The co-variations of tropical temperature and humidity across multiple timescales and their implication on the estimation of surface radiation budget

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1. At a fixed location in tropical troposphere, make high-frequency measurements, what would be the sign of the correlation coefficient of \(\langle T(t|x, y, p), q(t|x, y, p) \rangle\)? Why?

2. If average is done over a period, say, one month, what would be \(\langle T(\bar{t}|x, y, p), q(\bar{t}|x, y, p) \rangle\)? Same as the answer to #1 or not?

3. If average is done over a period and a geographical region, say, the entire tropics, what would be \(\langle T(\bar{t}, \bar{x}, \bar{y}|p), q(\bar{t}, \bar{x}, \bar{y}|p) \rangle\)? Why?

4. If we look at interannual anomalies correlation \(\langle T_a(\bar{t}, \bar{x}, \bar{y}|p), q_a(\bar{t}, \bar{x}, \bar{y}|p) \rangle\), will it differ from the results in #3? Why?

5. Which of above relations matter most for the climate change simulation and projection?
If this constant RH hypothesis is approximately true, then \(<T, q>\) must be strongly positive.
Interannual anomalies of tropical-mean T and q

(Sun & Held, 1996, J. Climate)

Obs: radiosonde
GCM: GFDL R15 model

Regression slope $\propto \text{Cov}(T_a, q_a)/\text{var}(T_a)$
Constant RH: $<T, q> = 1.0$

(Huang, Soden, and Jackson, GRL, 2005)

AM2: GFDL model for CMIP3 (AMIP run)
NCAR-NCEP/ERA40: 1st-generation reanalysis

NCEP-1
ERA-40
Correlation coefficient of interannual anomalies of tropical-mean T and q

(Based on Huang et al., 2005 GRL; 1978-2000)

AM2: GFDL model for CMIP3
NCAR-NCEP/ERA40: 1st generation reanalysis

AIRS: the IR hyperspectral sounder aboard NASA Aqua satellite
MERRA-2/ERA-5: latest reanalysis
If we include a few more CMIP6 models ...

(all AMIP simulations with observed SST and sea ice content)
At high temporal resolution ...

- Weak buoyancy gradient approximation (Charney, 1963; Sobel et al., 2001; Yang 2018)
  “the buoyancy gradient is negligible in the free troposphere without rotation because gravity waves can effectively smooth out buoyancy anomalies” which also leads to quasi-equilibrium tropical circulation approximation

- Buoyancy is measured by virtual temperature, $T_v = T (1+0.61q)$

- If $T_v (t|x, y, p)$ is fixed, $<T, q>$ must be negatively correlated with each other.
Year 2011, 6-hourly time series

\( <T(t | x, y, 600 \text{ hPa}), q(|x, y, 600 \text{ hPa}) > \)

At 6-hourly resolution, positive correlation is limited and weak
Year 2011, monthly-mean time series

\[
\langle T(\bar{\tau}|x, y, 600 \text{ hPa}), q(\bar{\tau}|x, y, 600 \text{ hPa}) \rangle
\]

At monthly-mean resolution, strong bi-modal correlation coefficient
Year 2002-2021, 600 hPa, interannual anomalies of T and q

\[
\langle T_a(x, y, 600 \text{ hPa}), q_a(x, y, 600 \text{ hPa}) \rangle
\]
The complexity of humidity above the convective boundary layer and in the mid-troposphere

1. In the UT (“the last point of saturation”)
2. In the PBL (homogenization by surface wind and evaporation)
3. Above the convective boundary layer? (lateral mixing, clear-sky descending, detrainment from cumulus, etc.)
How good can we measure mid-tropospheric T and q from space now?

Infrared sounders
• T: ~1K with 1-km resolution at a footprint ~10-20km
• q: ~15-20% with 2-km resolution at a footprint ~10-20km
• Dense sampling, very vulnerable to the presence of clouds
• Channel sensitivities vs. A priori: an issue often overlooked

Microwave sounders
• Usually coarser than IR sounders in vertical and horizontal resolutions
• Much less vulnerable to clouds

GPS occultations
• Much more robust and accurate retrievals
• Sampling is limited; different viewing geometry, other info is needed to get q(p)

Is there a synergistic way to remotely observe all-sky q(p) from 800-600 hPa?
The implication for the EBAF-surface calculation

Humidity adjustment is needed to match up the TOA flux in the EBAF-surface calculation
All-sky OLR anomaly (deviation from 2003) due to $q_{\text{anomaly}}$ and $T_{\text{anomaly}}$ alone

computed using kernels in Soden et al. (2008)
Discussions and reflections

• Tropical $<T(t), q(t)>$ differs at different time and spatial scales: no spectral coherence, and physics interpretation differs

• Over 30 years, discrepancies among model and obs still exist in the $<T, q>$ at the mid-troposphere and above the convective boundary layer
  • Reanalysis and observed T agree well. Humidity is a different story
  • What could we do in obs to help?
Thank You!
Back-up slides
Corr. coef. between $T$ and $q$

Year 2011 (6-hourly for January only)

Corr. coef. between $T_v$ and $q$
Year 2011 (Monthly—mean)

Corr. coef. between T and q

Corr. coef. between T_v and q
Correlation coefficients between $T$ and $q$

2011 monthly

Correlation coefficients (hPa)

Latitudes: $[20^\circ, 30^\circ]$, $[10^\circ, 20^\circ]$, $[0^\circ, 10^\circ]$, $[-30^\circ, -20^\circ]$, $[-20^\circ, -10^\circ]$, $[-10^\circ, 0^\circ]$

Models: AIRS L3, MERRA-2, ERA-5, NICAM
Correlation coefficients between T and q

2011Jan 6-hourly

Latitudes:
- [20°, 30°]
- [10°, 20°]
- [0°, 10°]
- [-30°, -20°]
- [-20°, -10°]
- [-10°, 0°]