Atmospheric Temperature Trends from Observations – an Update and Recent Advances

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WCRP/SPARC Activity on Temperature Changes

Activity on Atmospheric Temperature Changes & their Drivers (ATC)

The aim is to improve knowledge on atmospheric temperature variability and trends, and their uncertainty in climate data records (CDRs).

- Evaluation of atmospheric temperature observations
- With a focus on new high-vertically resolved RO observations
- Comparison with (chemistry) climate models and reanalyses
- Attribution of atmospheric temperature changes

<https://www.sparc-climate.org/activities/temperature-changes/>
Aim: Ensure that the climate system is monitored sufficiently homogeneous, stable and accurate

Climate monitoring principles
Fundamental Climate Data Records (FCDR & CDRs)
- traceability to reliable reference standards
- long-term stability
- homogeneity & reproducibility
- global and temporal coverage
- accuracy and adequate resolution in space and time

Essential Climate Variable (ECV) upper-air temperature
- horizontal resolution: 25 km in UT, 100 km in LS
- vertical resolution: 1 km UT, 2 km LS
- accuracy (root-mean-square) < 0.5 K
- stability of 0.05 K per decade (GCOS 2016)
Comparison of Atmospheric Observations

Radiosondes, Microwave sounders, GNSS Radio Occultation

- **Radiosondes (RS):** weather balloons, direct measurement
  + Long time series, high vertical resolution
  - Sparse spatial coverage, instrumentation changes need homogenization
Comparison of Atmospheric Observations

Radiosondes, Microwave sounders, GNSS Radio Occultation

- **Nadir sounders**: Earth’s radiance at MW or IR frequencies
  + Long time series (40 years), good spatial coverage
  – Low vertical resolution – layer average temperature, need sophisticated calibration

![Diagram of atmospheric layers with pressure and height axes](http://www.remss.com)
Comparison of Atmospheric Observations

Radiosondes, Microwave sounders, GNSS Radio Occultation

- **GNSS RO**: limb sounding, refraction of GPS signals
  - Long-term stability, high vertical resolution, good spatial coverage
  - High consistency and quality in UTLS, no inter-mission calibration
- Short time series (2001 – ongoing),
  - Influence of background field at high and lowest altitudes
Layer average brightness temperatures
- Stratospheric Sounding Unit (SSU) merged timeseries
- Microwave Sounding Unit (MSU) and Advanced MSU timeseries

Vertically resolved temperatures
- Radiosondes (RS), GNSS RO, ERA-Interim, ERA5

(MLS: Microwave Limb Sounder, SABER: Soundings of the Atmosphere using Broadband Emission Radiometry)
Revisiting the Mystery of Recent Stratospheric Temperature Trends


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Stratospheric Observations

- SSU observations 1978-2006
- IR radiances, 3 channels
- Differences in observations from NOAA & UKMO and to model simulations
- SSU reprocessed CDRs (different corrections and merging methods, overlap periods needed)
- Smaller differences (right), still some discrepancies
- Vertical consistency (bottom) improved in both data sets, better for NOAA

Maycock et al. 2018

Merged SSU-AMSU & (A)MSU observations compared to new chemistry climate models (CCMI)

Substantially better agreement between observed and modeled stratospheric temperature trends than in former data version

Due to improved observations while models have not changed much
- New SSU merged data
  SSU-MLS, SSU-AMSU
- MSU4-AMSU9
- Linear regression
- Global mean trends are consistent
- Magnitude of cooling increases with height
- Stratospheric trends
  -0.7 K/dec at 40-50 km
  -0.6 K/dec at 35-45 km
  -0.5 K/dec at 25-35 km
  -0.2 K/dec at 15-20 km

[Zou and Qian 2016, Randel et al. 2016]
- New SSU merged data
  SSU-MLS, SSU-AMSU
- MSU4-AMSU9
- Split trends
- Weaker stratospheric cooling after ~1995 (ozone recovery) compared to 1979-1995 (ozone depletion)

- 1979-1995 & 1995-2018
  -1.2 & -0.4 K/dec SSU3
  -1.0 & -0.3 K/dec SSU2
  -0.8 & -0.3 K/dec SSU1
  -0.5 & 0 K/dec at MSU4
- **MSU channels**
- TLS: MSU4+AMSU9
- TTS: MSU3+AMSU7
- TMT: MSU2+AMSU5
- Linear regression
- Global mean trends are consistent
- Trends 1979-2018
  - -0.21 K/dec for TLS
  - +0.09 K/dec for TTS
  - +0.15 K/dec for TMT

[Zou and Wang 2010, Mears and Wentz 2016, Mears et al. 2017]
- Multiple Linear Regression
- Variability Indices
- Solar
- ENSO
- Aerosol
- QBO
Stratospheric Trends 1979–2018

- **SSU merged**
  - SSU-MLS
  - SSU-AMSU

- Latitude-resolved trends 1979-2018

- Multiple linear regression

- Largest at N high lats

- Smaller at S high lats

- Larger uncertainty at high latitudes due to larger variability
- **MSU channels**
- Latitude-resolved trends 1979-2018
- Multiple linear regression
- Larger uncertainty at high latitudes
Overview on Layer Trends SSU & MSU

**Tropics 20°S–20°N**

- SSU3
  - SSU-MLS
  - SSU-AMSU

- SSU2
  - SSU-MLS
  - SSU-AMSU

- SSU1
  - SSU-MLS
  - SSU-AMSU

- MSU4
  - UAH
  - RSS
  - STAR

- MSU3
  - UAH
  - RSS
  - STAR

- MSU2
  - UAH
  - RSS
  - STAR

**Global 70°S–70°N**

- SSU-MLS
- SSU-AMSU

- UAH
- RSS
- STAR

Trend (K/decade)
Preliminary new radiosonde datasets: RISE (RICH) and RASE (Raobcore)
ERA5, Vaisala radiosondes, RO

RO WEGC: https://doi.org/10.25364/WEGC/OPS5.6:2019.1; Schwärz et al. (2016), Angerer et al. (2017)
Vertically Resolved Trends – RO, RS 2002-2017

More on trends from RO in presentations by:
- Florian Ladstädter on climatological trends from RO (today)
- Poster on temperature impact of volcanic eruptions (by M. Stocker)
- Gottfried Kirchengast on atmospheric heat content from RO (today)
- Hallgeir Wilhelmsen on double tropopauses from RO (Monday)
Conclusions

- Layer average temperature data SSU & MSU substantially improved
- Atmospheric temperature changes observed
- Stratospheric cooling 1979–2018 of -0.2 to -0.8 K/dec from SSU & MSU4
- Weaker stratospheric cooling after 1995 (ozone recovery)
- Tropospheric warming 1979–2018 of ~0.15 K/dec from MSU observations
- RO provide information on vertically resolved trends with global coverage

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