PDFS of Tropospheric Humidity: Measurements and theory

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Outline

- Introduction

- Examine Observed of Tropical and Subtropical Humidity (AIRS + MLS measurements).

- Theory for PDFs of Relative Humidity (RH)

- Analysis of climate model (very preliminary).

OBSERVATIONS

Examine Probability Distribution Functions (PDFs) of Relative Humidity (RH) measurements from sateliite instruments:

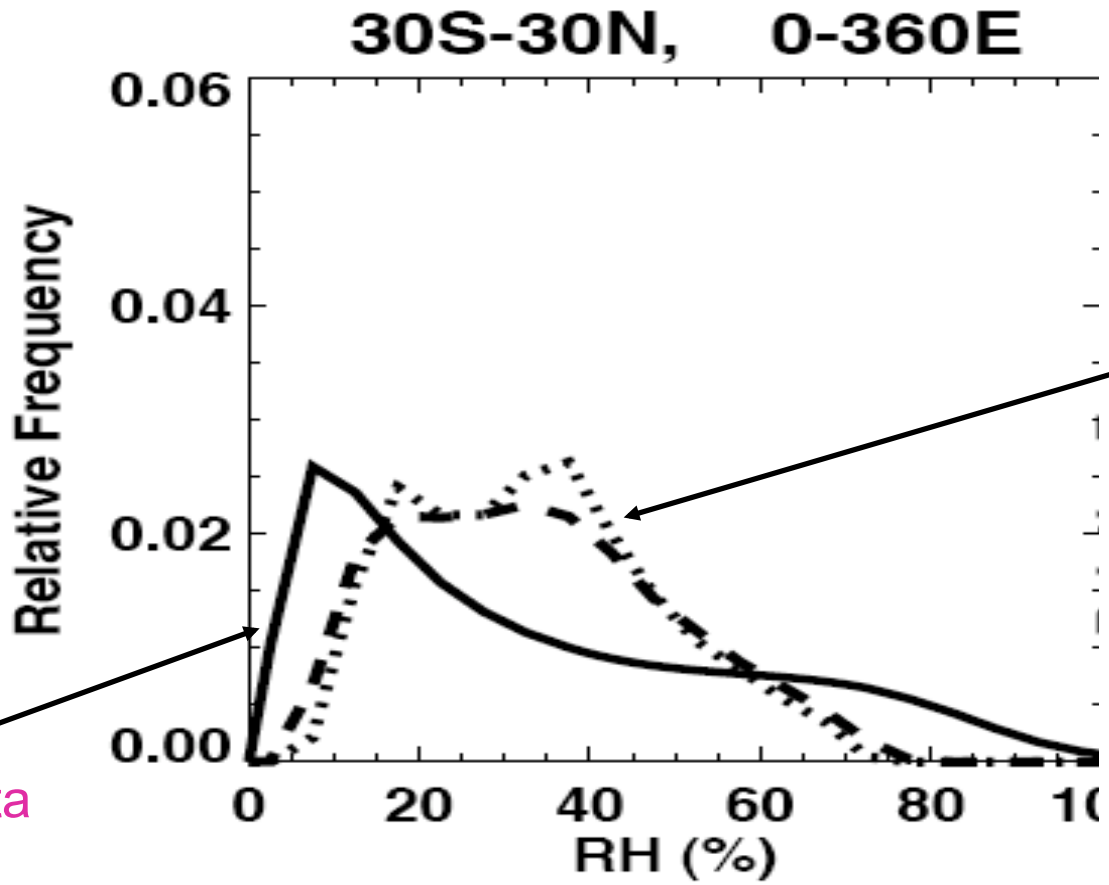
- AIRS (2002-2007)
- Aura MLS (2004-2007)
- UARS MLS (1992-2994)

Focus on PDFs for
10^{o} latitude x 20^{o} longitude regions
NH winter (Dec-Mar).

Probability Distribution Functions

PDFs depend on the space and time scales considered. E.g.,

AIRS RH
400hPa
1°x1°
DJF
2002-2007



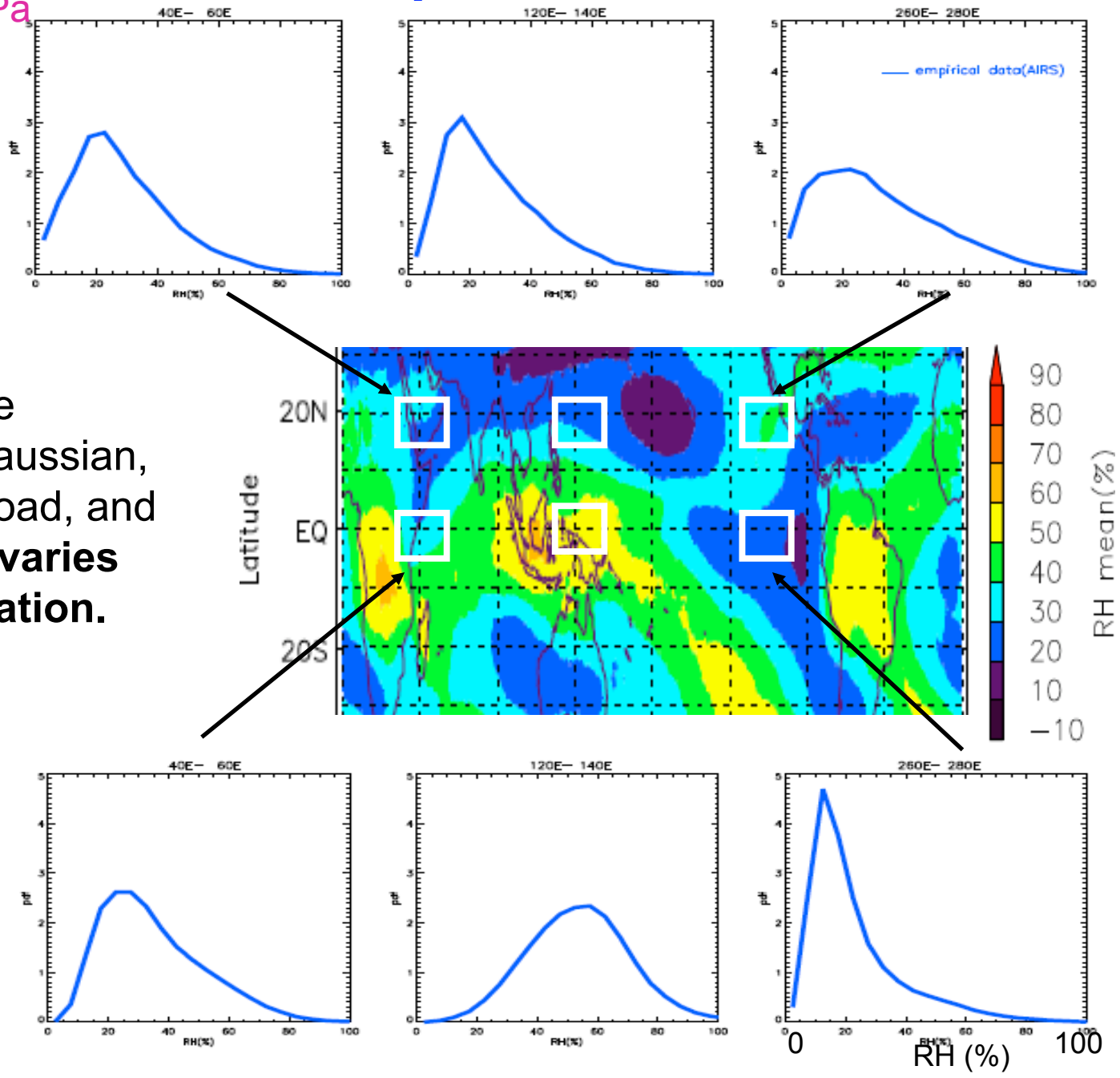
Monthy-Mean Data

Daily Data

We focus on **daily data** … extremes important for radiative considerations.

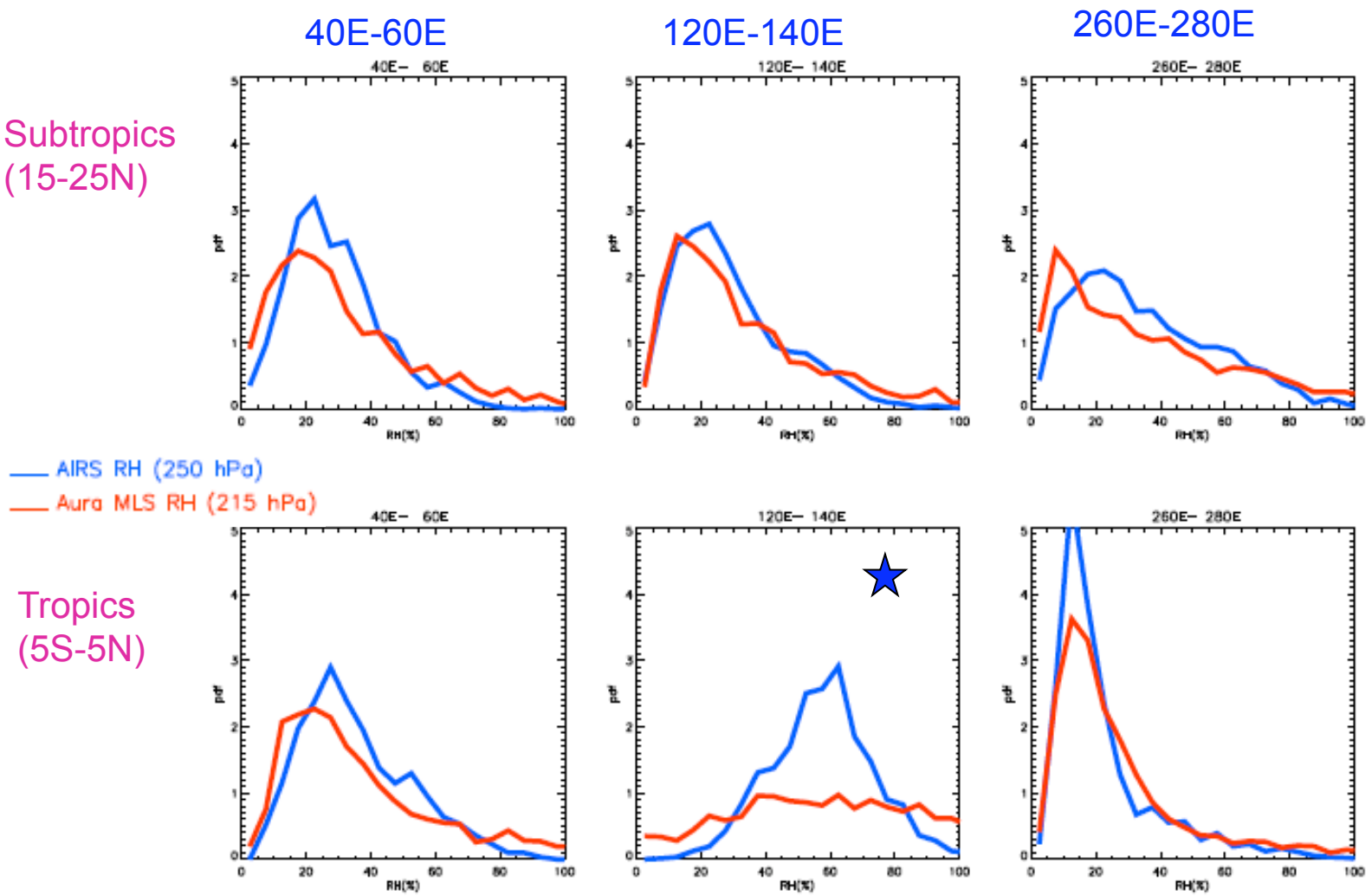
AIRS RH
200-250hPa

PDFs: Spatial Variations



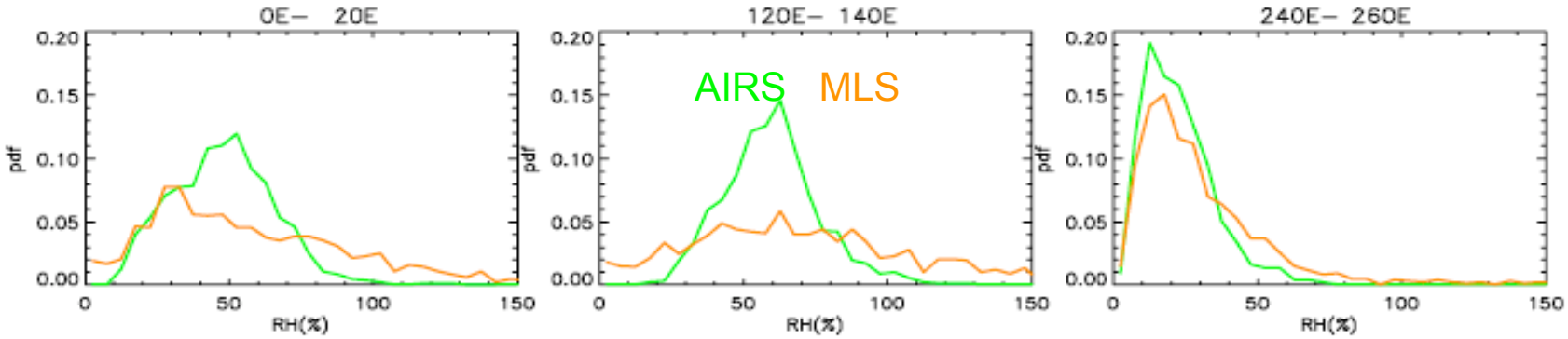
PDFs are
- non=Gaussian,
- very broad, and
- **shape varies with location.**

PDFS: AIRS - Aura MLS Comparison



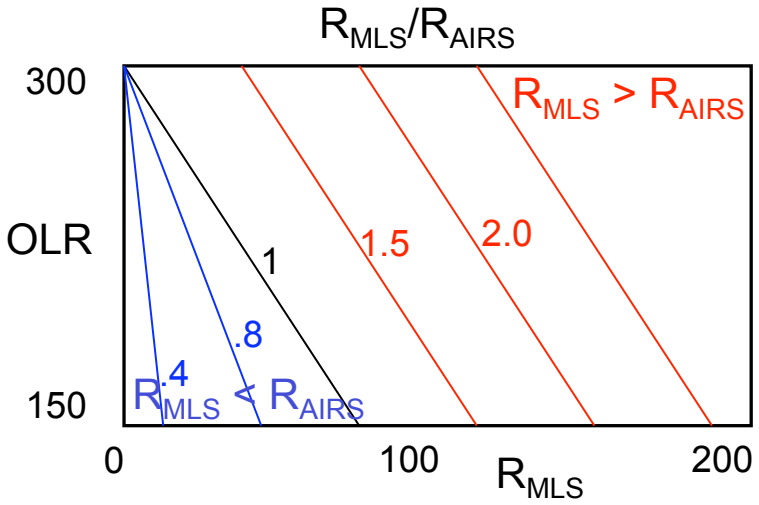
Good agreement between AIRS and Aura MLS, with some exceptions.

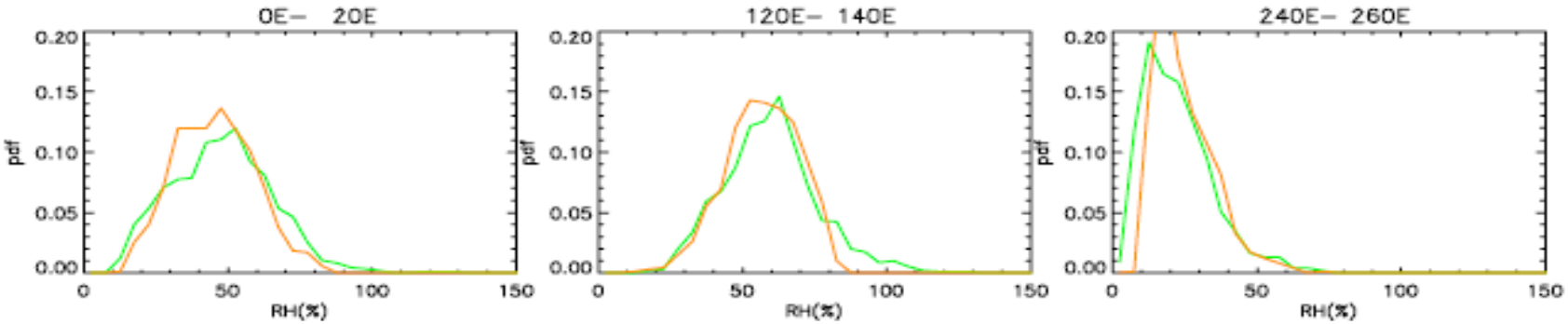
Aura MLS - AIRS bias



Transform MLS Data

$R_{MLS}/R_{AIRS} = f(R_{MLS}, OLR)$





Theoretical Model

Generalization of Sherwood et al (J. Clim, 2006) model for PDFs of Relative Humidity (R). Based on "time since last saturation" paradigm: Parcel's humidity = lowest saturation value experienced.
Two main assumptions:

1. Uniform subsidence between remoistening events.

$$R(t) \approx exp\left(-\frac{t}{\tau_{Dry}}\right)$$

τ_{Dry} is drying time by subsidence,
t is time since last saturation.

2. Random remoistening events models as Poisson process:
   PDF of time since last saturation is

$$P(t) = \frac{\left(\frac{1}{\tau_{Moist}}\right)^k exp\left(-\frac{t}{\tau_{Moist}}\right) t^{k-1}}{\Gamma(k)}$$

τ_{Moist} is mean time between remoistening events.

k is a measure of variability of moistening events (larger *k* => less random).

k=1 is Sherwood et al (2006) model.

Generalized Model for PDFs

Combining 1 and 2 yields PDF for Relative Humidity:

$$P(R) = \left(\frac{r^k R^{r-1}}{\Gamma(k)}\right)(-logR)^{k-1}$$

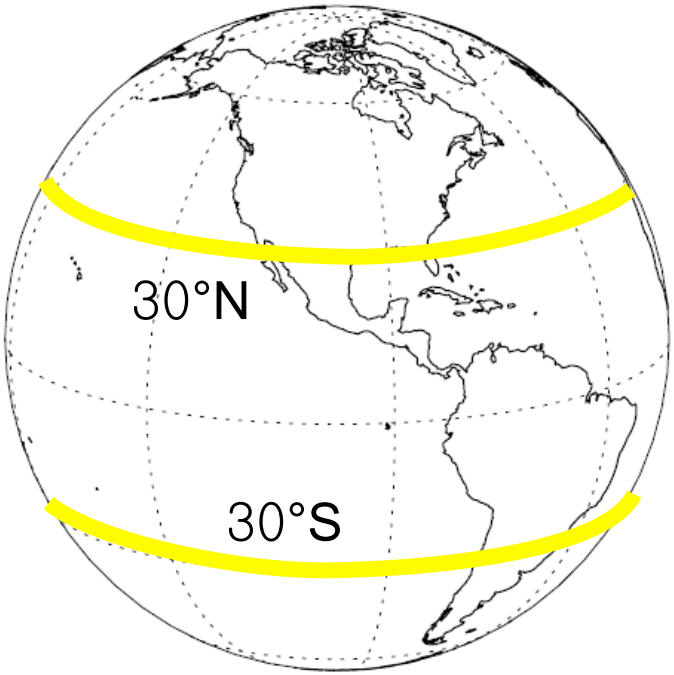
$r = \tau_{dry} / \tau_{moist}$

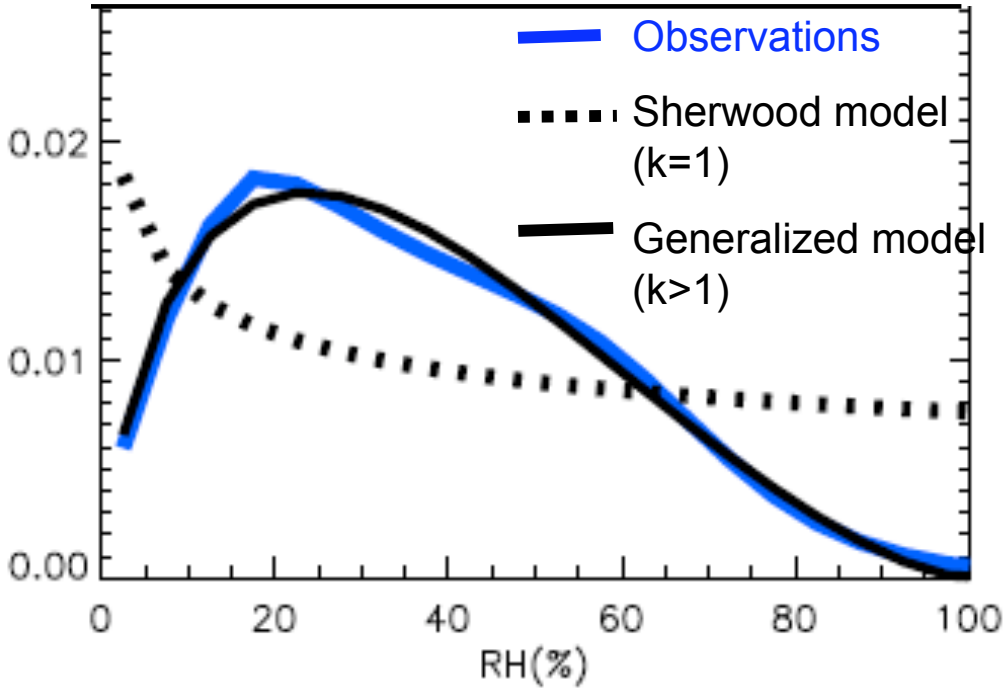
k=1 is original Sherwood et al. model.

- Larger r implies more rapid remoistening
- Larger k implies less random remoistening processes.

Comparison with Data

The Generalized model can reproduce AIRS 250hPa PDF for whole tropics (30S-30N).

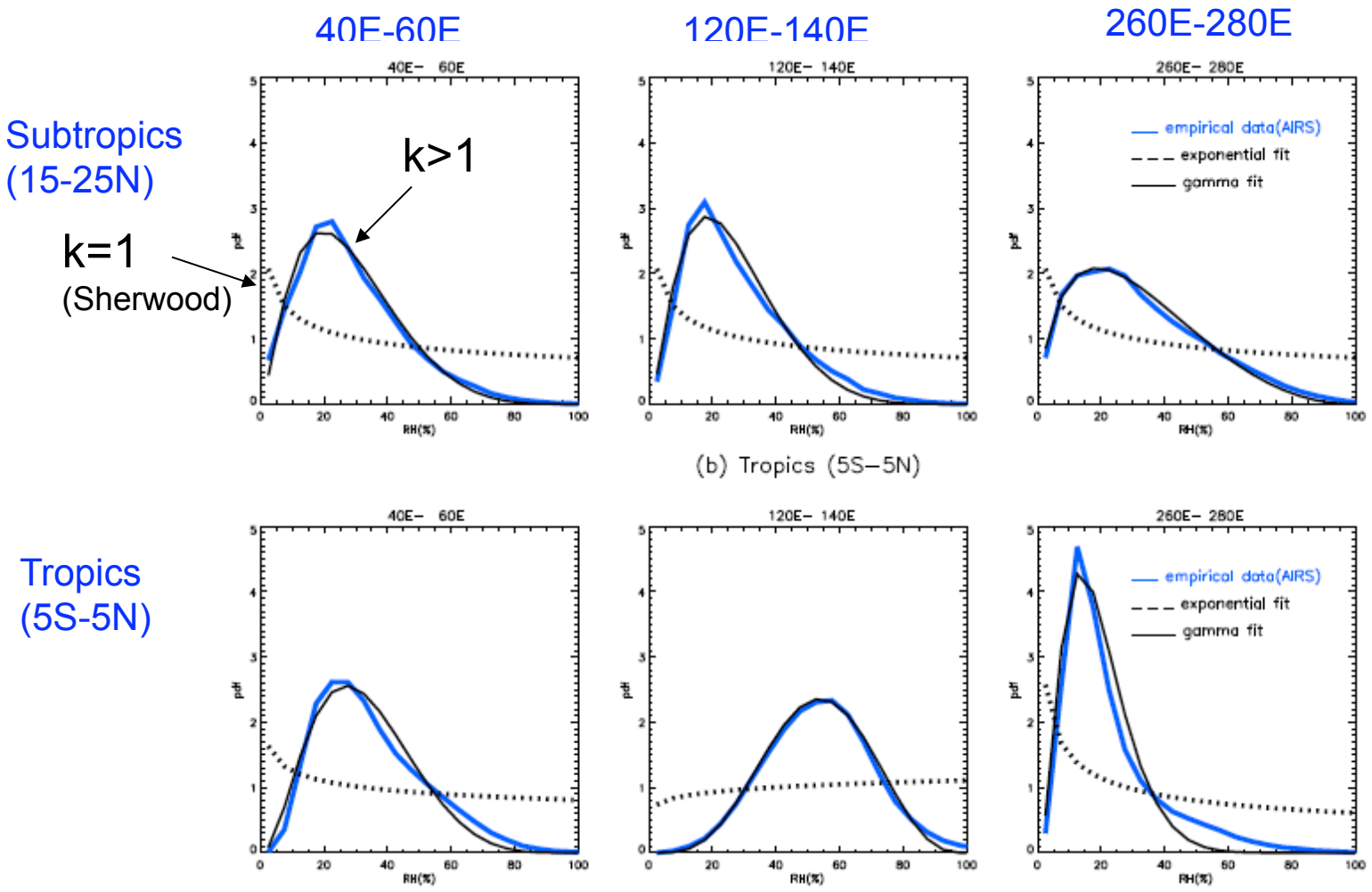




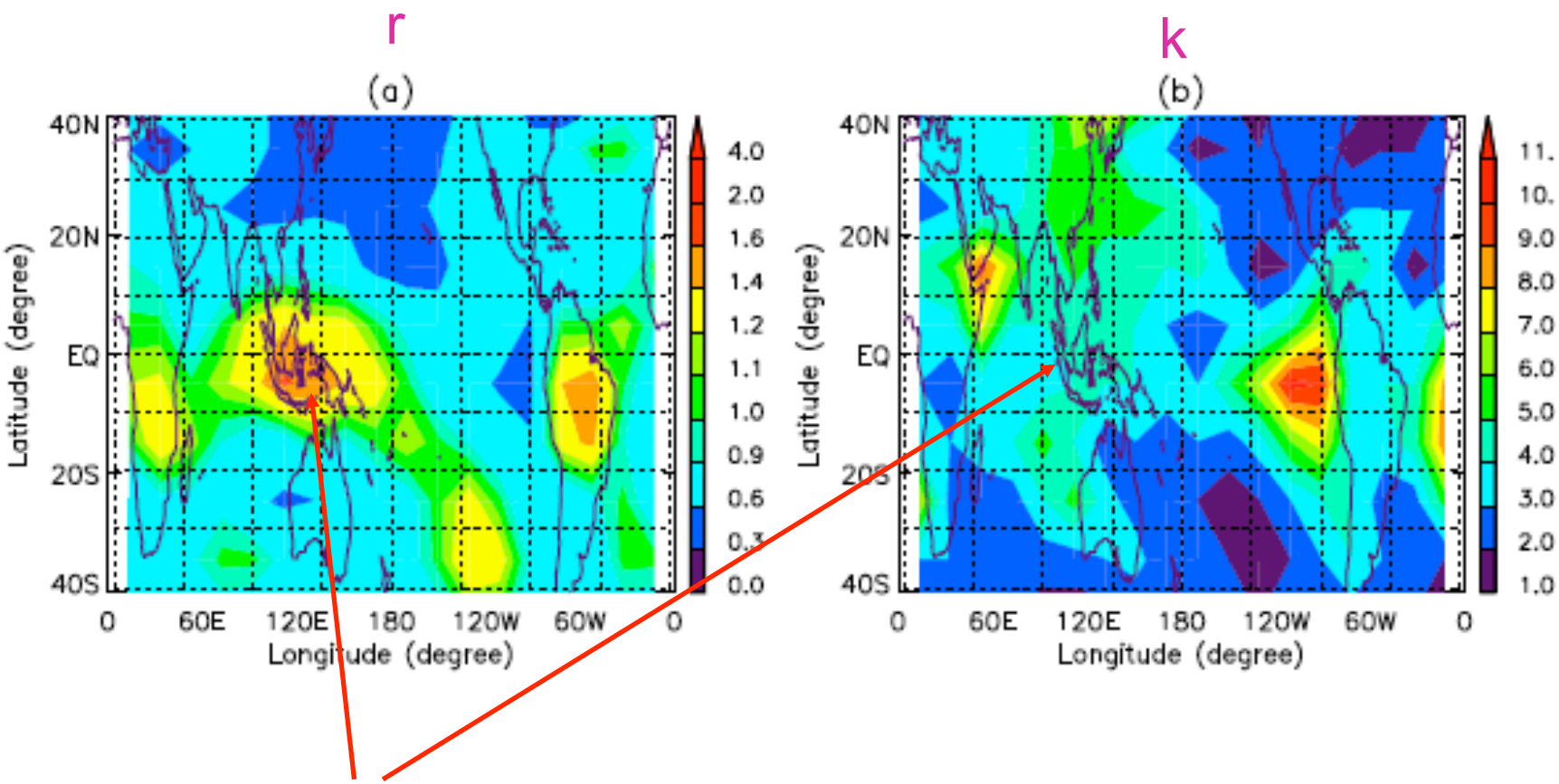
What about subregions?

Comparison with Data II

Generalized Model can also fit the observed PDFs for all $10^o x 20^o$ regions, with r and k varying with location.



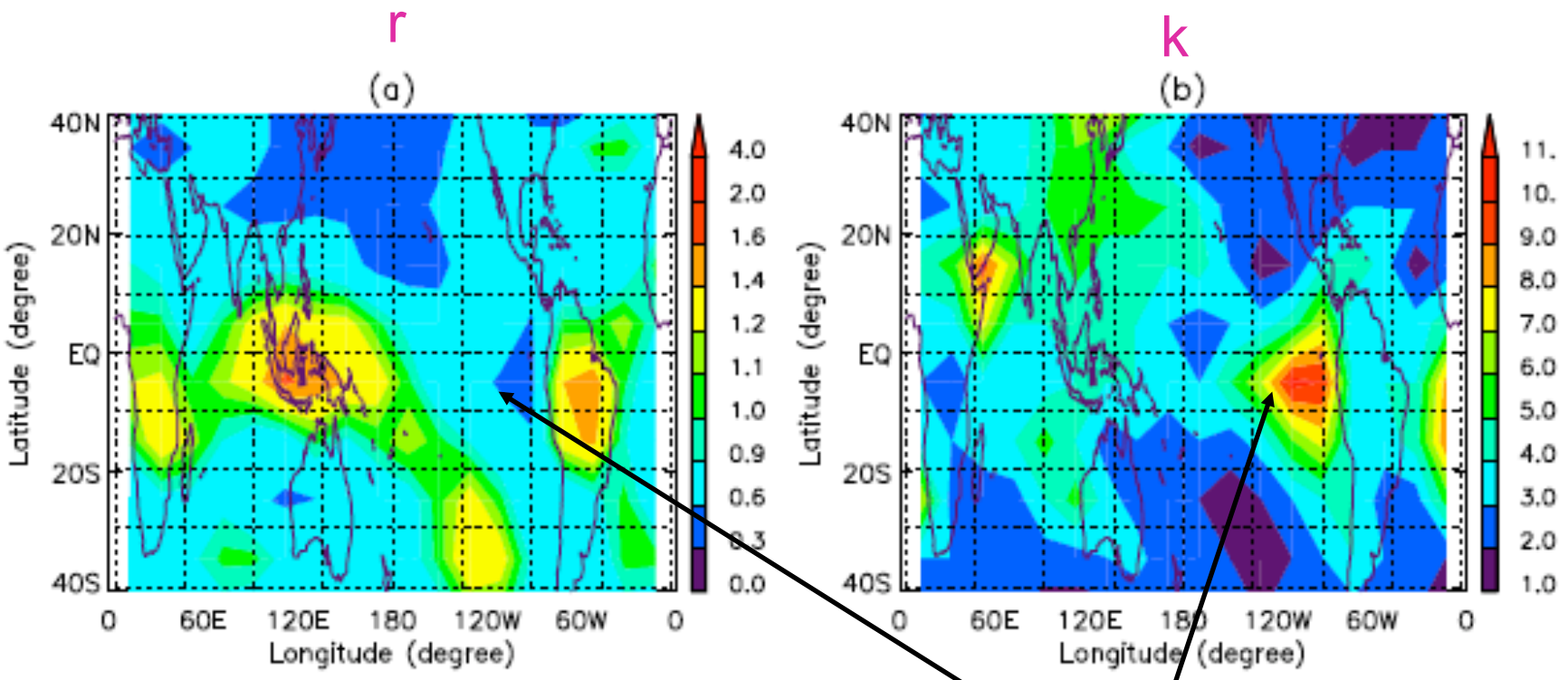
Spatial Variations of r and k



Convective Regions:

- r>1 and low k
- Rapid, random remoistening
- Consistent with remoistening by rapid vertical mixing.

Maps of r and k



Convective Regions:

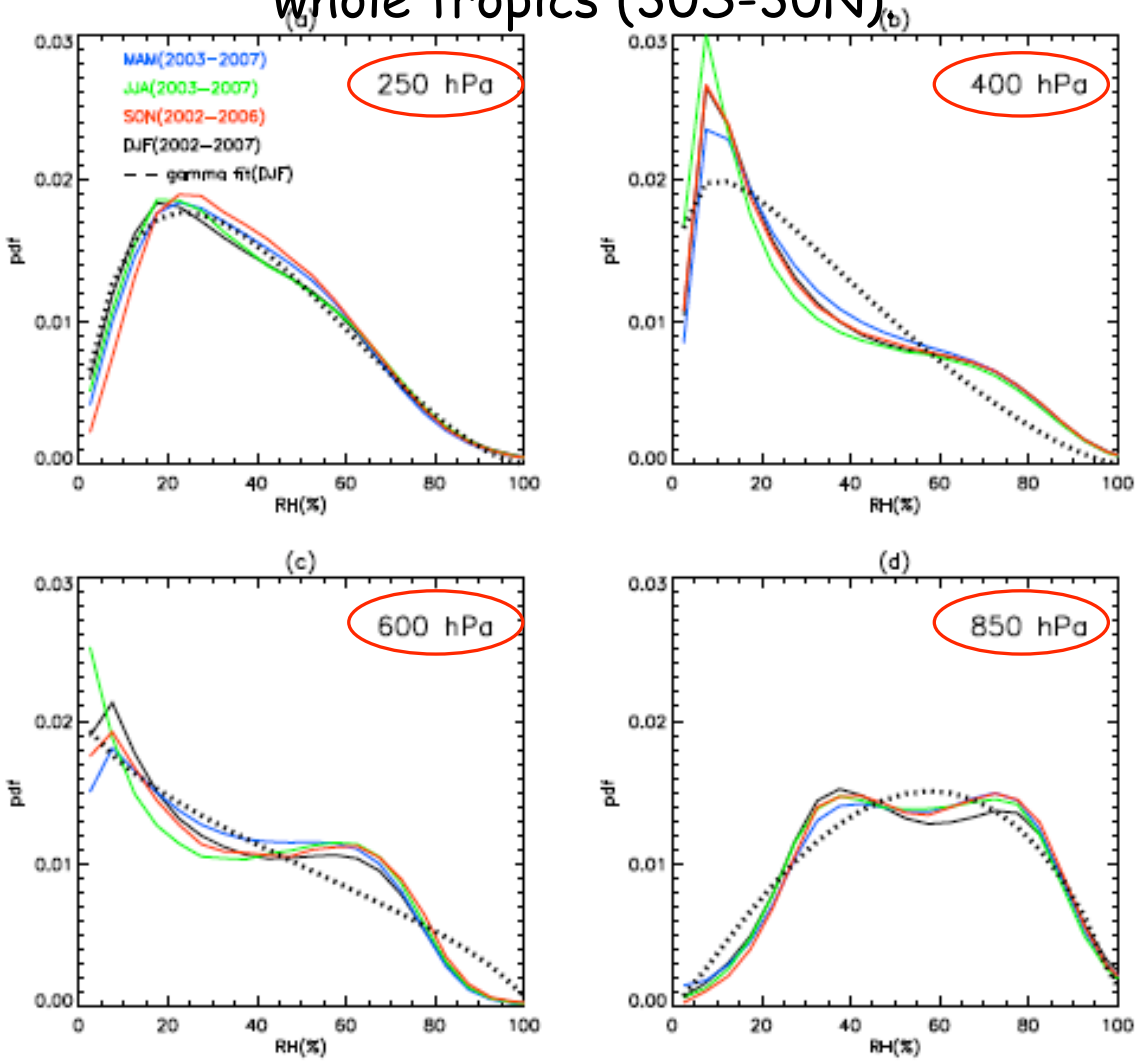
- r>1 and low k
- Rapid, random remoistening
- Consistent with remoistening by rapid vertical mixing.

Non-convective Regions:

- r<1 and high k
- Slower, more regular remoistening
- Consistent with remoistening by quasi-horizontal transport

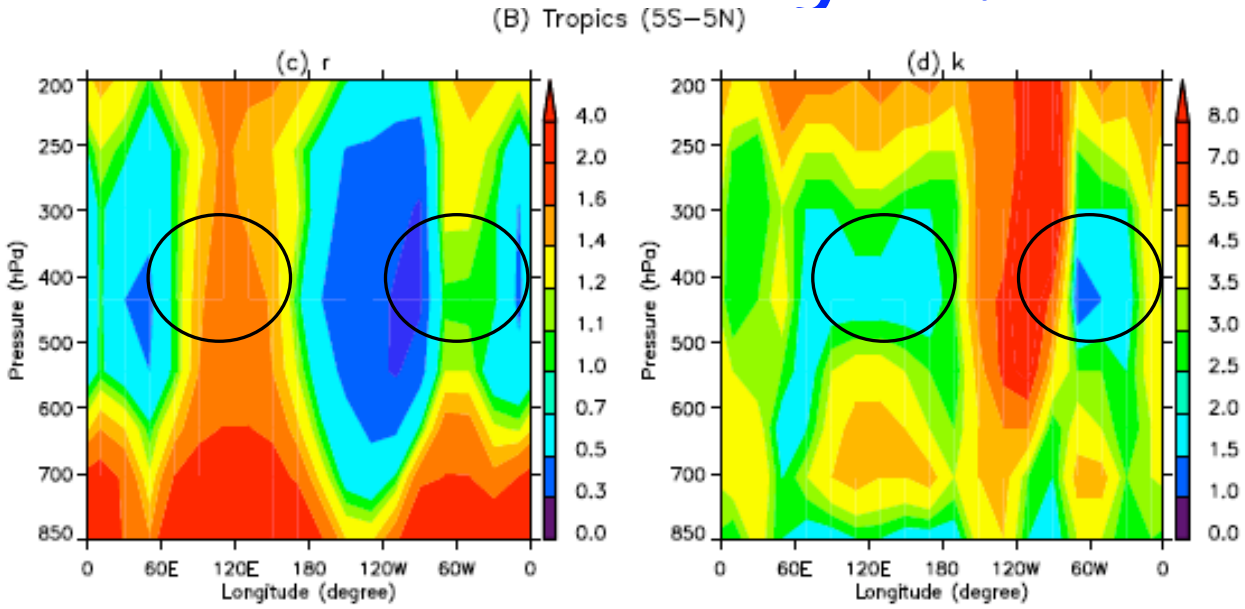
PDFs: Different Seasons and Altitudes

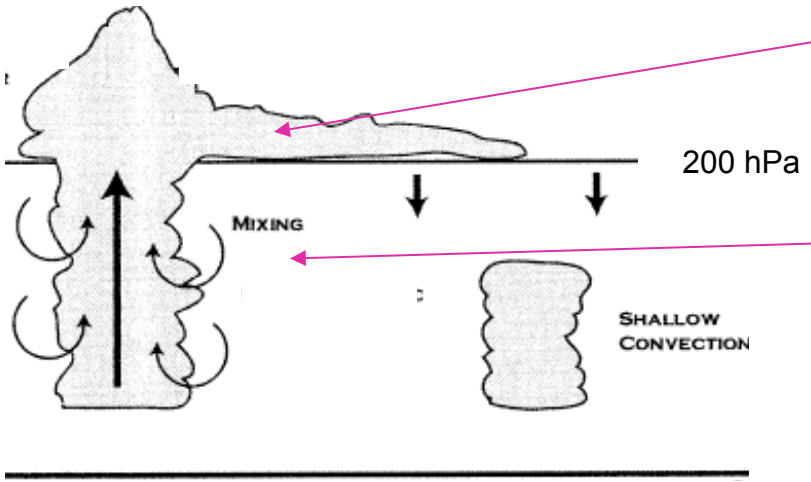
whole tropics (30S-30N)



- Only weak seasonal variations, but large vertical variations.
- PDFs for whole tropics are bimodal below 400hPa (but not in general for 10°x20° regions).
- Generalized model is unimodal, but still reasonable fit to observed PDFs.

Vertical Variation of r and k in convective regions.

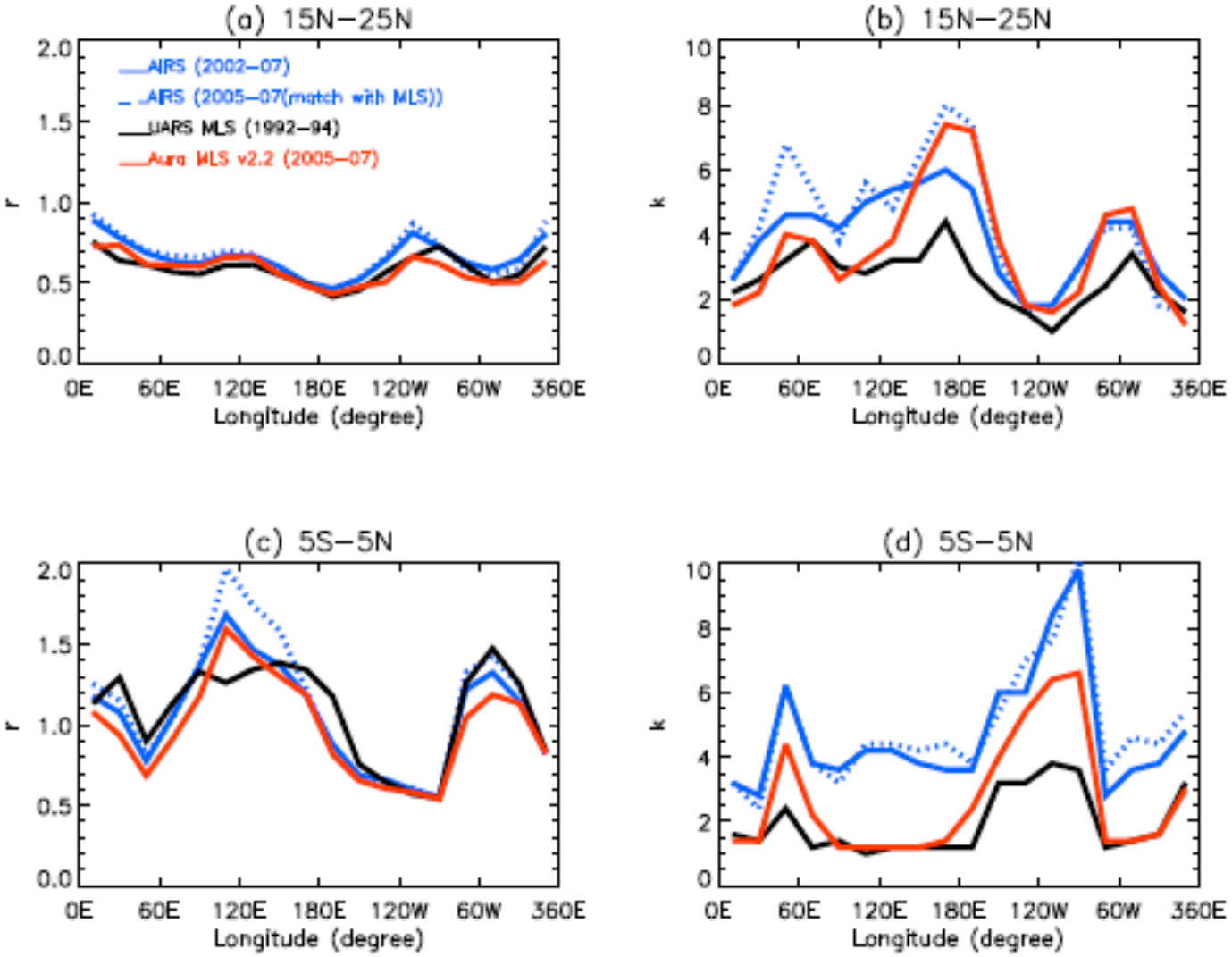




Strong detrainment (>200hPa)
-> large r, large k.

Weak detrainment, subsidence and mixing (~400hPa)
-> small r, small k.

r and k: AIRS - MLS



Conclusions

- PDFs of tropical and subtropical RH are non-Gaussian and very broad, with large spatial variations in characteristics of the PDFs.

- PDFs can be well fit by a generalized version of the Sherwood et al. (2006) theoretical model, with 2 parameters "r" (ratio of drying and moistening times) and "k" (variability of moistening process).

- Spatial variations in r and k can be related to variations in the physical processes controlling the RH distributions.

=> r and k provide a concise way to characterize the spatial variations in the PDFs and characteristics of processes controlling tropospheric RH.

Work in Progress

Compare PDFs from climate models with observations:
How well do they reproduce observations?
How do PDFs can with increased well-mixed GHGs?

Examine RH from the GEOS Chemistry-Climate Model (Pawson et al. 2008). Atmospheric only model (prescribed SSTs), with chemistry coupled to radiation/dynamics.

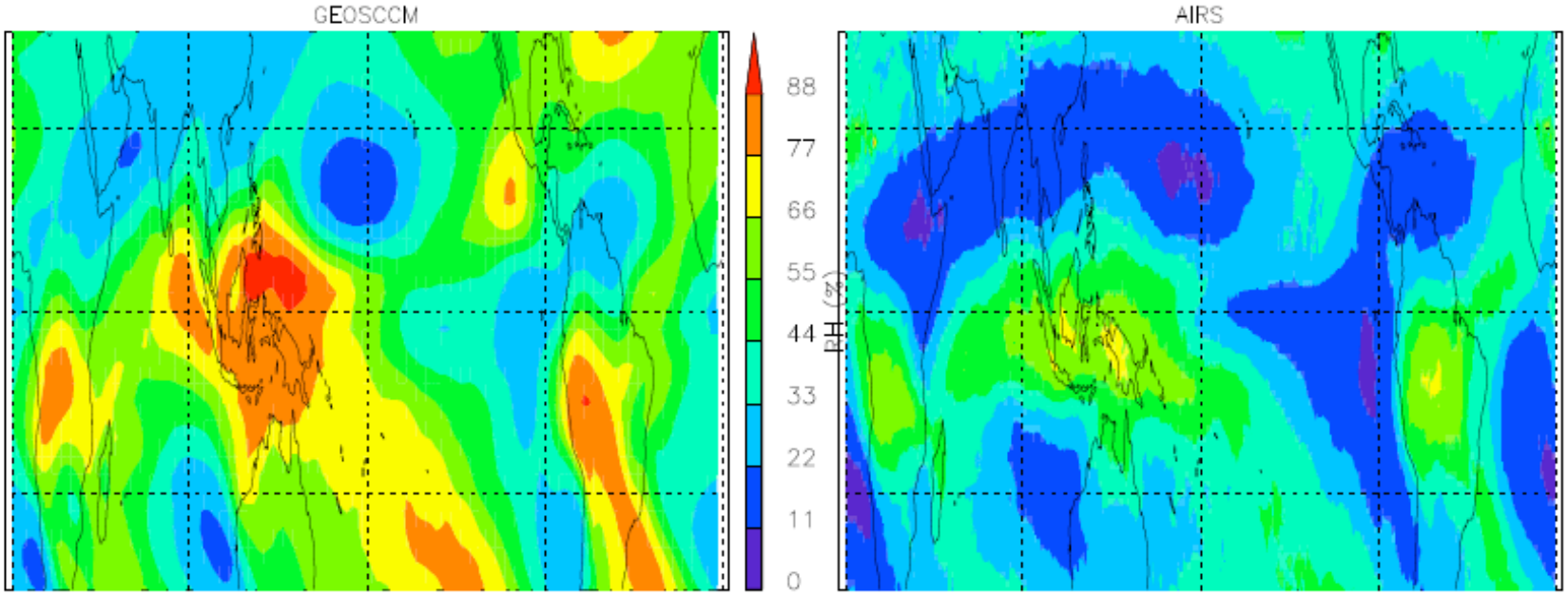
Daily RH @ 300 hPa for January and February, 1960 to 2040.

GEOS CCM - AIRS

Jan-Feb Mean RH @ 300 hPa for present conditions

GEOSCCM 2000-2004

AIRS 2004-2007



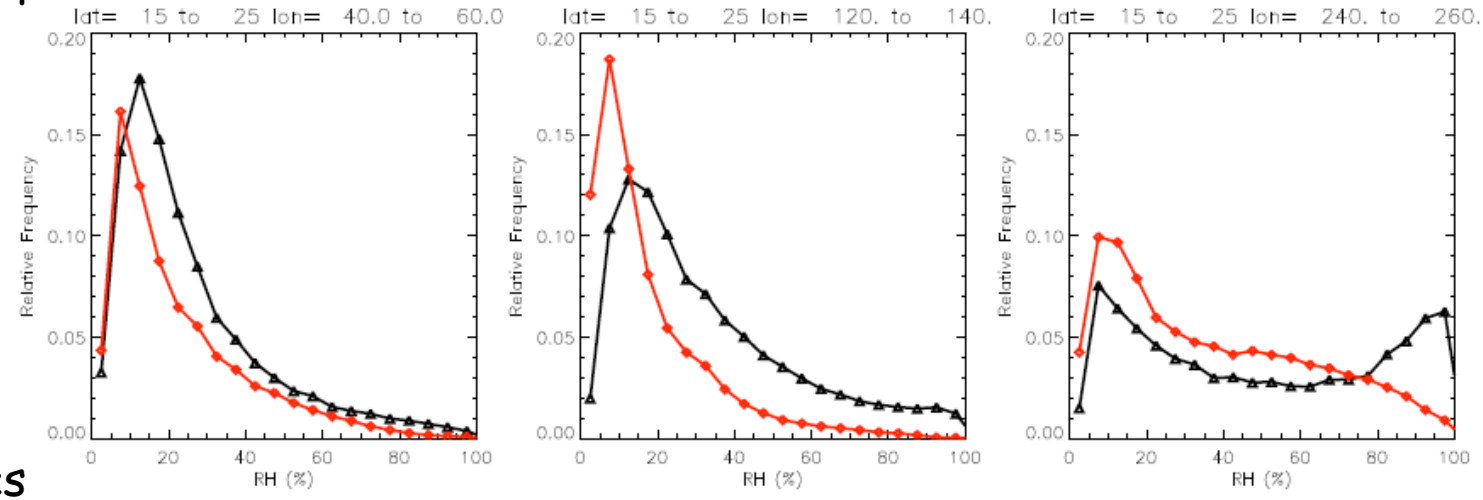
Model moister than AIRS, as found in other models.

GEOS CCM PDFs

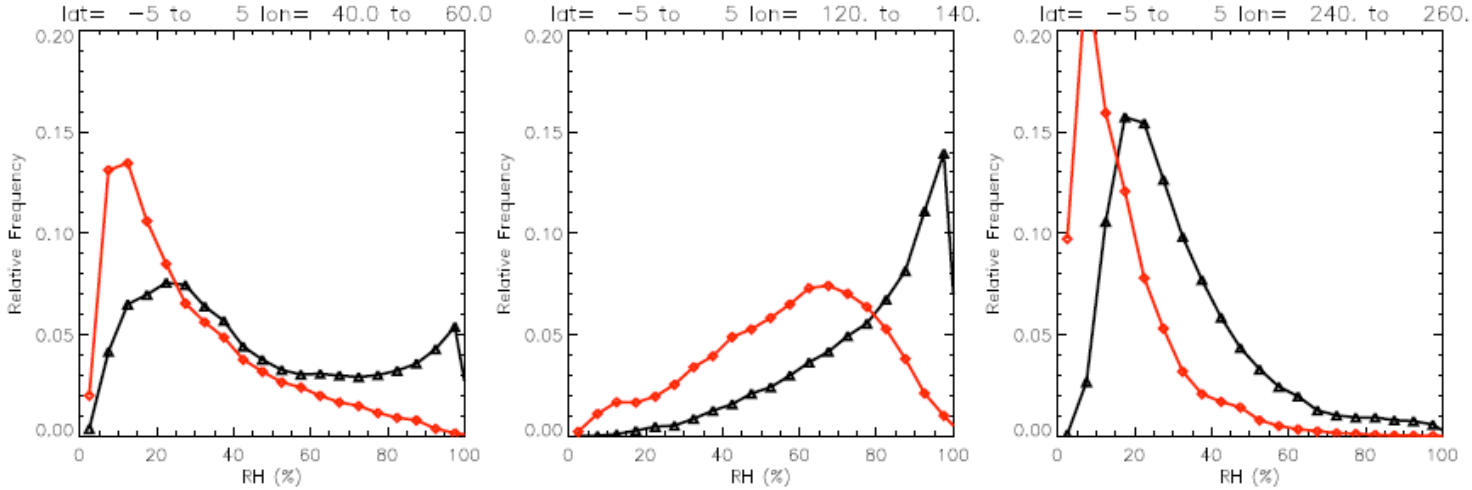
r and k larger in GEOSCCM

GEOSCCM AIRS

subtropics



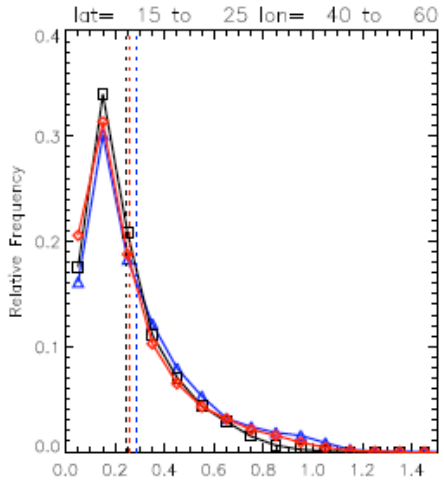
tropics

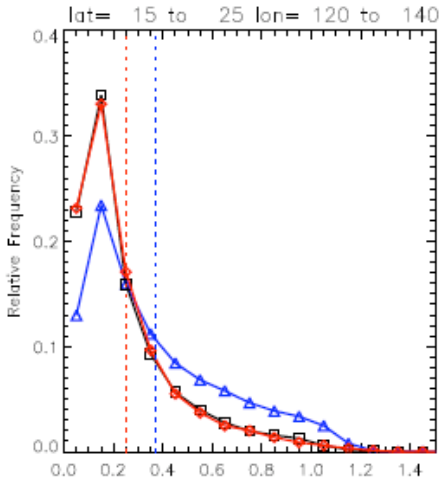


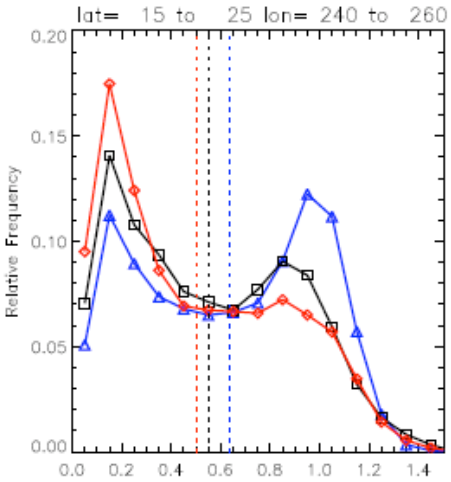
GEOSCCM PDFs: 1960 to 2050

1960s - 2000s - 2040s

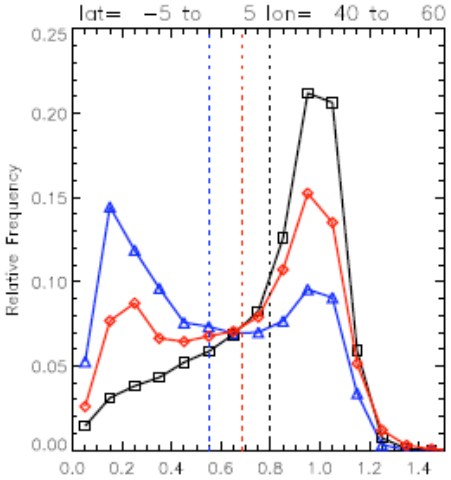
subtropics

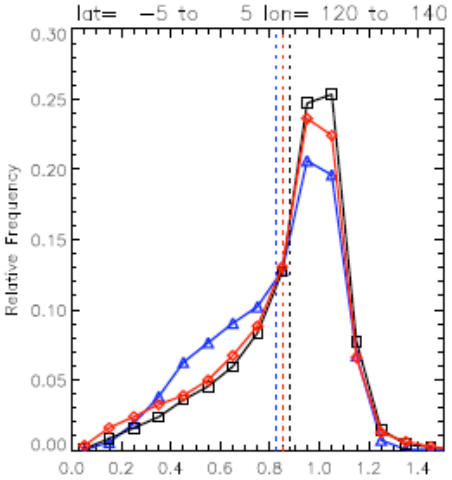


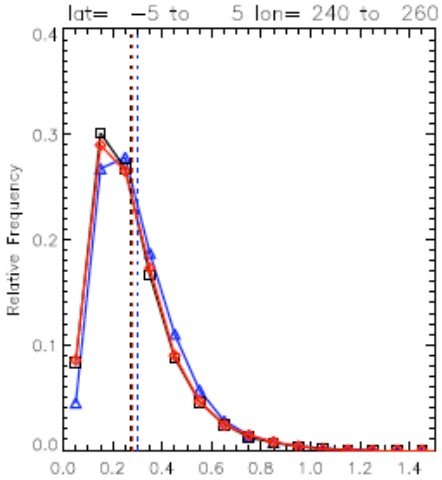




tropics







PDFs of RH ~ constant

THE END