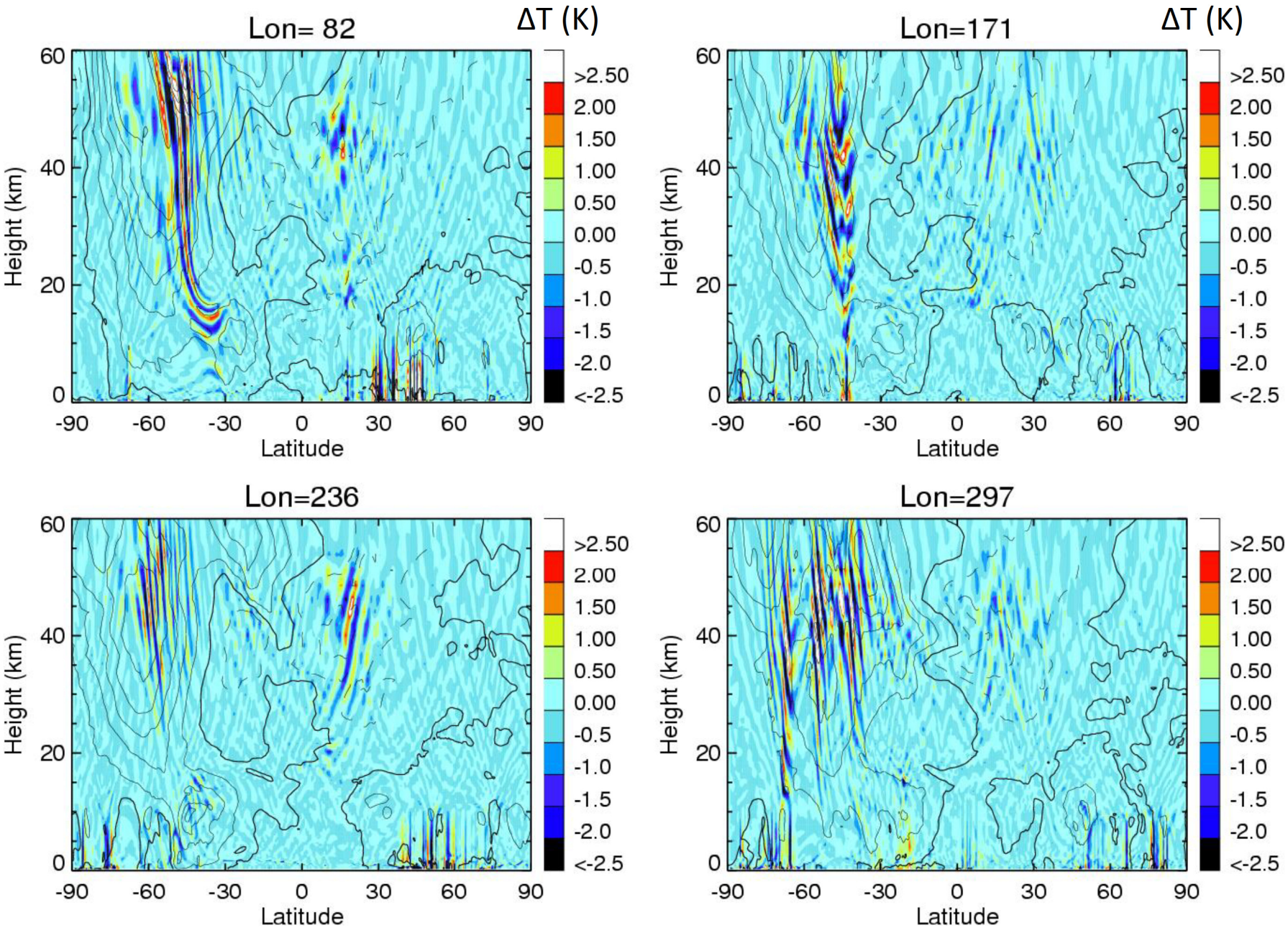
+ve: eastward

# Modern GCMs

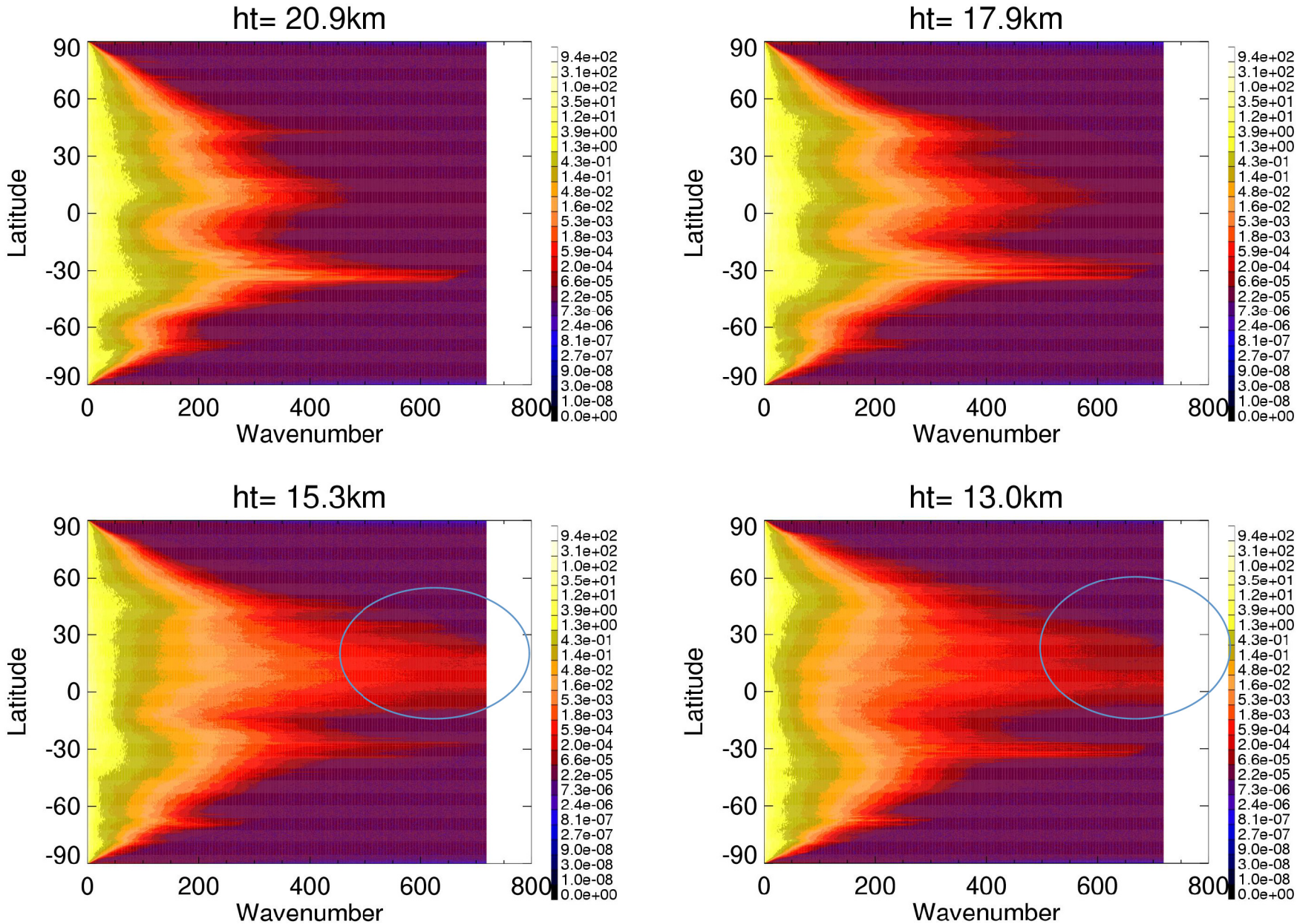
- Improved data input
- Improved resolution and coverage
  - 40 km x 60 km (e.g., UKMO)
  - $0.25^{o}$ x $0.25^{o}$ (ECMWF T799L91)
  - $0.5^{o}$ x $0.5^{o}$ (GMAO GEOS5)
- Improved physics?

ECMWF T799L91 Analyses on 21 August 2006

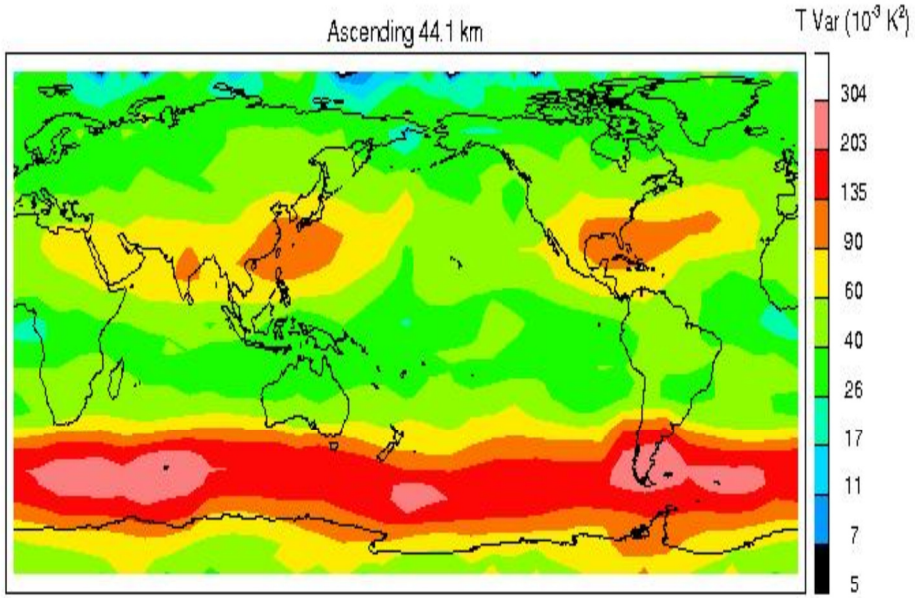



Lon= 82
ΔT (K)
Lon=171
ΔT (K)
Lon=236
Lon=297
Height (km)
Latitude
60
40
20
0
-90
-60
-30
0
30
60
90
>2.50
2.00
1.50
1.00
0.50
0.00
-0.5
-1.0
-1.5
-2.0
<-2.5

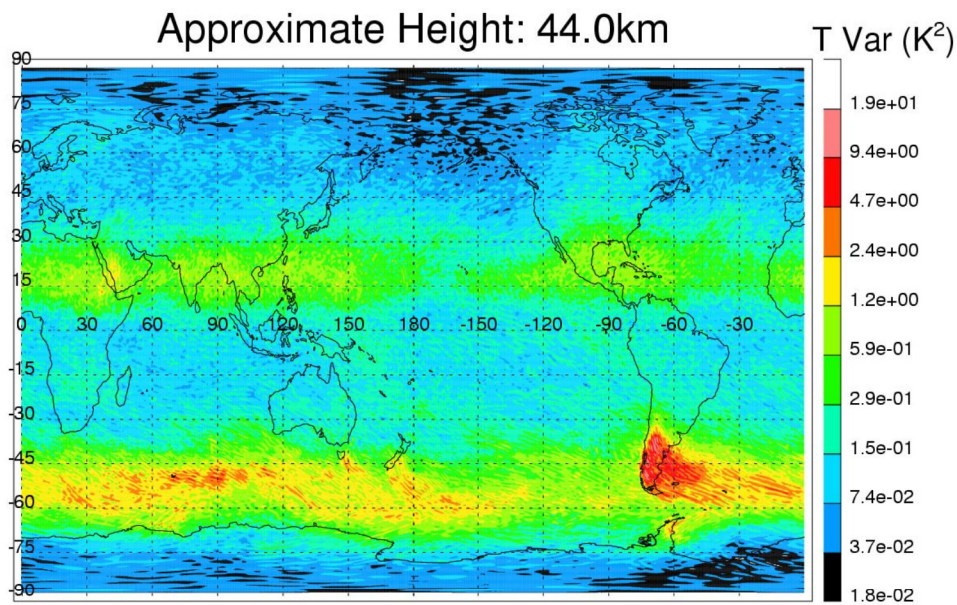
# ΔT Power Density in ECMWF T799L91 Analyses for August 2006



# GW variance maps




Aura MLS
August 2006




ECMWF T799L91
August 2006

MLS-like variance

$\lambda_h$ < ~300 km

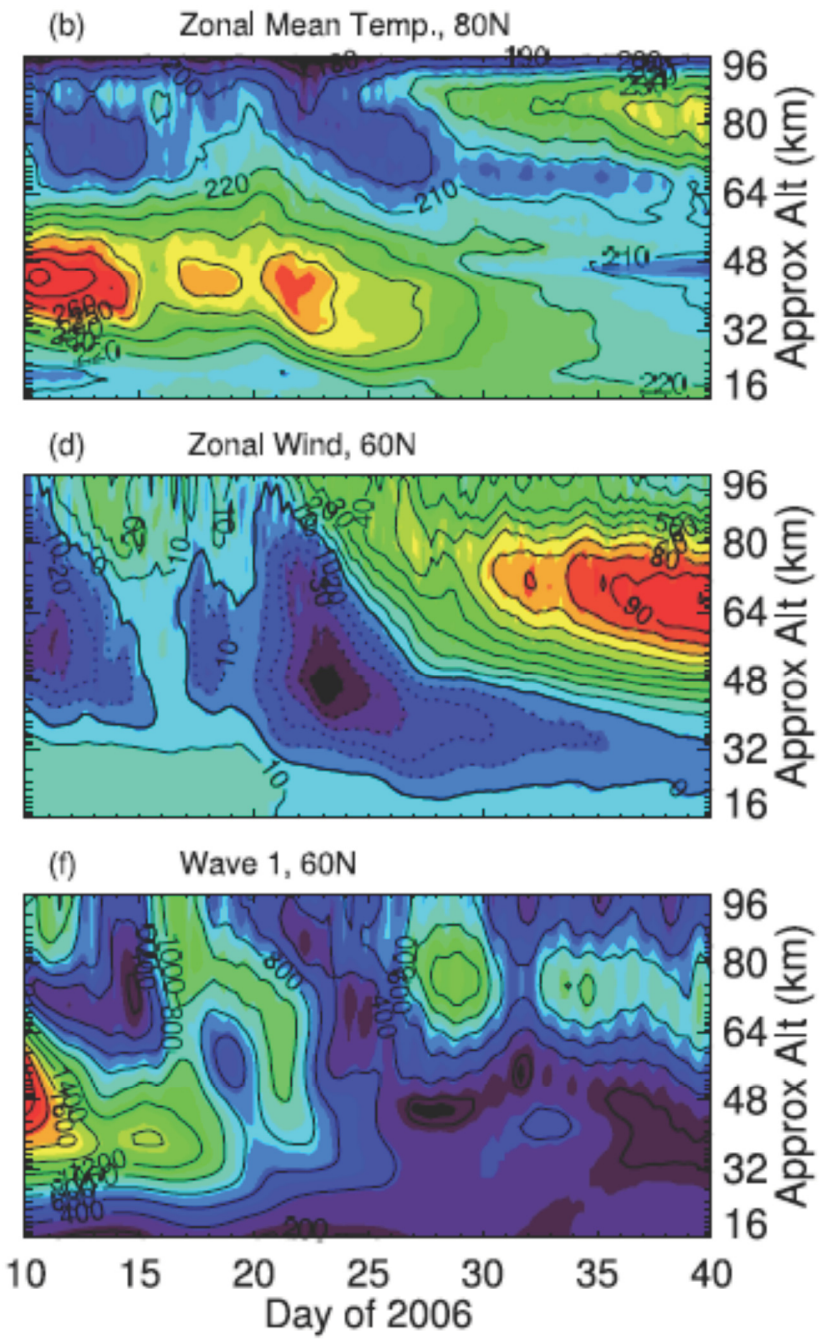
# GWs as the Key Agent in Coupling Polar Atmospheric Dynamics

- Stratospheric sudden warming events
- Aura MLS observations at 10-90 km

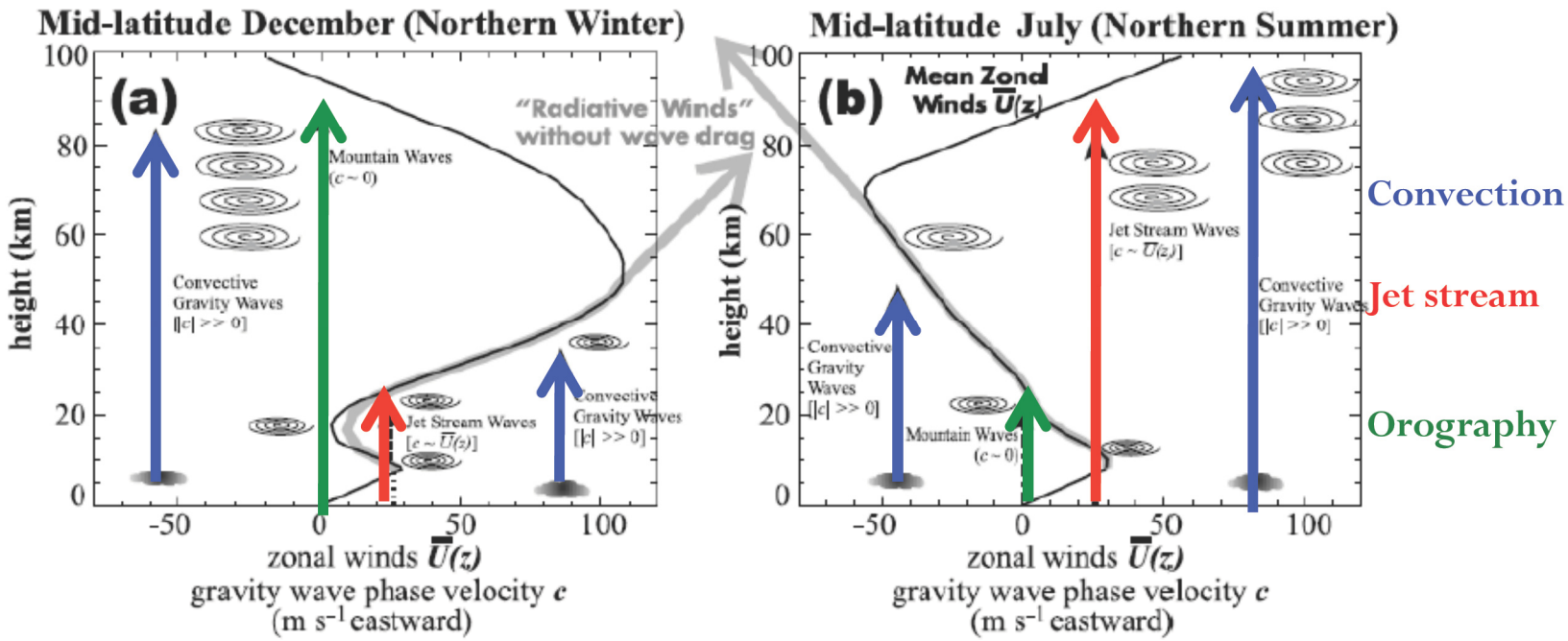
# Siskind et al. (2010)

- Minor warming (Jan 2008): deduction of the westward OGWD and weakened downward residual circulation, inclusion of non-OGWs increasing mesospheric cooling;

- Major warming (Jan 2006): nearly complete suppression of OGWD, cooling at 50 km, reformation of strong polar mesospheric vortex.



# Propagating gravity waves are subject to the filtering by background mean flow




(Kim et al., 2003, Atm-Ocn.)

$$\overline{p'w'} = -\overline{\rho}(\overline{u} - c)\overline{u'w'}$$

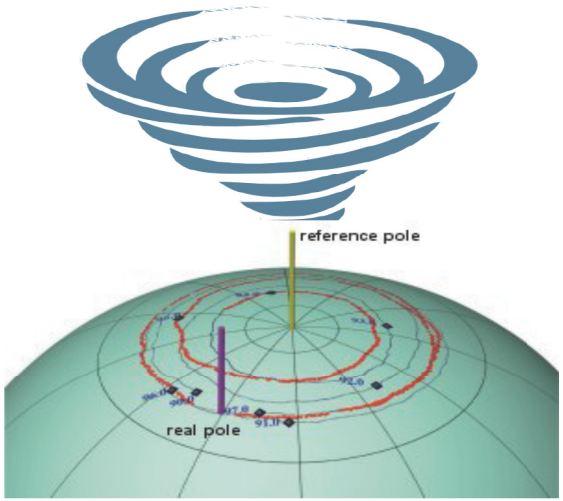
Energy flux

Mean wind

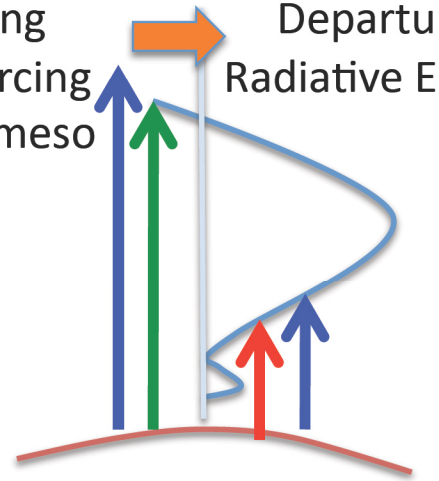
Phase speed

Momentum flux

**Critical-level filtering**

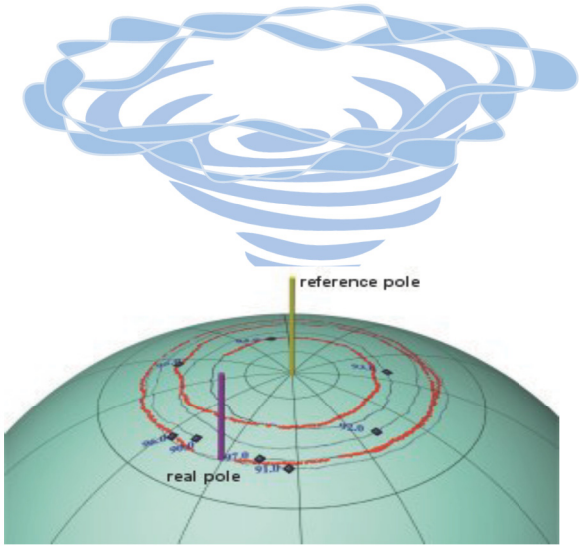



Strong
GW forcing
In the meso

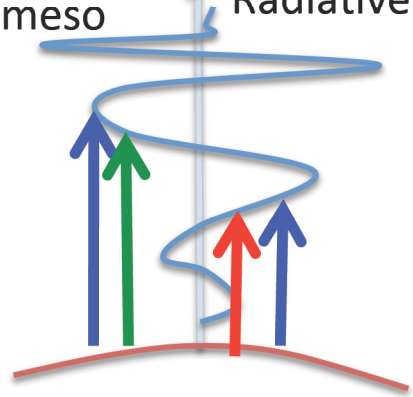


Departure from
Radiative Equilibrium

**Unfavorable** Condition for
Mesospheric Vortex
Formation



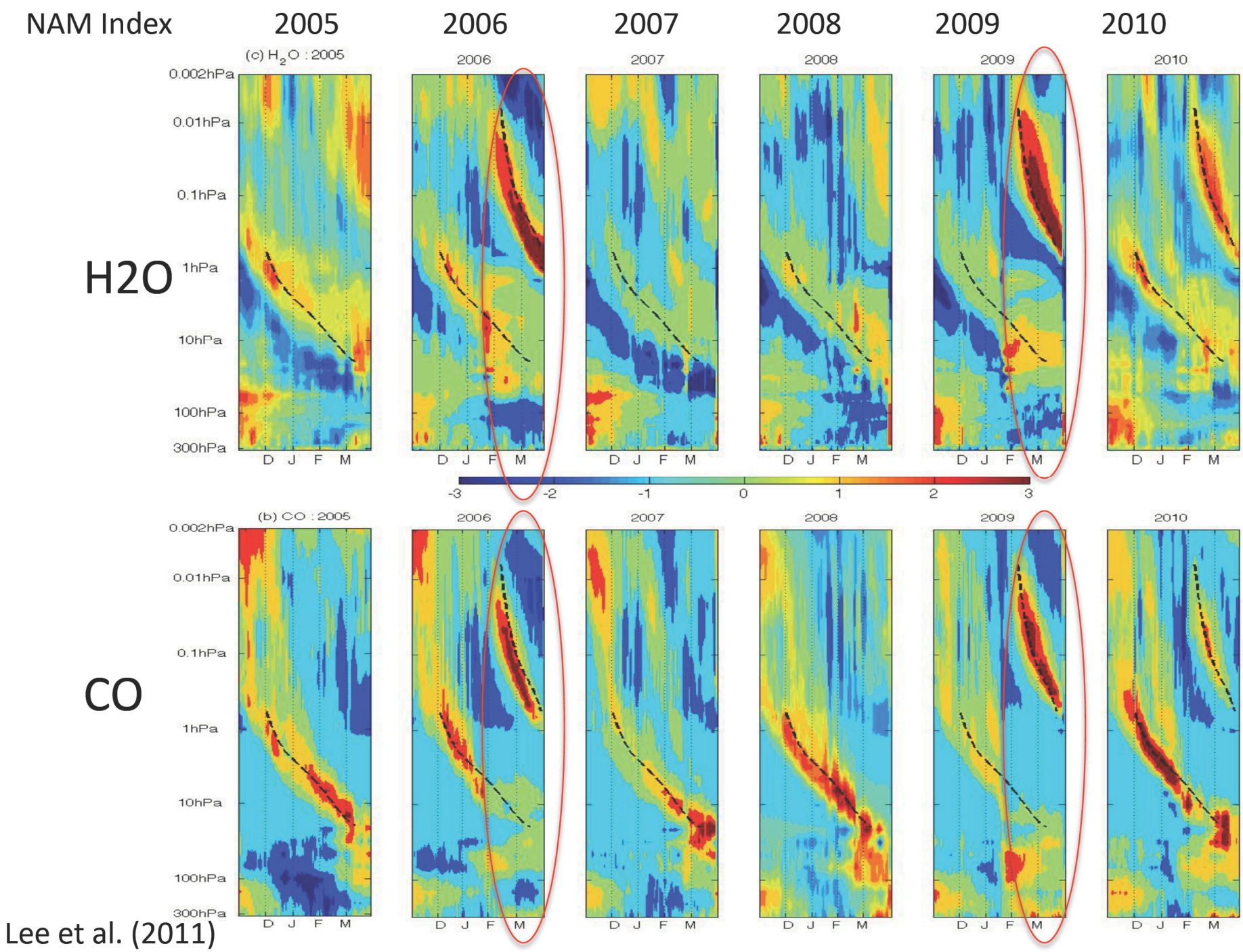

Weak
GW forcing
In the meso



Relax back to
Radiative Equilibrium

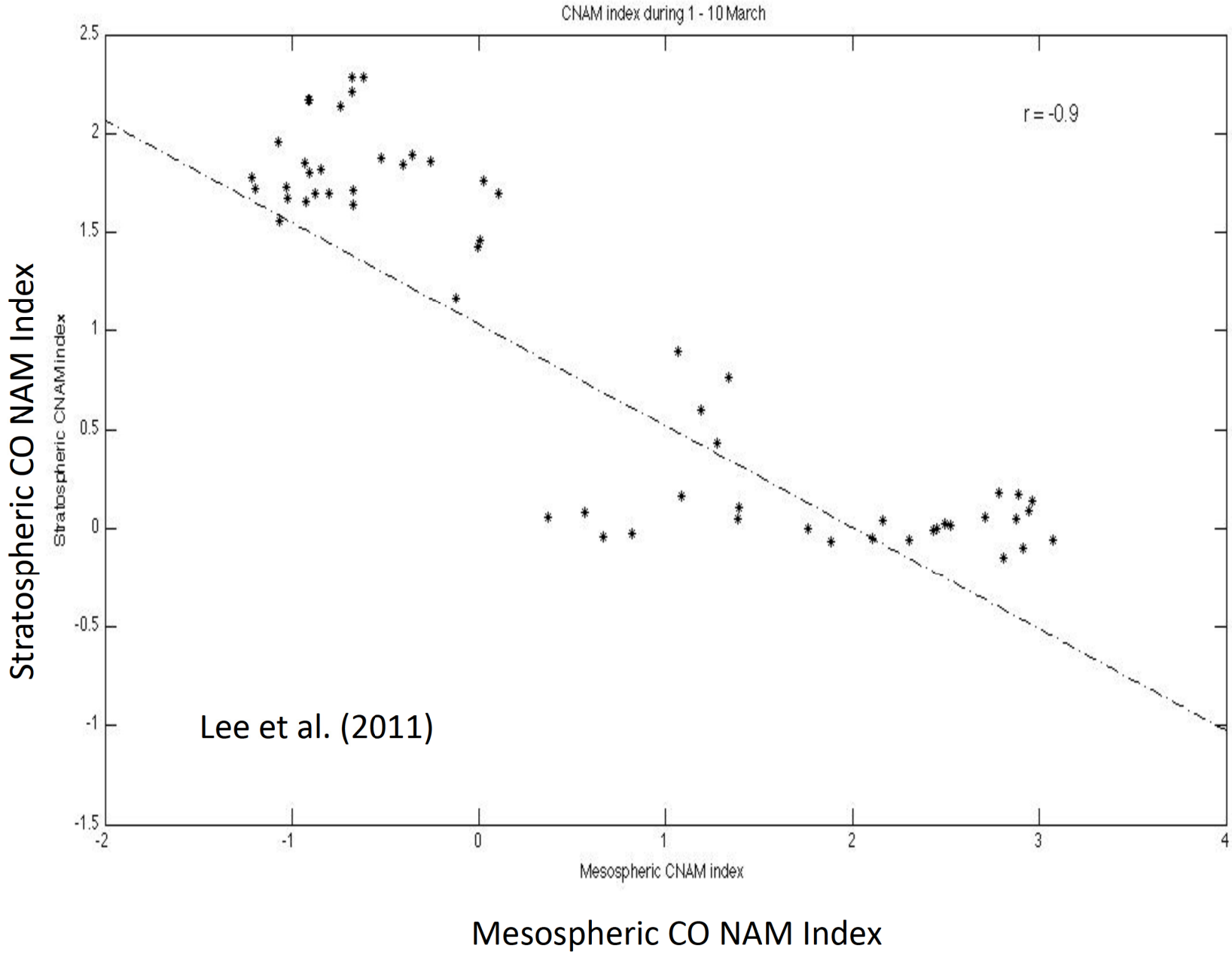
**Favorable** Condition for
Mesospheric Vortex
Reformation

Convection
Jet stream
Orography




Lee et al. (2011)

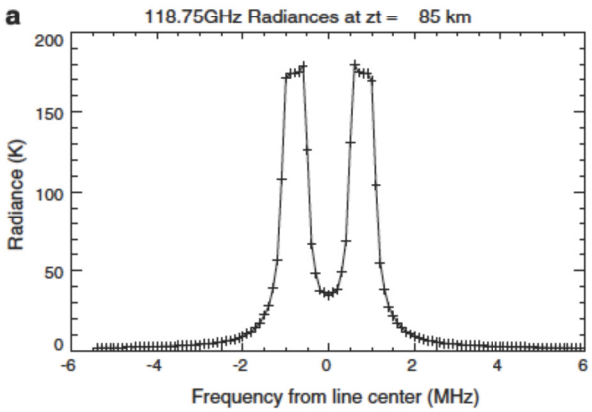
# Planetary and Gravity Wave Coupling

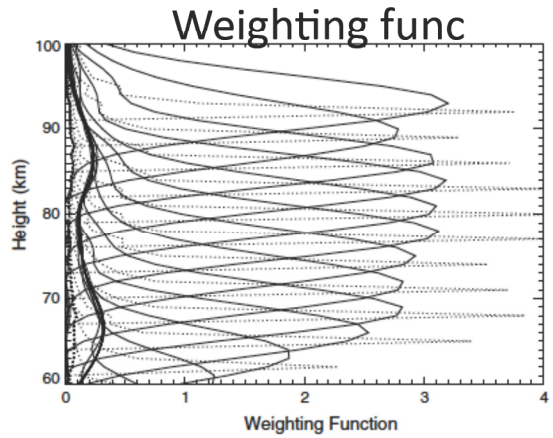


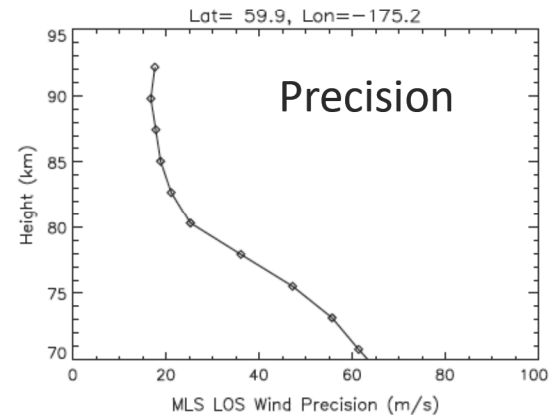
# Thoughts on More GW Studies

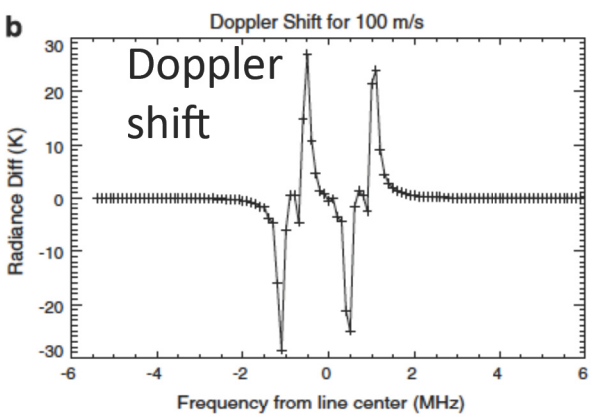
- Mesospheric winds and gravity waves
- MLS radiance residuals
- CALIOP PSC and gravity waves

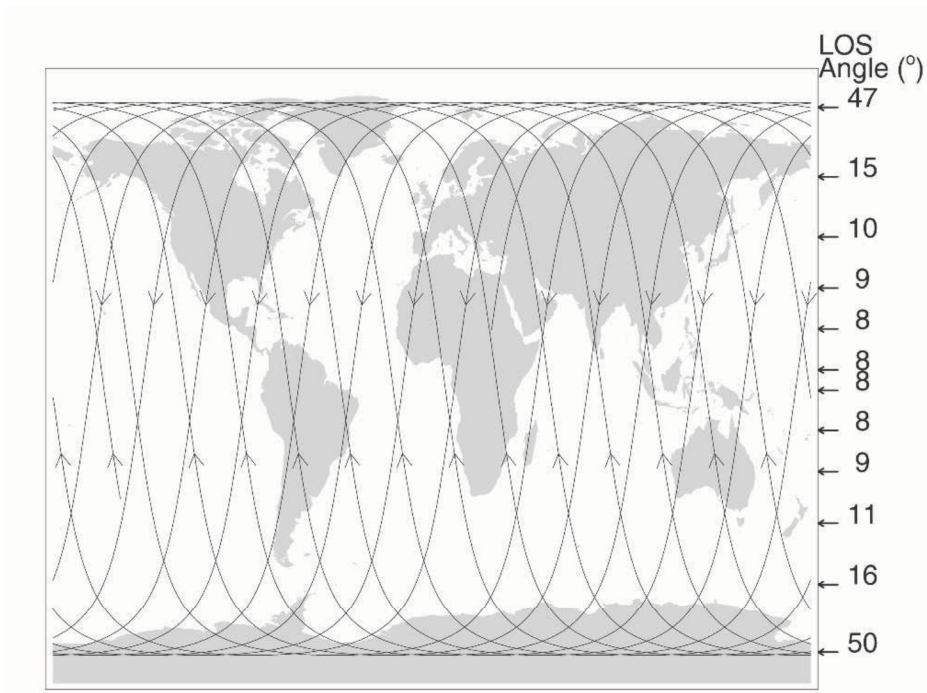
# MLS mesospheric line-of-sight (LOS) winds



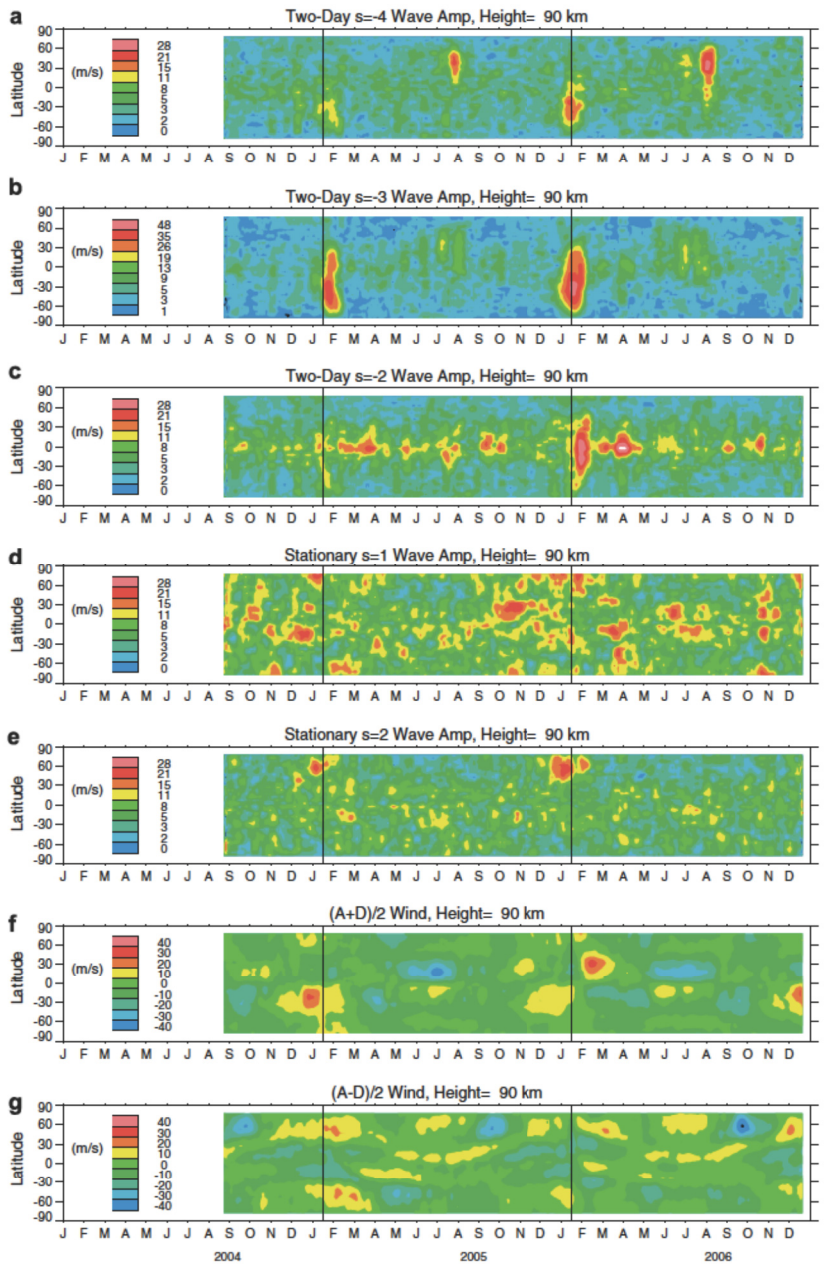



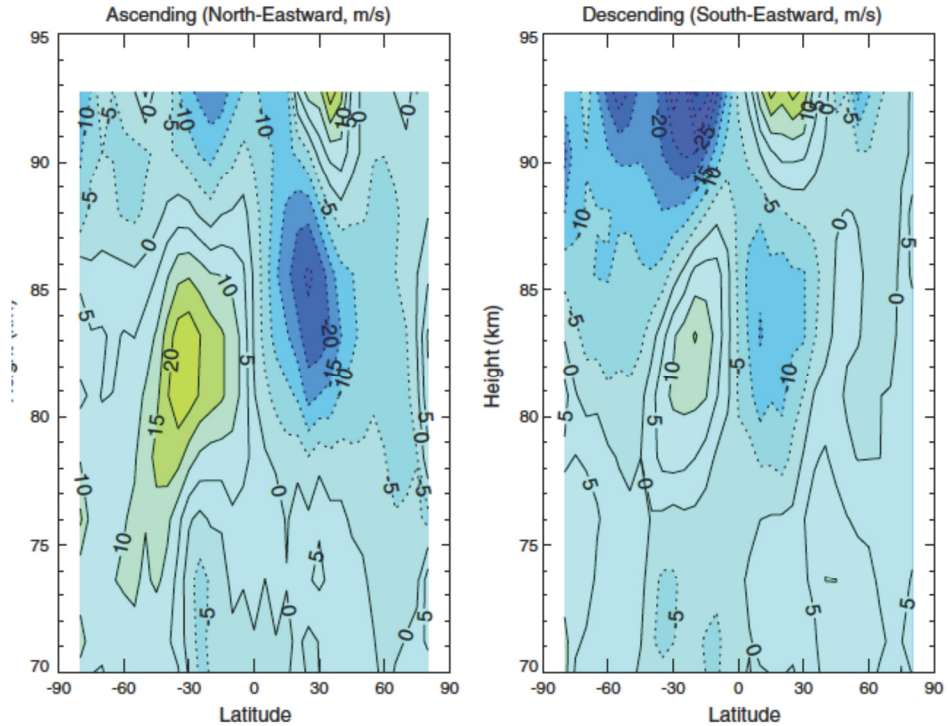




Wu et al. (2008)

# MLS LOS Mesospheric Winds

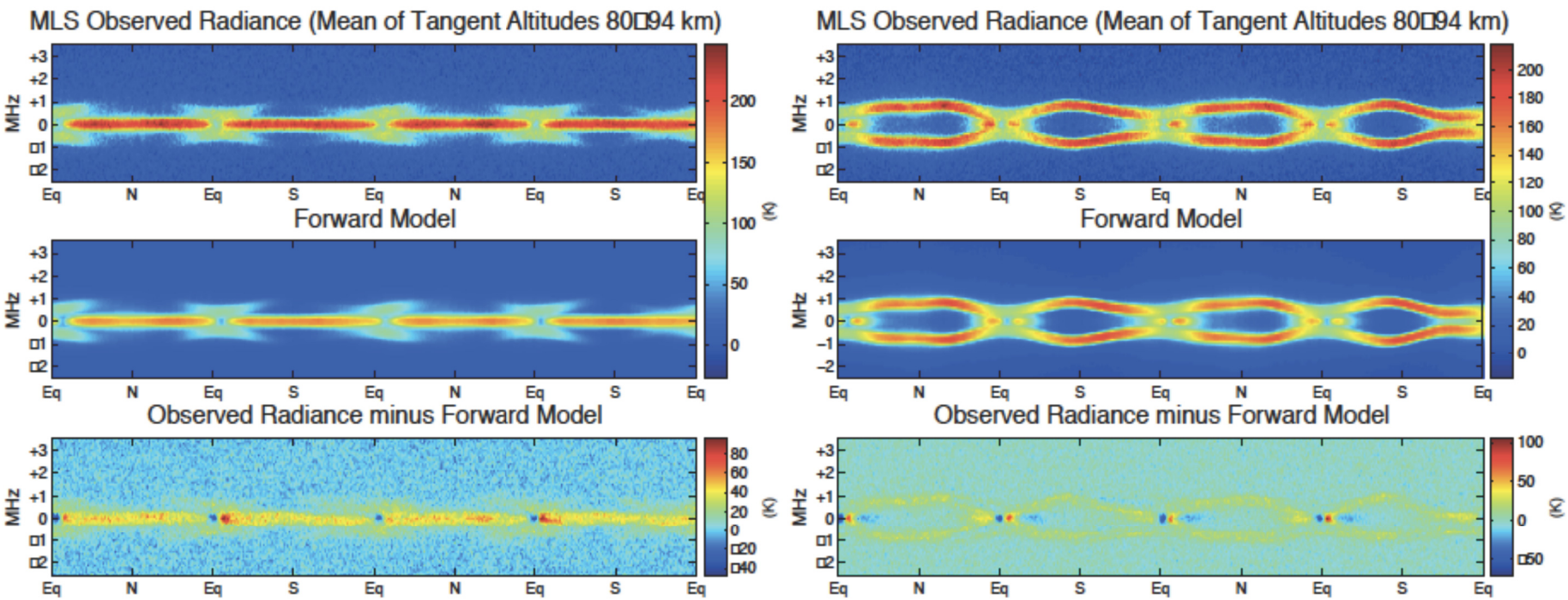


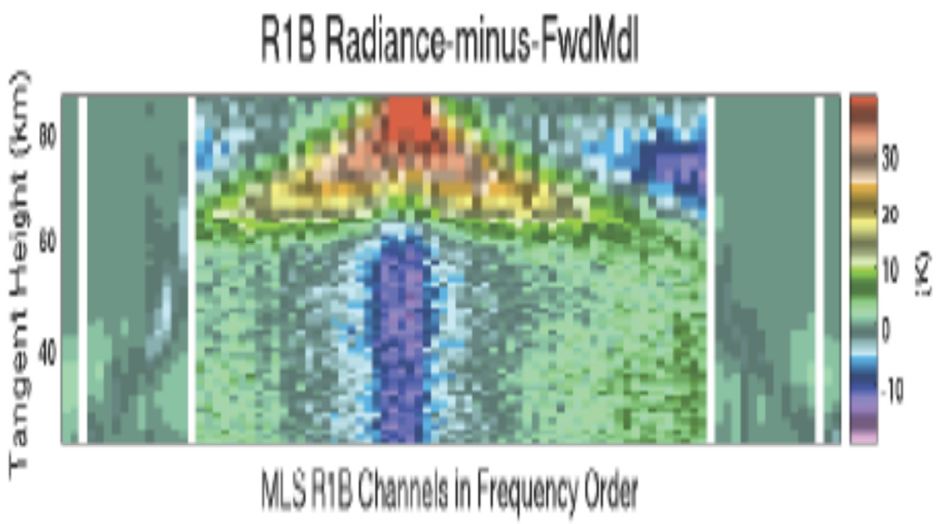



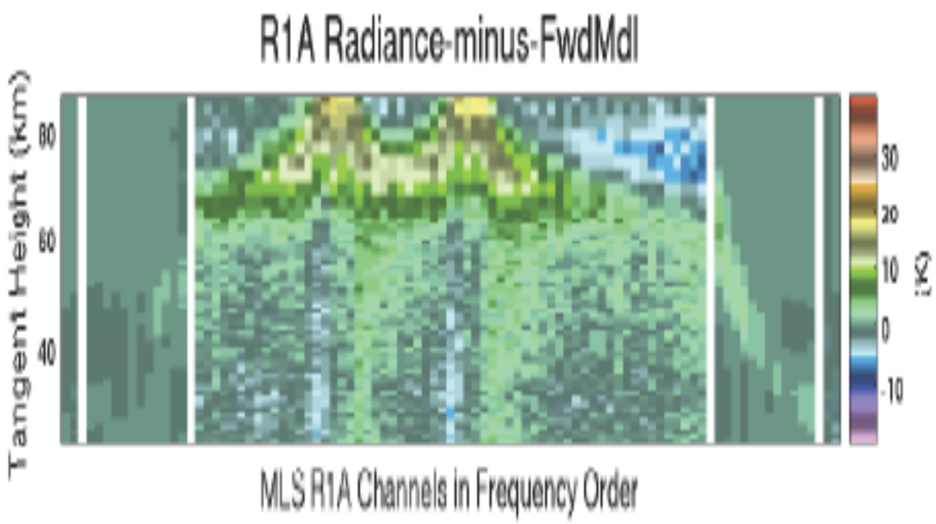

Wu et al. (2008)

- Diurnal tidal signatures in the MLS LOS winds
- Time series of two-day wave amplitudes (s=3, s=4)
- Significant perturbations seen during solar proton events

# MLS 118 GHz Radiance Residuals (Schwartz, Teleconf 2005.03.17)

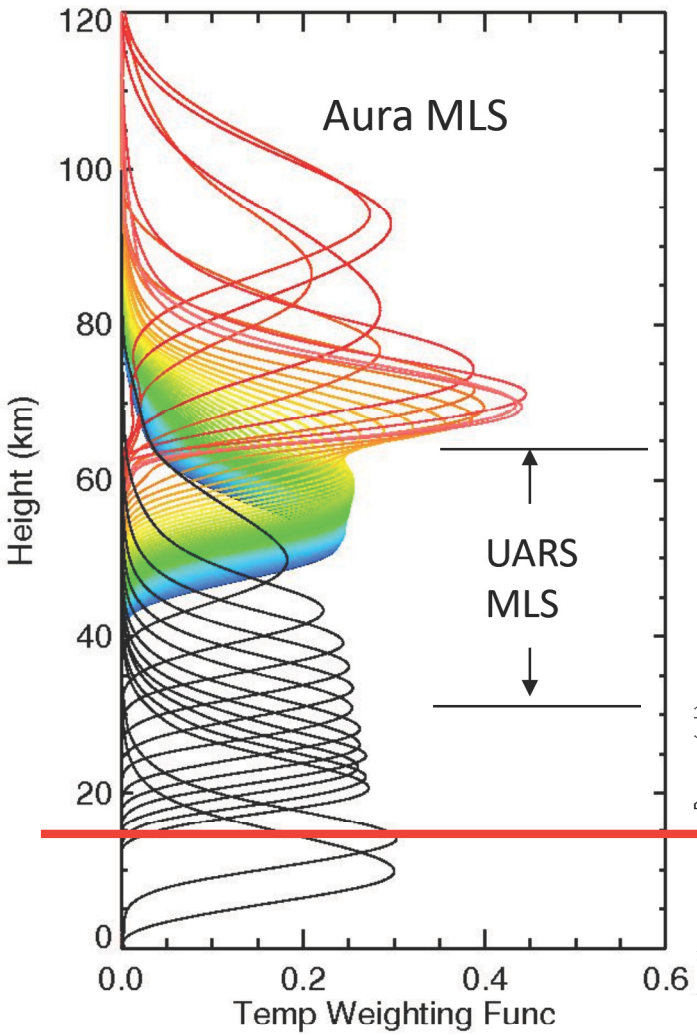


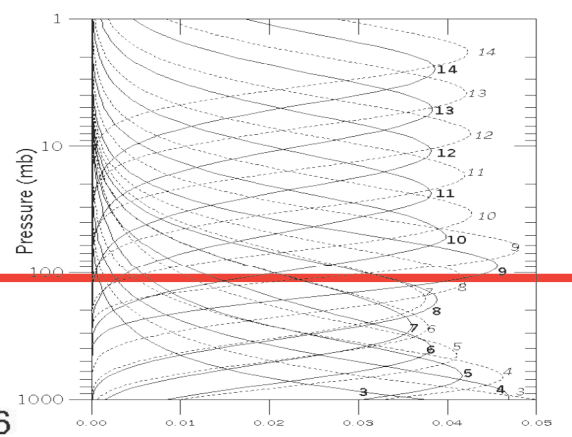



# Temperature Sounding

MLS
UARS (1991-1997)
Aura (2004-present)

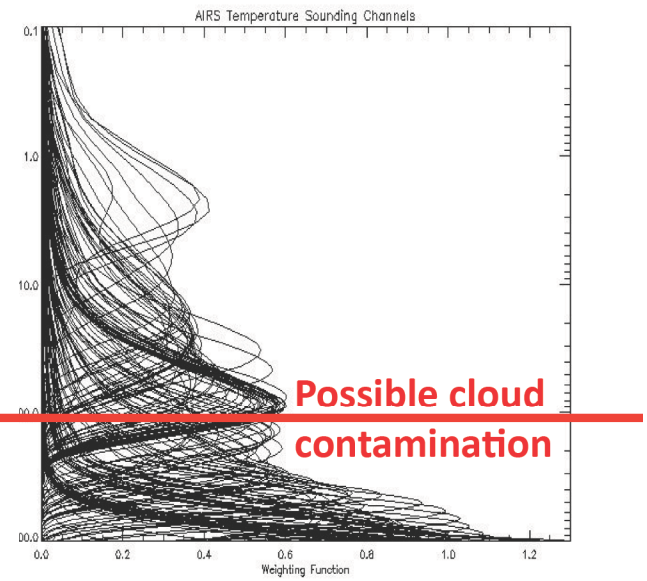



AMSU-A
N-15 (1998-)
N-16 (2000-)
N-17 (2002-2004)
N-18 (2005-)
Aqua (2002-)




**Temp Weighting Func**

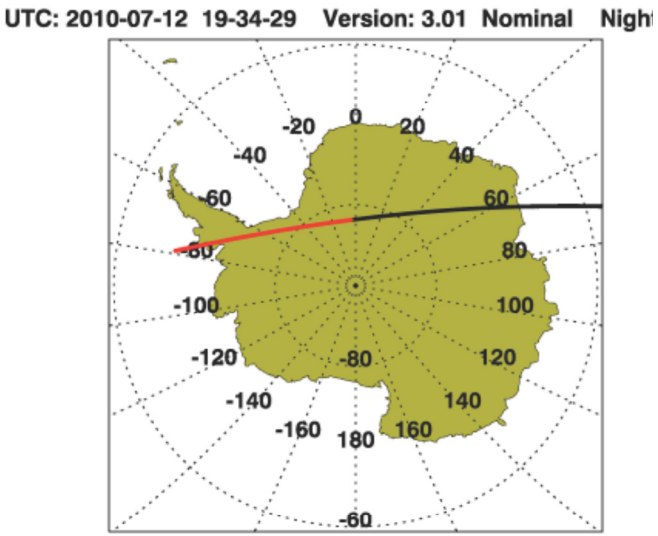
AIRS
(Aqua 2002-)

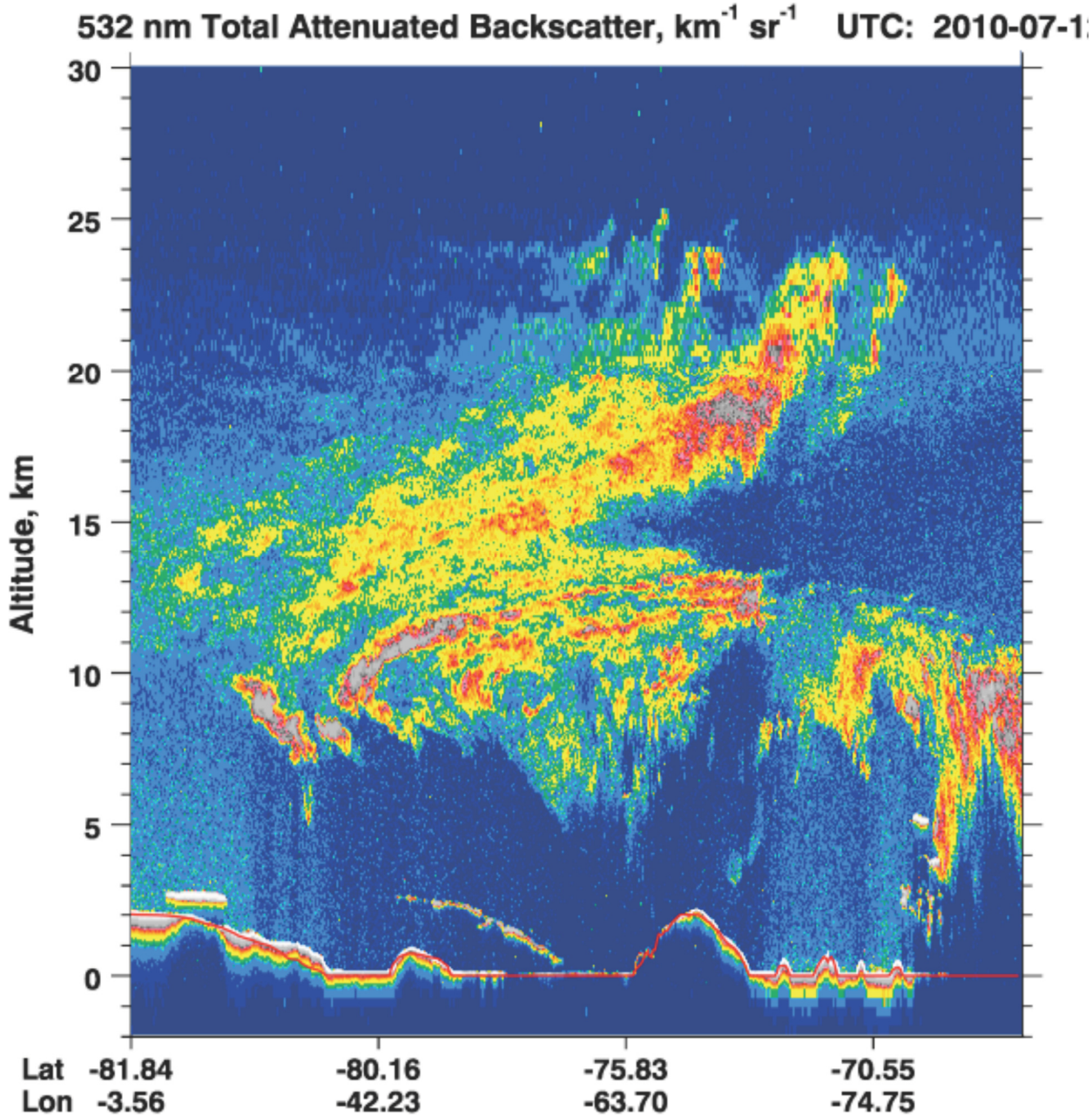



**Possible cloud contamination**

**Temp Weighting Func**

# CALIOP Backscatters
# 2010-07-12



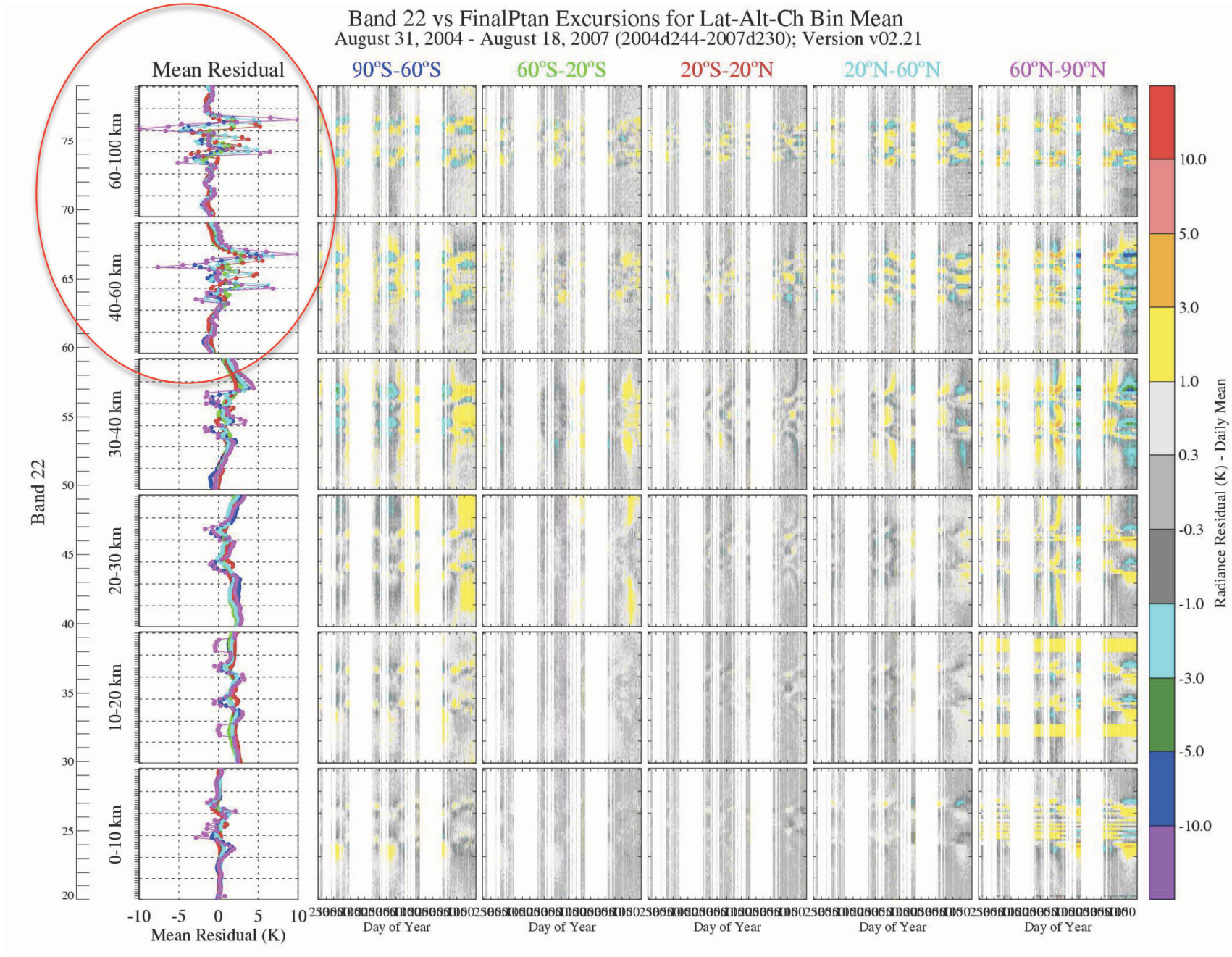
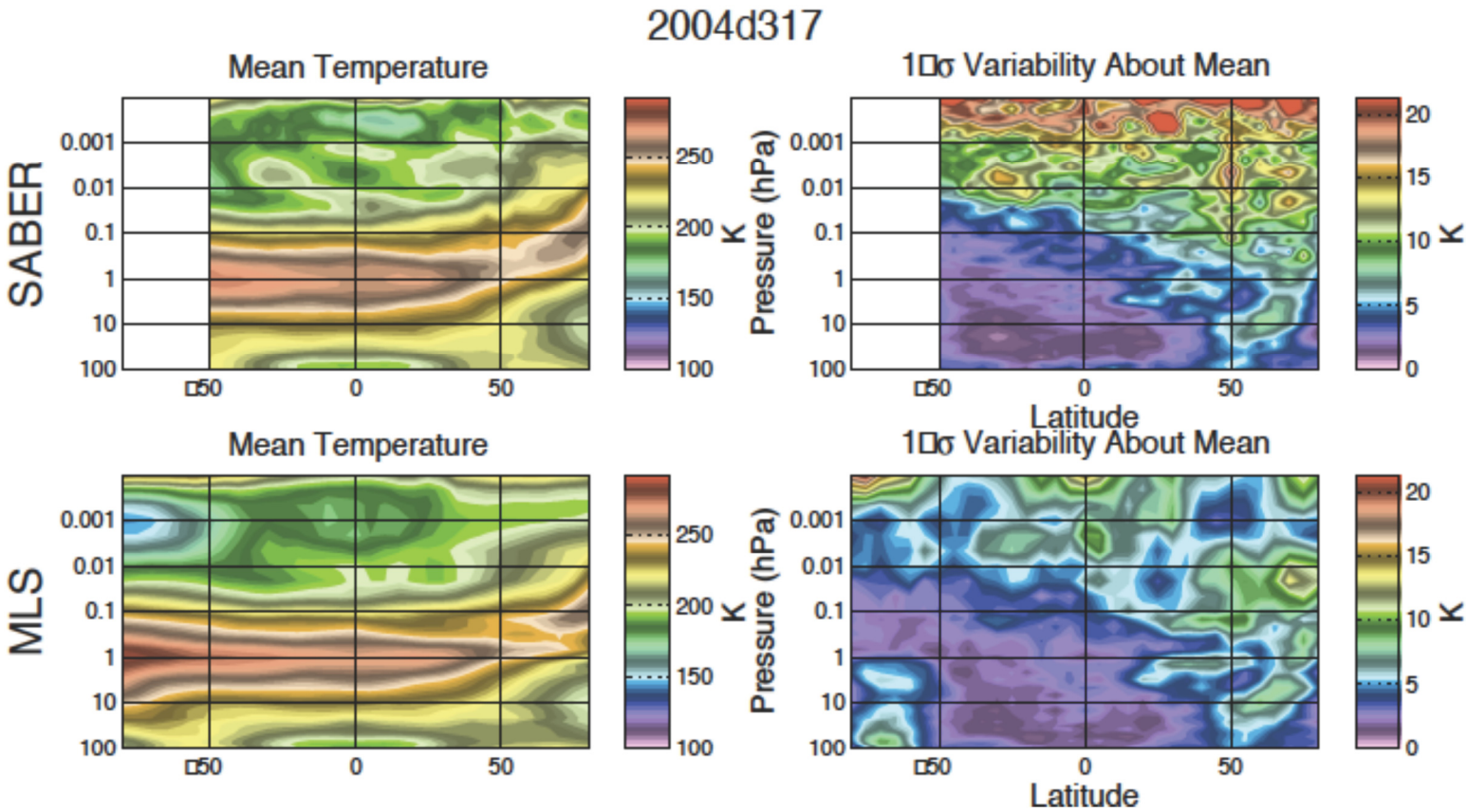



# Summary

- Satellite sensors can provide valuable observations on global GW source and propagation properties.
- Aura MLS 118 GHz radiances have useful information on GWs in the upper mesosphere, but require careful analyses.
- High-resolution GCMs are able to capture many GW features, but need constraints on wave sources and properties.
- MLS trace gas and GW measurements can be analyzed jointly to achieve a better understanding of polar vortex descent and the lower-upper atmospheric coupling.

# Extra

# MLS 118 GHz Radiance Residuals (Schwartz, Teleconf 2007.08.30)



MLS Temperature Perturbations (Schwartz, Teleconf 2007.05.10)