IONOSPHERIC AND ATMOSPHERIC REMOTE SENSING (IARS) GROUP

NASA

Quantifying the tropical upper tropospheric warming amplification using radio occultation measurements

Panagiotis Vergados[1], Chi O. Ao[1]

Anthony J. Mannucci[1], and Robert E. Kursinski[2]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

[2] PlanetiQ, Golden, CO, USA

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Outline

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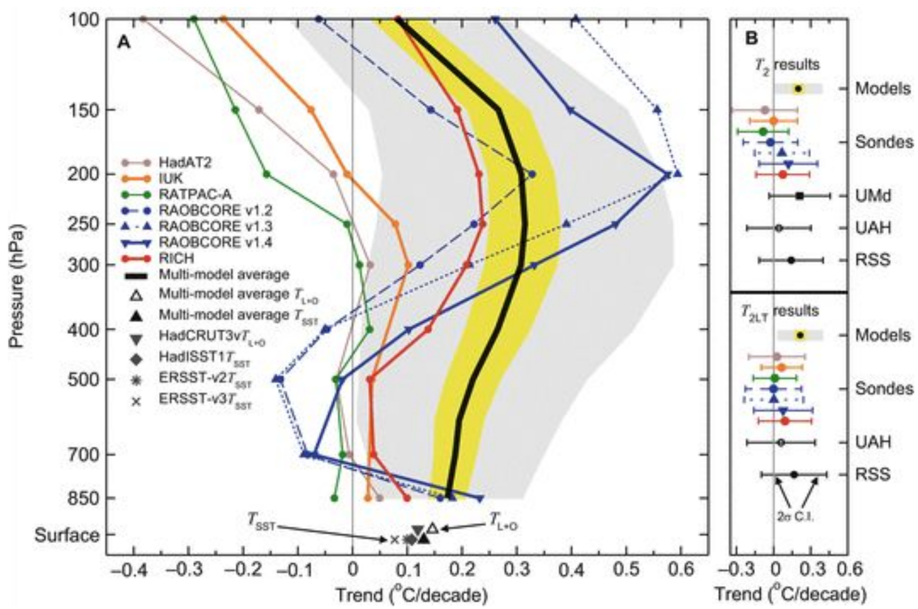
Objectives

1. **Assess** upper troposphere warming trends using ROs.

2. **Compare** CMIP6-AMIP UT trends and amplification with ROs.

(source: Santer et al., 2018)



How is surface warming expressed vertically?

Vertically-resolved pressure layers are needed!

Introduction

Warming Amplification:

Upper troposphere warming amplification, dT_{UT}/dT_s, describes the rate of change of the air temperature in response to surface temperature change [e.g., *Thorne et al.*, 2007]. Is mostly pronounced between 250 and 200 hPa, and plays key role in climate projections.

$$dT_{UT}/dT_s = (dT_{UT}/dt) / (dT_s/dt)$$

Surface temperature trend

UT temperature trend

Where T_{UT} is the upper troposphere temperature, T_s is the surface temperature, and t is time.

Introduction

Tropospheric temperature decadal trends (°C / decade) starting in 1958 and 1979 up to 2017

State of the Climate
Christy et al., 2018

	Global LTT		Tropical LTT		Tropical TTT	
Start Year:	**1958**	**1979**	**1958**	**1979**	**1958**	**1979**
Radiosondes						
RAOBCORE	+0.15	+0.15	+0.14	+0.13	+0.14	+0.13
RICH	+0.19	+0.20	+0.18	+0.17	+0.17	+0.17
RATPAC	+0.18	+0.20	+0.15	+0.15	+0.15	+0.15
UNSW (to 2015)	+0.17	+0.16	+0.15	+0.11	+0.13	+0.10
Satellites						
UAHv6.0[a]	—	+0.13	—	+0.12	—	+0.12
RSSv4.0[b]	—	+0.19	—	+0.15	—	+0.19
NOAAv4.0	—	—	—	—	—	+0.21
UWv1.0[c]	—	—	—	—	—	+0.17
Reanalyses and Climate Models after Reanalyses						
ERA-I	—	+0.13	—	+0.10	—	+0.13
JRA-55	—	+0.16	—	+0.13	—	+0.14
MERRA-2	—	+0.17	—	+0.14	—	+0.15
CMIP5 Mean	+0.21	+0.27	+0.22	+0.29	+0.25	+0.31

Radiosonde and MSU agree.

MSU databases and reanalyses agree.

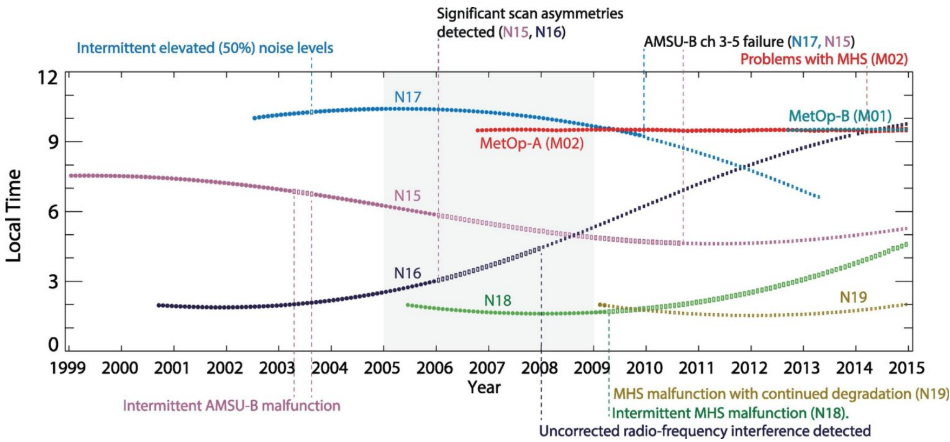
Climate models show **higher** warming trends than MSU, radiosondes, and reanalyses.

Models-to-observations discrepancies could arise from:

- Inter-model climate variability; sea surface temperature simulation errors; physics
- Inconsistent diurnal cycle; MSU stratospheric cooling; instrument calibration biases

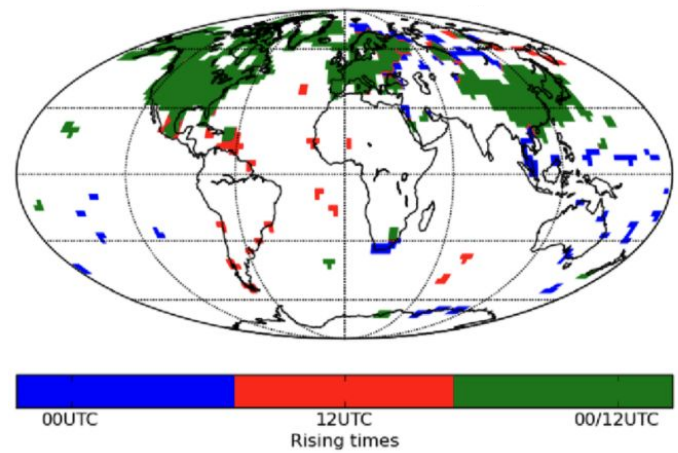
Introduction

AMSU/MSU Local Time Coverage

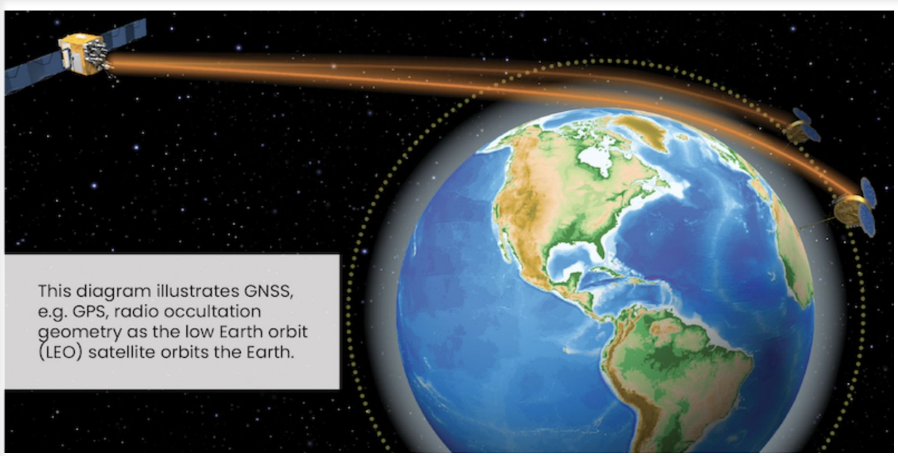


(source: Fanatsu et al., 2018)

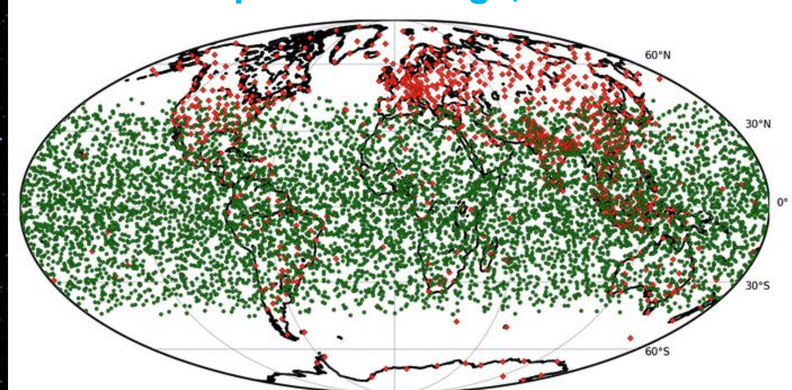
RAOBCORE Spatial Coverage



(source: Ladstadter et al., 2011)



24 Hrs spatial Coverage, COSMIC-2



Methodology

DATA | METHODOLOGY | ANALYSIS

Data

- JPL Obs4MIPs
- CMIP6-AMIP
- ERA-Interim
- Aqua/AIRS v6.0
- MERRA v2.0
- Surface Temps.

Set Up

- 01/2002–12/2018
- 20ºS–20ºN
- 300 – 200 hPa

Analyze

- Monthly zonal means
- 17–year time series
- T and T_s anomalies, linear regressions, and quantify dT/dT_s

Statistics

- Mean climatologies
- Monthly variabilities
- Decadal Trends

Results

- Compare dT/dT_s from Obs4MIPs, CMIP6-AMIP, ERA-Interim, AIRS v6, and MERRA v2 data sets.
- Assess Obs4MIPs performance on determining multi-decadal trends, and CMIP6 vertical amplification.

ERA-Interim
European Center for Medium-Range Weather Forecasts Re-Analysis Interim

Aqua/AIRS
Atmospheric Infrared Sounder

MERRA
Modern-Era Retrospective Analysis for Research and Applications

CMIP6-AMIP
Climate Model Intercomparison Project

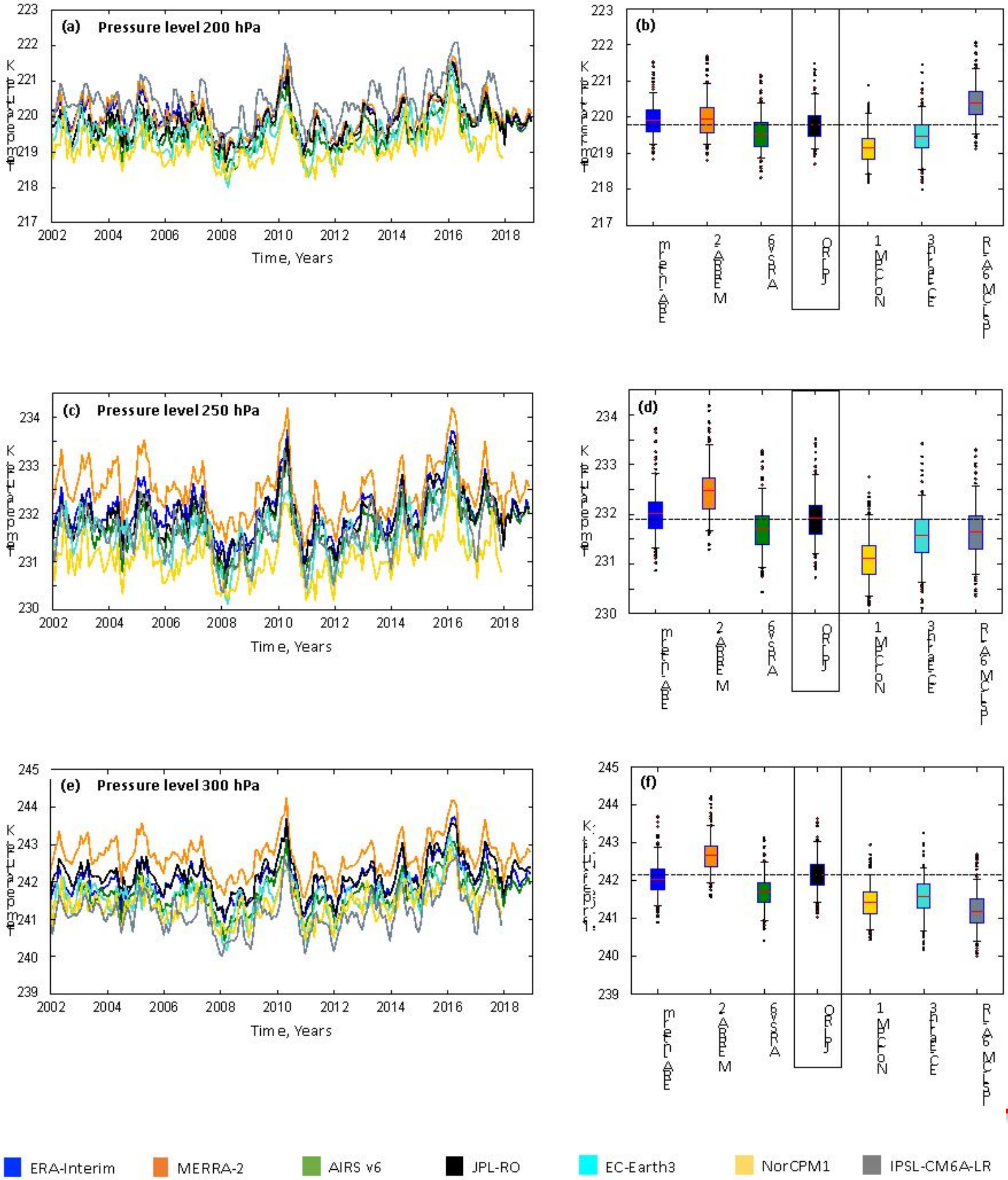
JPL Obs4MIPs – Observations for Model Intercomparison Project [e.g., Ao et al., 2021; in preperation]

- Gridded, 5.0º x 5.0º, monthly mean temperatures based on Bayesian interpolation [Leroy et al., 2012]
- Time period: January 2002 – December 2018
- Altitude coverage: 400 hPa up to 50 hPa
- Publicly available: https://genesis.jpl.nasa.gov/ftp/pub/genesis/

Multi-platform Tropical Upper Troposphere Temperature Climatology Comparison

Variability (left) and Interquartile Range Statistical Analysis (right)

Vergados et al. [2021], *Earth Space Science, 8*
doi:10.1029/2020EA001597



ERA-Interim and MERRA-2 agree with Obs4MIPs.

NorCPM1 and EC-Earth3 *agree with Obs4MIPs at low IQR values, with IPSL being the warmest.*

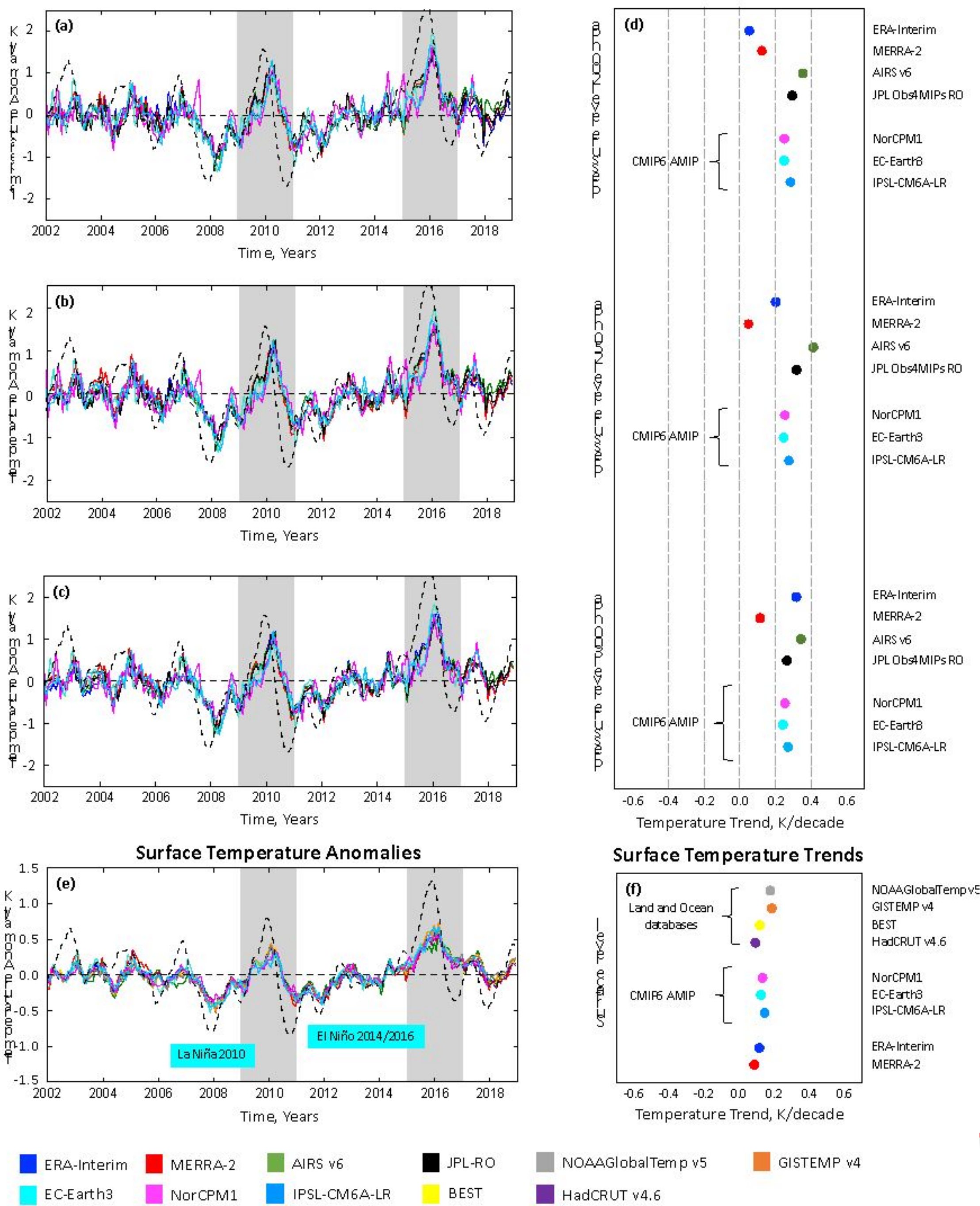
Similar behavior with 300 hPa

NorCPM1 *is the coldest, while EC-Earth3 and IPSL start showing similar temperatures with Obs4MIPs.*

CMIP6-AMIP show smaller absolute UT temperature than RO

ERA-Interim shows excellent agreement with Obs4MIPs with ***MERRA-2*** being the warmest.

Observed and modeled estimates of the 2002–2018 tropical UT (200-300 hPa) temperature trends and their vertical variability, and surface temperature variability and trends



Vergados et al. [2021], *Earth Space Science, 8*
doi:10.1029/2020EA001597

CMIP6-AMIP model runs present an excellent agreement with Obs4MIPs warming trends from 300 – 200 hPa.

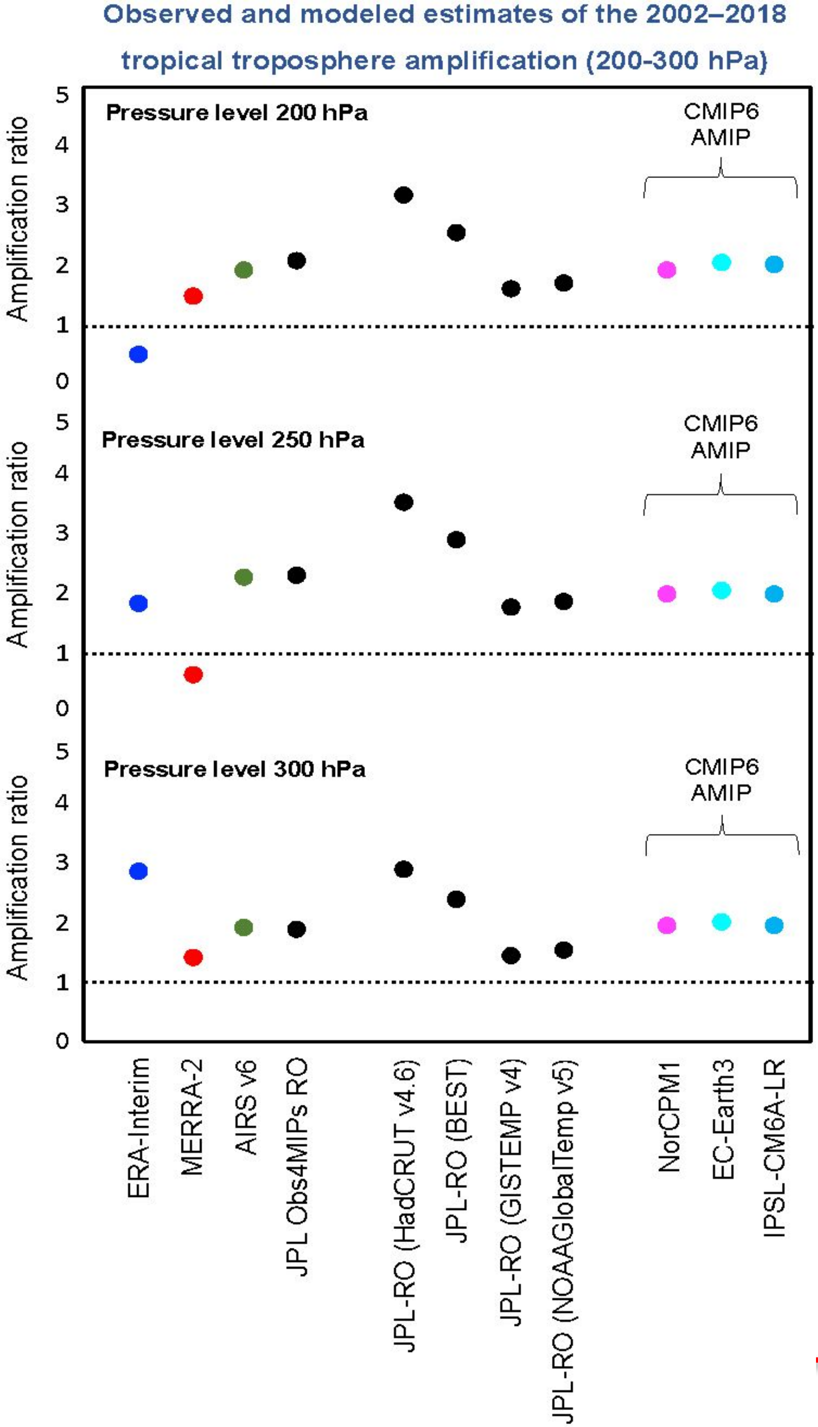
MERRA-2 shows almost no warming of the UT over time.

ERA-interim show excellent agreement with Obs4MIPs at 300 hPa, but shows no warming > 300 hPa.

AIRS v6 IR measurements show a very good agreement (within errors) with Obs4MIPs on the warming trends.

*Of the 3 CMIP6-AMIP models analyzed here, **IPSL shows excellent agreement** with the JPL's Obs4MIPs estimates.*

Obs4MIPs and CMIP6-AMIP indicate >0.20 K/decade, with maximum value at 250 hPa pressure level.



Vergados et al. [2021], *Earth Space Science, 8, doi:10.1029/2020EA001597*

CMIP6-AMIP model runs show that surface warming is amplified by a factor of 2 at 300 – 200 hPa.

Independently, Obs4MIPs (L-band RF) present the same surface temperature amplification at 300 – 200 hPa as CMIP6-AMIP, over 17 years of RO measurements.

Independent AIRS v6 (IR) show the same amplification as RO and CMIP6-AMIP model runs.

Reanalyses show a more complex behavior, with MERRA-2 indicating no amplification at 250 hPa, and slightly smaller amplification than IR, RF, and CMIP6-AMIP at 300 and 200 hPa. ERA-interim exhibits the strongest amplification at 300 hPa, with decreasing values with altitude, eventually presenting that small amplification occurs at 200 hPa.

Conclusions

1. CMIP6-AMIP models are colder (on average) than RO measurements, although they agree with the RO on both the temperature trends and amplification at 300 – 200 hPa.

2. AIRS v6 (IR) measurements also show an excellent agreement with RO observations on the warming trends and amplification.

3. The absolute temperature discrepancy, in combination with the agreement in warming trends and amplification, suggest that CMIP6-AMIP and AIRS do capture climate trends but they do not properly sense the vertical thermal structure.

Acknowledgments

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Data Availability:

BEST surface temperature: http://berkeleyearth.org/archieve/data

HadCRUT4.6 surface temperature: https://crudata.uea.ac.uk/cru/data/temperature

GISTEMP4.0 surface temperature: https://data.giss.nasa.gov/gistemp

NOAA surface temperature: https://www.ncdc.noaa.gov

JPL Obs4MIPs air temperature: https://genesis.jpl.nasa.gov/ftp/pub/genesis

CMIP6-AMIP surface and air temperature: https://esgf-node.llnl.gov/search/cmip6

MERRA v2 surface and air temperature: https://disc.gsfc.nasa.gov/datasets?keywords=MERRA2&page1

AIRS v6 surface and air temperature: https://disc.gsfc.nasa.gov/datasets?keywords=AIRS&page1

ERA-Interim surface and air temperature: https://apps.ecmwf.int/datasets/data/interim-full-moda/levtype=p1