RECONCILING TROPOSPHERIC TEMPERATURE TRENDS FROM THE MICROWAVE SOUNDING UNIT

Stephen Po-Chedley
NOAA STAR Seminar Series
COGS Presentation
AGENDA

Motivation.

Microwave sounding unit discrepancies.

NOAA-09.

Other differences.

Conclusions?
Motivation.

- Observations are an important check for models.
- Models predict temperature amplification in the tropics.
- Only some observations demonstrate amplification.

21st Century Warming.
Observations are an important check for models.

Models predict temperature amplification in the tropics.

Only some observations demonstrate amplification.

21st Century Warming.

Motivation.

- Observations are an important check for models.
- Models predict temperature amplification in the tropics.
- Only some observations demonstrate amplification.

**21st Century Warming.** [Anthropogenic Fingerprint.](#)

[Image of climate map and graphs showing temperature changes with latitude and pressure, labeled as Models, Radiosonde, and Difference.]

Motivation.

• How do we measure temperature in the atmosphere?
• Microwave Sounding Unit (MSU)
• Global coverage, 1979 - present
• NOAA STAR (v2.0), RSS (v3.3), and UAH (v5.3)
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Motivation.

• How do we measure temperature in the atmosphere?

• Microwave Sounding Unit (MSU)

• Global coverage, 1979 - present

• NOAA STAR (v2.0), RSS (v3.3), and UAH (v5.3)
Motivation.

• How do we measure temperature in the atmosphere?
• Radiosondes (weather balloon)
• Direct measurement of temperature
• Large biases due to solar heating effects
• Patchy coverage
• Measurements at discrete levels
• Temperature trends derived from radiosondes and satellites have led people to question “the fingerprint” and models.

• A battle in the literature has followed surrounding temperature trends.

*Singer, 2008: “[This information] clearly falsifies the hypothesis of anthropogenic global warming” (quote, CES)
• Temperature trends derived from radiosondes and satellites have led people to question “the fingerprint” and models.

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Motivation.

- Temperature trends derived from observations have led people to question “the fingerprint” of anthropogenic global warming.
- A battle in the literature has followed surrounding temperature trends.

We have tested the proposition that greenhouse model simulations and trend observations can be reconciled. Our conclusion is that the present evidence, with the application of a robust statistical test, supports rejection of this proposition. (The use of tropical tropospheric temperature trends as a metric for this test is important, as this region represents the CEL and provides a clear signature of the trajectory of the climate system under enhanced greenhouse forcing.) On the whole, the evidence indicates that model trends in the troposphere are very likely inconsistent with observations that indicate that, since 1979, there is no significant long-term amplification factor relative to the surface. If these results continue to be supported, then future projections of temperature change, as depicted in the present suite of climate models, are likely too high.

In summary, the debate in this field revolves around the idea of discrepancy in surface and tropospheric trends in the tropics where vertical convection dominates heat transfer. Models are very consistent, as this article demonstrates, in showing a significant difference between surface and tropospheric trends, with tropospheric temperature trends warming faster than the surface. What is new in this article is the determination of a very robust estimate of the magnitude of the model trends at each atmospheric layer. These are compared with several equally robust updated estimates of trends from observations which disagree with trends from the models.

The last 25 years constitute a period of more complete and accurate observations and more realistic modelling efforts. Yet the models are seen to disagree with the observations. We suggest, therefore, that projections of future climate based on these models be viewed with much caution.

* Singer, 2008: “[This information] clearly falsifies the hypothesis of anthropogenic global warming” (quote, CES)
• Turns out Douglass et al. applied a biased statistical test.

• Did not account for autocorrelation and used older versions of radiosonde datasets (when new ones were available).
Motivation.

But disagreement looms...

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Article

What Do Observational Datasets Say about Modeled Tropospheric Temperature Trends since 1979?

John R. Christy 1,*, Benjamin Herman 2, Roger Pielke, Sr. 3, Philip Klotzbach 4, Richard T. McNider 1, Justin J. Hnilo 1, Roy W. Spencer 1, Thomas Chase 3 and David Douglass 5
Motivation.

But disagreement looms...

**Abstract:** Updated tropical lower tropospheric temperature datasets covering the period 1979–2009 are presented and assessed for accuracy based upon recent publications and several analyses conducted here. We conclude that the lower tropospheric temperature ($T_{LT}$) trend over these 31 years is $+0.09 \pm 0.03$ °C decade$^{-1}$. Given that the surface temperature ($T_{sfc}$) trends from three different groups agree extremely closely among themselves ($\sim +0.12$ °C decade$^{-1}$) this indicates that the “scaling ratio” ($\mathcal{SR}$, or ratio of atmospheric trend to surface trend: $T_{LT}/T_{sfc}$) of the observations is $\sim 0.8 \pm 0.3$. This is significantly different from the average $\mathcal{SR}$ calculated from the IPCC AR4 model simulations which is $\sim 1.4$. This result indicates the majority of AR4 simulations tend to portray significantly greater warming in the troposphere relative to the surface than is found in observations. The $\mathcal{SR}$, as an internal, normalized metric of model behavior, largely avoids the confounding influence of short-term fluctuations such as El Niños which make direct comparison of trend magnitudes less confident, even over multi-decadal periods.
Motivation.

• What does theory say (in the tropics)?

• Tropics maintain a moist adiabatic lapse rate in the free troposphere
Motivation.

T24 = 1.75xΔSurface
TLT = 1.29xΔSurface
Motivation.

- There is an incongruence with amplification on different time scales.

Decadal Time Scale

Tropical (20N-S), 1979 - 2000

* See Santer et al, 2005
There are still large discrepancies in observational trend estimates.

Each group uses the exact same raw data!

Why are they different?
Table 1.1: Current least squares linear trend values (1979 - 2011) for NOAA, RSS, and UAH for various channels in units of K decade$^{-1}$.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Region</th>
<th>NOAA</th>
<th>RSS</th>
<th>UAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLT</td>
<td>Global</td>
<td>N/A</td>
<td>0.139</td>
<td>0.137</td>
</tr>
<tr>
<td></td>
<td>Tropical</td>
<td>N/A</td>
<td>0.125</td>
<td>0.072</td>
</tr>
<tr>
<td>T24</td>
<td>Global</td>
<td>0.197</td>
<td>0.141</td>
<td>0.113</td>
</tr>
<tr>
<td></td>
<td>Tropical</td>
<td>0.177</td>
<td>0.138</td>
<td>0.075</td>
</tr>
<tr>
<td>TMT</td>
<td>Global</td>
<td>0.130</td>
<td>0.083</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>Tropical</td>
<td>0.131</td>
<td>0.101</td>
<td>0.040</td>
</tr>
<tr>
<td>TLS</td>
<td>Global</td>
<td>-0.322</td>
<td>-0.302</td>
<td>-0.382</td>
</tr>
<tr>
<td></td>
<td>Tropical</td>
<td>-0.324</td>
<td>-0.264</td>
<td>-0.313</td>
</tr>
</tbody>
</table>
Where are differences in tropospheric temperature measurements?

Tropical Tropospheric Temperature Series (30° S – 30° N)

T24
Where are differences in tropospheric temperature measurements?
Where are differences in tropospheric temperature measurements?

MSU discrepancies.

- NOAA: 0.190 K/decade
- RSS: 0.146 K/decade
- UAH: 0.083 K/decade

Tropical Tropospheric Temperature Series (30° S – 30° N)
• Figuring out where the “jumps” are.

\[ T_B = \sum_{t+1}^{t+k} \frac{T_{\text{diff}}(t)}{k} - \sum_{t-k}^{t-1} \frac{T_{\text{diff}}(t)}{k} \]
• Can reconciling “jumps” reconcile trends?

MSU discrepancies.
MSU discrepancies.
Why would two datasets with the exact same data suddenly disagree?
• Complicated merging process...

MSU discrepancies.
The Effect of Diurnal Correction on Satellite-Derived Lower Tropospheric Temperature

Carl A. Mears and Frank J. Wentz

Nature 2004

Contribution of stratospheric cooling to satellite-inferred tropospheric temperature trends

Qiang Fu, Celeste M. Johanson, Stephen G. Warren & Dian J. Seidel

Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195, USA
2NOAA Air Resources Laboratory, Silver Spring, Maryland 20910, USA

From 1979 to 2001, temperatures observed globally by the mid-tropospheric channel of the satellite-borne Microwave Sounding Unit (MSU channel 2), as well as the inferred temperatures in the lower troposphere, show only small warming trends of less than 0.1 K per decade (refs 1–3). Surface temperatures based on in situ observations however, exhibit a larger warming of ~0.17 K per decade (refs 4, 5), and global climate models forced by combined anthropogenic and natural factors project an increase in tropospheric temperatures that is somewhat larger than the surface temperature increase. Here we show that trends in MSU channel 2 temperatures are weak because the instrument partly records stratospheric temperatures whose large cooling trend offsets the contributions of tropospheric warming. We quantify the stratospheric contribution to MSU channel 2 temperatures using MSU channel 4, which records only stratospheric temperatures.

The 17-year lower-tropospheric temperature record derived from the satellite Microwave Sounding Unit (MSU) shows a global cooling trend, from 1979 to 1995, of ~0.05 K per decade at an altitude of about 3.5 km (refs 4, 5). Air temperatures measured at the Earth's surface, in contrast, have risen by approximately +0.13 K per decade over the same period. The two temperature records are derived from measurements of different physical parameters, and thus are not directly comparable. In fact, the lower stratosphere is cooling substantially (by about ~0.5 K per decade), so the warming trend seen at the surface is expected to diminish with altitude and change into a cooling trend at some point in the troposphere. Even so, it has been suggested that the cooling trend seen in the satellite data is excessive. This difficulty in reconciling the information from these different sources has sparked a debate in the climate community about possible instrumental problems and the existence of global warming. Here we identify an artificial cooling trend in the satellite-derived temperature series caused by previously neglected orbital-decay effects. We find a new, corrected estimate of +0.07 K per decade for the MSU-based temperature trend which is in closer agreement with surface temperatures. We also find that the reported cooling of the lower troposphere, relative to the middle troposphere, is another artefact caused by uncorrected orbital-decay effects.
Orbital decay?

MSU discrepancies.

Wentz and Schabel, 1998

\[ \text{TLT} = 4 \times \text{NADIR} - 3 \times \text{LIMB} \]
MSU discrepancies.

Diurnal correction differences?

Tropical TLT Diurnal Cycle

Courtesy RSS (CCSM3)
Diurnal correction differences?

Mears et al, 2005

MSU discrepancies.
MSU discrepancies.

Target factor

\[ T_{\text{Earth}} = T_{\text{MEAS}} - \alpha T_{\text{TARGET}} + C + \epsilon \]

Something else?

Constant bias

Other errors

Christy et al, 2000; Mears et al, 2003; Zou et al, 2009
\[ T_{\text{Earth}} = T_{\text{MEAS}} - \alpha T_{\text{TARGET}} + C + \varepsilon \]

**Target factor**

- Constant bias
- Other errors

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Christy et al, 2000; Mears et al, 2003; Zou et al, 2009
\[ \Delta T_{m,n} = T_{W,m} \times \alpha_m + T_{W,n} \times \alpha_n + A_{m,n} \]

One equation for each time step and each pair of satellites used.

Christy et al, 2000
α-factor

NOAA-09.
\(\alpha\)-factor

NOAA-09.
This difference has been considered a structural uncertainty

\[ \alpha \text{-factor} \]
\[ H = \frac{1}{2}gt^2 \]
Structural uncertainty results when two equally valid methods yield different results.
\[ T_{\text{Earth}} = T_{\text{MEAS}} - \alpha T_{\text{TARGET}} + C + \epsilon \]

\[ \Delta T_{\text{Earth}} = \Delta \alpha \Delta T \]

\[ \Delta T_{\text{Earth}} \approx 0.06 \times 2.5K \]

\[ \Delta T_{\text{Earth}} \approx 0.15K \]
\[ T_{Earth} = T_{MEAS} - \alpha T_{TARGET} + C + \epsilon \]
John Christy, personal communication

NOAA-09.

UAH merger
RSS merger

Residuals

NOAA-6 minus NOAA-9

Mears et al, 2003
### NOAA-9 Target Factor

<table>
<thead>
<tr>
<th></th>
<th>RSS</th>
<th>UAH</th>
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<tbody>
<tr>
<td>Target Factor</td>
<td>0.0399</td>
<td>0.0986</td>
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<tr>
<td>Residual NOAA-9/NOAA-6 Trend</td>
<td>0.04 K/year</td>
<td>0.00 K/year</td>
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<td>Satellites used</td>
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UAH target factor is 2 times larger than that used for any other satellite.
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RSS leaves a larger residual trend between NOAA-6 and NOAA-9.
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RSS utilizes more satellites to constrain the target factor value.
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RSS uses only oceanic regions, which minimizes the influence of the diurnal cycle correction.
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Smoothing has seemingly small effects.
Is there a way forward?
Reported Signal

\[ T = T_o + \Delta T \]
Requested Signal Error

\[ T = T_o + \Delta T \]

\[ T_{MSU} - T_R = (T_o + \Delta T_{MSU}) - (T_o + \Delta T_R) \]
\[ T = T_o + \Delta T \]

\[ T_{MSU} - T_R = (T_o + \Delta T_{MSU}) - (T_o + \Delta T_R) \]

\[ T_{MSU} - T_R = \Delta T_{MSU} - \Delta T_R \]
Reported Error

\[ T = T_o + \Delta T \]

\[ T_{MSU} - T_R = (T_o + \Delta T_{MSU}) - (T_o + \Delta T_R) \]

\[ T_{MSU} - T_R = \Delta T_{MSU} - \Delta T_R \quad (\Delta T_{MSU} = -\Delta \alpha_i T_{TARGET,i} + \epsilon_i) \]
Reported Signal Error

\[ T = T_o + \Delta T \]

\[ T_{MSU} - T_R = (T_o + \Delta T_{MSU}) - (T_o + \Delta T_R) \]

\[ T_{MSU} - T_R = \Delta T_{MSU} - \Delta T_R \quad (\Delta T_{MSU} = -\Delta \alpha_i T_{TARGET,i} + \epsilon_i) \]

Regress versus the Target Temperature
NOAA-09.

- UAH TMT – NOAA TMT:
  \[ m = -0.053 \pm 0.010 \]
  \[ r^2 = 0.81 \]

- UAH TMT – RSS TMT:
  \[ m = -0.043 \pm 0.011 \]
  \[ r^2 = 0.69 \]

- RSS TMT – NOAA TMT:
  \[ m = -0.010 \pm 0.007 \]
  \[ r^2 = 0.25 \]
UAH radiances are significantly influenced by the temperature of the satellite itself.
UAH radiances are significantly influenced by the temperature of the satellite itself.
What is the impact of this bias?

47% of UAH-NOAA Difference
All of UAH-RSS Difference

\[ N9 \text{ drift} \]

TMT Trends
NOAA  0.127
RSS    0.080
UAH    0.038
Adj. UAH 0.080
(all in K/decade)
Surface Trend (K decade\(^{-1}\))

T24 Trend (K decade\(^{-1}\))

Slope: 1.60

- BCCR–BCM2.0
- CCCMA–CGCM3.1–T47
- CCCMA–CGCM3.1–T63
- CNRM–CM3
- CSIRO–Mk3.0
- CSIRO–Mk3.5
- GFDL–CM2.0
- GFDL–CM2.1
- GISS–AOM
- GISS–EH
- GISS–ER
- FGOALS–g1.0
- INGV–ECHAM4
- INM–CM3.0
- IPSL–CM4
- MIROC3.2–hires
- MIROC3.2–medres
- MPI–ECHAM5
- NCAR–CCSM3.0
- UKMO–HadCM3
- UKMO–HadGEM1
- RSS
- UAH
- NOAA
- HADAT2
- IUK
- RAOBCORE
- RICH
- RATPAC
Surface Trend (K decade$^{-1}$)

T24 Trend (K decade$^{-1}$)

Slope: 1.60

Graph showing the relationship between Surface Trend and T24 Trend with various symbols for different models and datasets.
NOAA-09.

Surface Trend (K decade$^{-1}$)

T24 Trend (K decade$^{-1}$)

Slope: 1.60

"Old" Radiosondes

BCCR–BCM2.0
CCCMA–CGCM3.1–T47
CNRM–CM3
CSIRO–Mk3.0
CSIRO–Mk3.5
GFSL–CM2.0
GFSL–CM2.1
GISS–AOM
GISS–EH
GISS–ER
FGOALS–g1.0
INGV–ECHAM4
INM–CM3.0
IPSL–CM4
MIROC3.2–hires
MIROC3.2–medres
MPI–ECHAM5
NCAR–CCSM3.0
UKMO–HadCM3
UKMO–HadGEM1
RSS
UAH
NOAA
HADAT2
IUK
RAOB
RICH
RATPAC
NOAA-9 addresses some of the differences. What about the others?
Other discrepancies.

Tropical (30° NS) RSS – UAH TMT Difference

Tropical (30° NS) RSS – UAH TLT Difference

TLT versus TMT

38/52
Other discrepancies.

CCSM3.0 TLT Diurnal Cycle (RSS)
Other discrepancies.

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Other discrepancies.
Other discrepancies.
Other discrepancies.

• The effect of the diurnal cycle drift can be similar to warm target effect

• Diagnosing drifts in the diurnal cycle correction or warm target temperature is important in reconciling trends

• No perfect reference

• Some studies using radiosondes (e.g. Randall and Herman, 2008; Christy et al. 2010) indicate that the diurnal drift correction for RSS is too large for TLT

• Over long time scales, radiosondes are a less reliable reference
Conclusions Part I.

- UAH has a significant bias that reduces the mid-tropospheric trend
  - The UAH merging procedure is biased
- UAH should increase \( \sim 0.04 \) K/decade
- There is evidence that tropical differences are related to the treatment of diurnal drift
Mears et al, 2011

Uncertainties are large...
Upper Tropospheric Warming

Model Estimated Warming

Similar to Thorne et al, 2011

But maybe models are overestimating amplification...
Future work.

- Continue to work on diurnal drift discrepancy
- Explore differences between CMIP5 and observations
  - Amplification
  - Land/Ocean differences
- Stability changes between the mid- and upper-troposphere
- Mean tropical temperature profile
• Professor Qiang Fu and Dr. Celeste Johanson

• Fu Research Group

• Dr. Cheng-Zhi Zou (NOAA), Dr. Carl Mears (RSS), Dr. John Christy (UAH) for helpful comments and criticisms

• NOAA Grant NA08OAR4310725 and NESDIS-NESDISPO-2009-2001589 (SDS-09-15)
Questions?