Scale dependence of temperature and water vapor from AIRS, aircraft, and models: Continuation into the NPP/JPSS era

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KE Power Spectra in AFES & Aircraft Obs

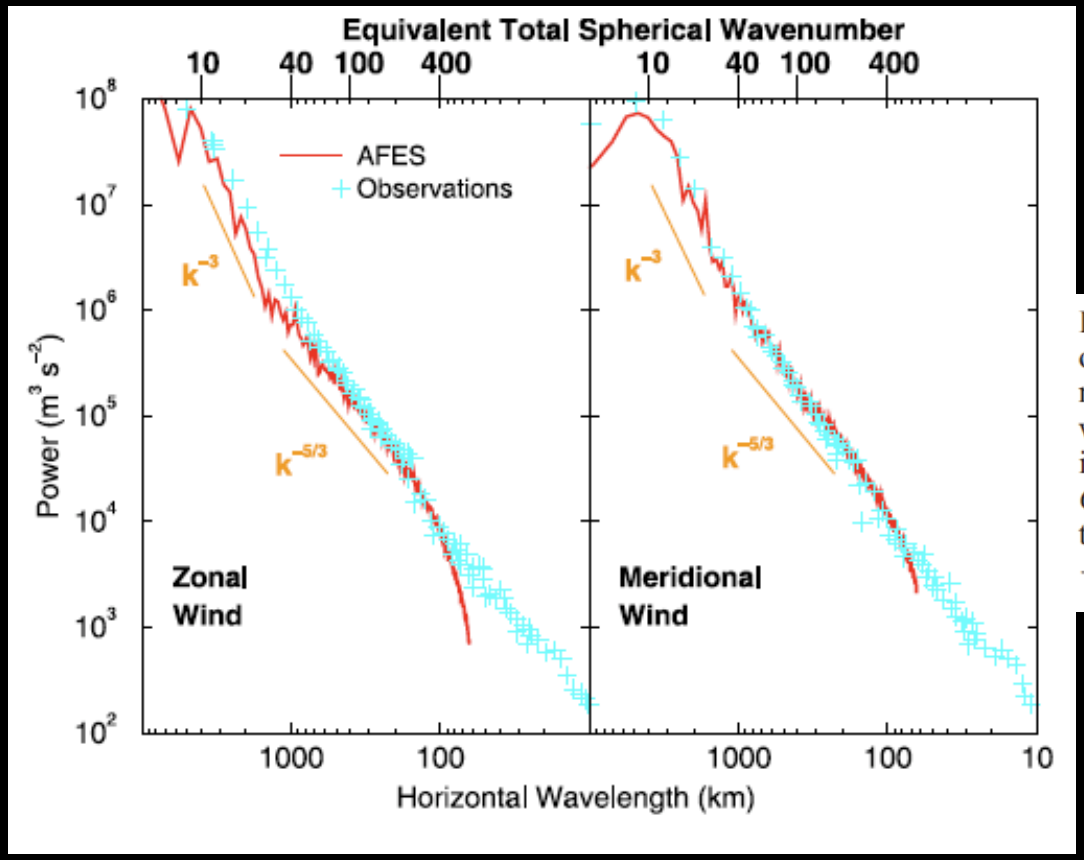


Figure 1. The one-dimensional horizontal power spectra of (left) zonal wind and (right) meridional wind variations near the tropopause. The red curves are computed from wind values taken along the 45N latitude circle at 200 hPa in the T639L24 AFES. The crosses are from *Nastrom and Gage* [1985] and are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

Takahashi et al. (2006), *GRL*

Climate sensitivity depends on subgrid-scale diffusion, noise, numerics, model resolution, etc.

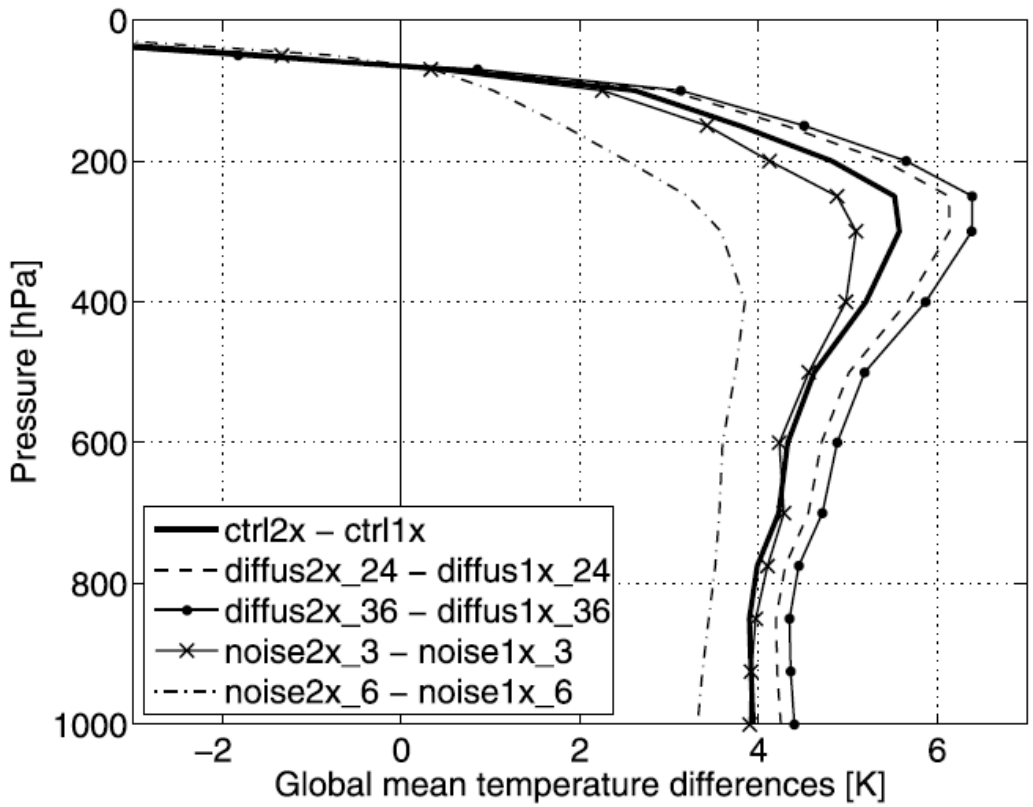


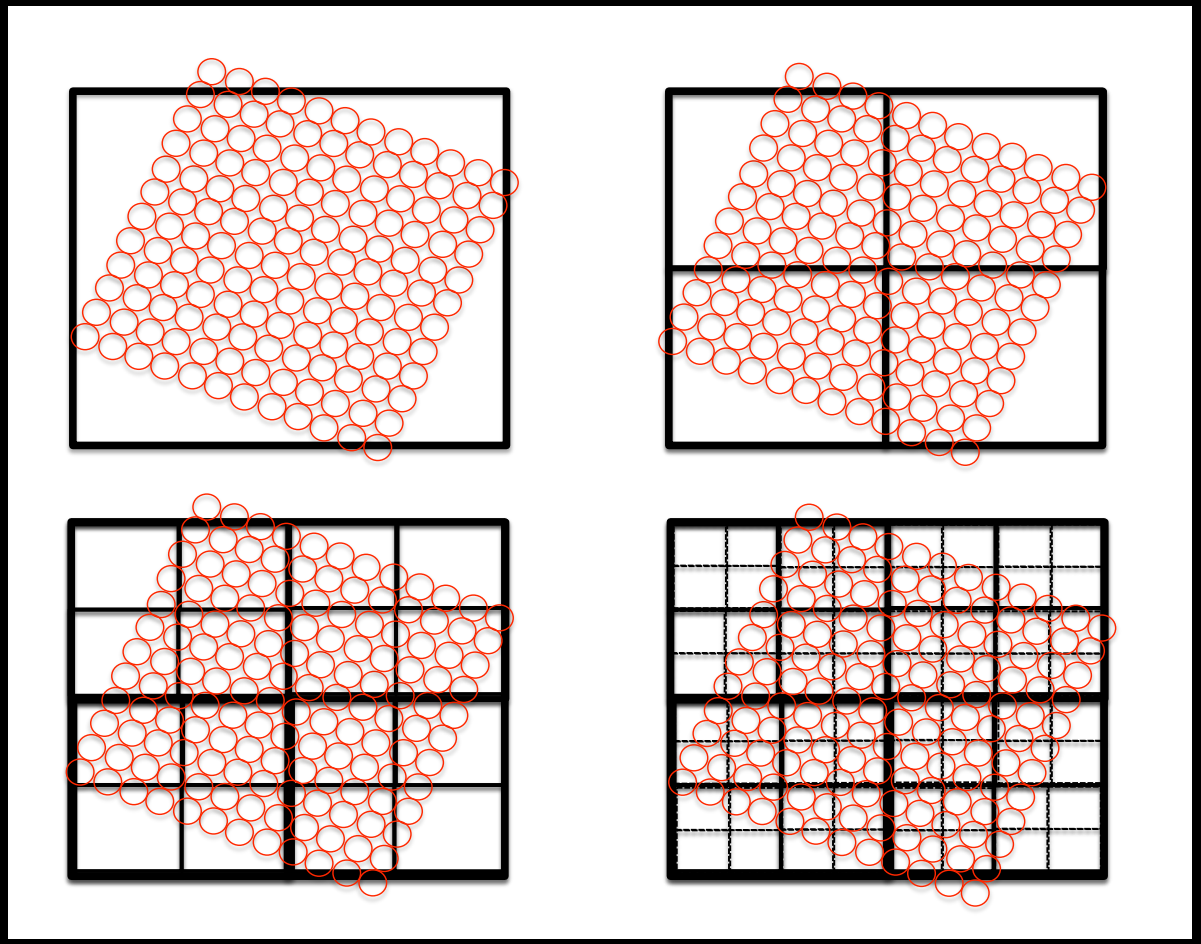
Figure 2. Climate response of temperature to CO_2 forcing obtained from experiments with different representations of small scale fluctuations.

Seiffert and von Storch (2008), *GRL*

Variance Scaling Research Thrusts

- **Scale dependence of temperature & water vapor variance**
  - Satellite observations: Atmospheric Infrared Sounder (AIRS)
  - Free-running climate models: NCAR CAM3 and GFDL C180HIRAM2.1
  - Models with data assimilation: ECMWF (YOTC) and MERRA
  - Cloud-resolving model: Multi-scale Modeling Framework (MMF)
  - Aircraft observations: VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS)
- **Implications for future satellite observations of temperature & water vapor**

“Poor Man’s” Power Spectral Analysis



Variance scaling exponents of 1.0, 0.5 and 0.33 ≅ –3, –2, and –5/3, respectively

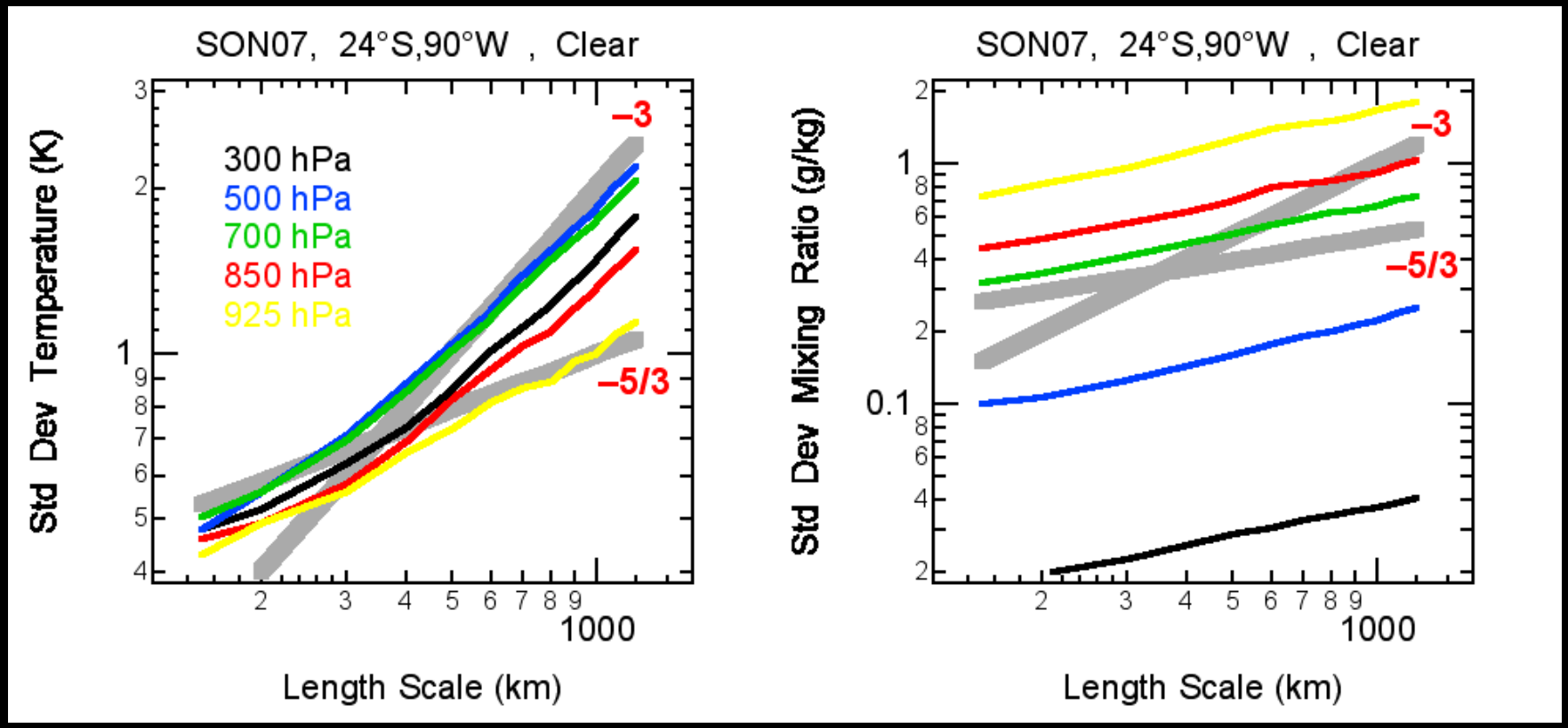
Daily ‘snapshots’ averaged to season

Variance calculated for 1.5, 2.0, 3.0, 4.0, 6.0 and 12.0° boxes

Results for “clear-ish” skies only: ECF < 0.1 for AIRS and CF < 0.5 in models

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

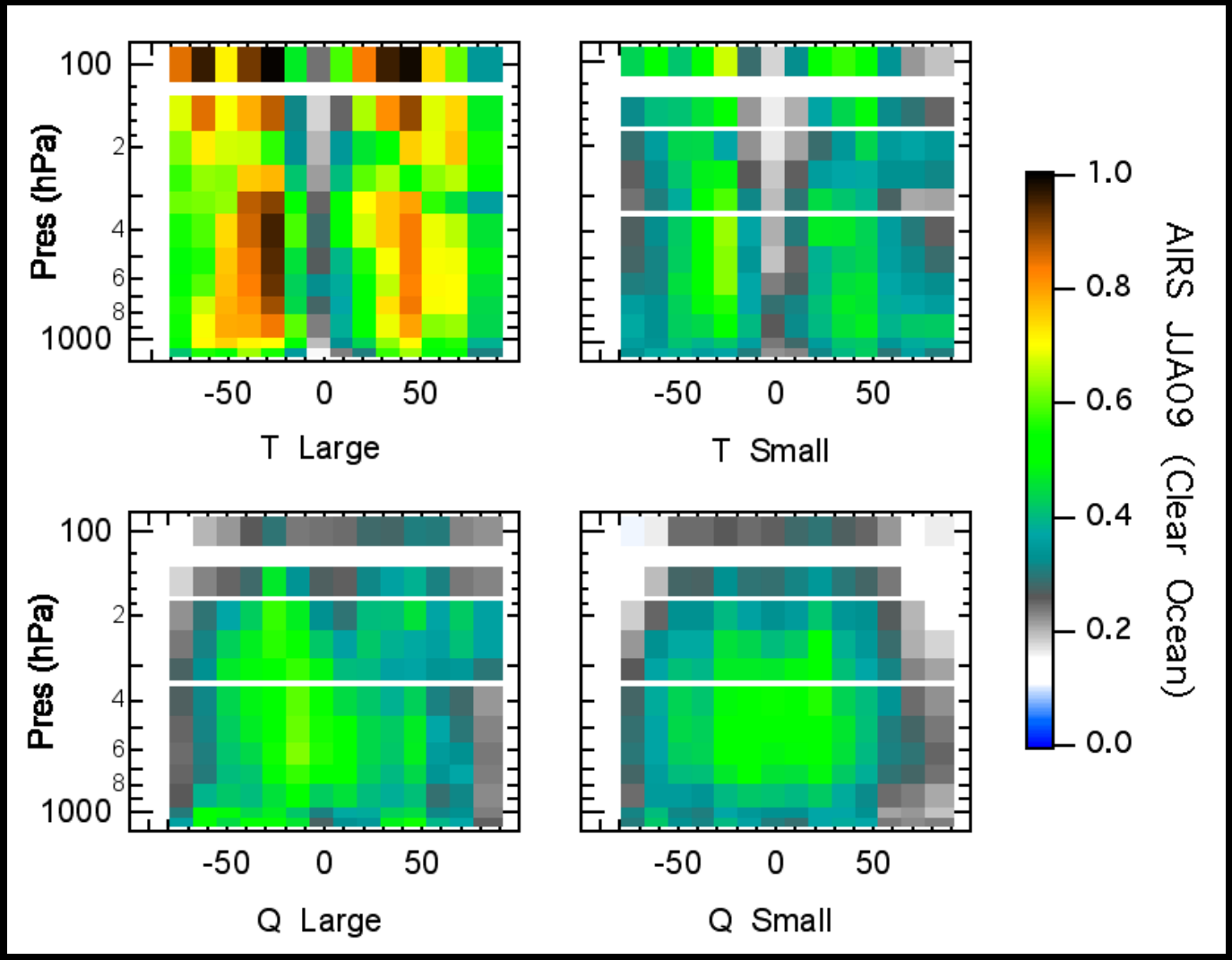
Scaling exponents & breaks observed with AIRS



Variance scaling/structure function exponents: 1.0, 0.5 and 0.33 ≅ –3, –2, and –5/3, respectively

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

Mesoscale break for *T* – not for *Q* – in AIRS



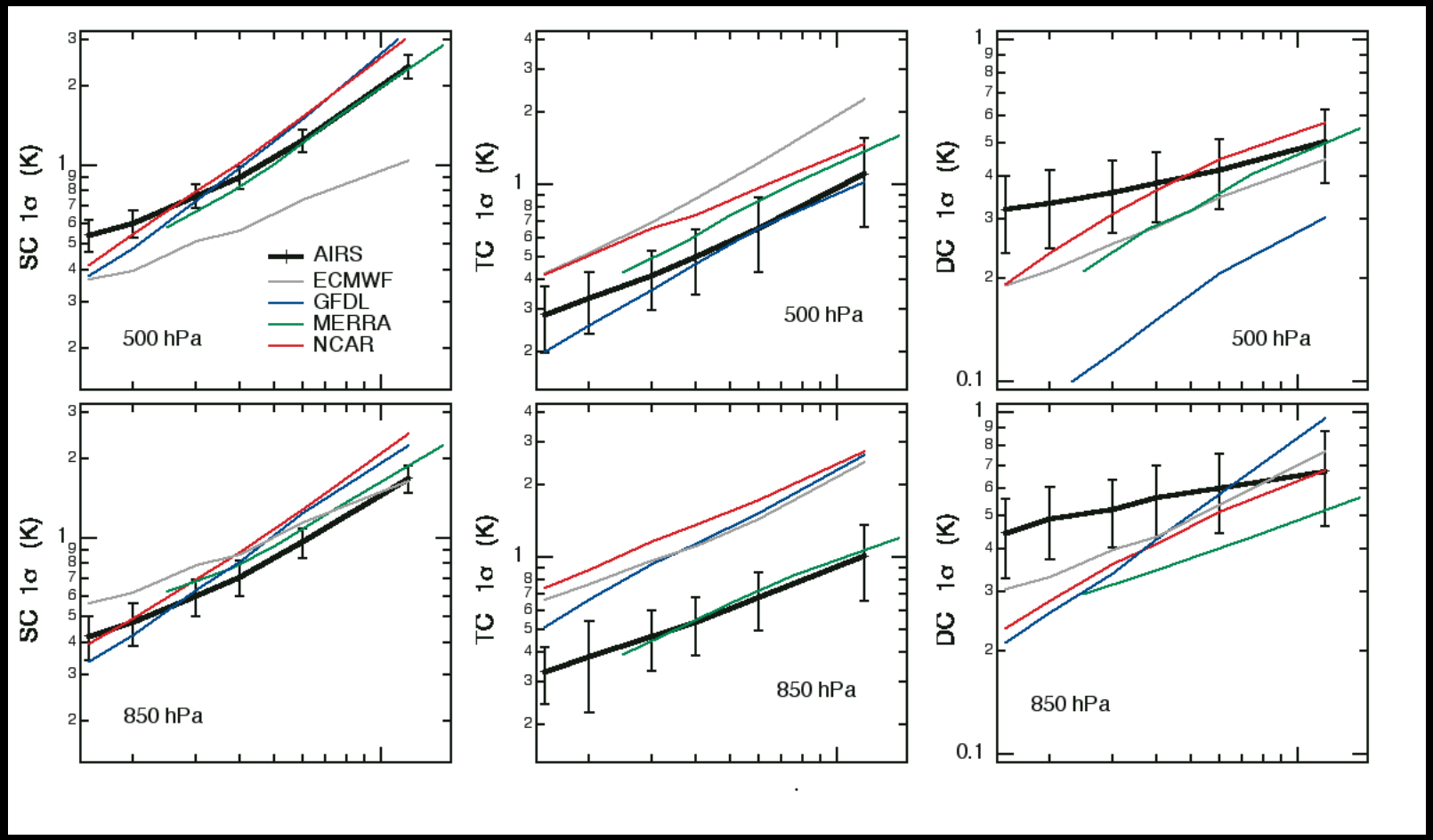
Kahn and Teixeira (2009), *J. Climate*

Models Used in this Comparison

Model	Resolution	Data assimilation?	Simulation Period
GFDL C180HIRAM2.1	0.5° × 0.625°	NO	01 September 1995 – 30 November 1995
NCAR CAM3	0.31° × 0.23°	NO	01 June 2005 – 31 August 2005
ECMWF (YOTC)	0.5° × 0.5°	YES	01 June 2009 – 31 August 2009
MERRA	1.25° × 1.25°	YES	01 June 2009 – 31 August 2009
SP-CAM	2.5° × 2.0° Embedded 2D CRM with 64 columns of 4 km resolution	NO	01 September – 30 November for the years 1998–2001

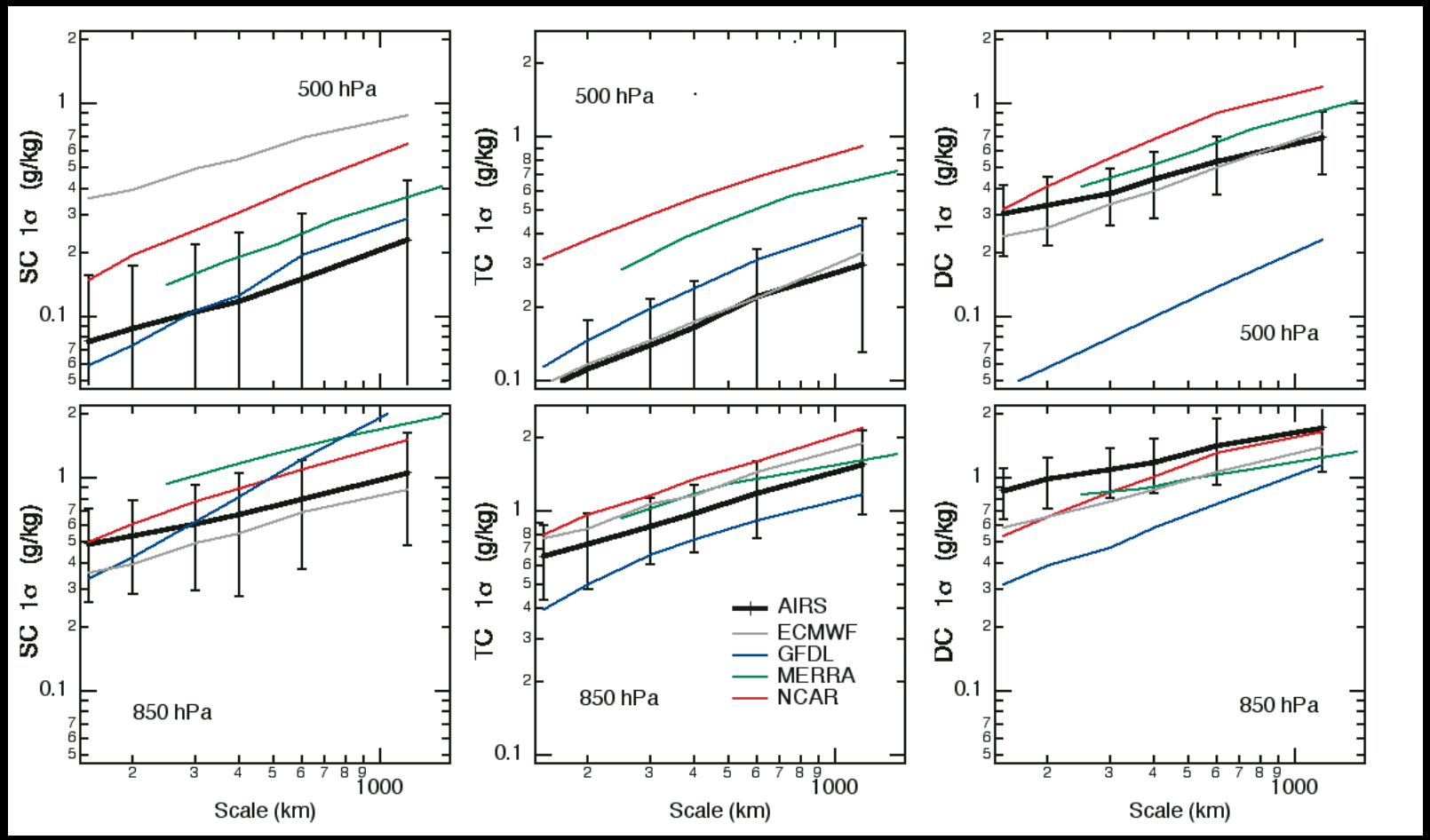
Kahn et al. (2011), *J. Atmos. Sci.* (in press)

Model *T* variance too steep & no break



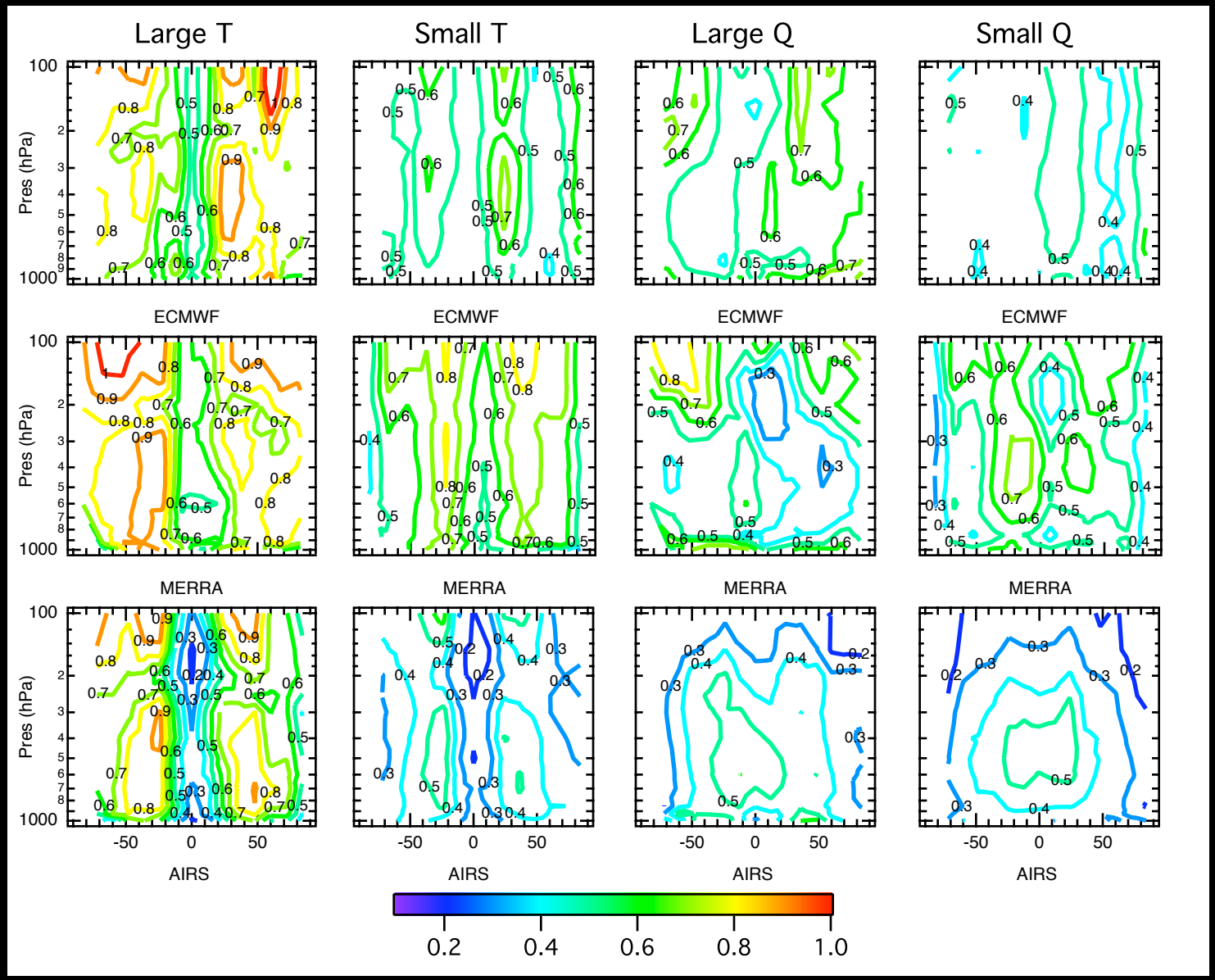
Kahn et al. (2011), *J. Atmos. Sci.* (in press)

Model *q* variance too steep but closer than *T*



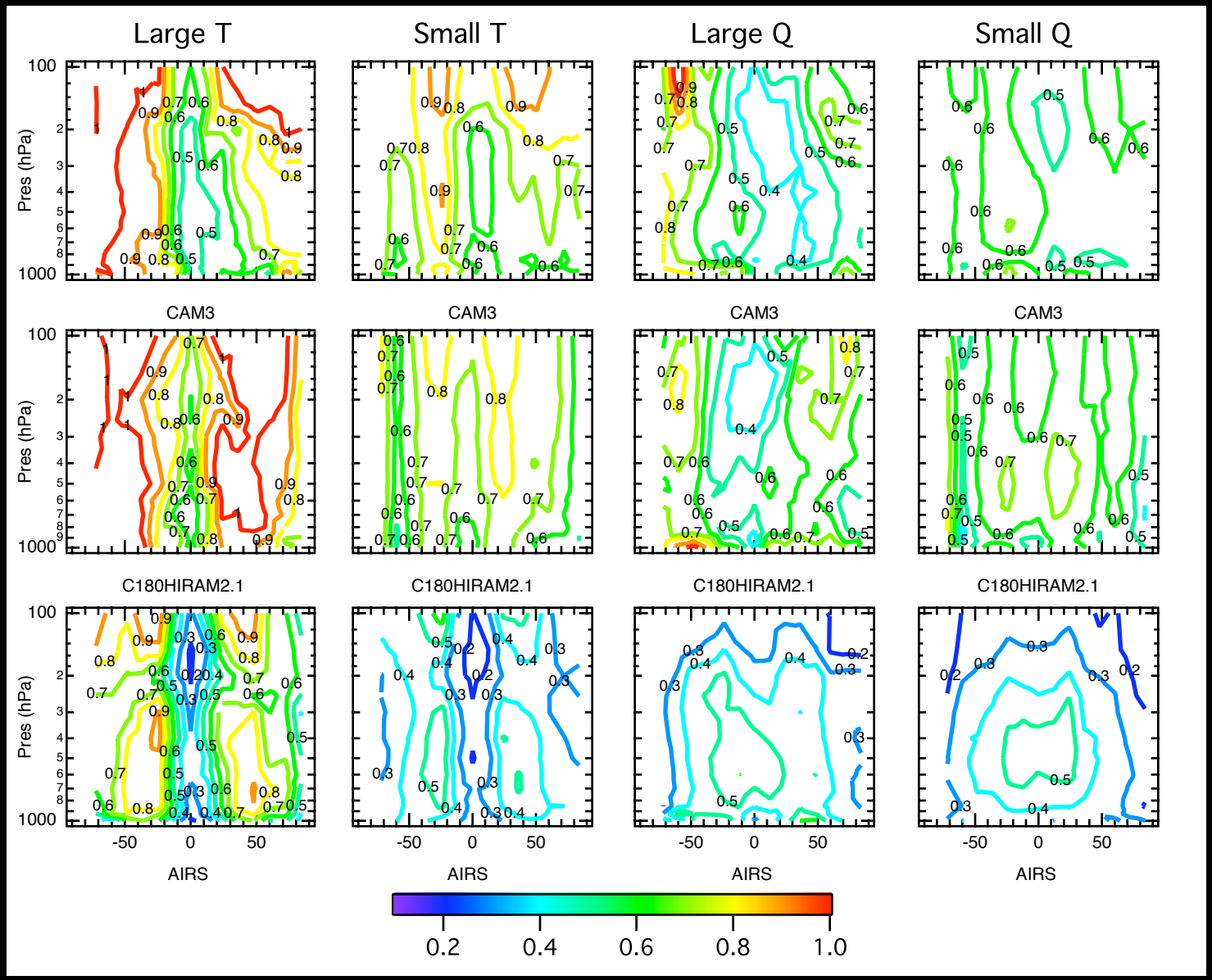
Kahn et al. (2011), *J. Atmos. Sci.* (in press)

Models with data assimilation closer to AIRS



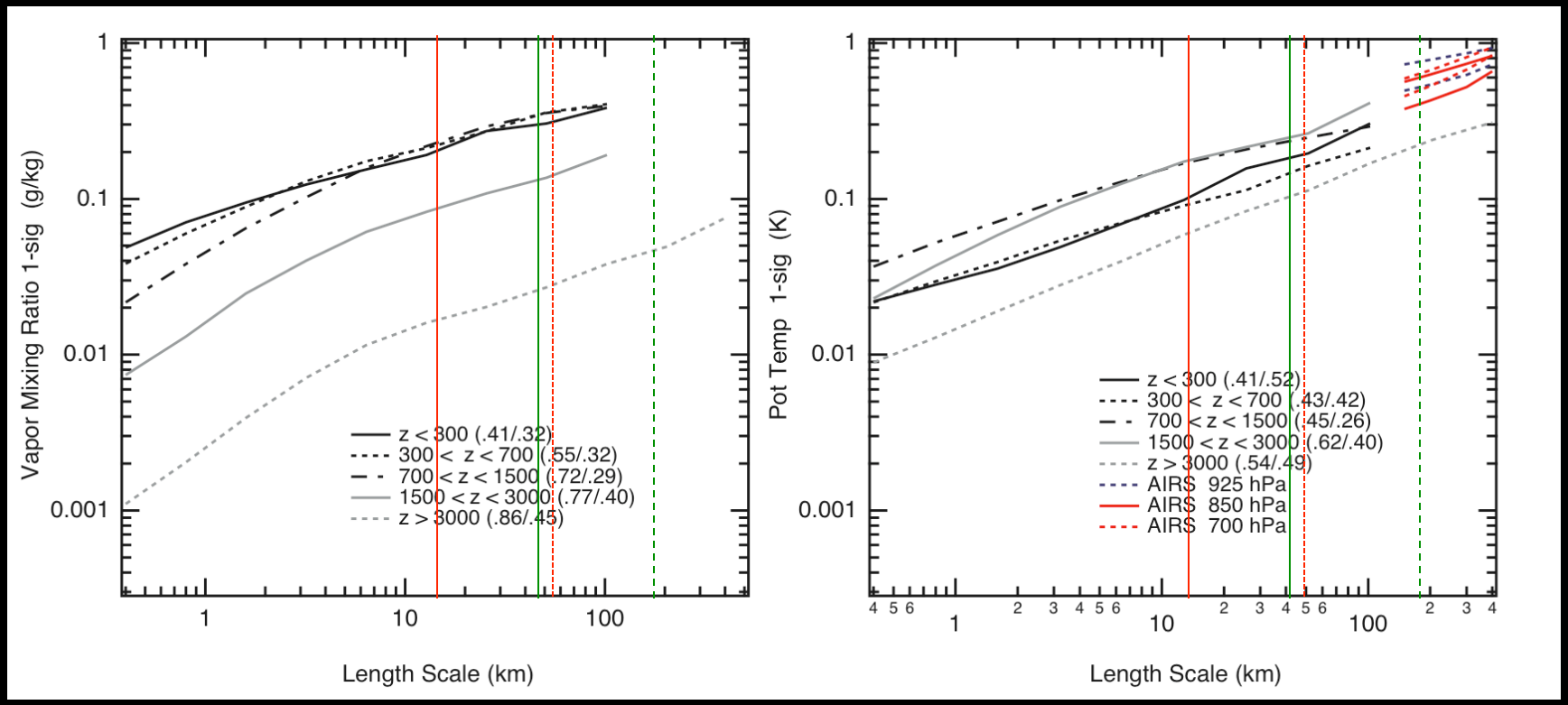
Kahn et al. (2011), *J. Atmos. Sci.* (in press)

“Free-running” models further away from AIRS



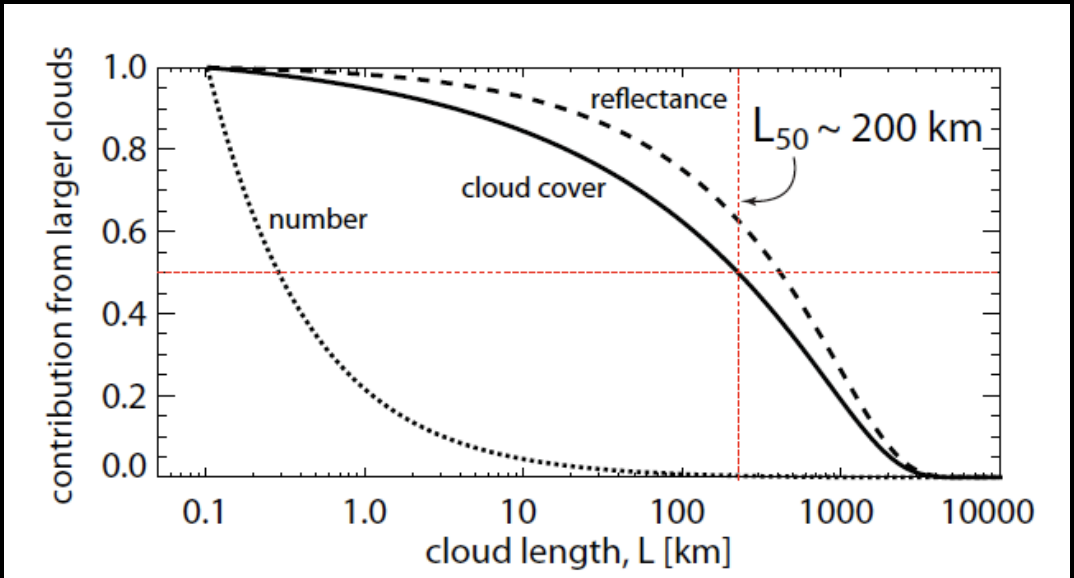
Kahn et al. (2011), *J. Atmos. Sci.* (in press)

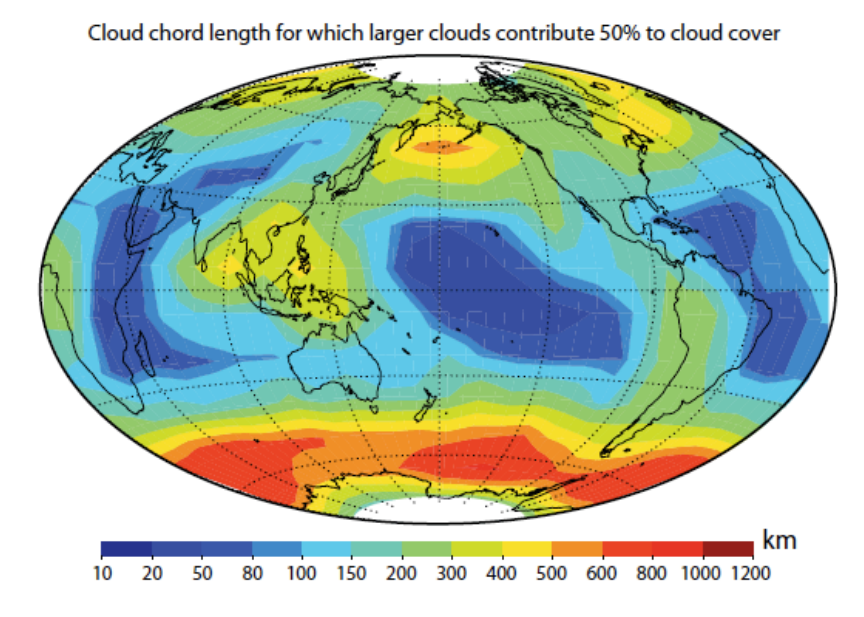
VOCALS-Rex Scaling Breaks in *T* and *q*



Kahn et al. (2011), *J. Atmos. Sci.* (in press)

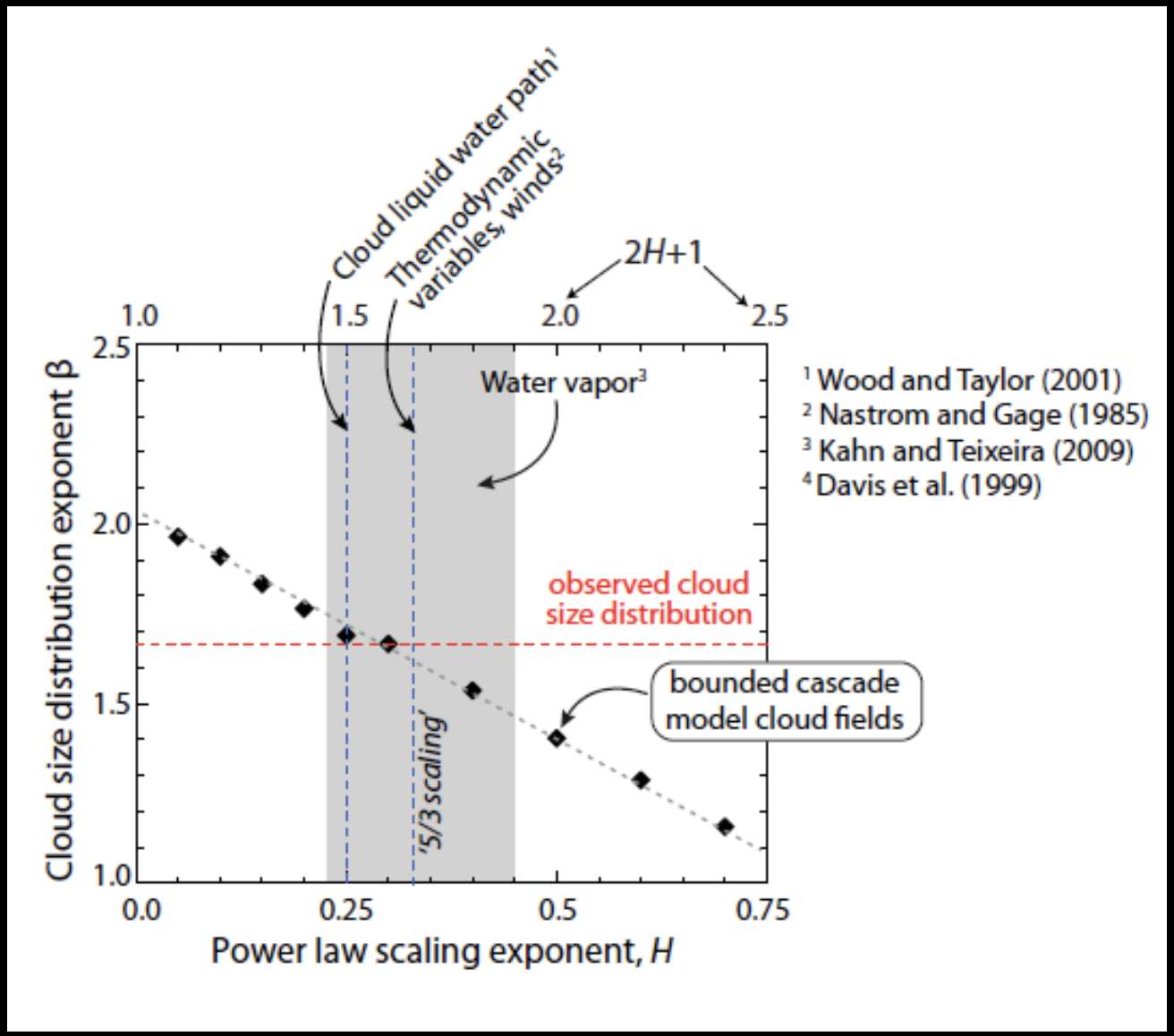
Scaling relationships between clouds and q





Wood and Field (2011), *in review.*

Scaling of cloud size and q inversely related



Wood and Field (2011), *in review.*

Take Home Messages

- **AIRS scaling reveals lots of structure in *T* and *q***

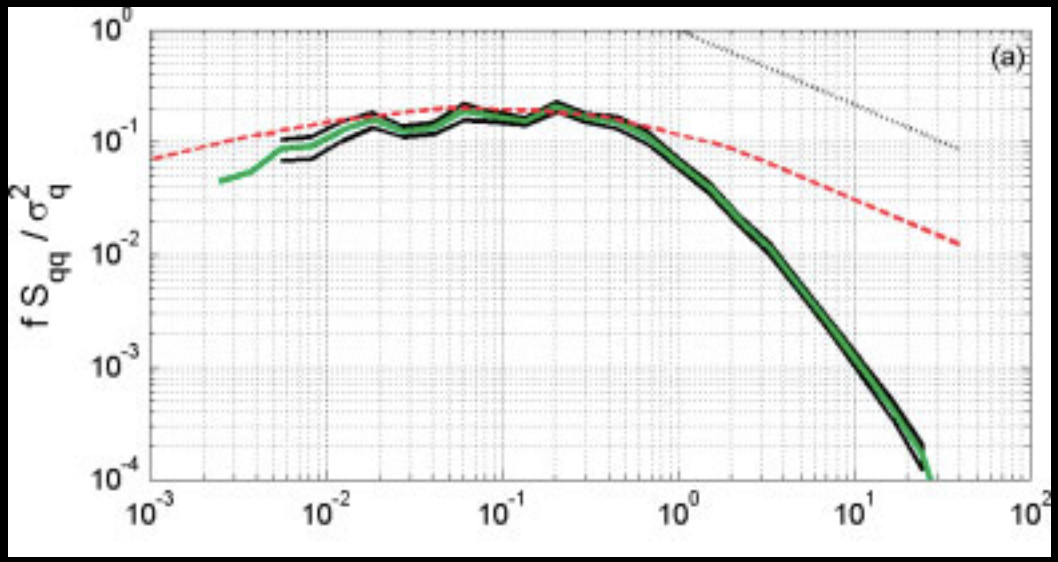
- **Comparisons of AIRS to Models**
  - All models have scaling exponents that are too steep
  - "Free-running" model exponents > those with "data assimilation"

- **Scale breaks at scales below AIRS in models and obs**
  - VOCALS T and q have increasing slopes < 10–20 km around scales of Sc
  - Scale changes for potential temperature and water vapor in TCs
  - Strong connection of cloud and q variability – not two independent problems

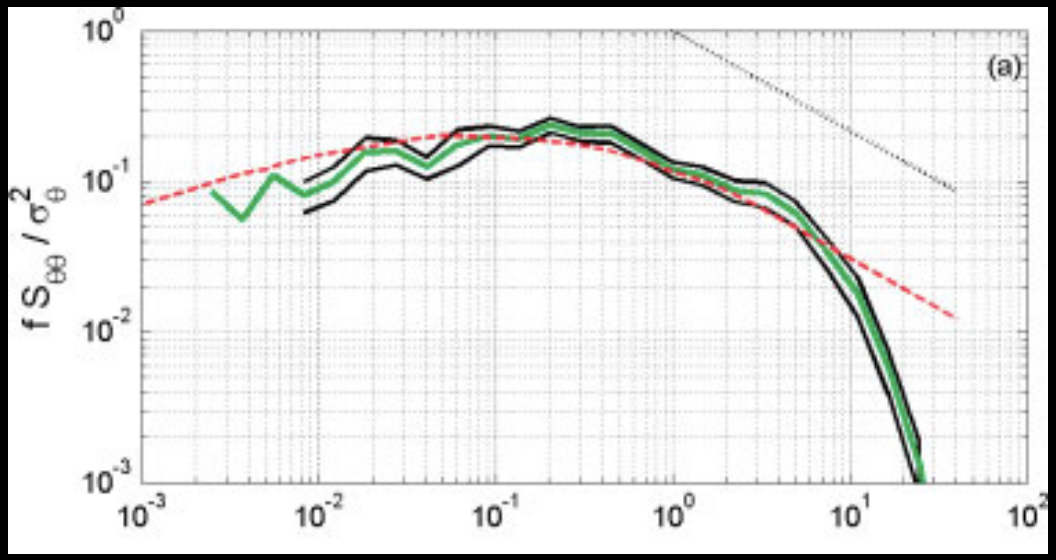
- **Need higher spatial resolution sat obs – not planned for NPP/JPSS era**
  - Scale-dependent variability – is the "turbulence" right in climate models?
  - Importance of subgrid-scale variability in modeling
  - Critical role for in situ aircraft and surface observations

Back-Up Slides

Scale breaks in tropical cyclones



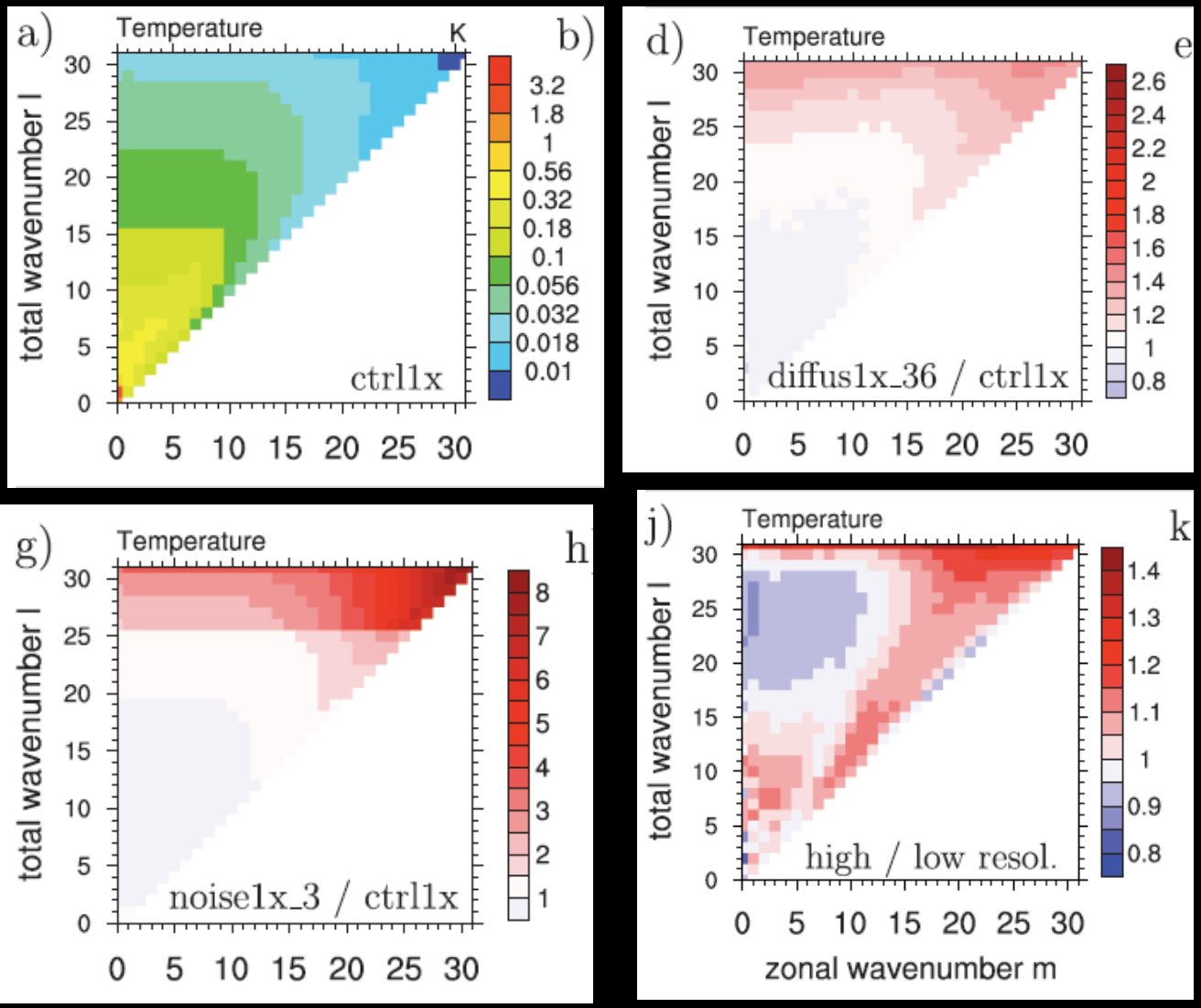
Water vapor scaling



Potential temperature scaling

Zhang (2010), *Q. J. Royal Met. Soc.*

Scale-dependent variance in ECHAM5 temperature



Seiffert and von Storch (2008), *GRL*