Internal Variability in Simulated and Observed Tropical Tropospheric Temperature Trends

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1. Introduction

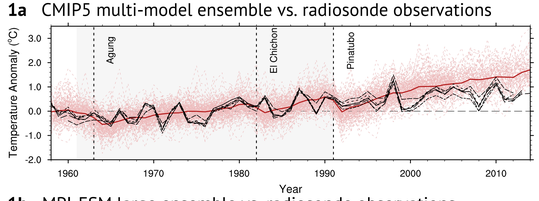
- Climate models robustly simulate the vertical **amplification of tropical warming** aloft in the troposphere as a response to increasing concentrations of greenhouse gases, as predicted by the moist adiabatic lapse-rate theory
- The warming in the upper tropical troposphere is a major **hotspot of anthropogenic climate change**, and has substantial implications for the accuracy of model-based projections for future climate and climate sensitivity [*Flato et al.*, 2013]
- There is ongoing debate on whether this **simulated response adequately captures the real-world** behavior described by observations [*Douglass et al.*, 2007; *Santer et al.*, 2008; *Fu et al.*, 2011; *Seidel et al.*, 2012; *Mitchell et al.*, 2013; *Sherwood and Nishant*, 2015]
- For the most often studied period, 1979-2008, the **observed** tropical upper troposphere temperature (TTT) trend estimates range **from 0.07 to 0.25°C/dec** for different radiosonde compilations, while the **CMIP5 ensemble mean** trend for this period is about **0.4°C/dec**

What dominates differences between observed and simulated warming in the upper troposphere?

- We analyze **all available overlapping trends** for different trend lengths over the period 1958-2014 from 6 radiosonde compilations and two model ensembles: the CMIP5 multi-model ensemble and the recently developed **MPI-ESM 100-realization large ensemble**
- Our new approach allows us to identify the **contribution of internal variability and observational uncertaint**y to the difference between observed and simulated TTT trends

2. Annual Tropical Tropospheric Temperature Anomalies

1a CMIP5 multi-model ensemble vs. radiosonde observations



1b MPI-ESM large ensemble vs. radiosonde observations

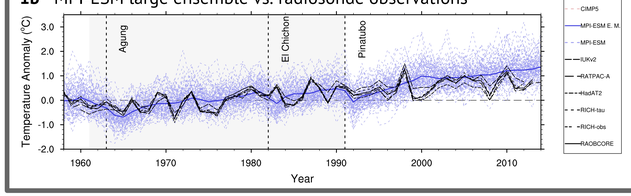


Fig. 1: Annual Tropical Tropospheric Temperature (TTT) anomalies at the 300 hPa level and for the 20°N-20°S latitude range, for six radiosonde compilations vs. historical and RCP4.5 simulations from two model ensembles:

1a. The CMIP5 multi-model ensemble of 171 realizations from 44 models. The CMIP5-ensemble spread arises from a combination of intermodel differences and internal variability.

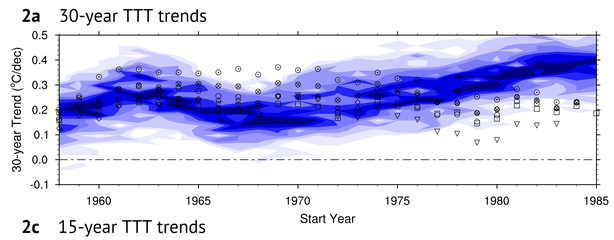
1b. The MPI-ESM large ensemble of 100 realizations from one model. The large-ensemble spread arises only from internal variability.

Results:

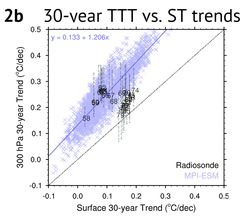
- The spread of the CMIP5 multi-model ensemble arises mostly from internal variability and is not readily distinguishable from the spread of the MPI-ESM large ensemble
- Simulations of annual TTT anomalies from both ensembles show good agreement with radiosonde observations
- Different radiosonde compilations present a wide spread of observational estimates, particularly toward the end of the record

3. Tropical Tropospheric Temperature Trends and Trend Amplification in the MPI-ESM Large Ensemble vs. Radiosonde Observations

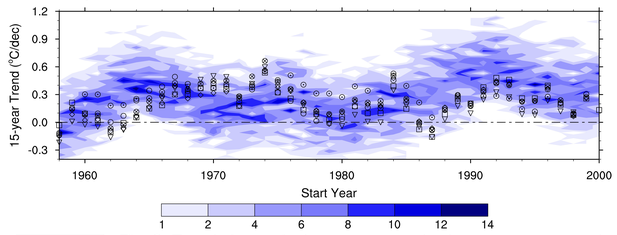
2a 30-year TTT trends



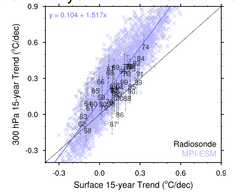
2b 30-year TTT vs. ST trends



2c 15-year TTT trends



2d 15-year TTT vs. ST trends



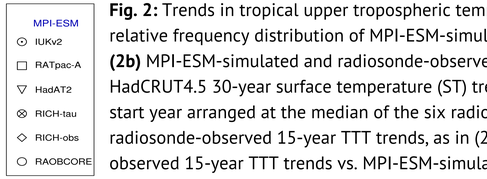


Fig. 2: Trends in tropical upper tropospheric temperatures and tropospheric amplification. **(2a)** Joint relative frequency distribution of MPI-ESM-simulated and radiosonde-observed 30-year TTT trends. **(2b)** MPI-ESM-simulated and radiosonde-observed 30-year TTT trends vs. MPI-ESM-simulated and HadCRUT4.5 30-year surface temperature (ST) trends. Observational estimates are represented by start year arranged at the median of the six radiosonde estimates. **(2c)** MPI-ESM-simulated and radiosonde-observed 15-year TTT trends, as in (2a). **(2d)** MPI-ESM-simulated and radiosonde-observed 15-year TTT trends vs. MPI-ESM-simulated and HadCRUT4.5 15-year ST trends, as in (2b).

Results:

- MPI-ESM-simulated 30-year TTT trends show good agreement with radiosonde trend estimates for about two thirds of the record, while simulated trends with start years after 1978 are larger than those observed
- Radiosonde-observed 30-year TTT trend for the period 1979-2008, the most often studied period, is the lowest trend estimate for the whole observational record
- Different radiosonde trend estimates present a wide observational spread of about 0.2°C/dec, that is about half of the large ensemble spread for 30-year trends, indicating large remaining observational uncertainty
- MPI-ESM-simulated 15-year TTT trends show good agreement with radiosonde trend estimates for the whole observational record, and are more influenced by interannual internal variability
- The MPI-ESM-simulated amplification of tropical surface temperatures aloft in the troposphere is consistent with both theoretical expectations and observations on annual time scales and for the majority of the trend record
- Some of the older radiosonde compilations present tropospheric dampening (less warming aloft than at the surface) for some trend estimates during the second half of the record
- Remaining observational biases appear to be more relevant for 30-year trends, since these biases do not cancel over time, and the amplitude of internal variability decreases with trend length

4. Conclusions

- Trend differences between observed and simulated tropical upper tropospheric warming are dominated by **observational uncertainty and chaotic internal variability**
- Trend differences are largest for the amplification of tropospheric over surface warming aloft for 30-year trends during the second half of the record
- Tropical tropospheric amplification in MPI-ESM is consistent with theoretical expectations and observations
- Radiosonde observations show overall good agreement with the MPI-ESM single-model 100-member ensemble

5. References

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Do you have any comments or questions? Would you like to have some more details? Please do not hesitate to ask!

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IMPRS-ESM International Max Planck Research School on Earth System Modelling