Comparison of tropospheric humidity from AIRS, MLS, and theoretical Models

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Introduction

• Climate is sensitive to upper tropospheric humidity, and it is important to know
  ➢ distributions of water vapor in this region, and
  ➢ processes that determine these distributions.

• We examine the probability distribution functions (PDFs) of upper tropospheric relative humidity (RH) for measurements from
  ➢ Aqua AIRS
  ➢ Aura MLS
  ➢ UARS MLS

• Consider spatial variations of PDFs. Focus here on DJF, ~250hPa

• Also compare with theoretical models (generalization of Sherwood et al (2006) model).
Subtropics is drier than the Tropics
But also significant zonal variations
Large variation in PDFs - peak, spread, skewness, ...

200-250hPa

PDFs: AIRS

Subtropics (15-25N)

Tropics (5S-5N)
**Theoretical Models**

**Basic Assumption:**
- Moistening by random events
- Uniform Subsidence (water is conserved)

$\cdot t$ : age (time) of parcel since last saturation
Theoretical Model: Generalized Version

As in the Sherwood et al. (2006) model, given uniform subsidence, RH can be approximated as

\[ R(t) \approx \exp \left( -\frac{t}{\tau_{\text{Dry}}} \right) \]

Time since last saturation is now modeled as random moistening events but includes randomness of these events (\( k \)).

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

Eliminate \( t \) from above equations, yields the generalized PDFs of RH as

\[ P(R) = \frac{k^k r^k R^{kr-1}}{\Gamma(k)} (-\log R)^{k-1} \]

When \( k=1 \) it is the same as Sherwood et al. (2006)

\[ P(R) = r R^{r-1} \]

where, \( \Gamma(k) \) : Gamma function

\( r \): ratio of drying time (\( \tau_{\text{Dry}} \)) to moistening time (\( \tau_{\text{Moist}} \))

\( k \): measure of randomness of remoistening events
How well do the theoretical models fit the observed PDFs?

Generalized Model can fit the observed PDFs (peak, spread, skewness), with \( r \) and \( k \) varying with location.
Maps of “$r$” and “mean RH”

Strong resemblance between maps of $r$ and mean RH ($\mu_R$)

AIRS (2002-2007)
Maps of “r” and “k”

Convective Regions:
- large $r$ ($r>1$) and small $k$

=> Rapid, random remoistening
Non-convective Regions:
- small $r$ ($r < 1$) and large $k$
  
  => Slower, more regular remoistening (horizontal transport)
PDFS: AIRS - Aura MLS Comparison

Subtropics (15-25N)

Tropics (5S-5N)

Good agreement between AIRS and Aura MLS, with some exceptions.
Spatial Variations in \( r \)

\[ r = \frac{\tau_{\text{dry}}}{\tau_{\text{moist}}} \]

- Good agreement between different data sets.

- All show
  \( r > 1 \) in tropical convective regions,
  \( r < 1 \) in dry regions.

- Expected as larger \( r \) implies more rapid remoistening

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__AIRS (2002-07)__

__AIRS (2005-07) (match with MLS)__

__UARS MLS (1992-94)__

__Aura MLS (2005-07)__
There are some differences between AIRS and MLS PDFs.

Differences are not simply a function of RH.

Is there a simple parameterization of the AIRS-MLS difference?
Bias between data: $R_{\text{MLS}}/R_{\text{AIRS}}$

NOAA spatially and temporally interpolated OLR (2005-2006)

PDFs of MLS data

PDFs of MLS data after transform
AIRS - Aura MLS bias

Transform MLS Data

\[ \frac{R_{MLS}}{R_{AIRS}} = f(R_{MLS}, OLR) \]
Conclusions

• Several robust features (peak, range, skewness) are found in the observed PDFs from all three data-sets (Aura and UARS MLS, AIRS).

• All can be well fit by a generalized version of the Sherwood et al. (2006) theoretical model.

• Consistent spatial variations in “r” (ratio of drying and moistening times) and “k” (randomness of moistening process).

  • Large $r$, small $k$ in tropical convective regions
    → rapid, random remoistening
  • Small $r$, large $k$ in dry regions
    → slow, more regular remoistening

• A more quantitative link between the different physical processes and the parameters $r$ and $k$ is needed. This would be performed by trajectory-based water vapor simulations.

Sherwood et al. (2006) assumed that if parcels uniformly subside, RH can be approximated as

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

Time since last saturation is modeled as time between random moistening events

\[
P(t) = \exp(-t/\tau_{moist})/\tau_{moist}
\]

Eliminate \(t\) from above equations, yields the PDFs of RH as

\[
P(R) = r R^{r-1}
\]

where,

\[
r = \frac{\tau_{dry}}{\tau_{moist}}
\]

\(\tau_{dry}\) is the uniform drying time by subsidence

\(\tau_{moist}\) is the time between remoistening events.
Characteristics of the Gamma PDF

$k = 1$  \hspace{1cm} \text{Gamma PDF = Exponential PDF}

$k > 1$

\[
k \propto \left( \frac{\text{mean}(\text{RH})}{\text{standard deviation}(\text{RH})} \right)^2
\]

$k = 3$

$k = 10$

$k_i$ : randomness parameter

Large $k_i$ => less random moistening events
Variations in $r$ and $k$ characterize variations in the moistening processes.

The maps of $\mu_R$ and $\sigma_R$ show a strong resemblance to those of $r$ and $k$, respectively, i.e., there is large $\mu_R$ where $r$ is large and large $\sigma_R$ where $k$ is small.

$r \sim \mu_R$
$k \sim 1/(\sigma_R)^2$