Interannual Variability of Tropospheric Moisture and Temperature and Relationships to ENSO using COSMIC-1 GNSS-RO Retrievals

Ben Johnston [1,2], Bill Randel [1,3], and John Braun [1]

[1]UCAR COSMIC Program Office
[2]NOAA Atlantic Oceanographic and Meteorological Laboratory
[3]NCAR Atmospheric Chemistry Observations and Modeling Laboratory

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Background

- Key driver of tropical tropospheric variability is ENSO
  - Linked to changes in atmospheric circulation patterns, tropical Pacific SSTs, tropospheric temperature/moisture, and precipitation
- ENSO-related temp variability has been studied considerably
- However, moisture variability has been studied much less
  - Focus of this work
- RO data is ideal for analyzing the full vertical and spatial structure of moisture variability
  - COSMIC-1 (C1): Long data record, high vertical resolution, global coverage, insensitive to precipitation

Study Objectives

The main goals of this research are as follows:

1. To evaluate the zonal mean specific humidity and temperature variability during the C1 data record as part of data validation and quantify large-scale changes associated with ENSO from the tropics into the midlatitudes
2. To assess ENSO variability in WACCM, a global climate model simulation forced with observed SSTs, in order to evaluate model ENSO variability compared to the C1 observations
3. To evaluate the spatial variability during several El Niño and La Niña case studies, highlighting local moisture anomalies and their relationship to changes in precipitation

Data

- C1 specific humidity (q) and temperature (T) profiles obtained from CDAAC's wetPf2 retrieval
  - Uses low-res ERA5 as a priori
- q and T profiles obtained from NCAR's WACCM model for comparison
- Oceanic Niño Index (ONI) data obtained from NOAA's CPC
  - 3 month running mean of SST anomalies in the Niño 3.4 region
- Outgoing longwave radiation (OLR) data obtained from NOAA's CPC

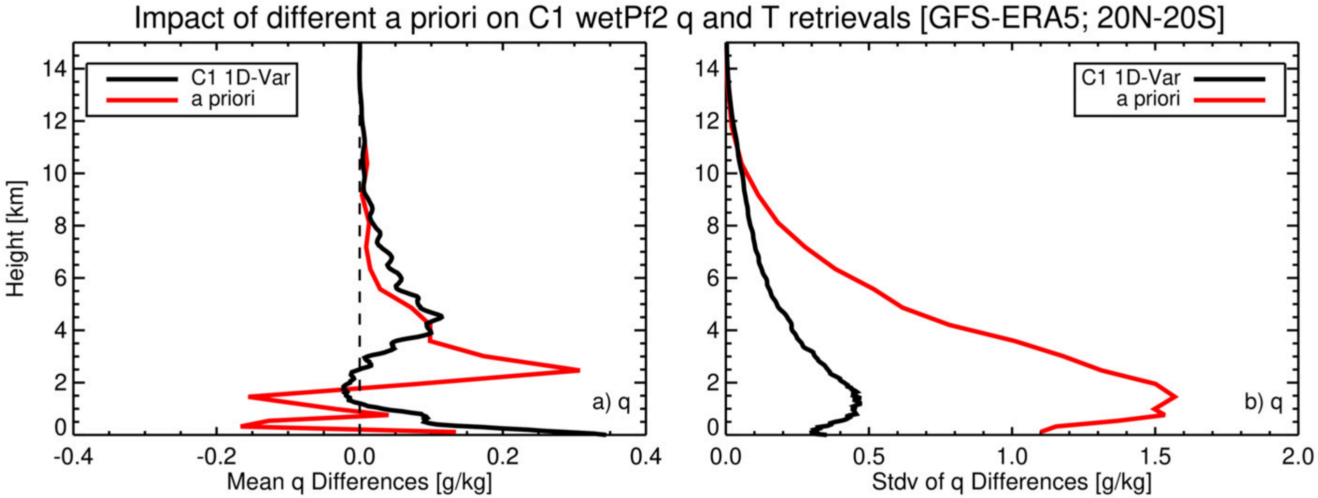
Methodology

- Study period: Jan 2007 - Dec 2018
- C1 QC: remove "bad-flagged" prof
  - e.g., observation bending angles exceed climatology by a specific threshold
- Monthly/seasonal fractional q and T anomalies are obtained by subtracting the background 12 - year means within each grid
- Linear regression analysis is used to identify the ENSO signal

C1 Data Evaluation

1D-Var dependence on a priori

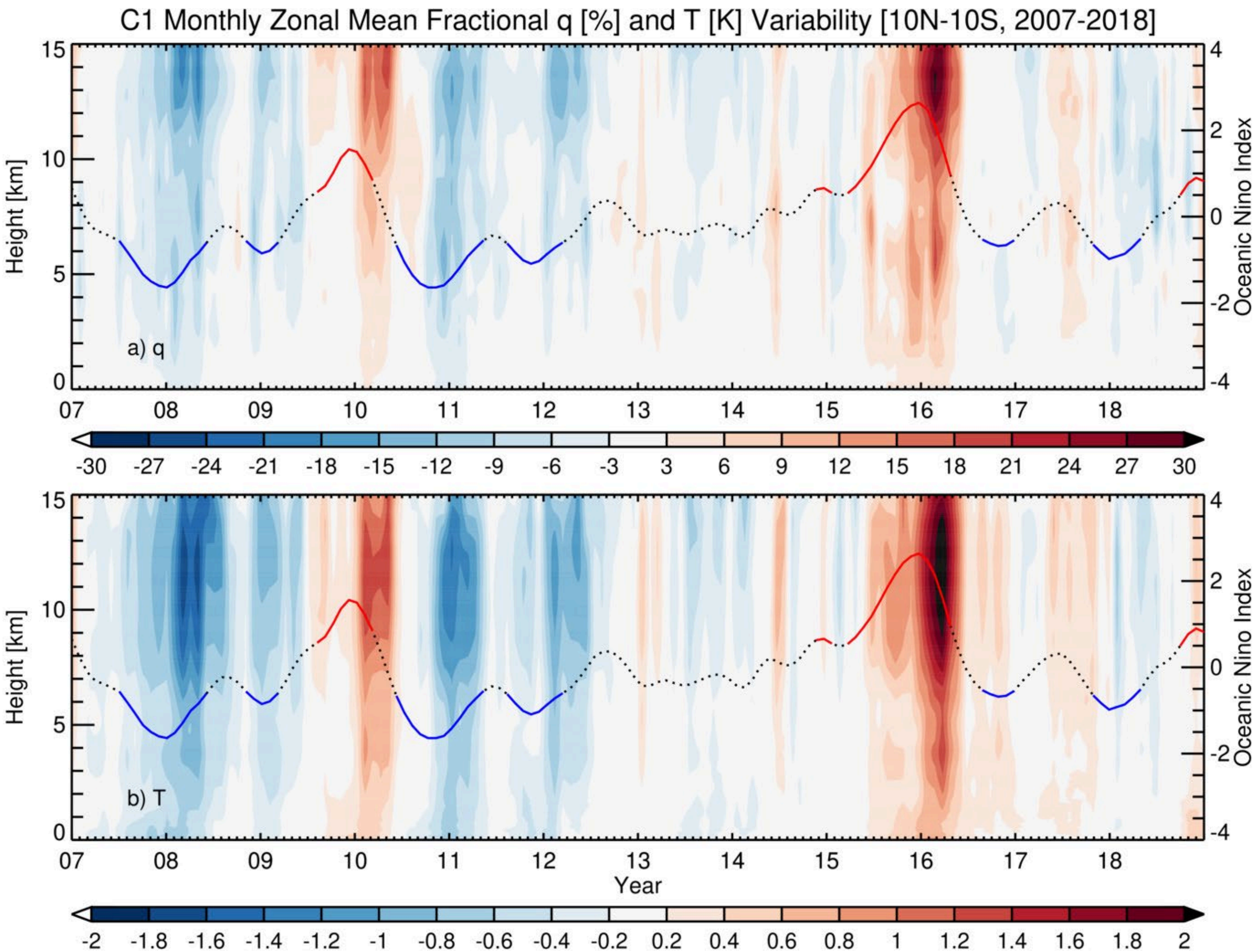
$$\textbf{dependence} = \frac{|C1_{GFS} - C1_{ERA5}|}{|GFS - ERA5|}$$



- **q: Smaller mean bias and uncertainty in low/mid trop**
- **T: Smaller mean bias and uncertainty in upper trop and lower strat**
- **These respective heights (q=0-10km, T=10-25km) display weak dependence on the first guess, while a stronger dependence is seen at other heights**

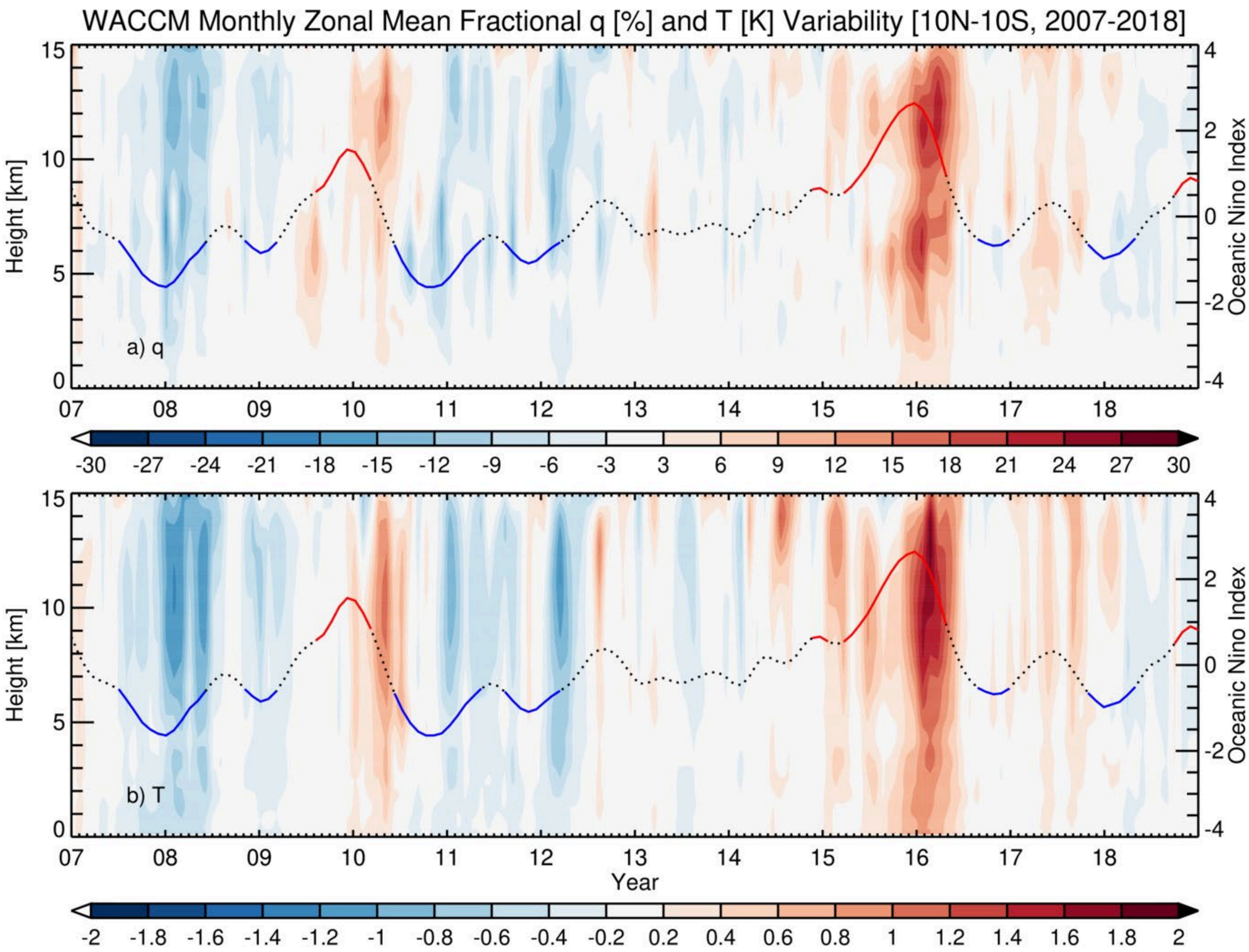
Zonal Mean q and T Variability

C1 Tropical Zonal Mean q and T Anomalies (Time/Height)



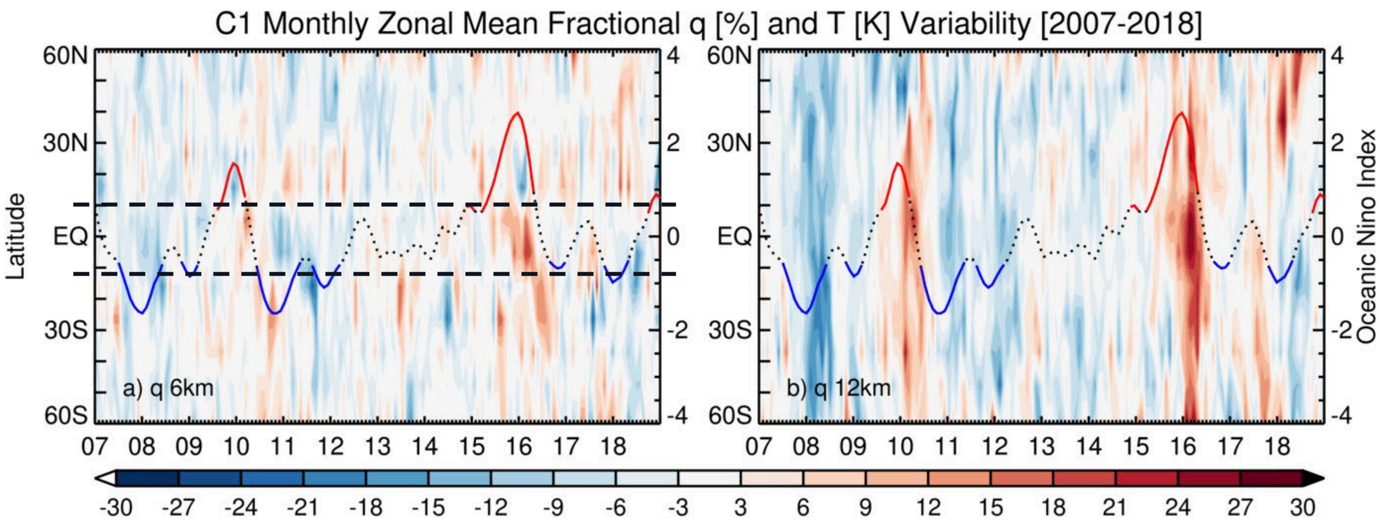
- **Positive anomalies are observed during El Niño while negative anomalies occur during La Niña for q and T**
- **Anomaly magnitude increases steadily with height**
- **q and T anomaly magnitudes are strongly dependent on SST anomaly magnitudes**

WACCM Tropical Zonal Mean q and T Anomalies (Time/Height)



- **Similar anomaly patterns are observed for WACCM, as well as anomaly magnitude increases with height**
- **However, anomaly magnitudes are generally smaller relative to C1 (q up to 6% and T up to 0.4 K)**

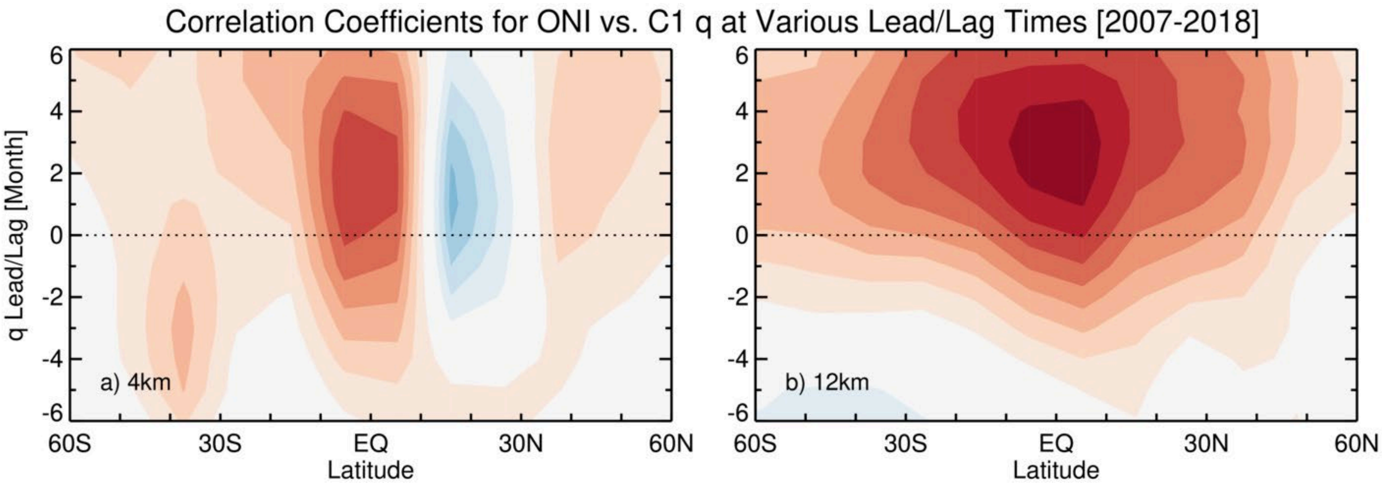
C1 Zonal Mean q and T Anomalies (Time/Latitude)



- **q anomalies show good agreement with ENSO phase only between ~10N-10S at 6km, while anomaly coherency with ENSO is visible from nearly 60N-60S at 12km**
- **In contrast, T anomalies show good agreement with the ENSO phase between ~35N-35S at both 6km and 12km**

Linear Regression Analysis

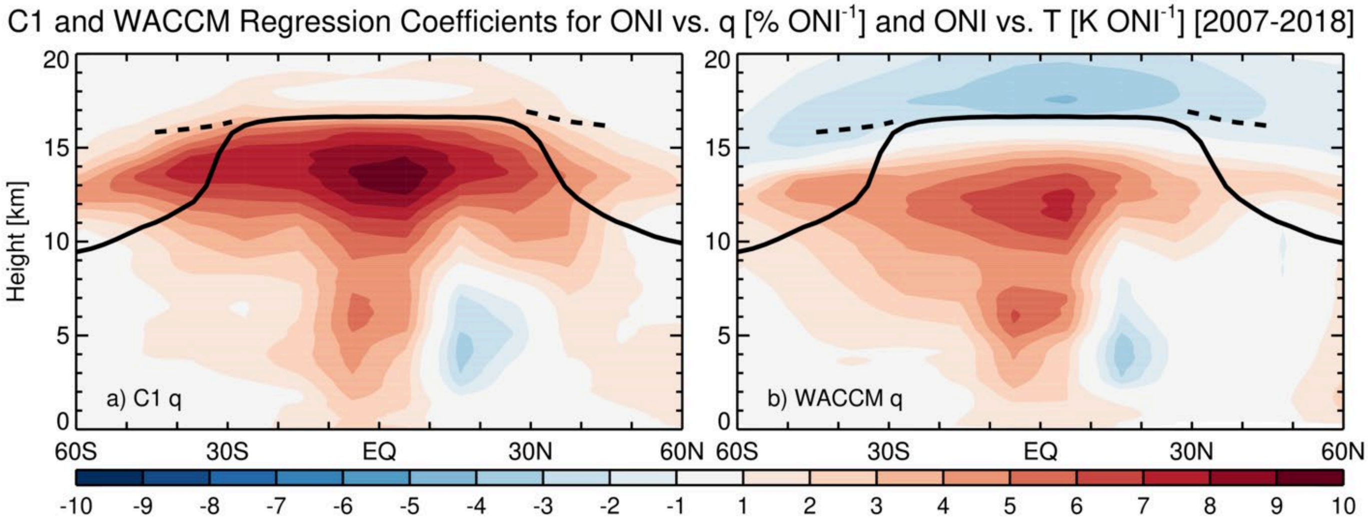
Correlations for ONI at Different q Lead/Lag Times



- **Strong positive correlations for q are confined to the deep tropics at 4km, while they expand considerably (~60N-60S) and become stronger at 12km**

- **In the deep tropics, the q response lags the SST anomalies by 2 months in the lower troposphere and increases to 3 months in the upper troposphere**

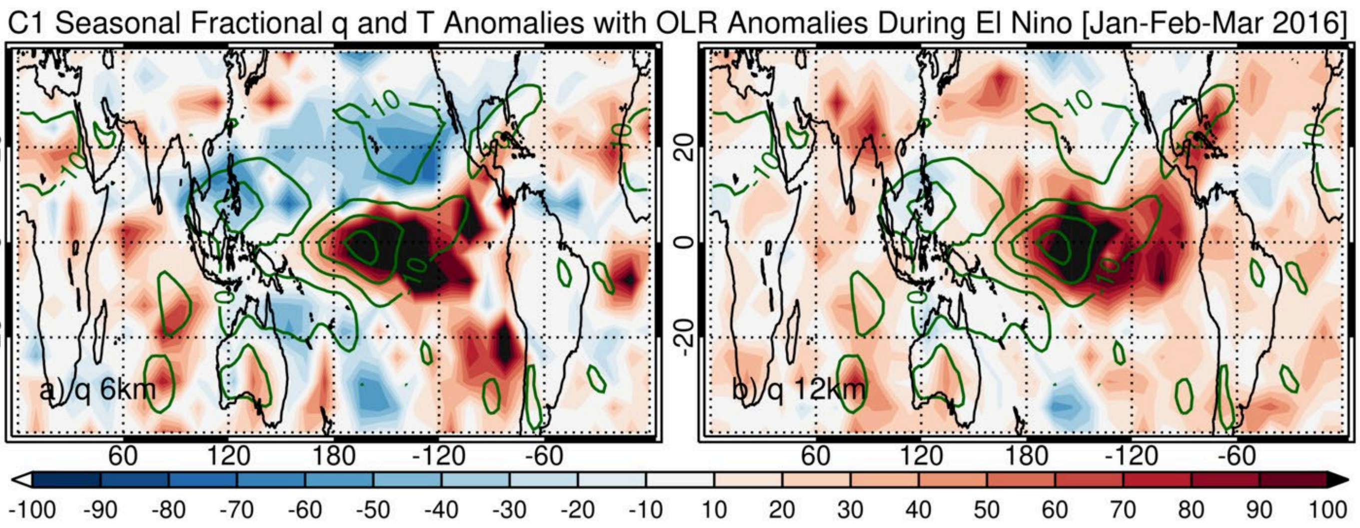
Regression Coefficients for ONI and C1/WACCM q/T



- **Positive β values for q (2-5%/ONI) are confined to the LT/MT tropics, and then increase in magnitude (6-10%/ONI) and expand into the midlatitude UTLS**
- **Positive β values for T are seen ~30N-30S and again increase with height (~0.7K/ONI)**
- **Good agreement between C1/ WACCM except near the LS, and WACCM has slightly smaller coefficients**

ENSO Case Studies

El Niño JFM 2016 q/T anomalies ("CP/EP hybrid")



- **Pacific q anomalies much stronger (>100% SH increase at 6 and 12km) – note the OLR decreases of >50 W/m² in same area**

- **T increases observed within ~all of 20N-20S, with anomalies of 3-5 K in the eastern Pacific at 12km (correspond to the positions of the anticyclonic gyres at the jet stream level)**

Conclusions

- Large zonal mean tropospheric interannual variability is observed and is closely related to the ENSO phase
  - q and T anomaly magnitudes are strongly dependent on ENSO-forced SST anomalies
  - Magnitudes increase with height and are largest in the upper troposphere
  - WACCM agrees well with C1 (albeit with slightly smaller magnitudes)
- Linear regression shows q lags SST anomalies by 2-3 months and strong correlations are observed for ONI vs. q and T
  - q anomalies expand in extent into the midlatitude lower stratosphere
- q anomalies during El Niño are more localized and closely related to changes in tropical precipitation
  - T anomalies are more widespread (~entire tropics)