A global climatology of temperature and water vapor variance scaling from AIRS: Implications for future sounding requirements

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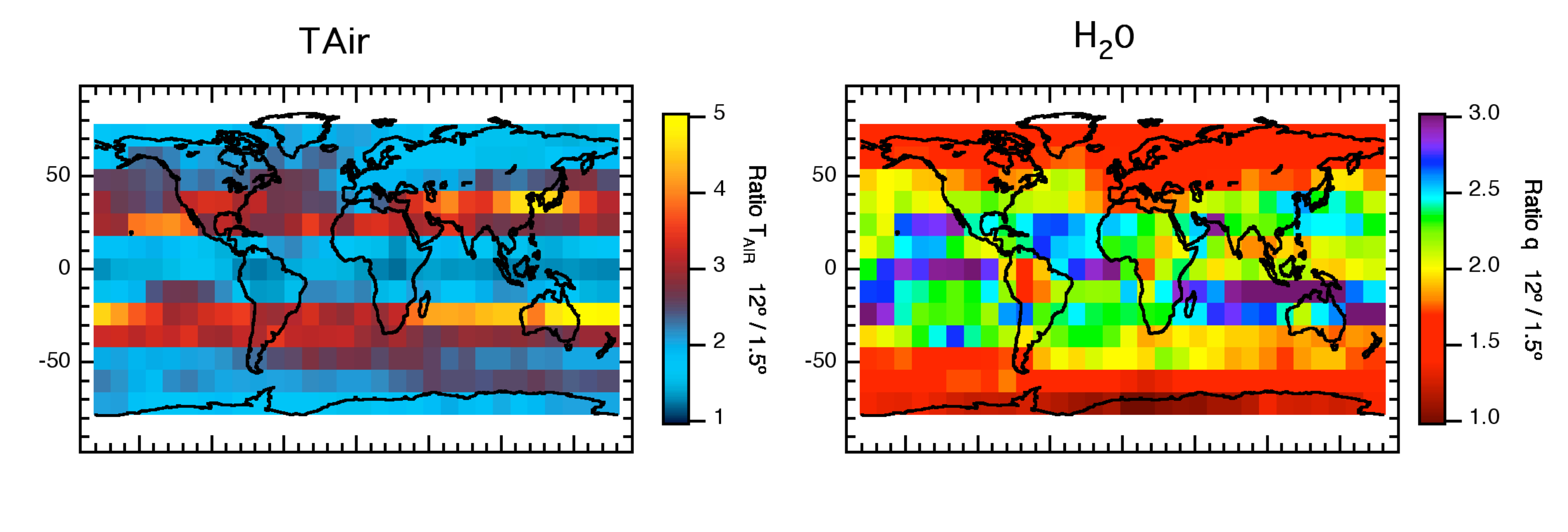
Take-home Messages

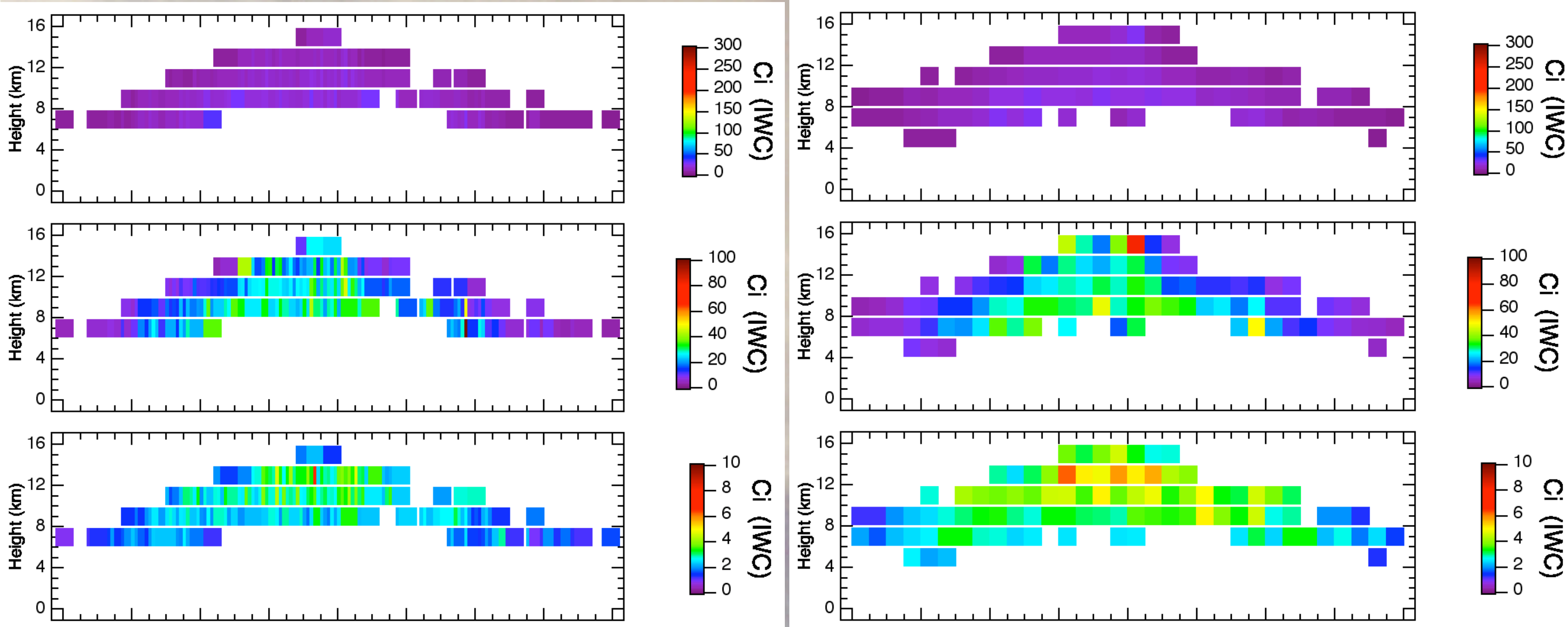
- **Scale dependence of moments of temperature, water vapor & cloud properties important at small scales**
    - Model parameterizations
    - Observing systems
- **Scale dependence of AIRS temperature and water vapor variance have:**
    - Very different characteristics
    - Large temporal/spatial variability
- **CloudSat has similar complex structure – no universal PDF**
- **Implications for climate modeling and future satellite observations**

Ratio of Variability at Different Scales



Kahn and Teixeira (2009), submitted to *J. Climate*

Cirrus IWC from CloudSat



1 degree

5 degree

How to Summarize Variance Information Over Scales?

- **Power spectral density/structure function exponents**
  - Popular with u and v wind components, θ, trace gas concentrations, LWP

- **Theory and numerical modeling:** e.g., Kolmogorov (1941); Charney (1971); Lilly (1983); Lindborg (1999); Tung and Orlando (2003); many others…

- **Observations:** e.g., Nastrom and Gage (1985); Cahalan et al. (1989;1994); Davis et al. (1994); Tjemkes and Visser (1994); Bacmeister et al. (1996); Pierrehumbert (1996); Cho et al. (1999a,b), many others…

- **Mesoscale "break" near 500–800 km (observations, models, and theory)**

- **Generally, –3 power law scaling at $>$ 800 km, –5/3 at $<$ 400 km**
  - Structure function exponents of 1.0 and 0.33, respectively

Aircraft-derived Power Law Scaling in the Mesoscale

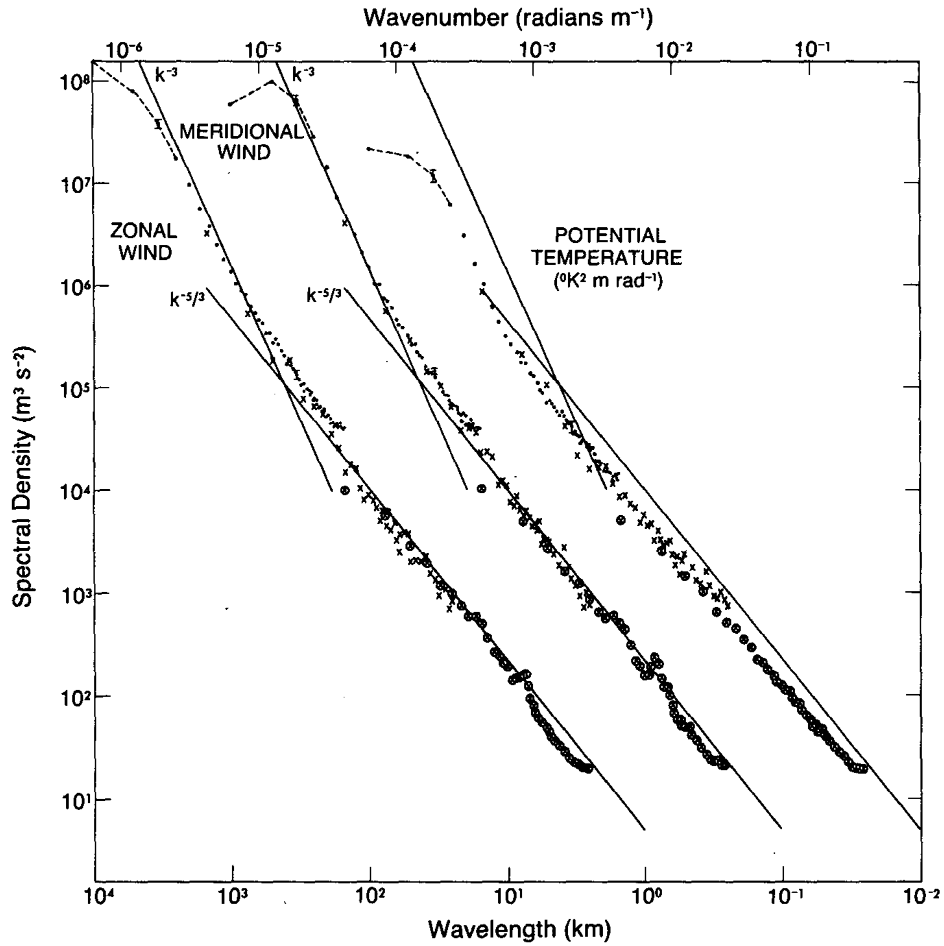


FIG. 3. Variance power spectra of wind and potential temperature near the tropopause from GASP aircraft data. The spectra for meridional wind and temperature are shifted one and two decades to the right, respectively; lines with slopes −3 and −5/3 are entered at the same relative coordinates for each variable for comparison.

Nastrom and Gage (1985), JAS

Power Spectrum of LWP in Sc from Landsat

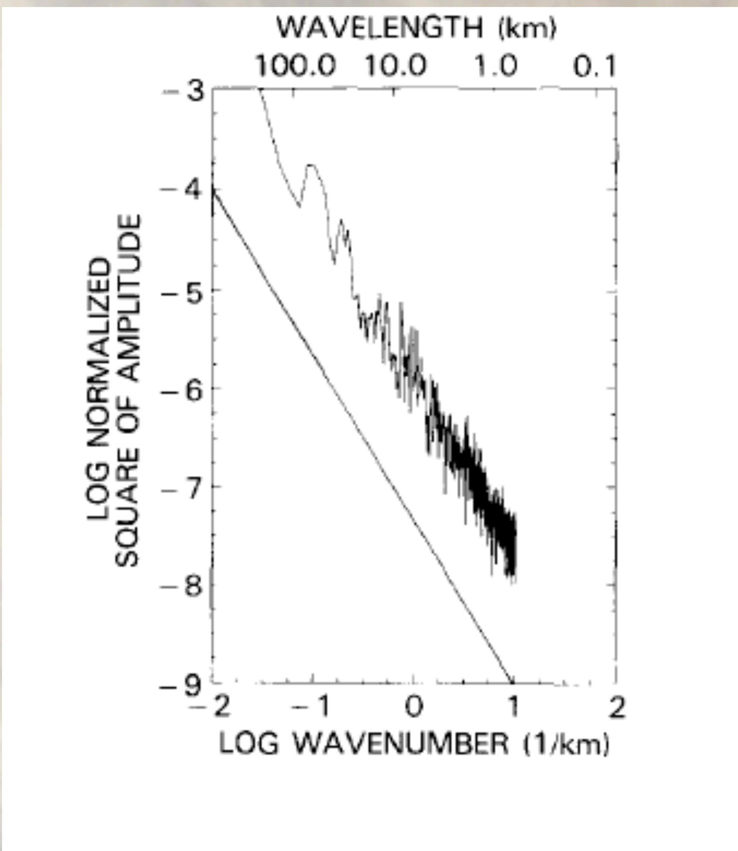


Figure 9. Spectrum of vertically integrated liquid water for 6 days of data similar to Fig. 8, converted from frequency to wavenumber assuming frozen turbulence with a mean 5 m/s advection. The least-square fit gives a 5/3 power-law decrease, suggesting that the liquid water fluctuates with the vertical velocity and may be treated as a passive scalar for the scales shown.

Cahalan and Snider (1989), RSE

Power Spectra of LWP in Sc from MODIS

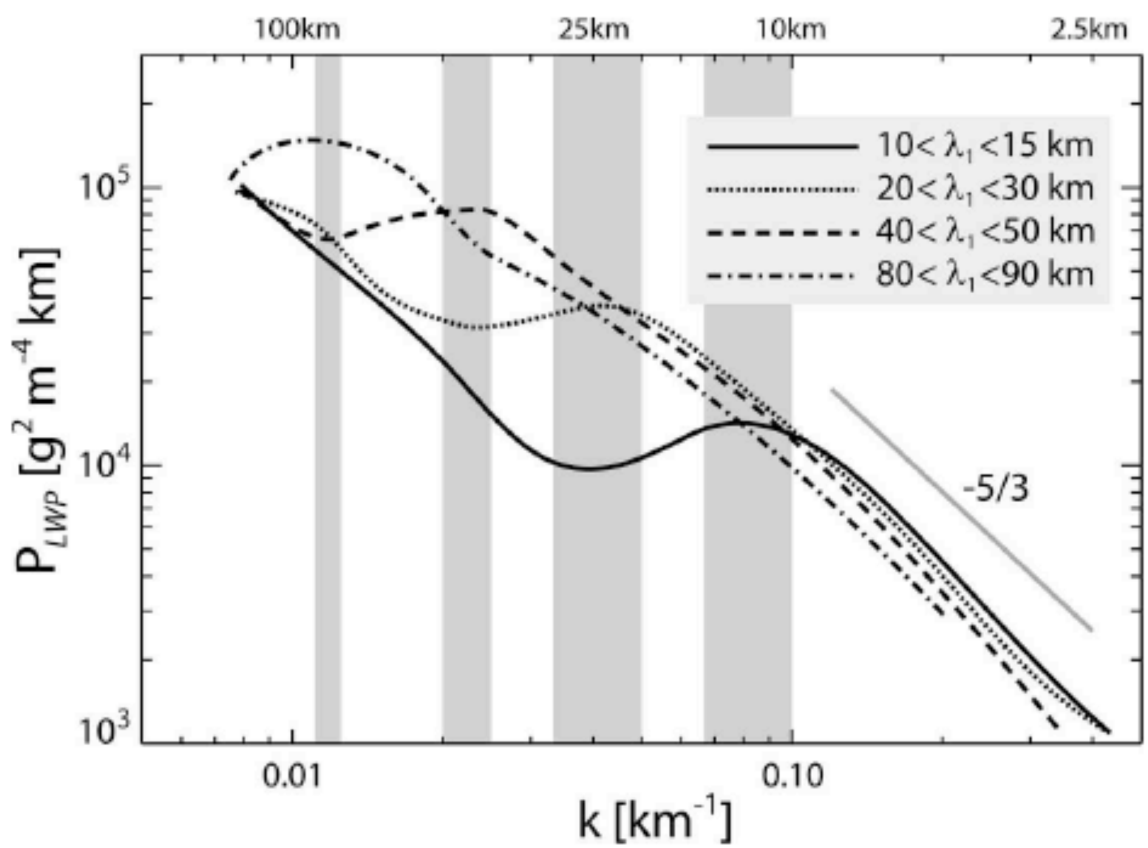


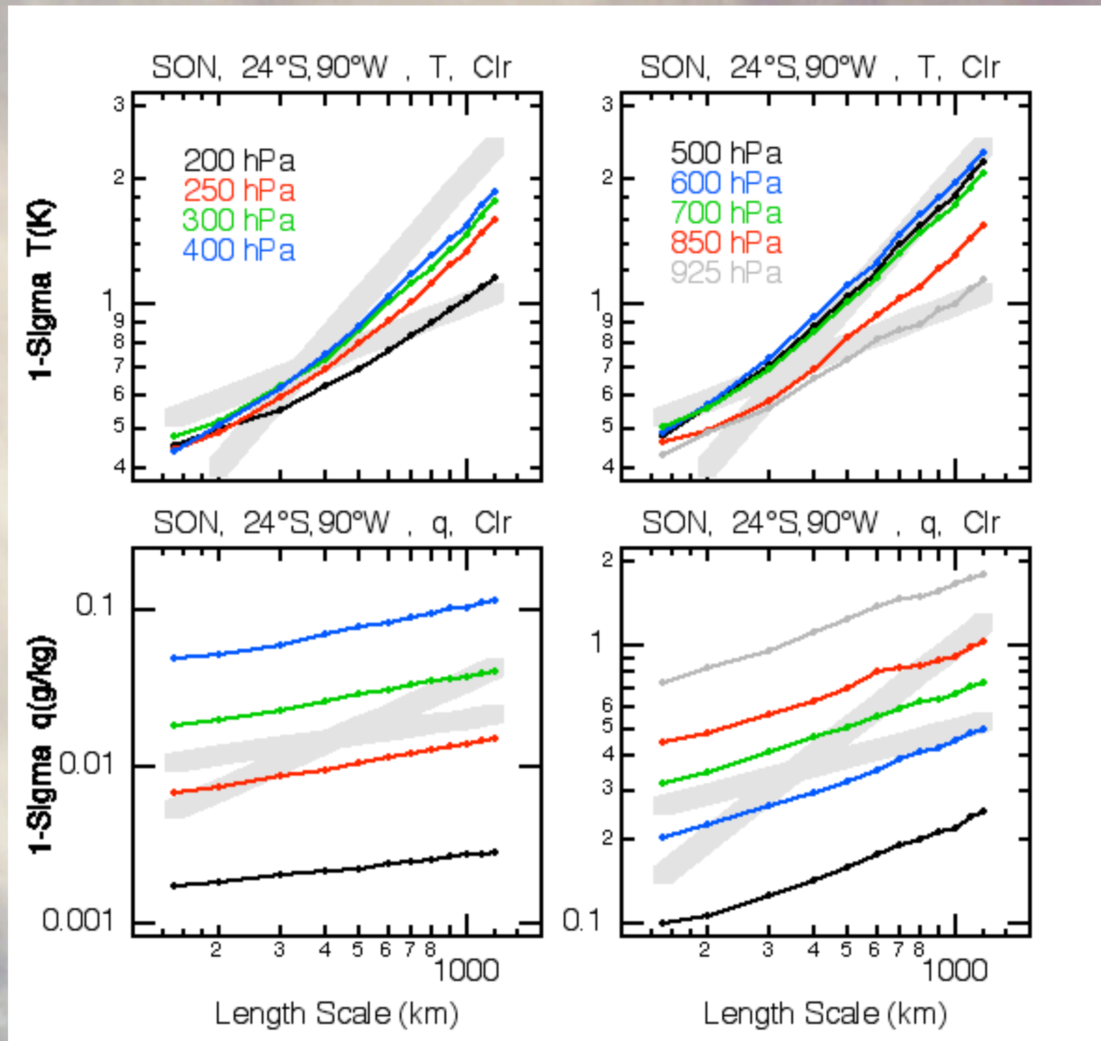
FIG. 10. Averaged power spectra four different ranges of the characteristic cell length scale λ_1. Vertical gray bars indicate extent of λ_1 ranges used for compositing. Data are taken from the NE Pacific region only; composite spectra are almost identical for the SE Pacific data.

Wood and Hartmann (2006), *J. Climate*

Variance Scaling with AIRS

- **Spectra of *T* and *q* variance**
  - "Poor Man's spectral analysis": Cahalan et al. (1994); Wood et al. (2002)
  - Power spectrum scaling of [–5/3, –2, –3] ≅ [0.33, 0.5, 1.0] for variance scaling
- **Scaling derived separately:**
  - For *T* and *q* in clear/cloudy pixels
  - For length scales of 150–400 km (small) and 800–1200 km (large)
    - Differences between exponents highlight mesoscale "break"
  - For each AIRS standard pressure level in troposphere
- **Derive over entire globe from September 2006 to August 2007**
  - First global climatology of *T* and *q* to our knowledge
  - Organize by season (SON, DJF, MAM, JJA)

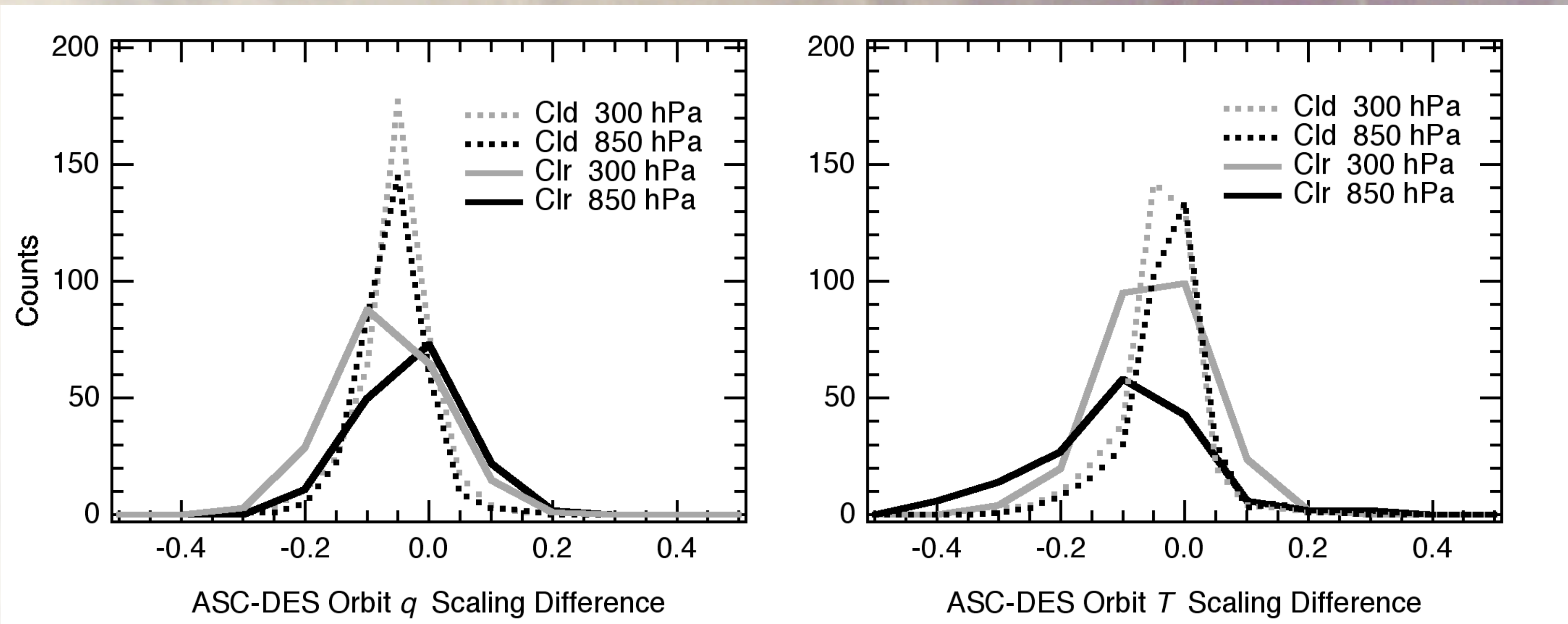
Scaling of *T* and *q* near coast of S. America



Length scale spectra of σ_T (top) and σ_q (bottom) for clear scenes. Gray lines are illustrative spectra for $\alpha = 0.33$ (weaker slope) and $\alpha = 1.0$ (steeper slope).

Kahn and Teixeira (2009), submitted to *J. Climate*

Diurnal differences in Scaling of *T* and *q*



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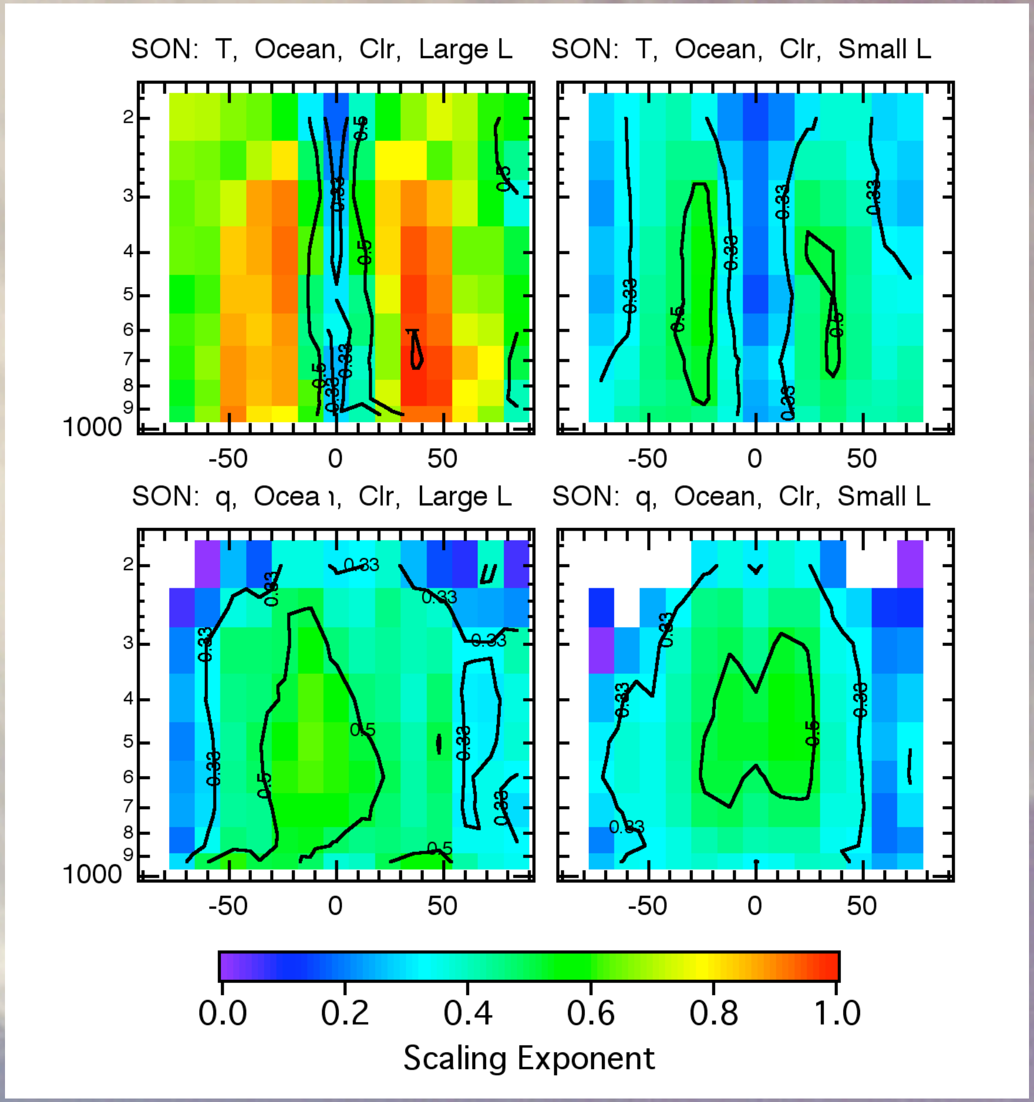
Zonal-averaged differences between *T* and *q*

“Large” L

“Small” L

Temperature

Water Vapor



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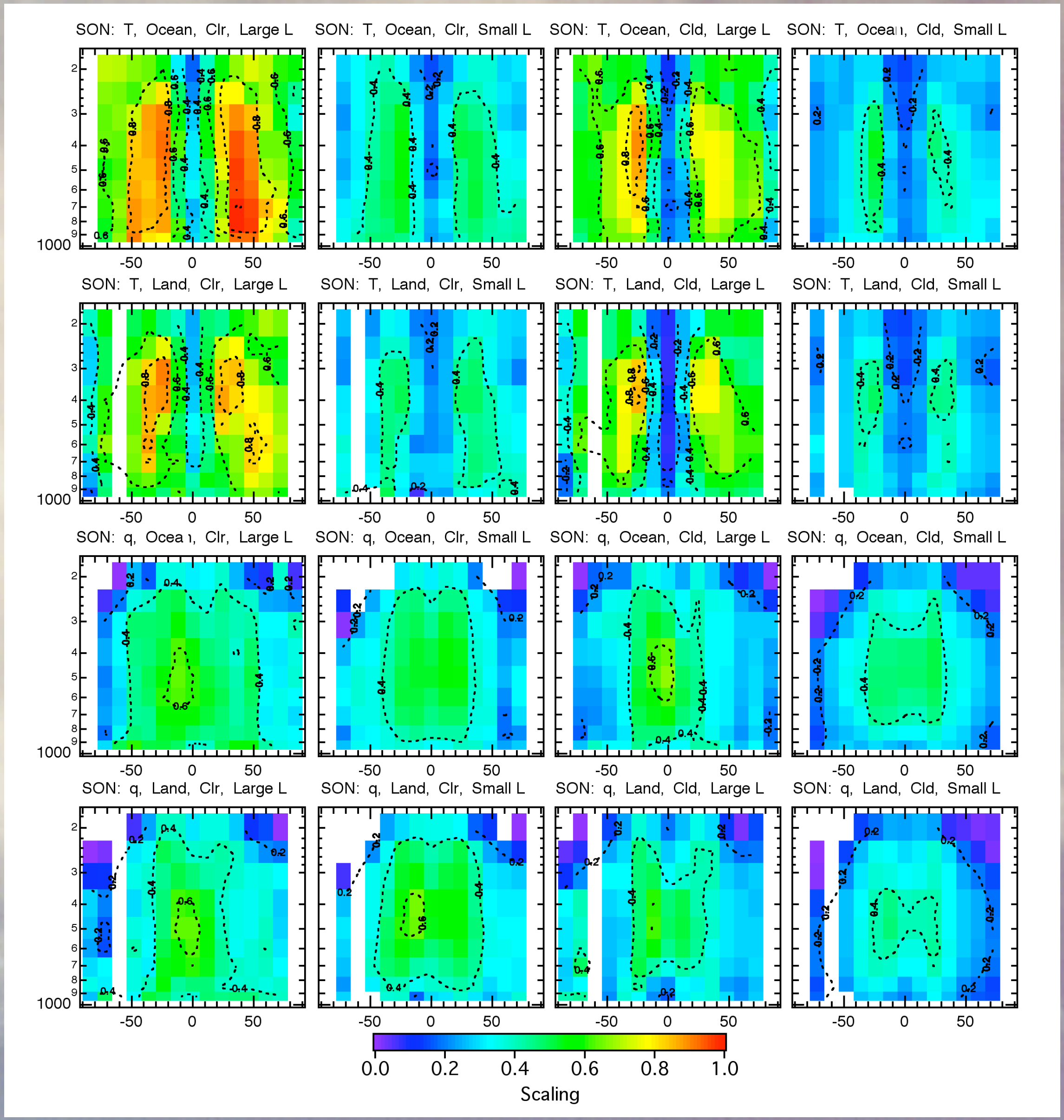
As a function of land/ocean, clear cloud, etc.



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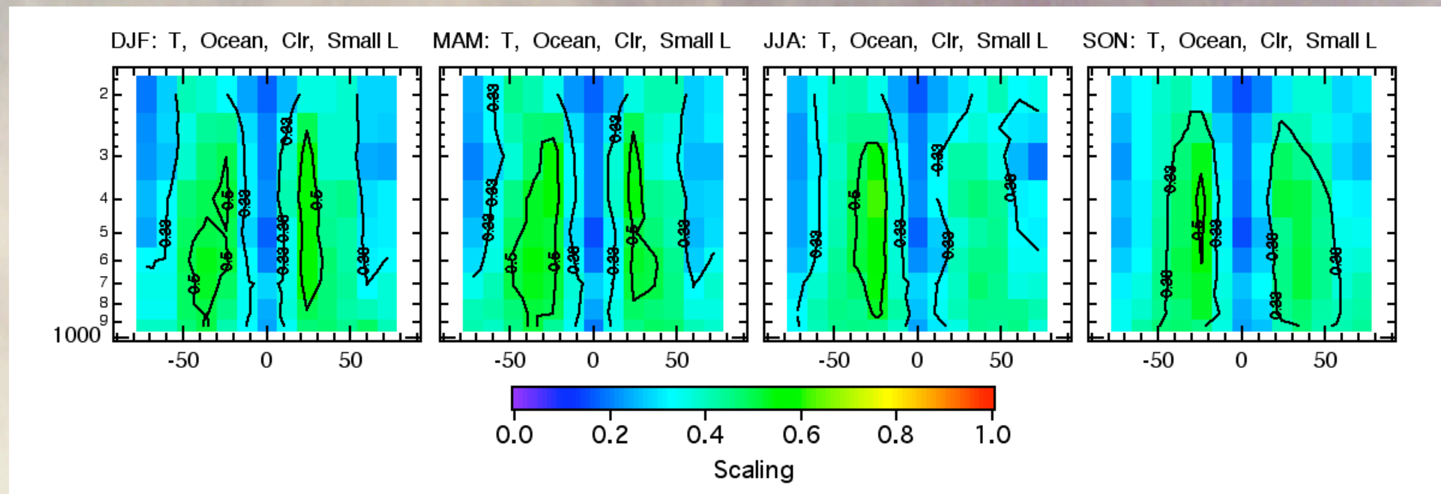
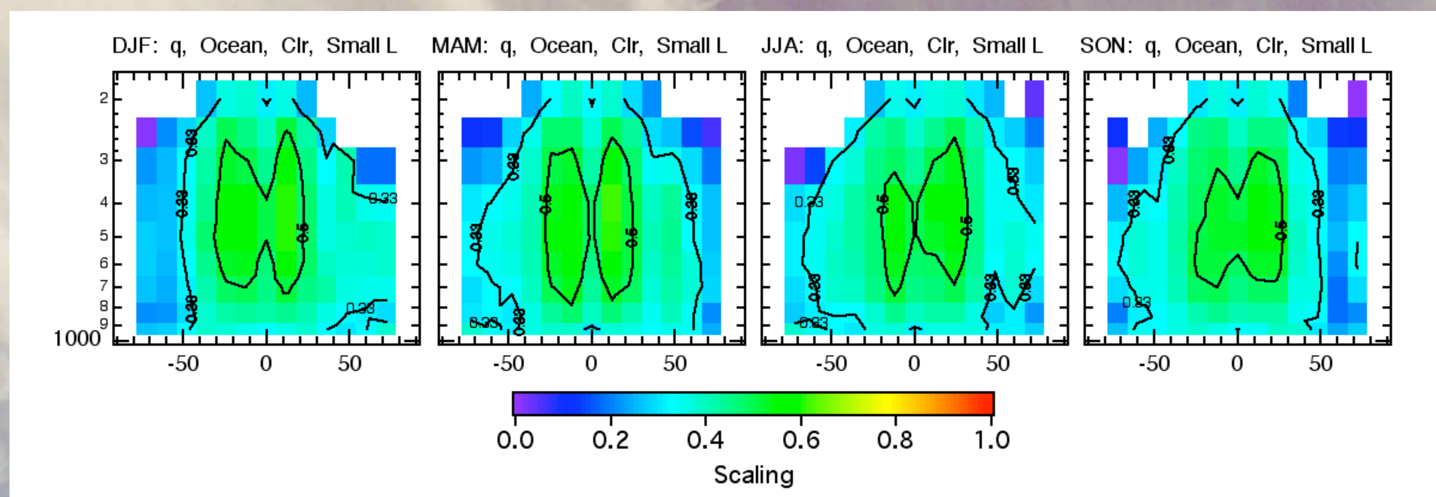
Zonal-averaged/seasonal differences at small scales

Temperature



Water Vapor



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(At Least) Two Possible Pathways to Use AIRS Variance Scaling with Models:

- **Compare simulations to observations**

  - Different models >> different parameterizations/model architecture >> different scaling laws?

  - Satellite sampling not complete & model-observational parameters not necessarily equivalent >> how comparable to models?

Compare Simulated and Observational Power Spectra

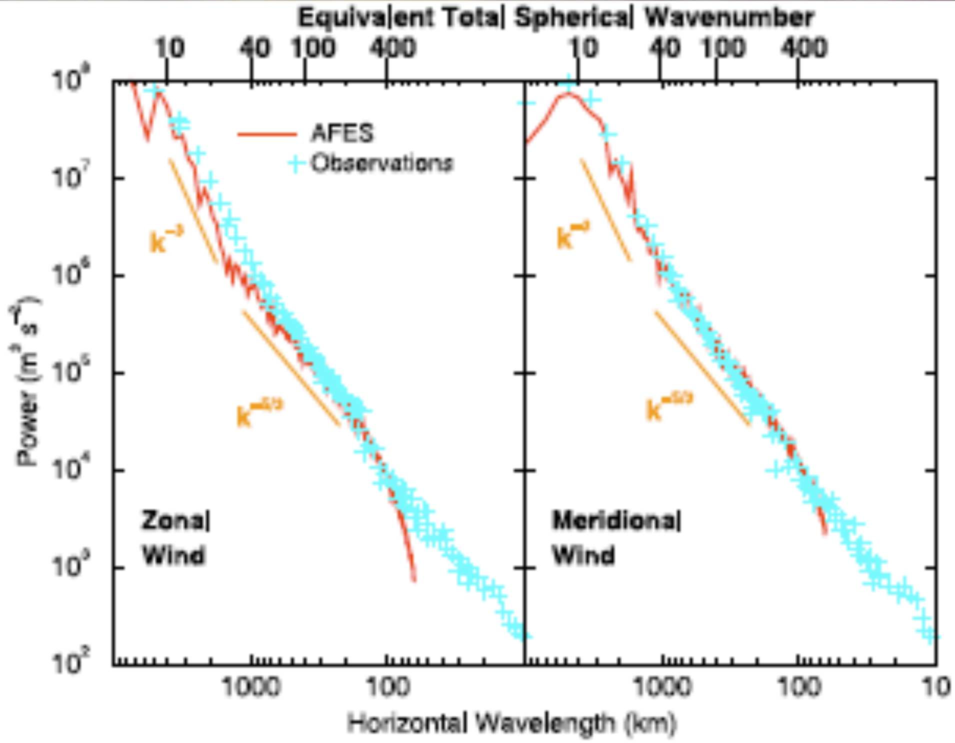


Figure 1. The one-dimensional horizontal power spectra of (left) zonal wind and (right) meridional wind variations near the tropopause. The red curves are computed from wind values taken along the 45N latitude circle at 200 hPa in the T639L24 AFES. The crosses are from *Nastrom and Gage* [1985] and are computed from wind observations taken by commercial airliners. Orange lines show −3 and −5/3 slopes.

Takahashi et al. (2006), *GRL*

(At Least) Two Possible Pathways to Use AIRS Variance Scaling with Models:

- **Compare simulations to observations**
  - Different models >> different parameterizations/model architecture >> different scaling laws?
  - Satellite sampling not complete & model-observational parameters not necessarily equivalent >> how comparable to models?
- **Constrain model physics with scaling observations**
  - Use scaling exponents to constrain PDF-based parameterizations

Constrain model physics with scaling observations

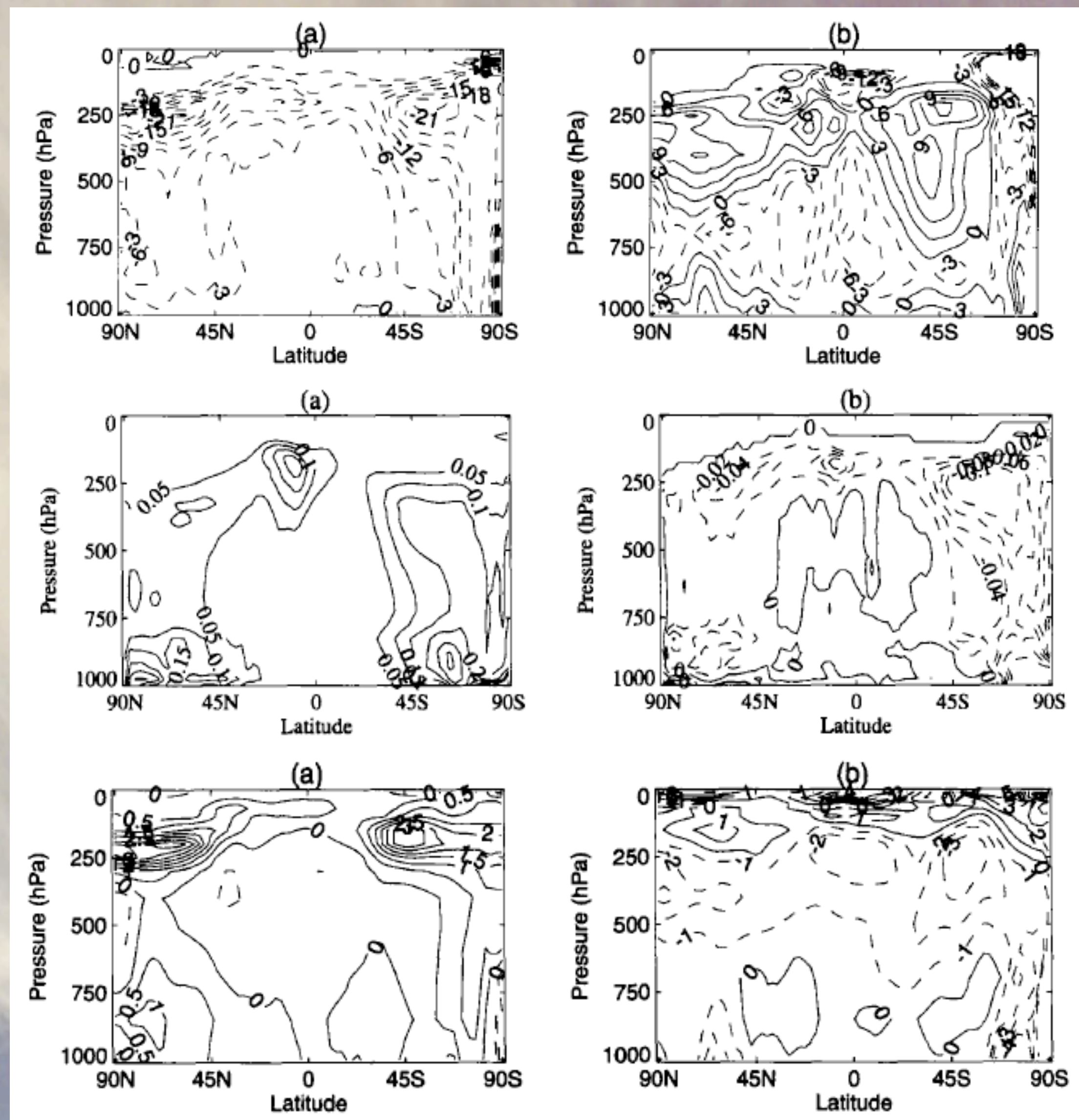
“Scaling” – Control

“Scaling” – ECMWF Re-analysis

Zonal Mean Relative Humidity

Zonal Mean Cloud Fraction

Zonal Mean T_{AIR}



Cusack et al. (1999), *QJRMS*

Summary: What is AIRS scaling useful for?

- **TBD**
- **Is tightness of agreement between model/observational exponents related to "model performance"?**
    - Probably one of many measures that are necessary – TBD
- **Can AIRS scaling be extrapolated to scales < 150 km?**
    - TBD
    - Little aircraft *in situ* evidence for T and q scale breaks < 150 km
    - Phase changes (i.e., clouds) perturb T and q fields – adjustment in variance
        - Cloud type/regime scaling differences?
    - Cusack et al. (1999) show simple adjustment to –5/3 helps a lot!

A Few Wishes and Desires for Future Sounding

- **Higher spatial and vertical resolution *T* and *q***
  - Do breaks exist at scales < 150 km?
  - What spatial/vertical resolution do we really need?
  - Vertical resolution important for boundary layer, tropopause, small-scale *T* and *q* features

- **Sounding within clouds – importance of microwave**

- **Simultaneous observations of *T*, *q* and cloud property PDFs**
  - Leave no samples behind!