Use of Satellite and Aircraft Observations to Characterize Properties of Atmospheric Gravity Waves during START08

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Outline:

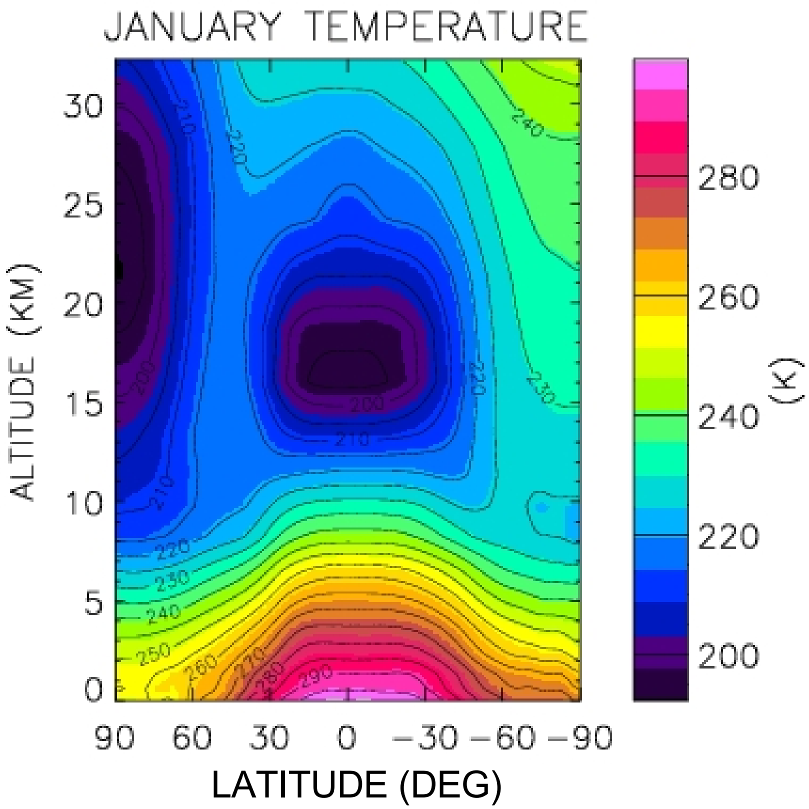
- Motivation for gravity wave observations April/June in NH
- Key observations on HIAPER for characterizing gravity waves
- Satellite observations of gravity waves for START08

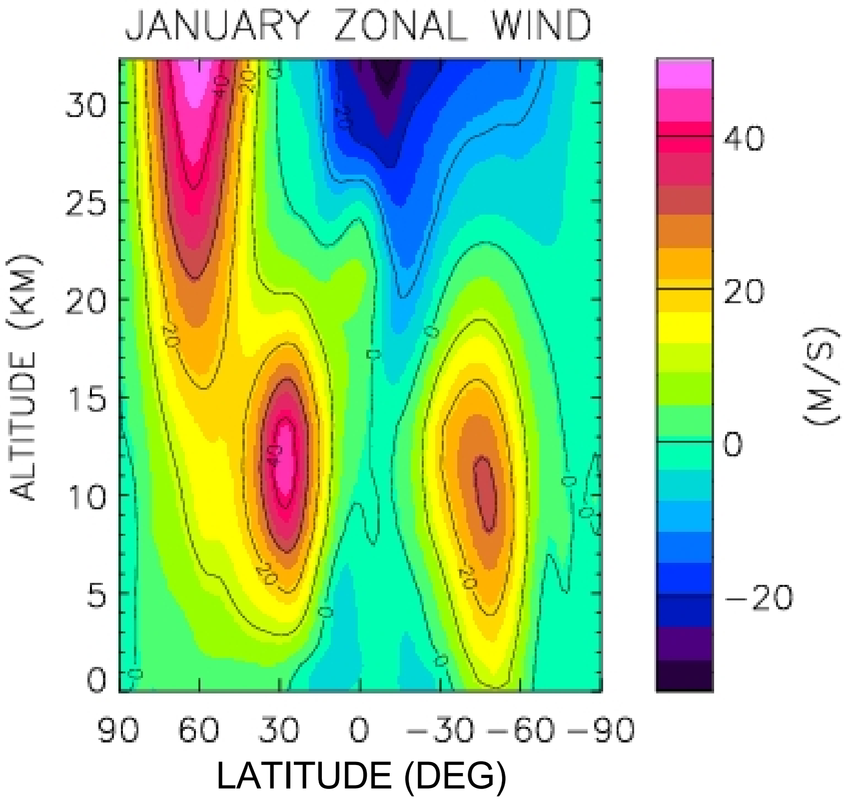
April Period: Springtime Transition to Stratospheric Easterlies

- A “cold-pole problem” plagues most GCMs in the winter stratosphere.

- Related ~ one-month delay in the transition to easterlies in springtime.

- Associated effects on planetary wave propagation, errors in the number and timing of sudden stratospheric warming events, and the stratospheric transport circulation..





April Period: Springtime Transition to Stratospheric Easterlies

Scaife et al. [2002, JAS]
The delay in the transition is improved in the Met Office GCM with inclusion of non-orographic gravity wave drag.

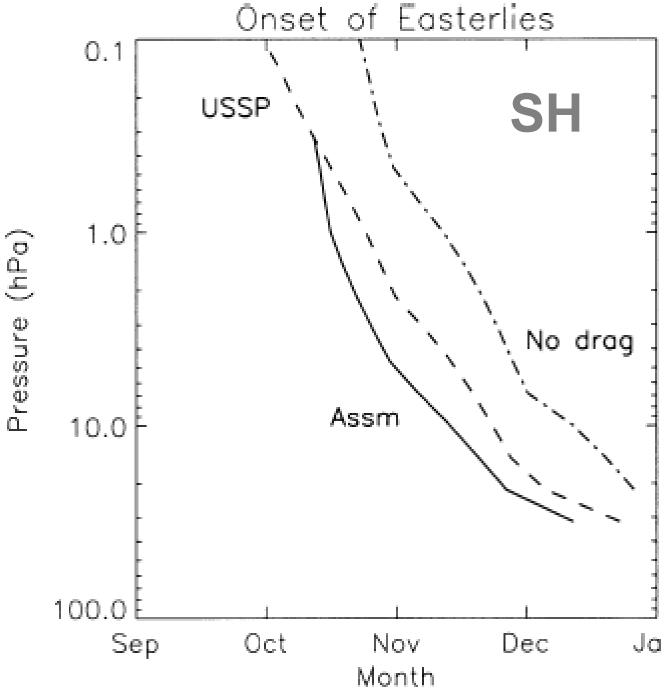
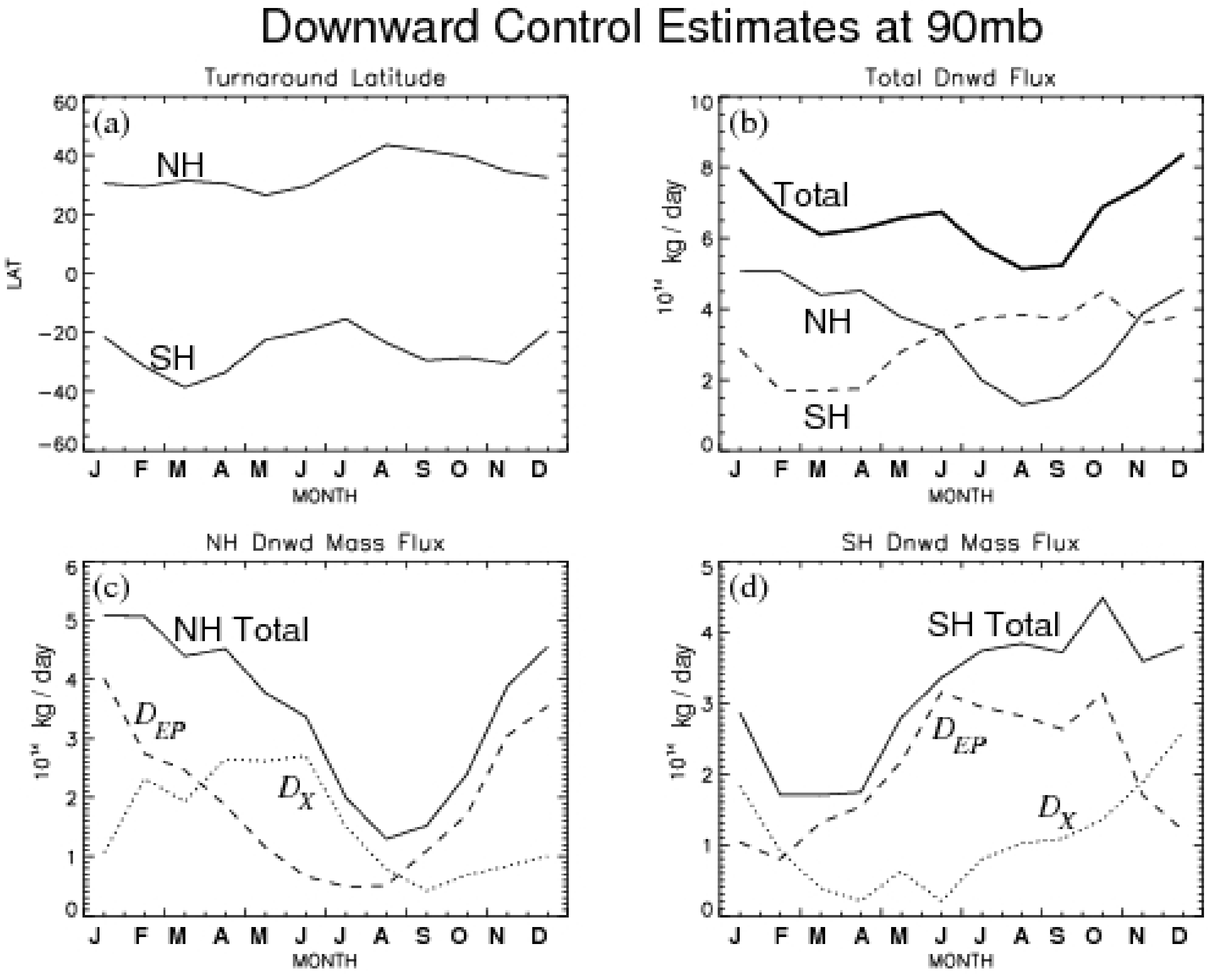


FIG. 7. Seasonal descent of the zero zonal mean wind line at 61.25°S starting from Sep. The dashed curve shows the 20-yr mean from the model with the USSP. The dot–dashed curve shows a 10-yr mean from the model with no parameterized drag and the solid line shows an 8-yr mean of assimilated observational data.



Alexander and Rosenlof [2003, JGR]
The missing (gravity wave) forcing in UKMO dominates the residual circulation term in the springtime transition period.

June Period likely better for observing waves generated by convection:

- Known to be an important source in the tropics.

- May be important for spring/summer driving of the stratospheric residual circulation.

- Momentum flux from this source still highly uncertain:
  - Observational validation needed for cloud-resolving model studies and GCM parameterizations of waves from this source.

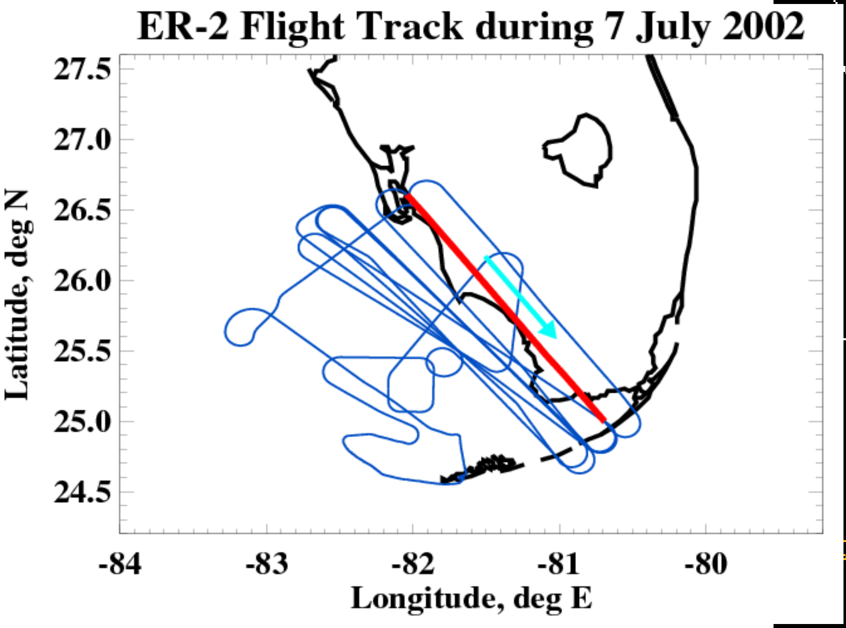
- Parameterizations based on the properties of convective heating. An ideal situation to test the parameterizations would be to fly over a storm located within a precipitation radar site:
  - Use the radar to characterize the convective heating.
  - Compare the aircraft wave observations to the parameterization.

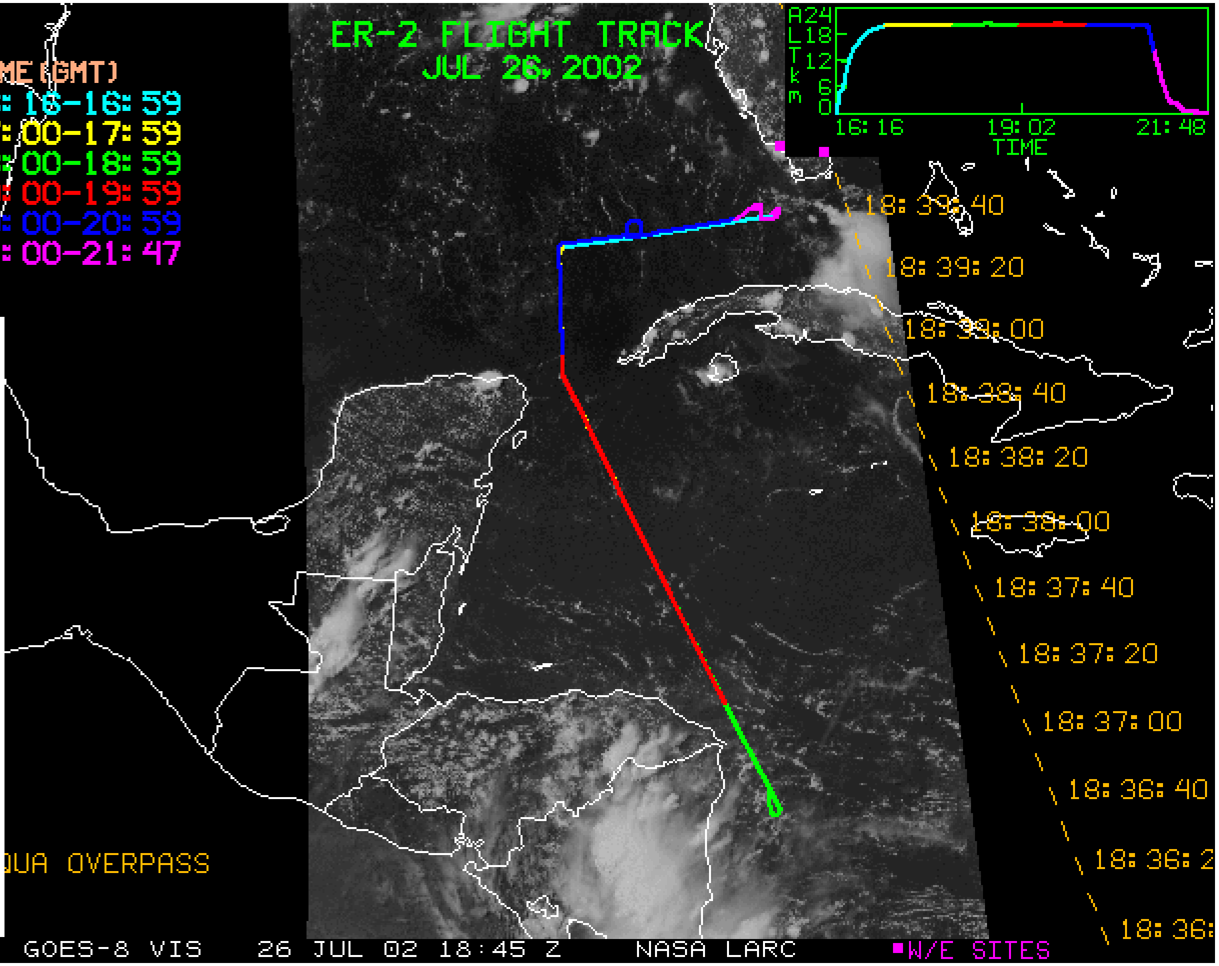
Key Observations for Characterizing Gravity Waves and their Sources via Aircraft

1. Long, level, and straight flight legs: The length of the flight leg limits the maximum horizontal wavelength that can be observed.

CRYSTAL-FACE: *Wang et al. [2006, ACP]*

- Short segments limited to wavelengths O ~100 km.
- Two flights allowed long waves to be observed.



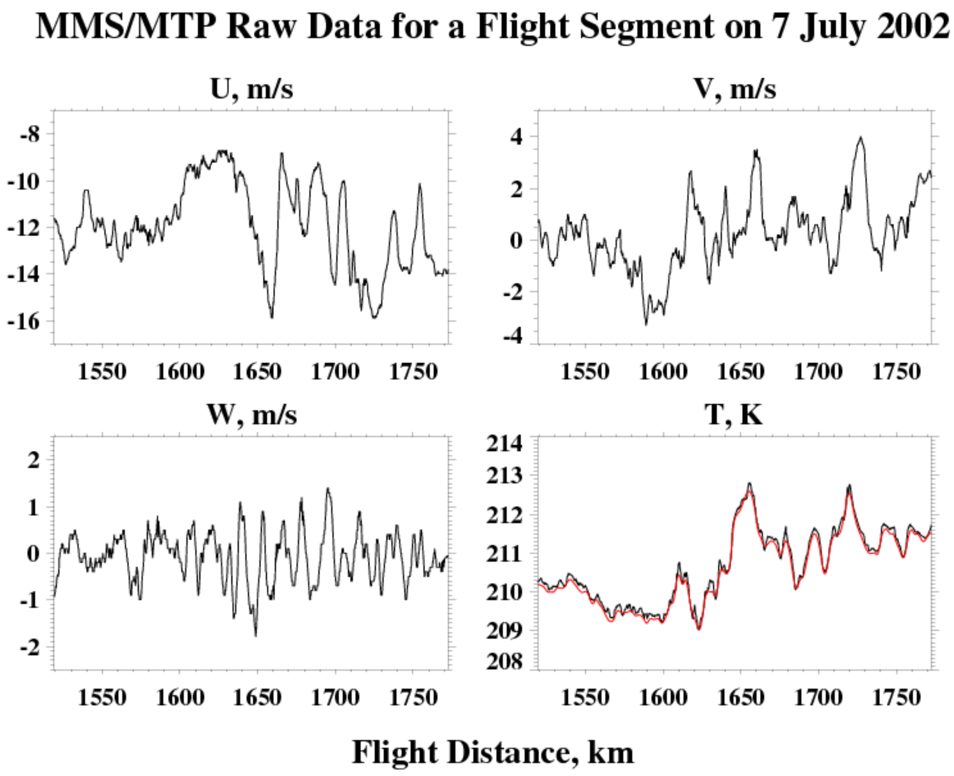


Key Observations for Characterizing Gravity Waves and their Sources via Aircraft

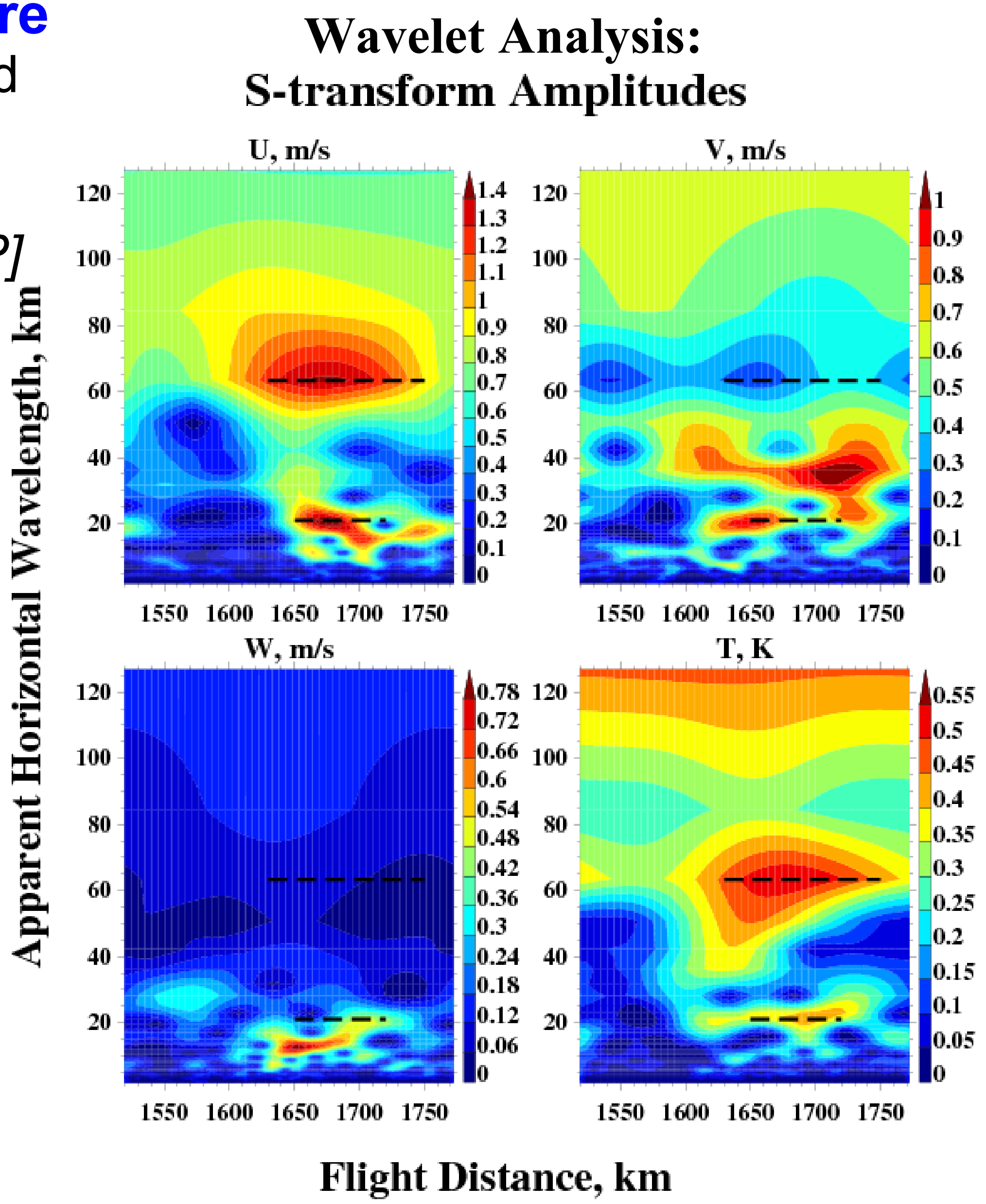
2. MMS for in situ wind & temperature

Gives apparent horizontal wavelength and propagation direction

CRYSTAL-FACE: *Wang et al. [2006, ACP]*



MMS/MTP Raw Data for a Flight Segment on 7 July 2002

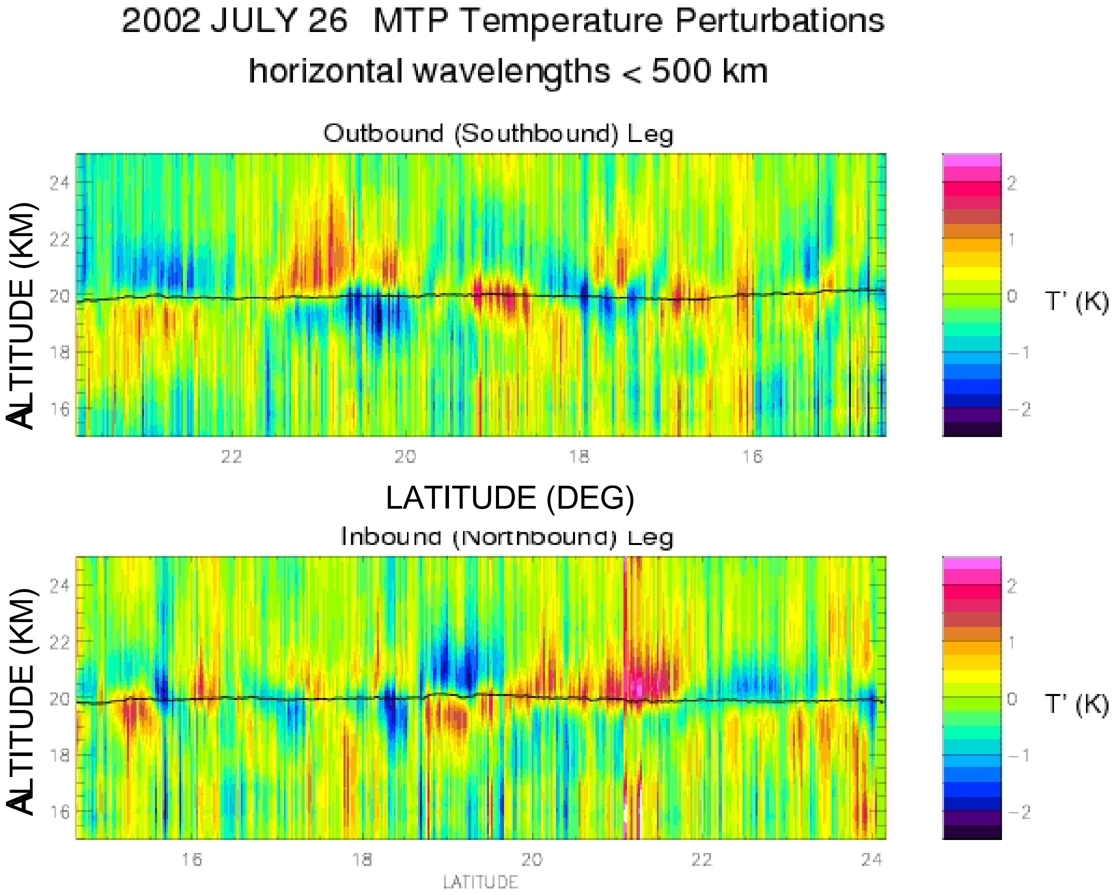


Wavelet Analysis: S-transform Amplitudes

Key Observations for Characterizing Gravity Waves and their Sources via Aircraft

3. MTP for vertical wavelength

Gives phase speed, intrinsic frequency, group velocity, and allows ray tracing to identify sources.



CRYSTAL-FACE:
Wang et al. [2006]

- Highest vertical resolution near the flight level.
- Compute vertical wavelength from flight-level vertical gradients.

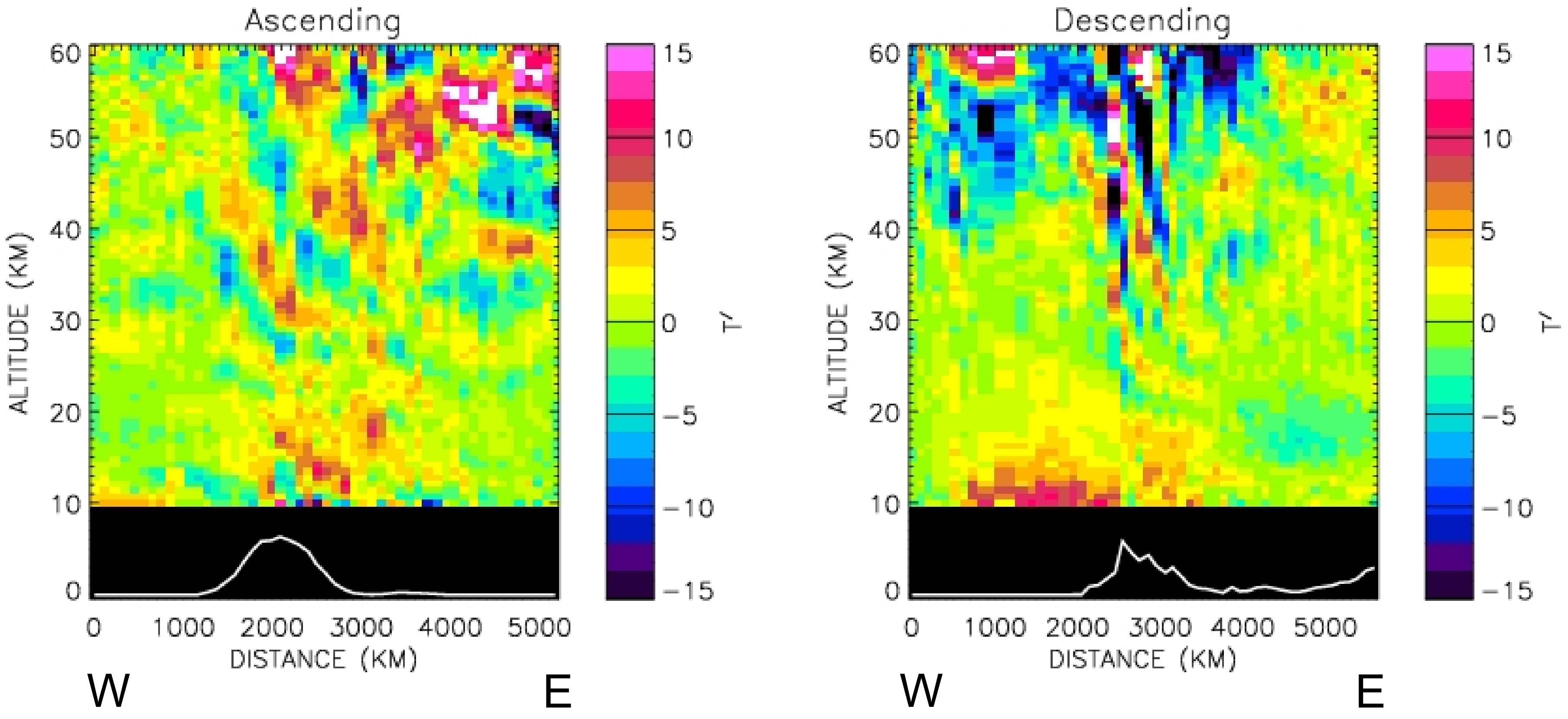
$$\lambda_z = 2\pi \left| \frac{iT'}{dT'/dz} \right| \sim 2\pi \frac{\sigma(T')}{\sigma(dT'/dz)}$$

Satellite Observations

HIRDLS = High Resolution Dynamics Limb Sounder

- Infrared limb scanning instrument
- High vertical resolution (1.2 km)
- High horizontal resolution along-track (~100 km)

HIRDLS Cross-Sections Over the Patagonian Andes: 16 May 2006

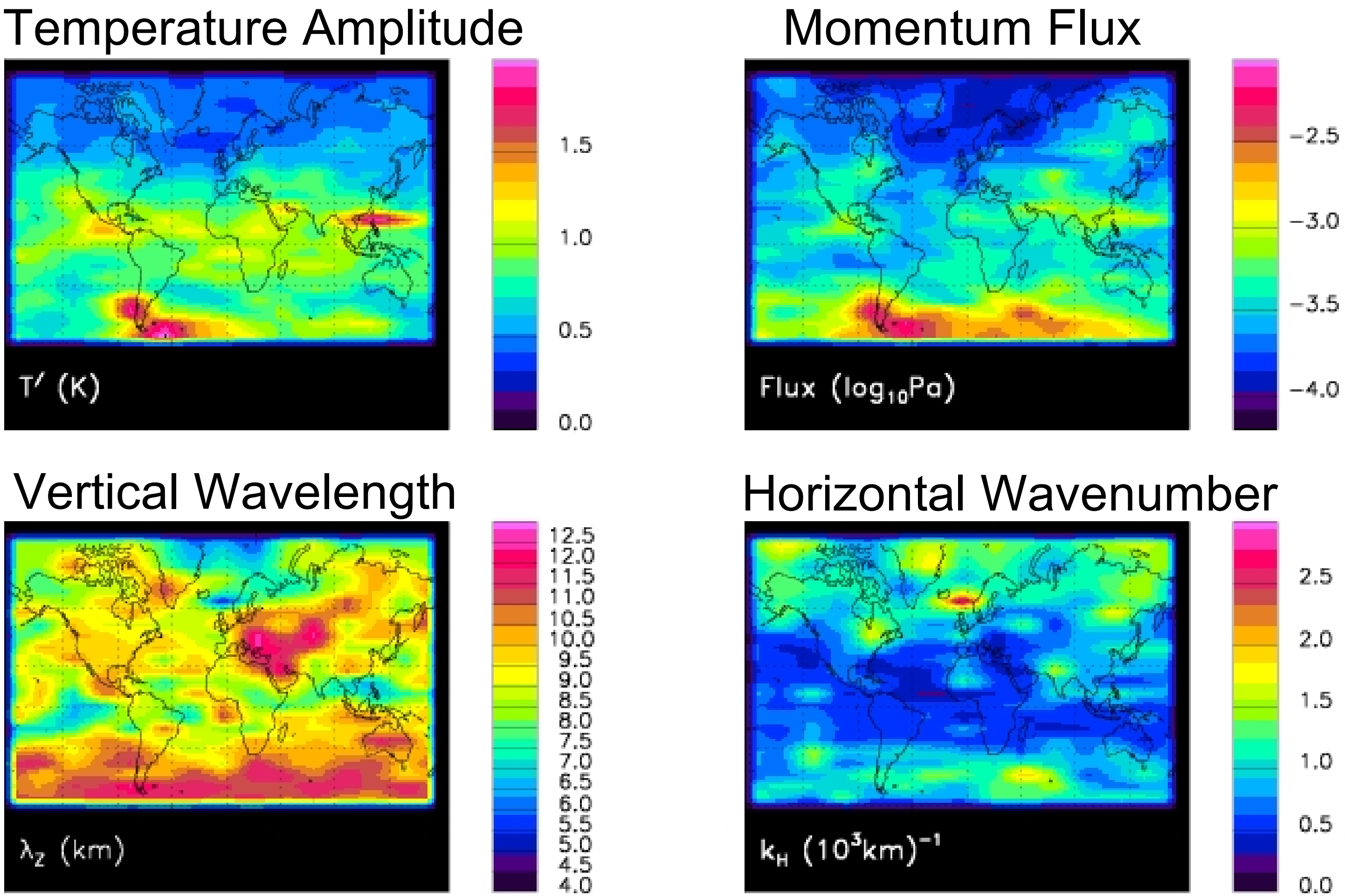


Alexander et al., [2008, JGR]

Satellite Observations

HIRDLS: Global Properties 16 May 2006

Derived from wavelet covariance of adjacent pairs of vertical profiles



Temperature Amplitude

Momentum Flux

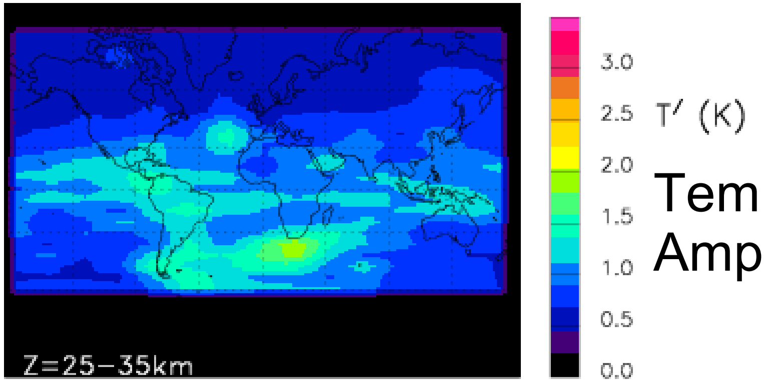
Vertical Wavelength

Horizontal Wavenumber

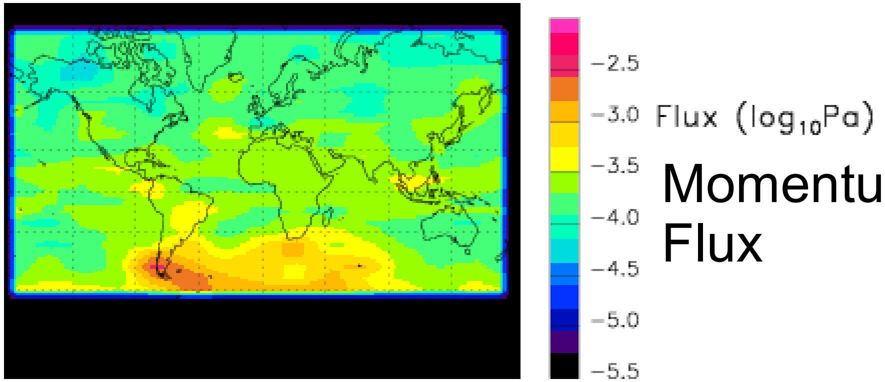
Alexander et al., [2008, JGR]

Satellite Observations

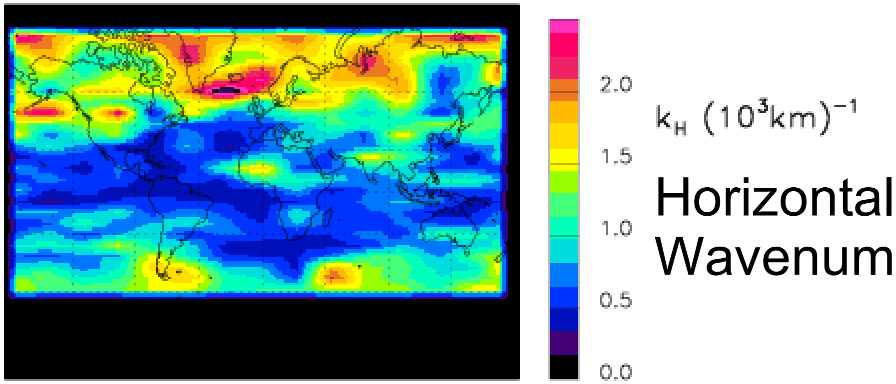
HIRDLS: 20 April 2005



Temperature Amplitude



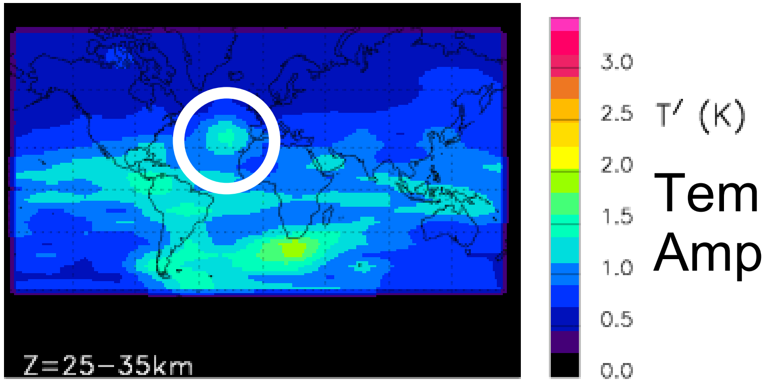
Momentum Flux



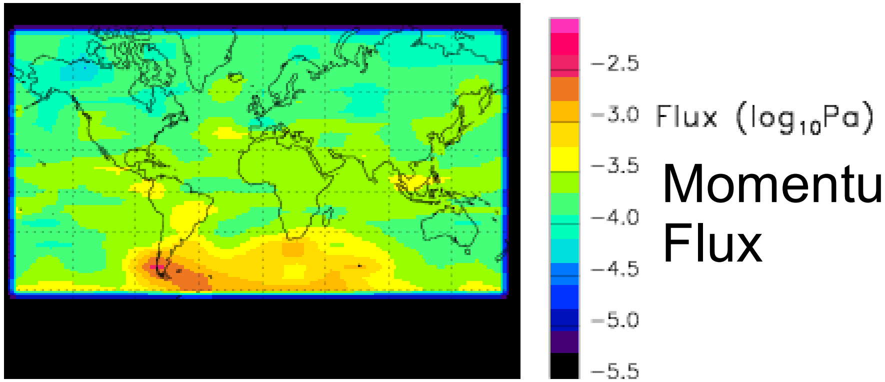
Horizontal Wavenumber

Satellite Observations

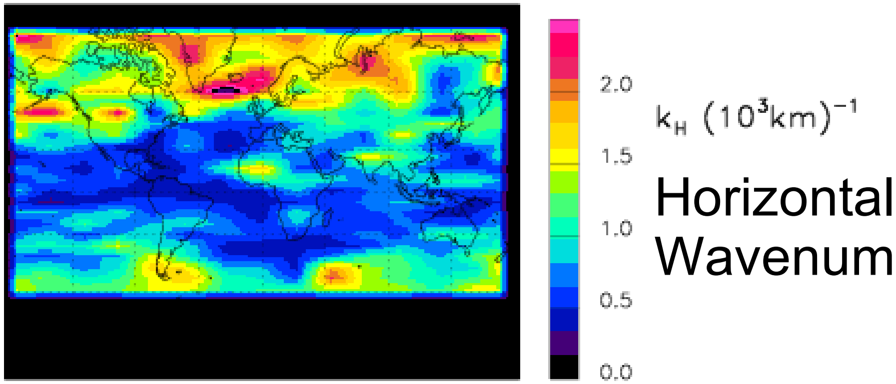
HIRDLS: 20 April 2005



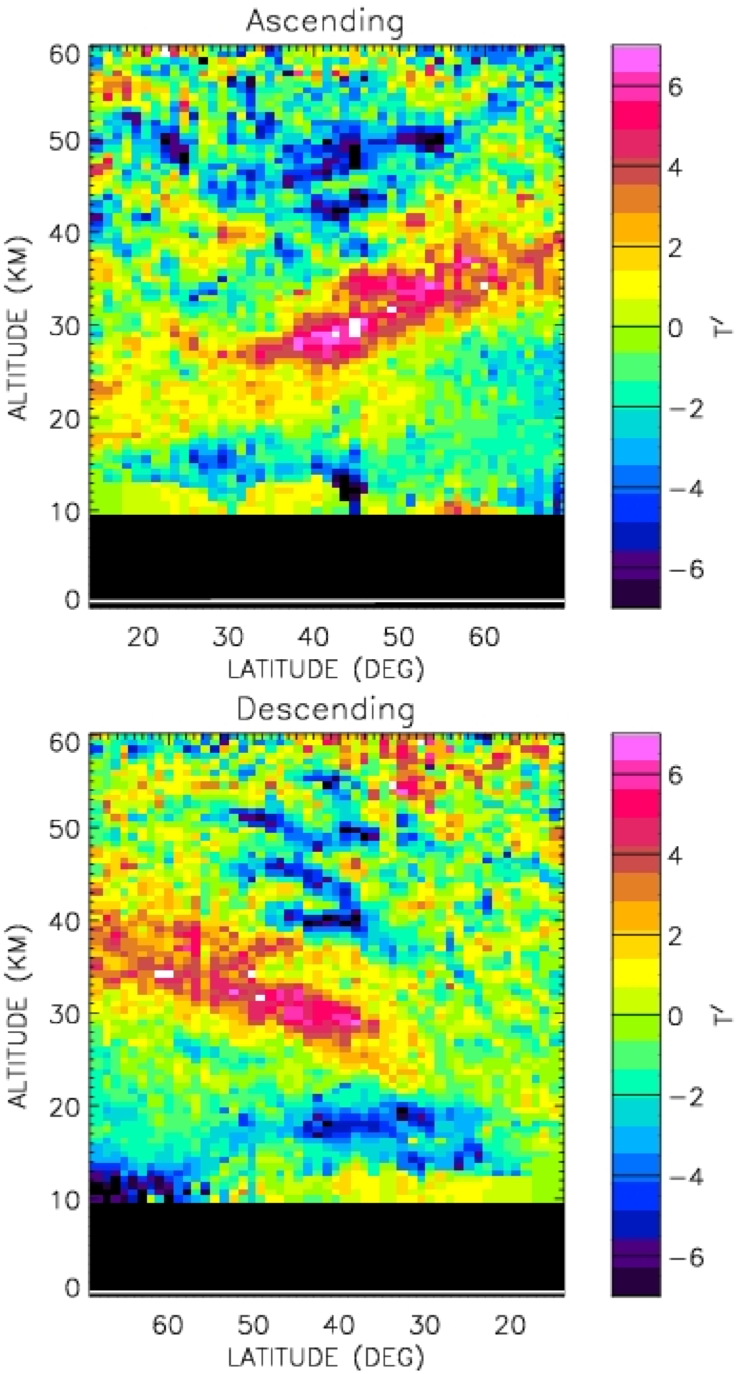
Temperature Amplitude



Momentum Flux



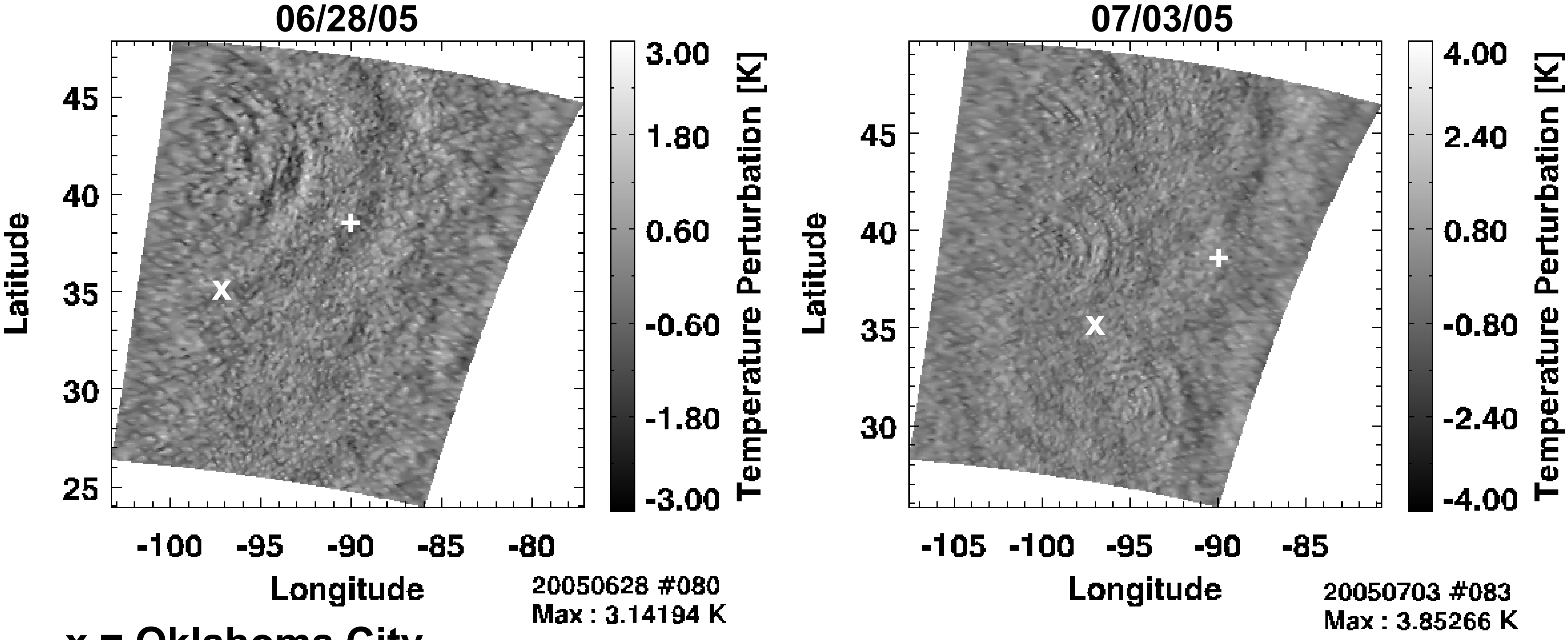
Horizontal Wavenumber



Satellite Observations

AIRS = Atmospheric Infrared Sounder

- Infrared near-nadir sounding instrument
- Image swaths with high horizontal resolution (13.5 km at nadir)
- Low vertical resolution (waves with vertical wavelengths > 12 km)



Waves Observed by AIRS Over Summer Storms in the Continental US

06/28/05

07/03/05

x = Oklahoma City
+ = St. Louis

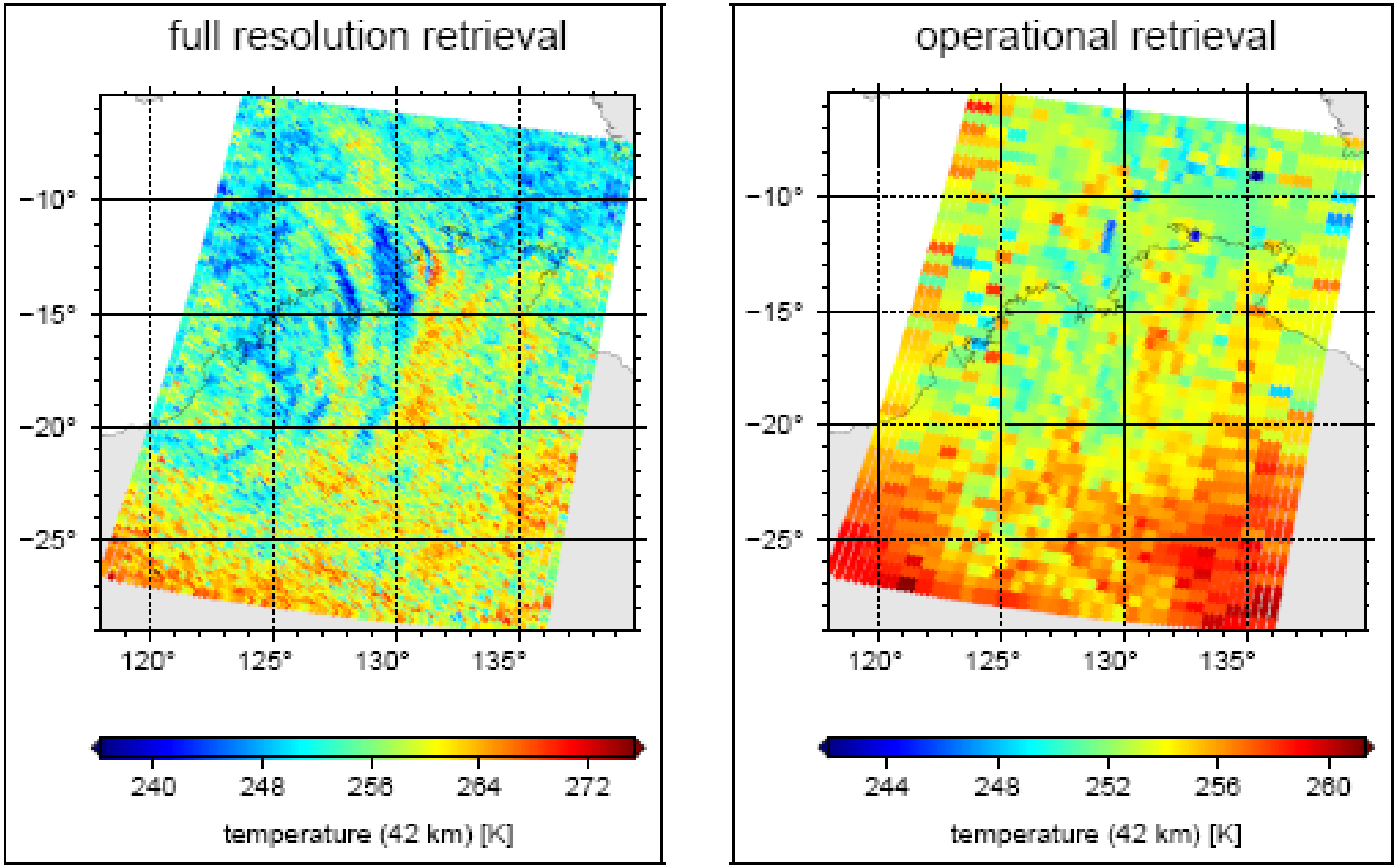
Michele Kuester, Ph.D. Thesis 2007

Satellite Observations

AIRS = Atmospheric Infrared Sounder

Hoffmann and Alexander [2008, in preparation]: New full resolution AIRS temperature retrievals in the stratosphere to give full 3D wave structure.

Gravity waves produced by deep convection...



⇒ Retrieval at full horizontal resolution reveals small-scale structures.

Summary Points

1. Jet imbalance may be an important source in April, but the nature of waves driving the springtime transition to stratospheric easterlies is of general interest. In June, more likely to observe waves from convection.

2. Need three ingredients to characterize gravity waves observed from aircraft:
    A. Long, straight, level flight legs
    B. In situ winds and temperatures at high precision (0.1m/s, 0.1K)
    C. MTP for vertical wavelength information

All three are needed to determine where the waves come from and their subsequent effects on the atmosphere.

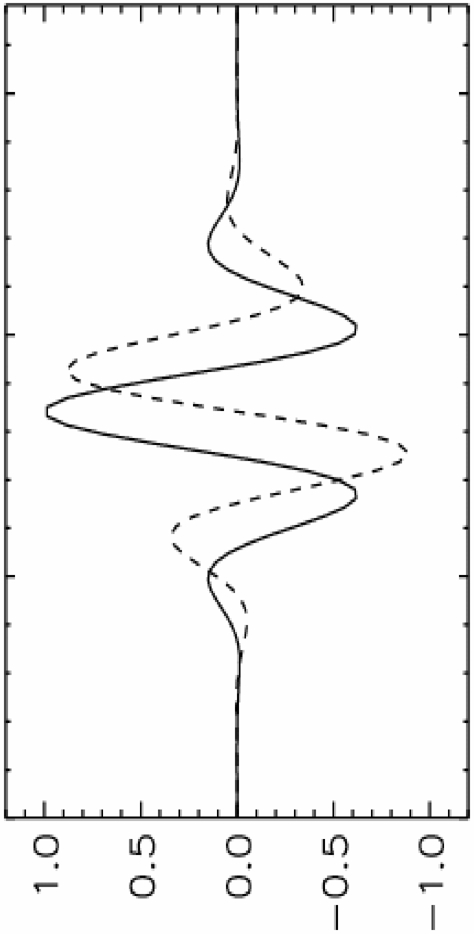
3. Satellite observations of gravity waves for START08:
    - HIRDLS' high vertical resolution particularly valuable for waves from jet sources.
    - AIRS will become useful in June for waves from convection.

Extra Slides

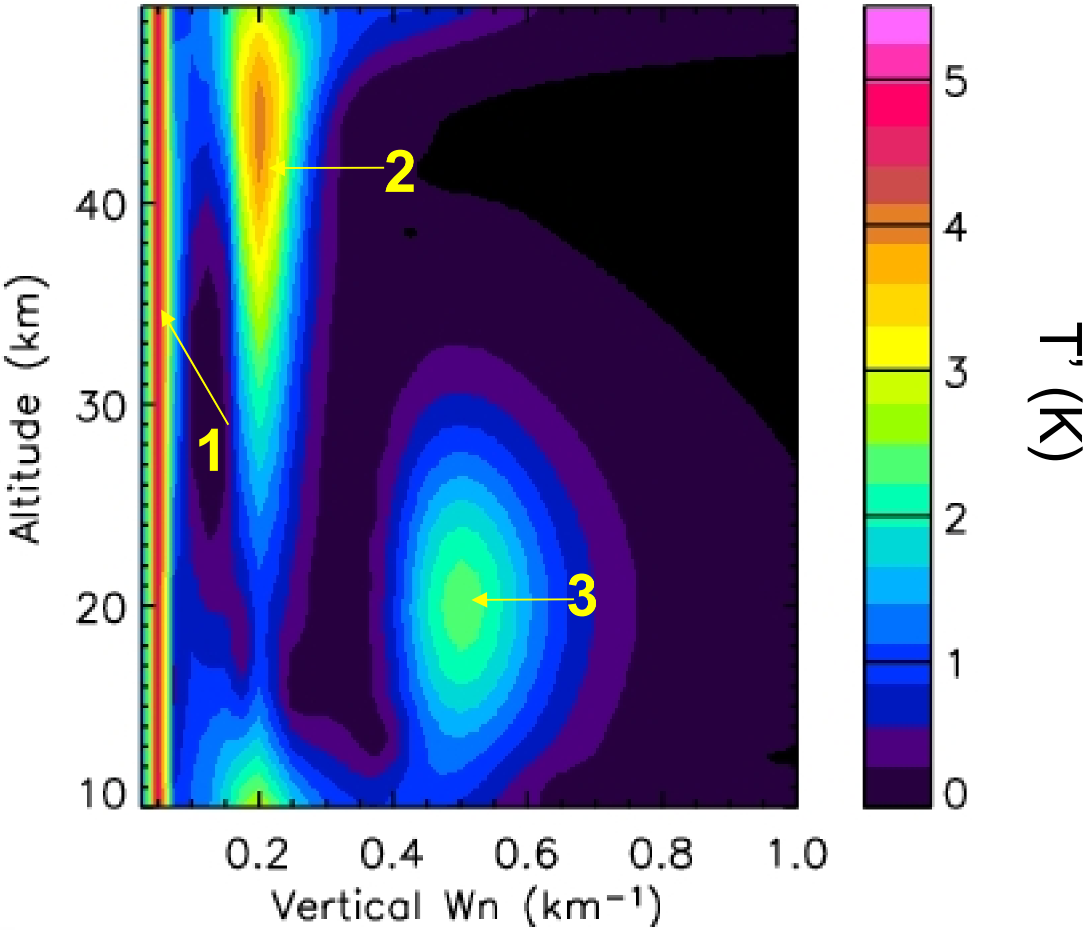
Along-Track: Wavelet Analysis

S-transform analysis of a synthetic vertical temperature profile

Example S-transform wavelet basis functions



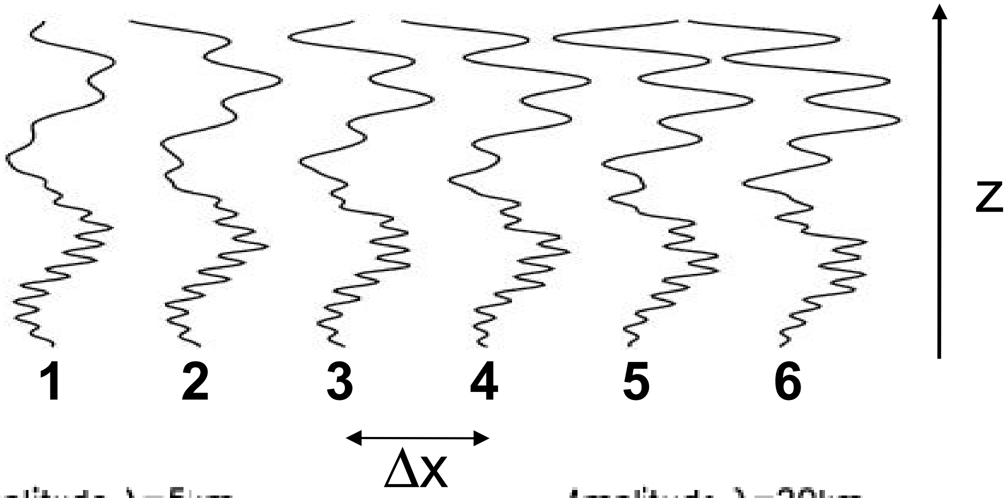
Wavelet transform amplitude spectrum of theoretical 3-wave T' profile

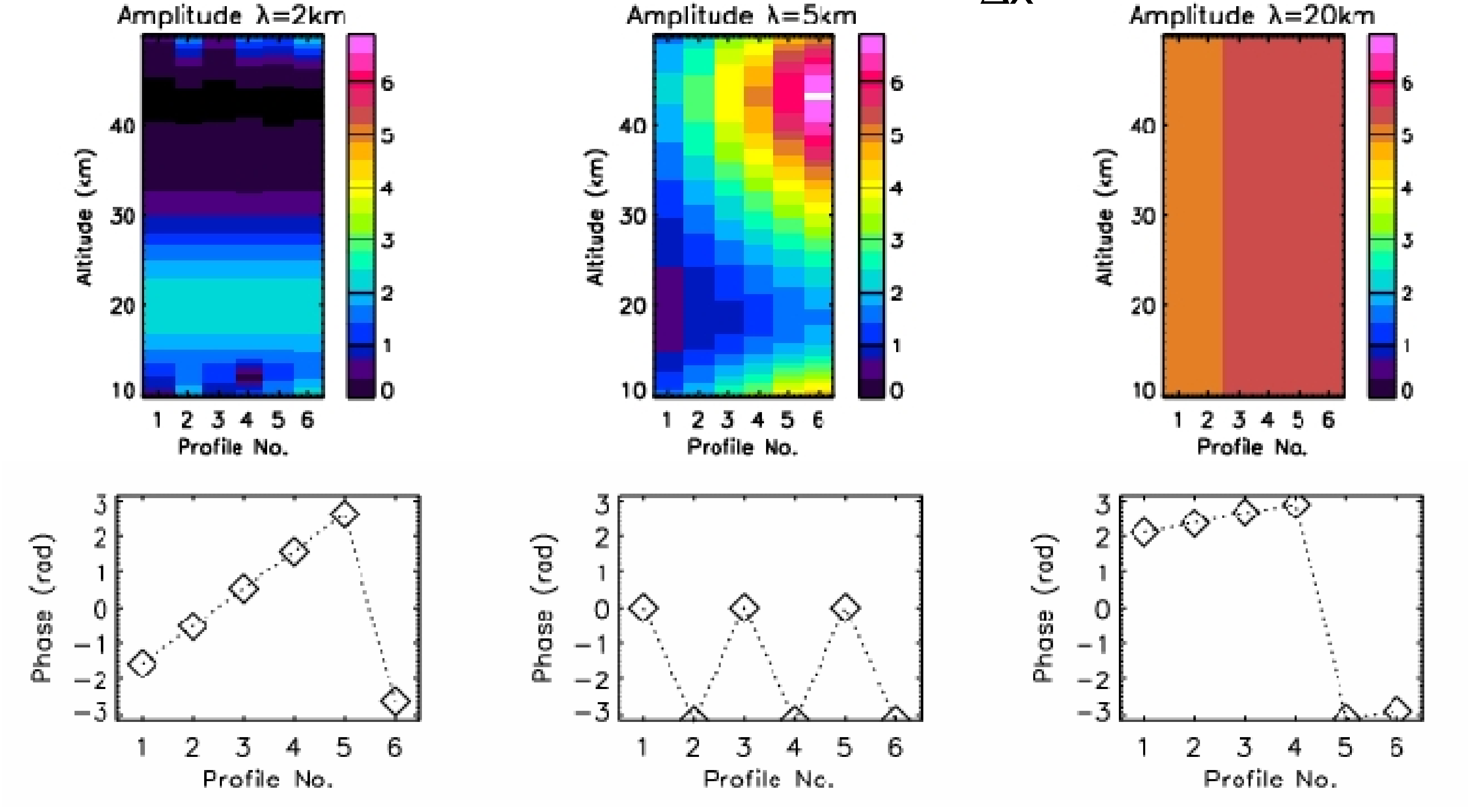


Wavelet Analysis of profile series

Phase difference Δϕ between adjacent profiles gives:

Horizontal wn = k ~ Δϕ/Δx





Gravity Waves in HIRDLS

Wavelet covariance analysis: adjacent profile pairs

- Find maximum T' covariance and associated λ_Z, $\Delta\varphi$ (lon, lat, z)
- $\Delta\varphi$ -> λ_H along the line joining adjacent profiles.

- Result = T' covarying amplitude (lon, lat, z, λ_Z, λ_H)

- Method similar to Ern et al. (2004)[1] as applied to CRISTA.
- Horizontal spacing between profiles is proportional to minimum derivable horizontal wavelength
- CRISTA spacing ~200-250km; HIRDLS spacing ~100km
- CRISTA Δz ~2.5-3km; HIRDLS Δz ~1.2km

[1] Ern, M., P. Preusse, M.J. Alexander, and C.D. Warner, 2004: Absolute values of gravity wave momentum flux derived from satellite data. *J. Geophys. Res.*, 109, D20103, doi:10.1029/2004JD004752.

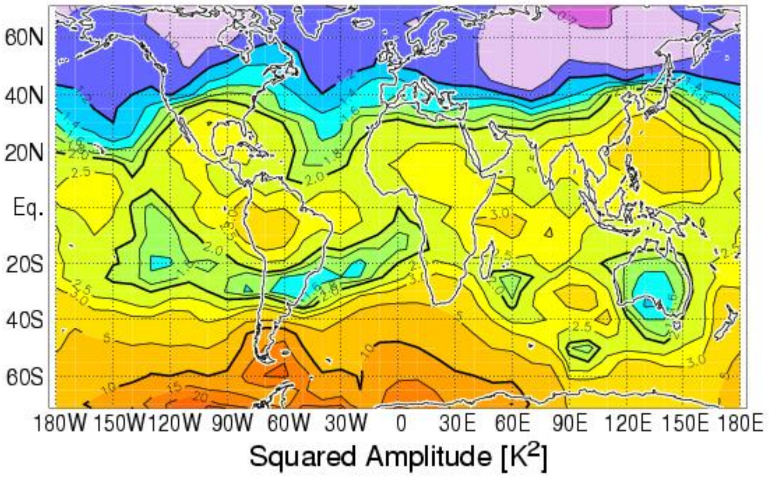
Key Observations for Characterizing Gravity Waves and their Sources via Aircraft

- MMS: **M**eteorological **M**easurement **S**ystem (Scott et al., 1990)
  - Measures 3-D vector winds and T at aircraft flight level.
  - Excellent data quality (0.1 m/s for winds, 0.1 K for T)
  - Horizontal resolution ~ 200 m
- MTP: **M**icrowave **T**emperature **P**rofiler (Denning et al., 1989)
  - Measures vertical T profiles along flight path by microwave remote sensing
  - Data quality is best at the flight level (0.25 K).
  - Horizontal resolution ~ 2 km
  - Vertical resolution is ~ 160 m at the flight level.

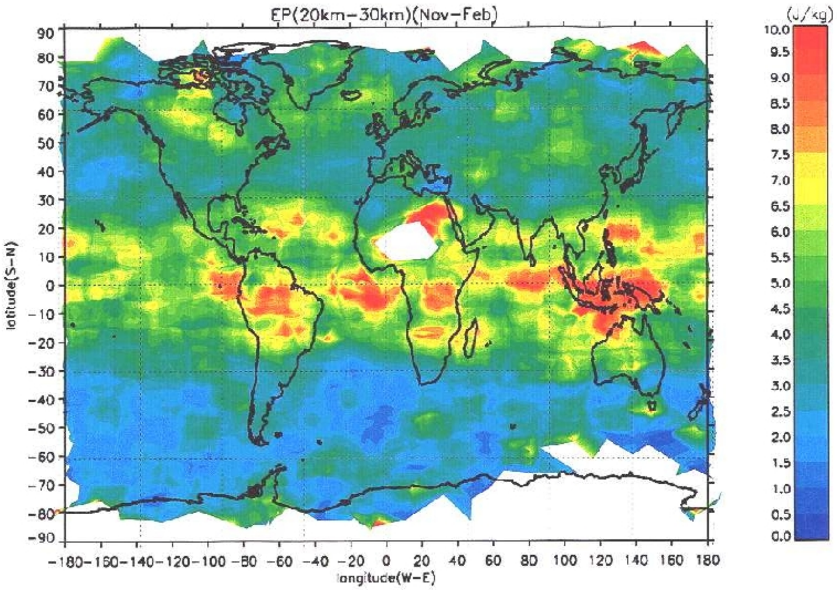
Wang et al. [2005, ACP]

Gravity Waves in Other Data Sets

CRISTA (Ern et al., 2004)



GPS (Tsuda et al., 2000)



- CRISTA measurements from one week of data Aug 1997, z=25 km, includes longer λ_Z than these HIRDLS results.
- GPS/MET from many months of observations Nov-Feb, z=20-30 km, include only short λ_Z waves similar to HIRDLS.
- Both show the equatorial peak and winter > summer seasonal asymmetry.