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Atmospheric Temperature Trends from Observations – an Update and Recent Advances

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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


1st ATC Workshop 2016, Graz, Austria


2nd ATC Workshop 2018, Paris, France

<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

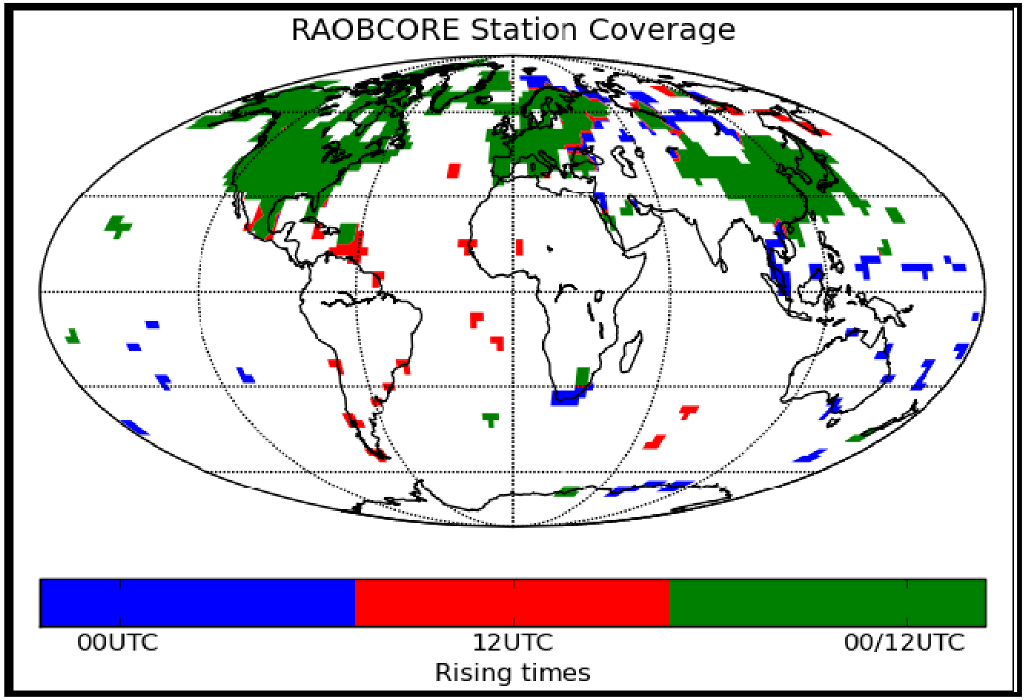
Essential Climate Variable (ECV) upper-air temperature

- 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)

[GCOS-154 2011, GCOS-200 2016: Box 8 and Table 23, Annex A]

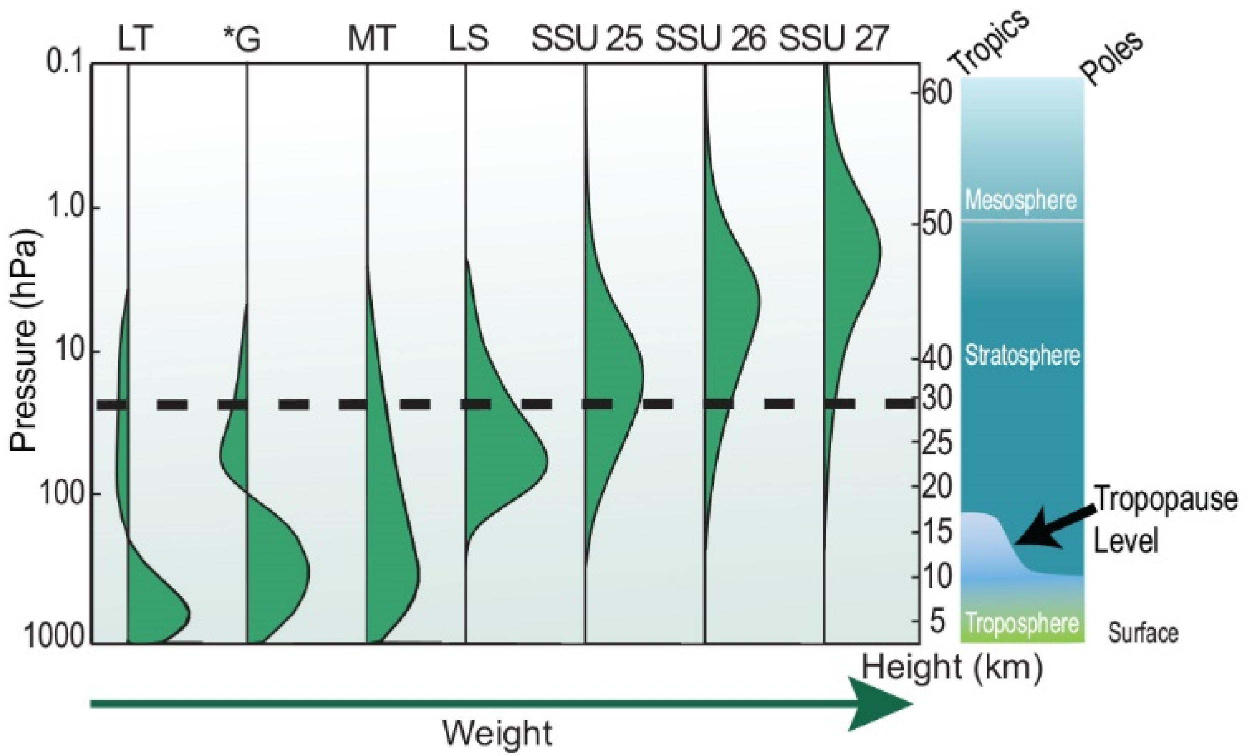
Radiosondes, Microwave sounders, GNSS Radio Occultation

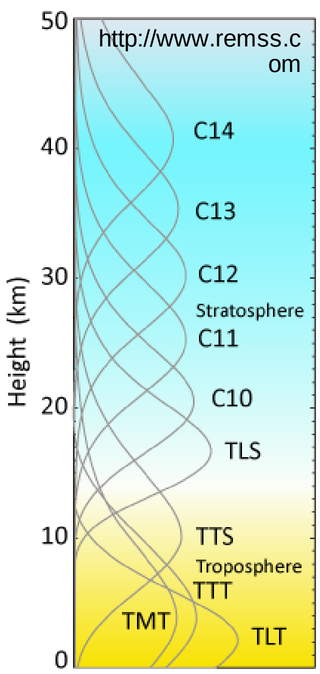
- **Radiosondes (RS):** weather balloons, direct measurement
  + Long time series, high vertical resolution
  – Sparse spatial coverage, instrumentation changes
  need homogenization



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



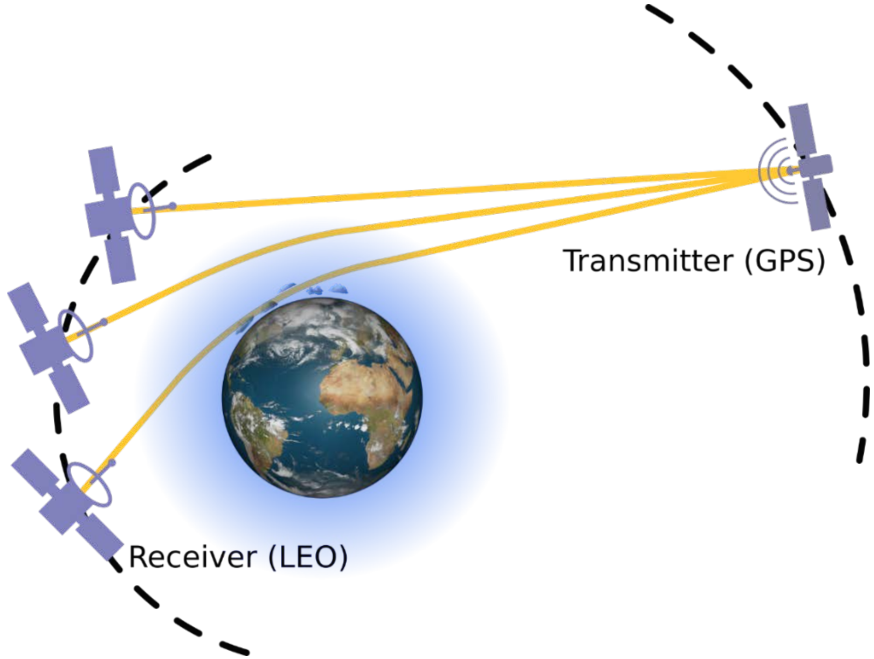


Radiosondes, Microwave sounders, GNSS Radio Occultation

- **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

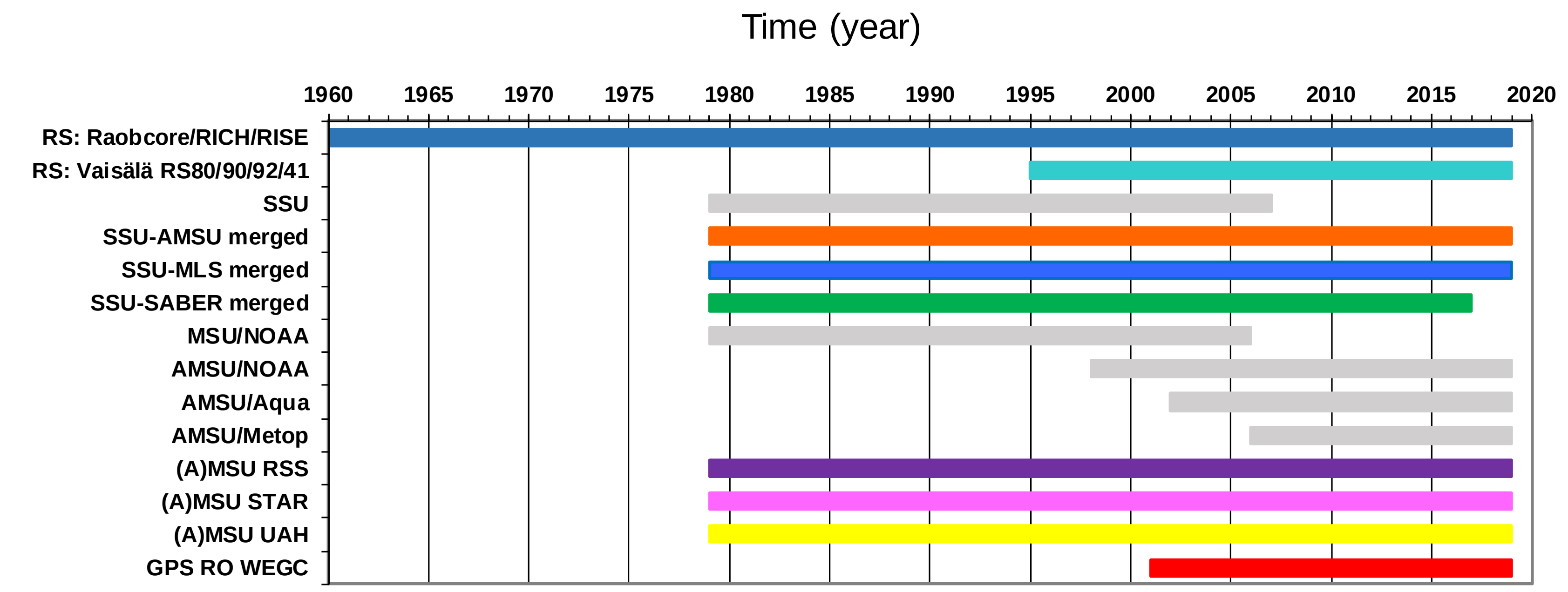


Layer average brightness temperatures

- 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, SABERSounding of the Atmosphere using Broadband Emission Radiometry

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Geophysical Research Letters

FRONTIER ARTICLE

10.1029/2018GL078035

Key Points:

- There is substantial improvement in the comparison between modeled and observed stratospheric temperature trends over the satellite era
- Observations and models show weaker stratospheric cooling since ~1998 when ozone-depleting substances have been declining in the atmosphere
- Larger differences exist between modeled and observed stratospheric temperature trends at high latitudes partly due to internal variability

Revisiting the Mystery of Recent Stratospheric Temperature Trends

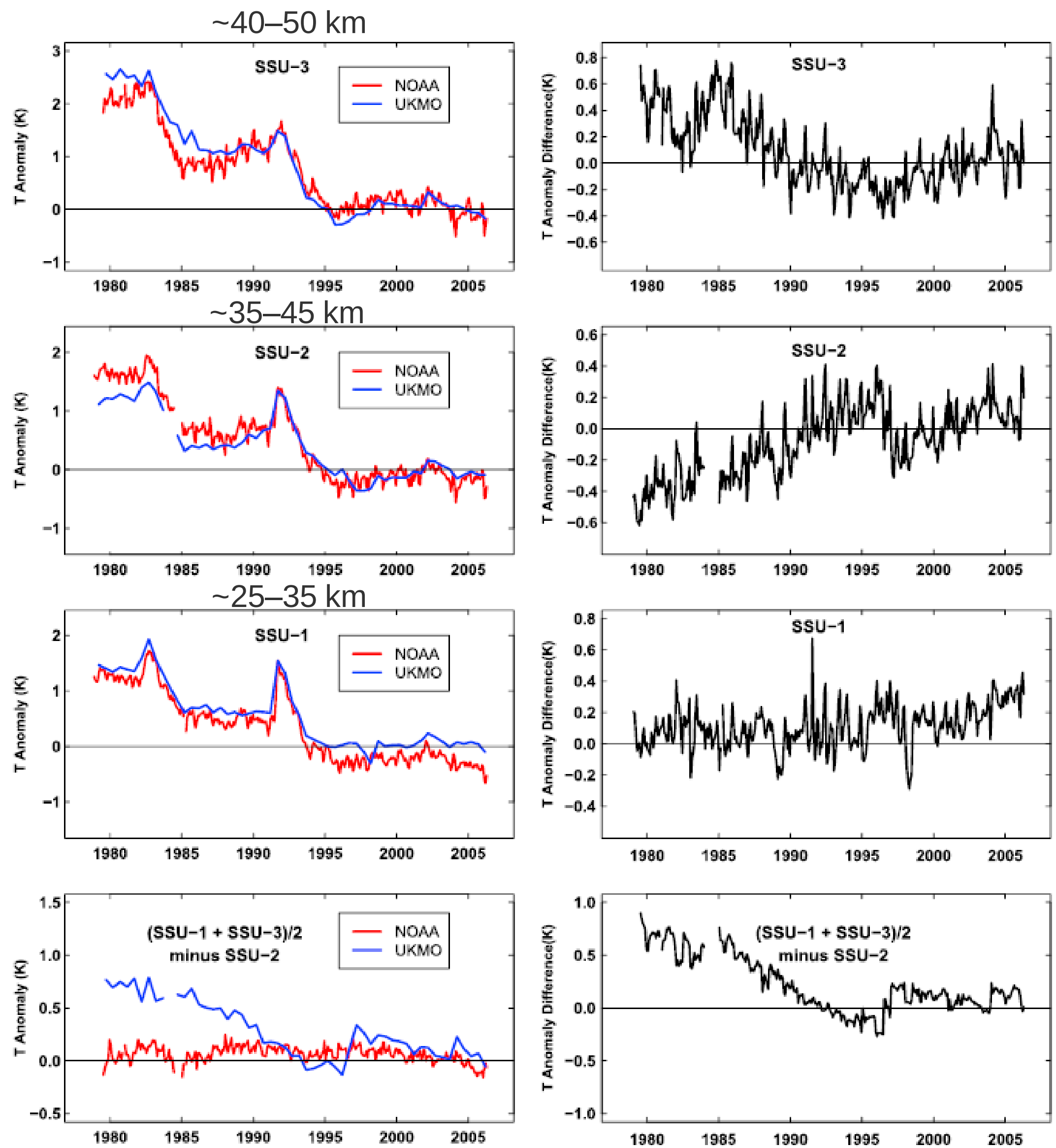
Amanda C. Maycock[1], William J. Randel[2], Andrea K. Steiner[3,4], Alexey Yu Karpechko[5], John Christy[6], Roger Saunders[7], David W. J. Thompson[8], Cheng-Zhi Zou[9], Andreas Chrysanthou[1], N. Luke Abraham[10,11], Hideharu Akiyoshi[12], Alex T. Archibald[10,11], Neal Butchart[13], Martyn Chipperfield[1], Martin Dameris[14], Makoto Deushi[15], Sandip Dhomse[1], Glauco Di Genova[16], Patrick Jöckel[14], Douglas E. Kinnison[2], Oliver Kirner[17], Florian Ladstädter[3,4], Martine Michou[18], Olaf Morgenstern[19], Fiona O'Connor[13], Luke Oman[20], Giovanni Pitari[21], David A. Plummer[22], Laura E. Revell[23,24,25], Eugene Rozanov[24,26], Andrea Stenke[24], Daniele Visioni[16,21], Yousuke Yamashita[27,28], and Guang Zeng[19]

[1]School of Earth and Environment, University of Leeds, Leeds, UK, [2]Atmospheric Chemistry, Observations and Modeling Laboratory, National Center for Atmospheric Research, Boulder, CO, USA, [3]Wegener Center for Climate and Global Change, University of Graz, Graz, Austria, [4]Institute for Geophysics, Astrophysics, and Meteorology/Institute of Physics, University of

<https://doi.org/10.1029/2018GL078035>

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



[Thompson et al. 2012, Zou et al. 2014, Nash and Saunders 2015, Seidel et al. 2016]

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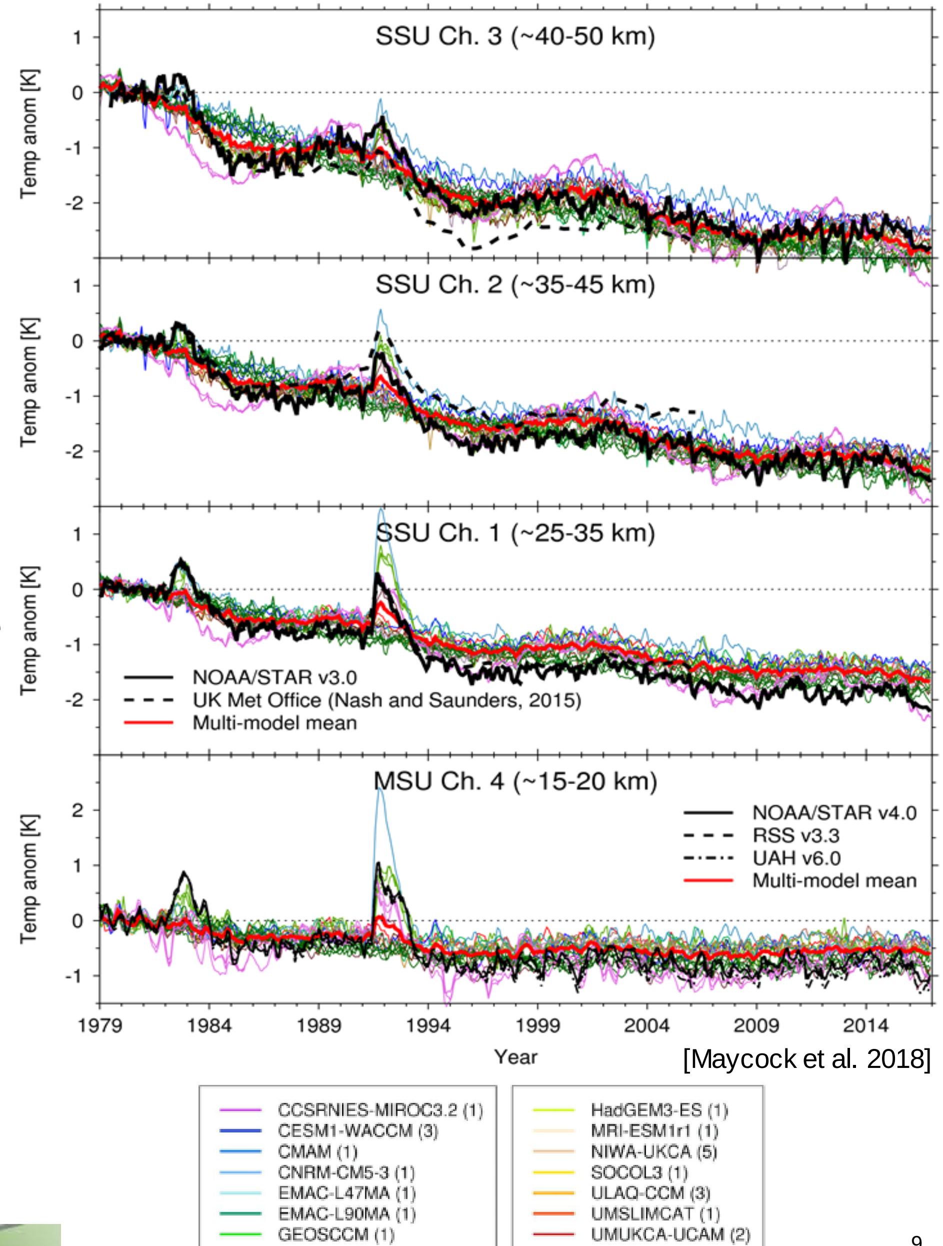
- **Maycock et al. 2018**
- Merged SSU-AMSU & (A)MSU observations compared to new chemistry climate models (CCMI)
- Substantially better agreement between observed and modeled stratospheric temperature trends than in former data version
- Due to improved observations while models have not changed much

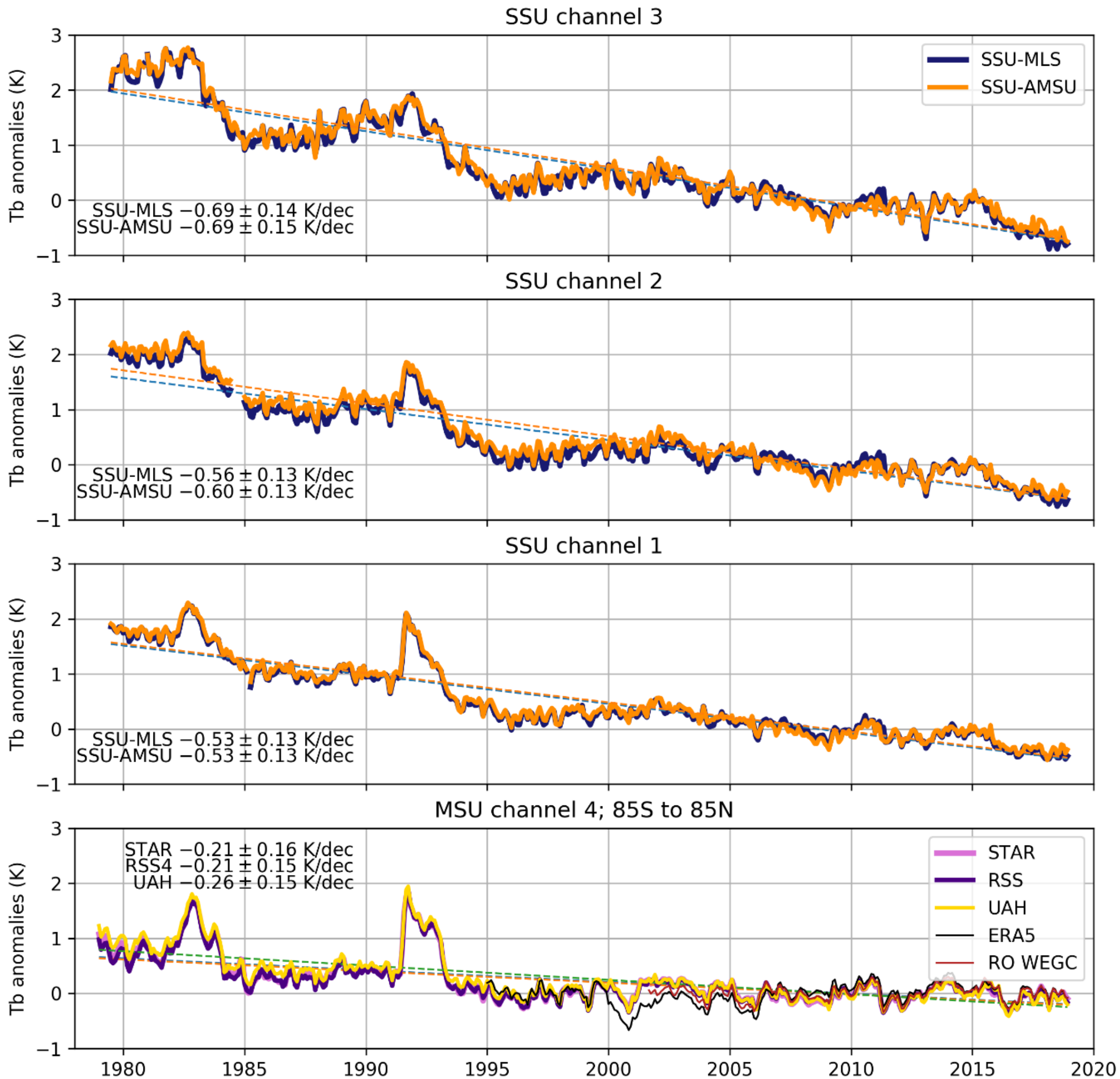


[Maycock et al. 2018]

Reference period 1979-1981

Stratospheric Observations 1979–2018

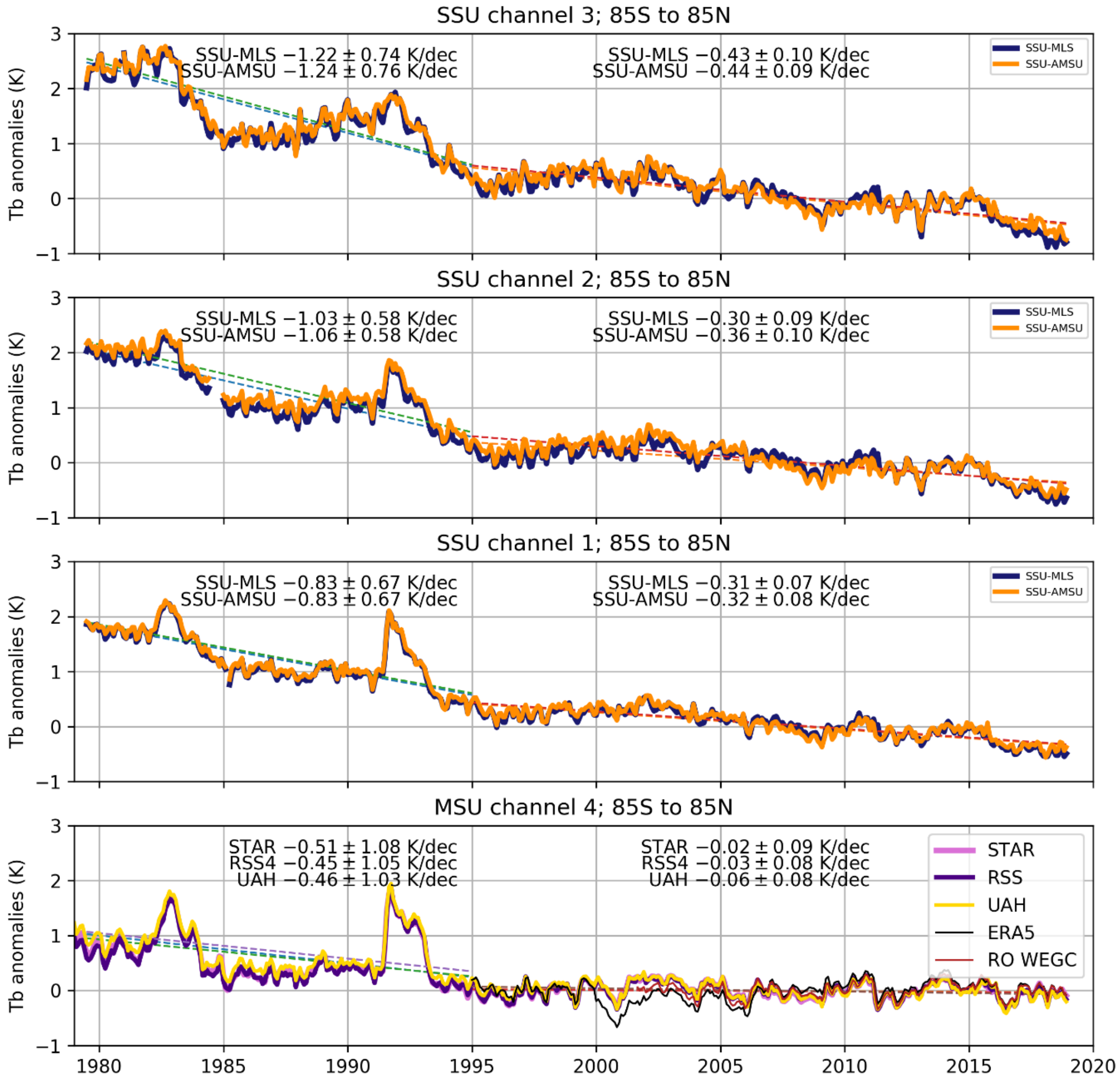
- **New SSU merged data SSU-MLS, SSU-AMSU**
- **MSU4-AMSU9**
- Anomaly reference period 2002–2016
- Linear regression
- Global mean trends are consistent
- Magnitude of cooling increases with height
- Stratospheric trends
  -0.7 K/dec at 40-50 km
  -0.6 K/dec at 35-45 km
  -0.5 K/dec at 25-35 km
  -0.2 K/dec at 15-20 km



[Zou and Qian 2016, Randel et al. 2016]

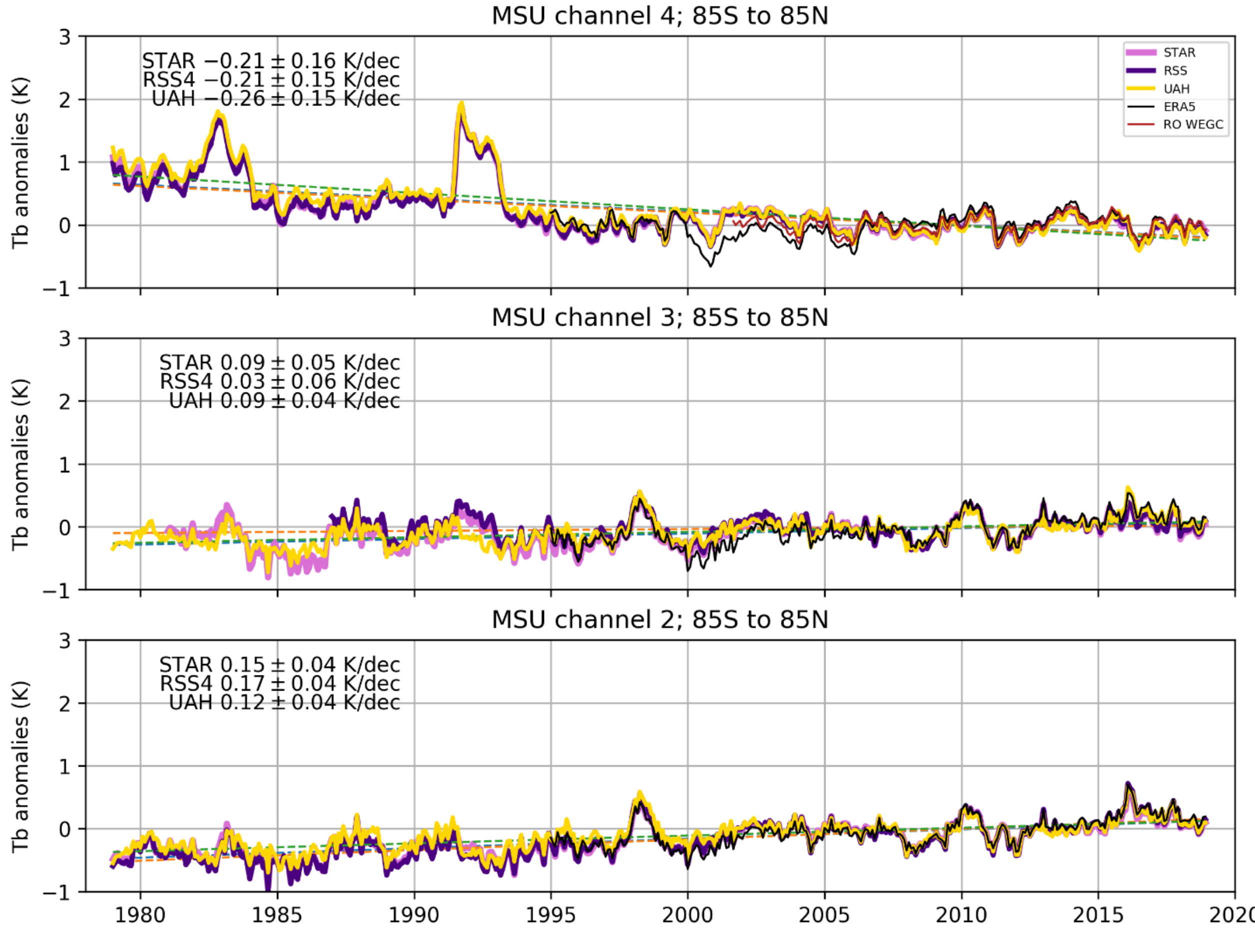
Stratospheric Observations 1979–2018

- **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



Tropospheric/Stratosph. Observations 1979–2018

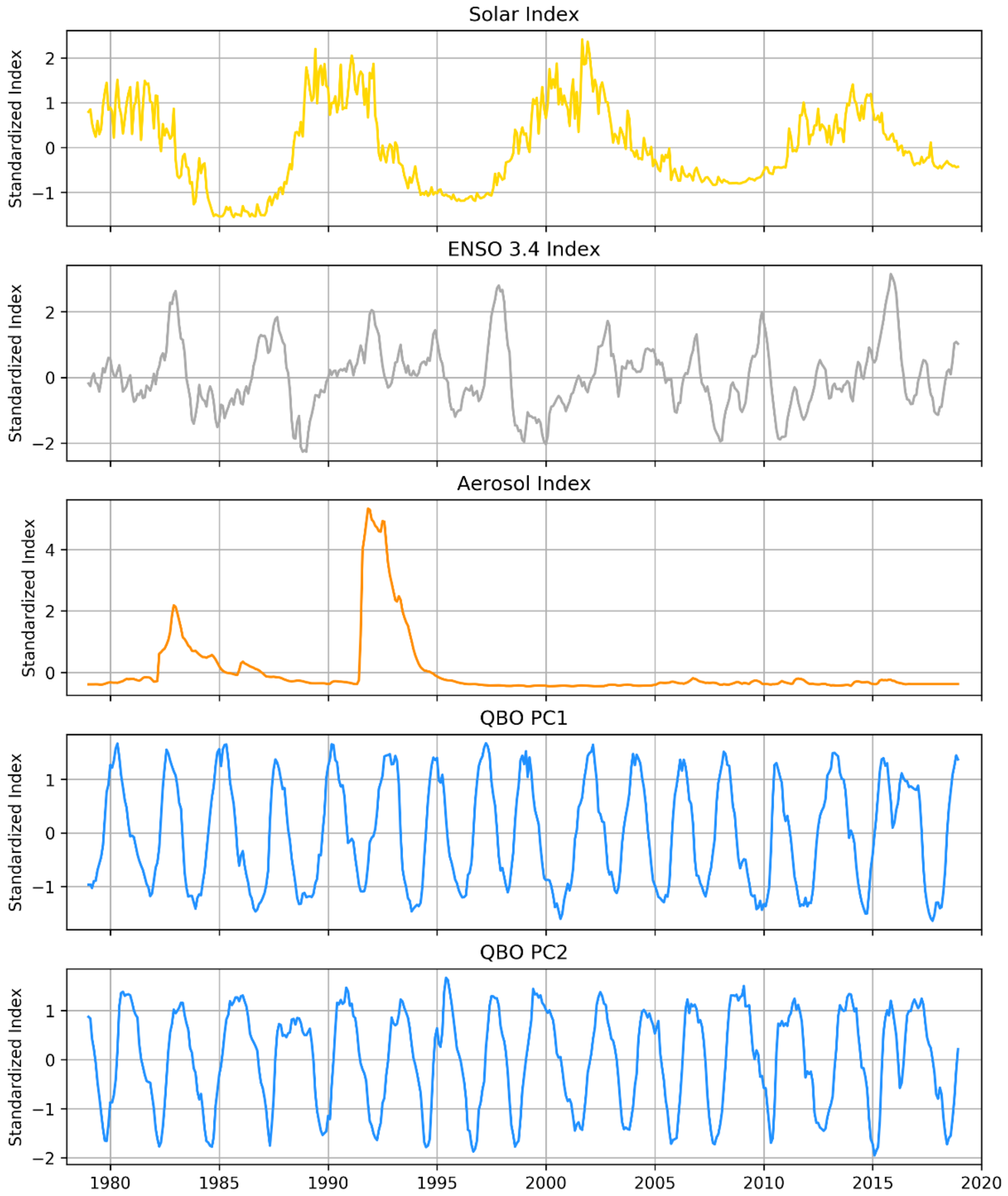
- **MSU channels**
- TLS: MSU4+AMSU9
  TTS: MSU3+AMSU7
  TMT: MSU2+AMSU5
- Anomaly reference period 2002–2016
- Linear regression
- Global mean trends are consistent
- Trends 1979-2018
  -0.21 K/dec for TLS
  +0.09 K/dec for TTS
  +0.15 K/dec for TMT



[Zou and Wang 2010, Mears and Wentz 2016, Mears et al. 2017]

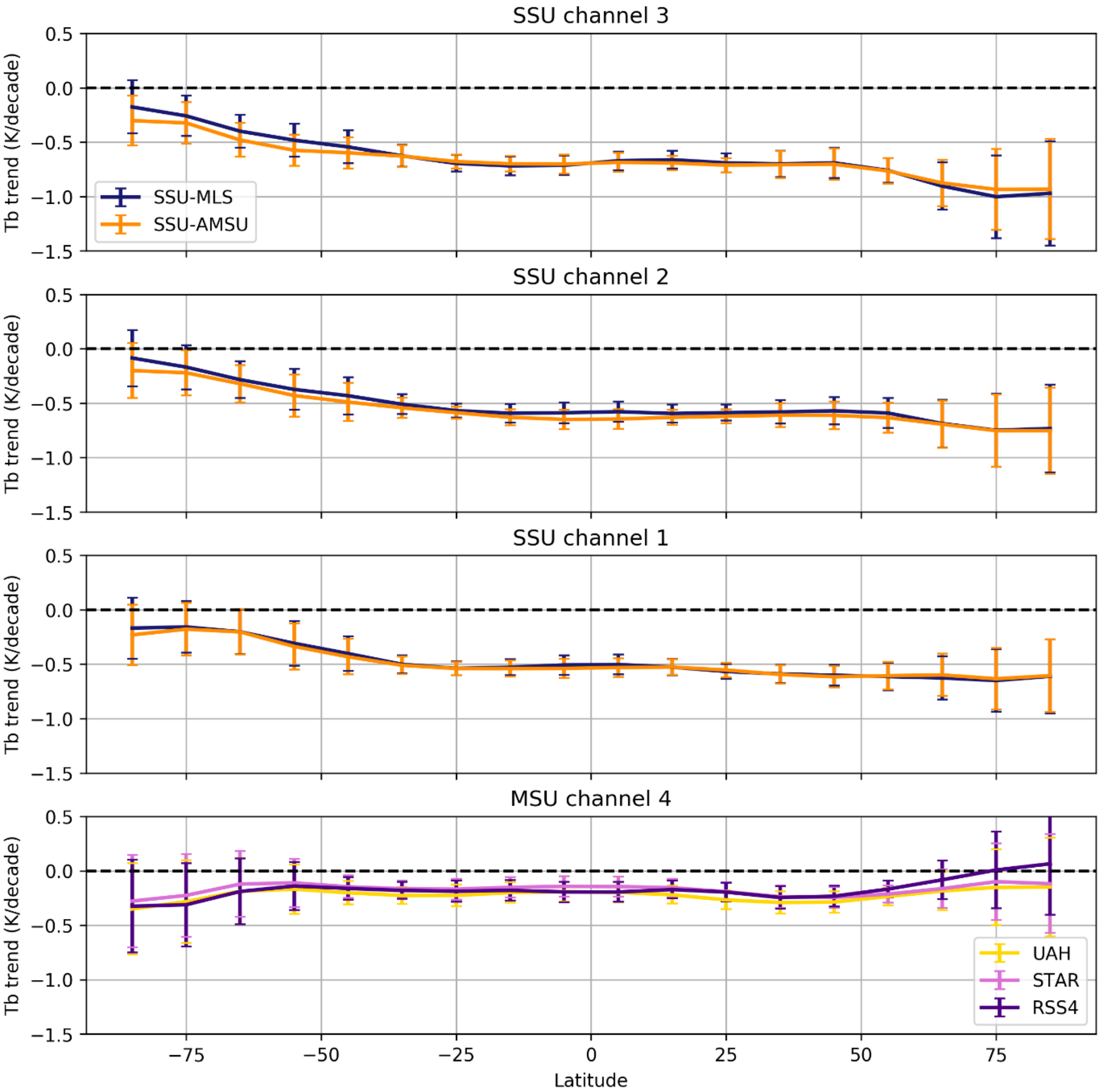
Atmospheric Variability Indices

- **Multiple Linear Regression**
- **Variability Indices**
- Solar
- ENSO
- Aerosol
- QBO



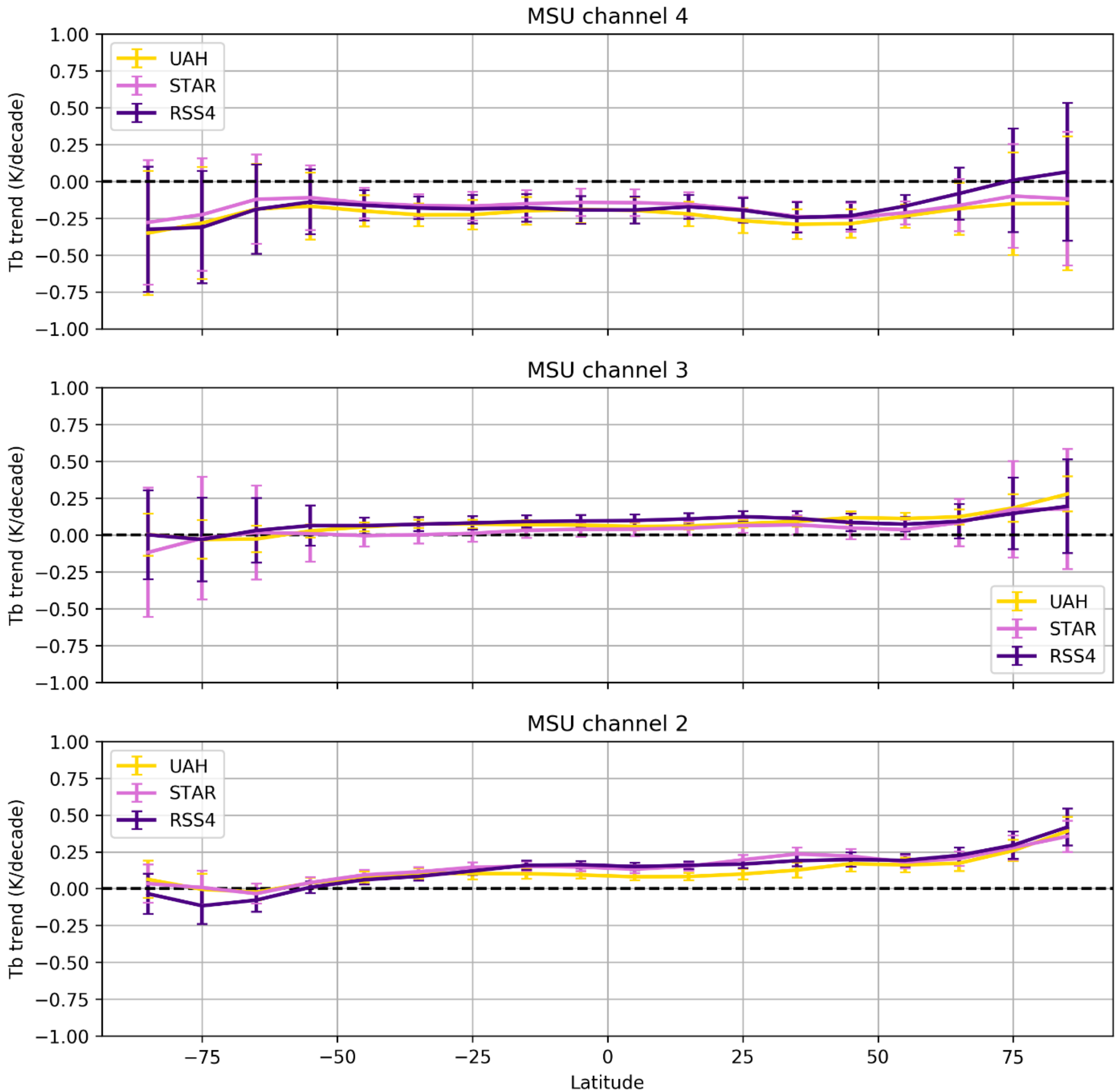
Stratospheric Trends 1979–2018

- **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

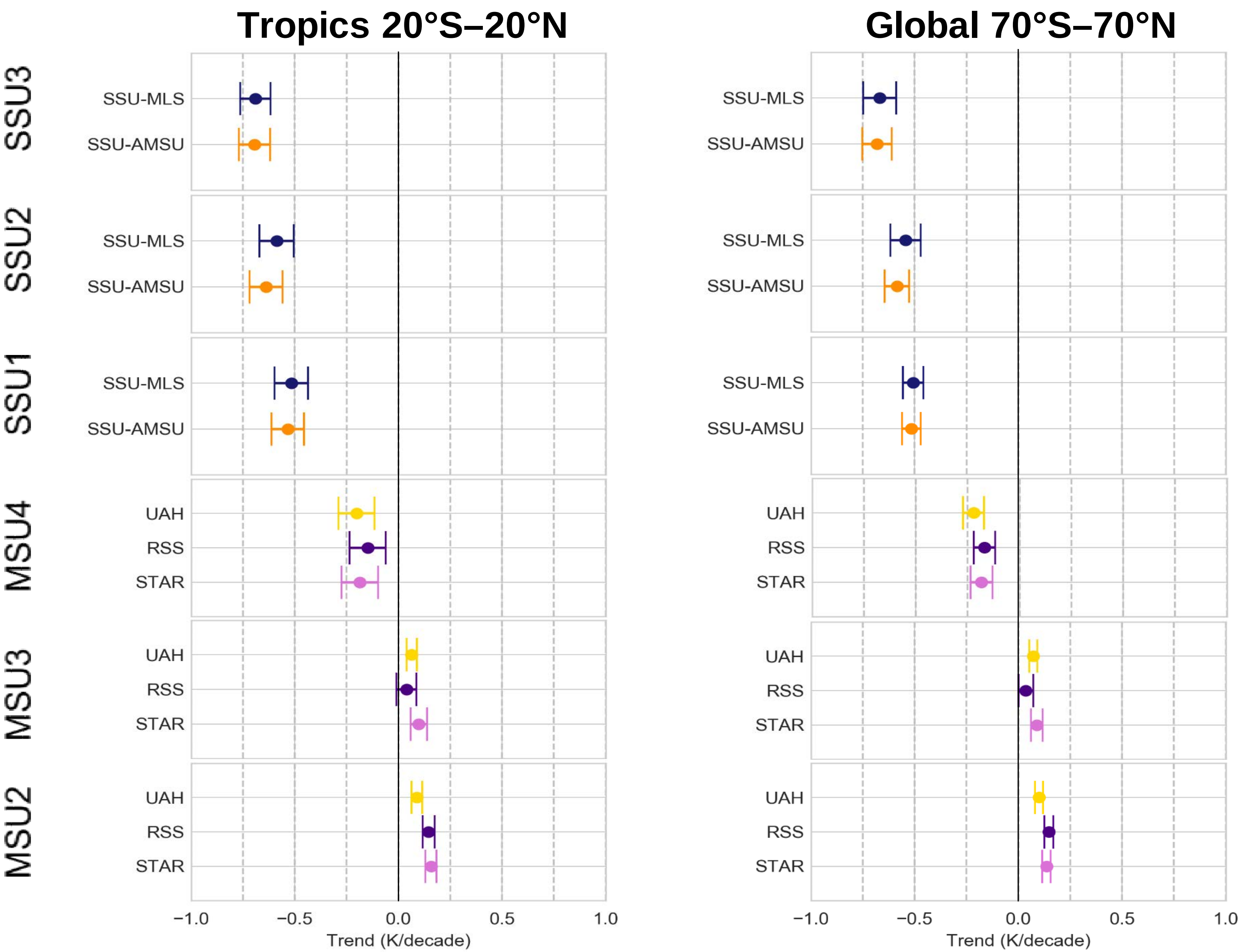


Tropospheric/Stratospheric Trends 1979–2018

- **MSU channels**
- Latitude-resolved trends 1979-2018
- Multiple linear regression
- Larger uncertainty at high latitudes



Overview on Layer Trends SSU & MSU



Vertical Trends 1980–2018 – Radiosondes

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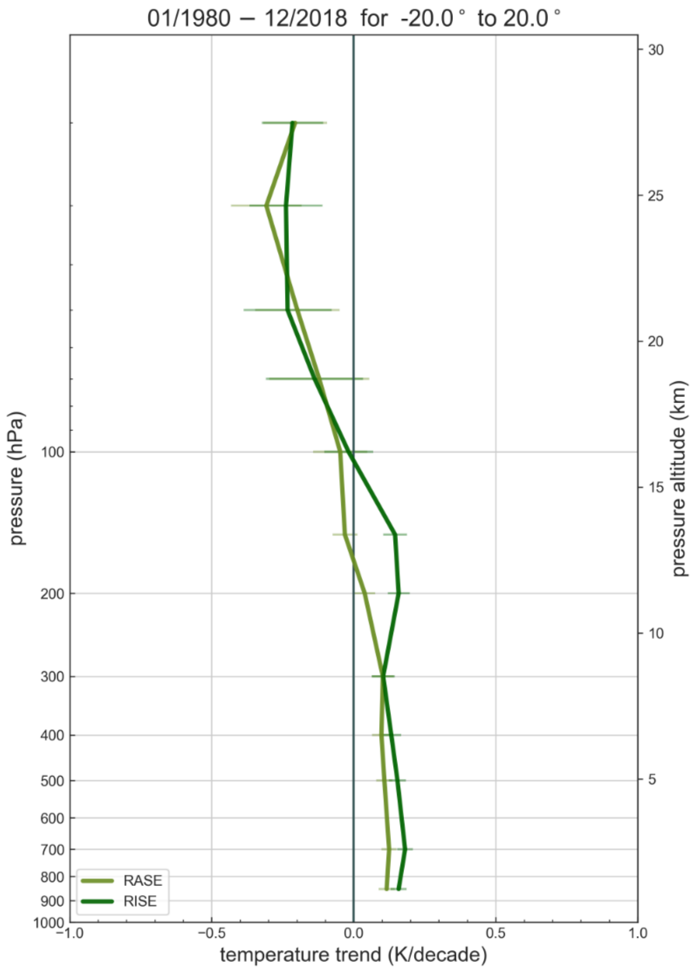
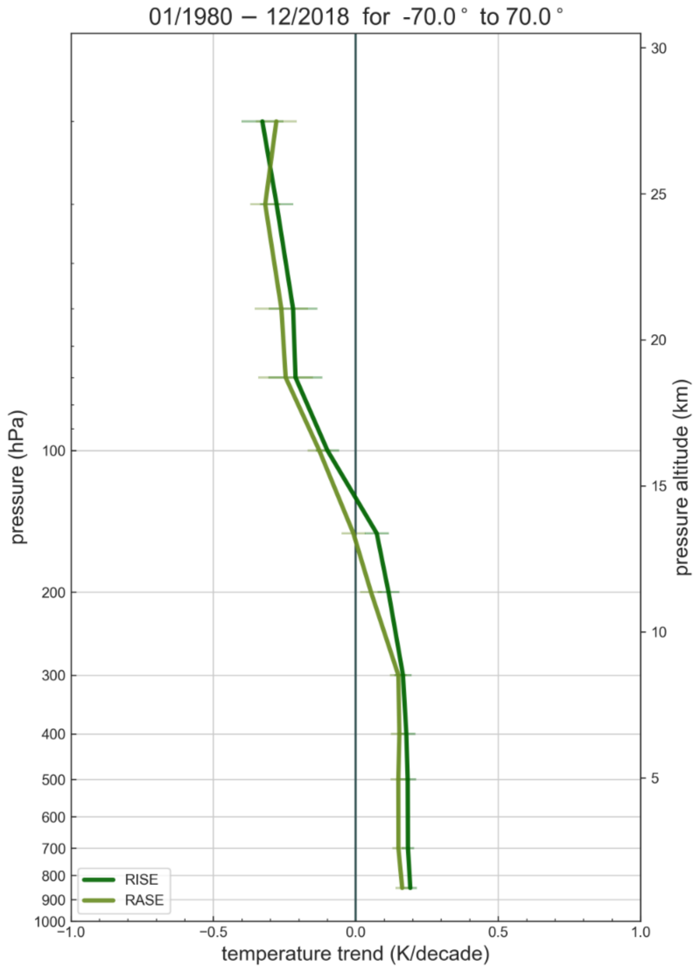
Tropics 20°S–20°N



Global 70°S–70°N

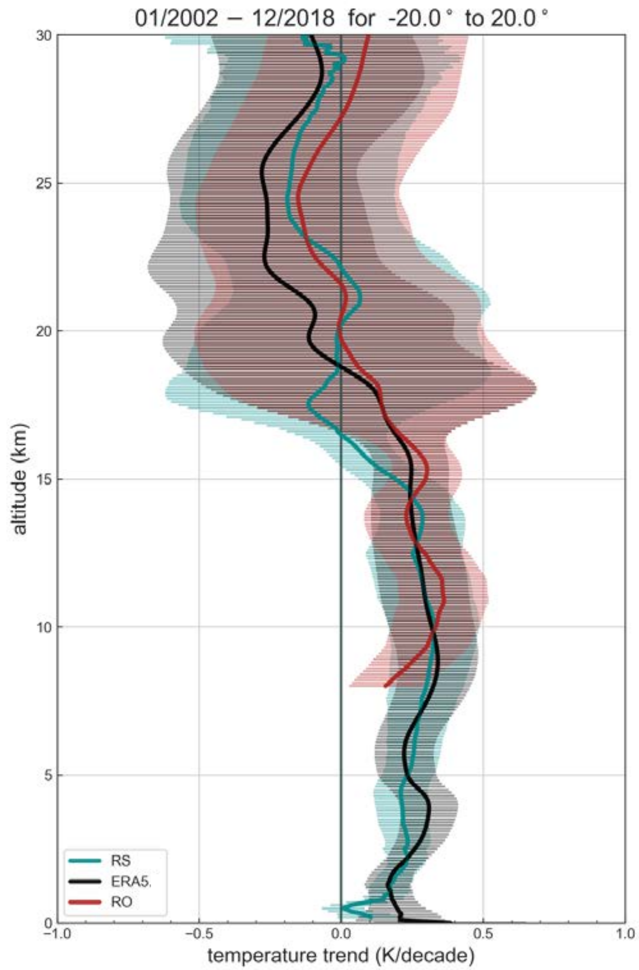


- **Prelim.new radiosonde datasets: RISE (RICH) and RASE (Raobcore)**

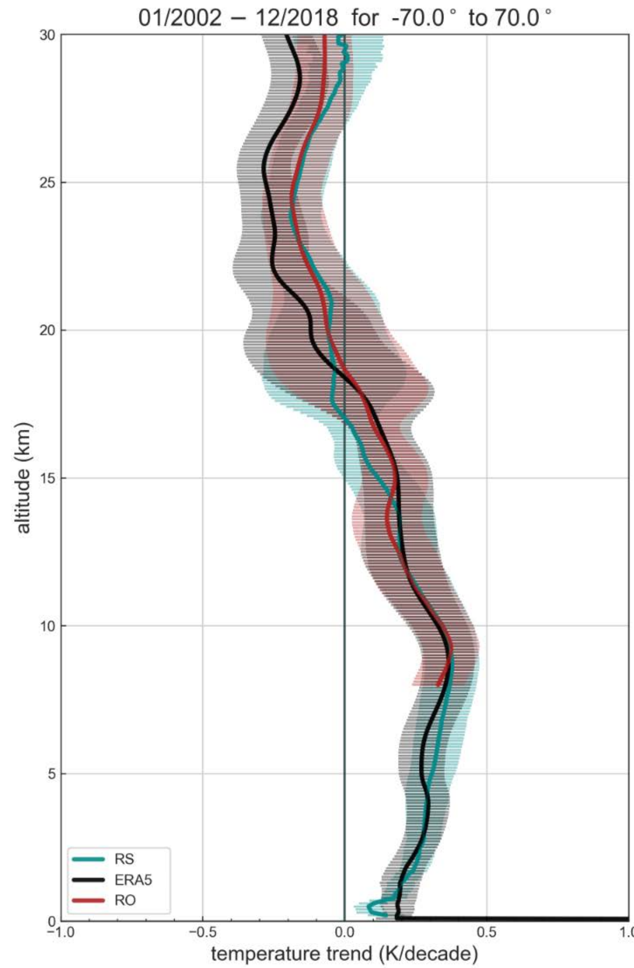
[Haimberger, University of Vienna]

Vertical Trends 2002–2018 – RS, ERA5, RO

Tropics 20°S–20°N



Global 70°S–70°N

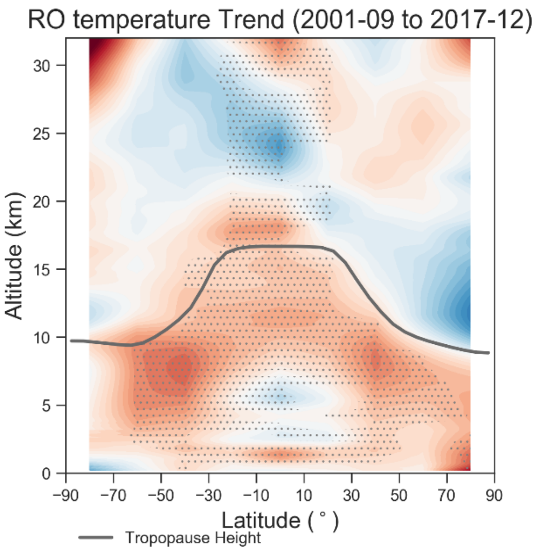


- **ERA5, Vaisala radiosondes, RO**

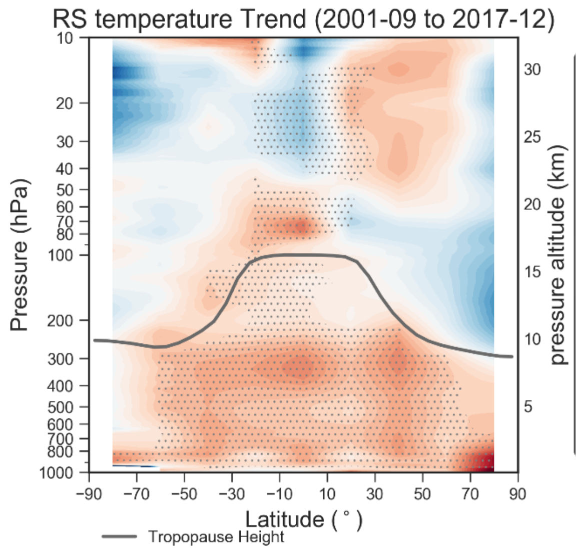
RO WEGC: https://doi.org/10.25364/WEGC/OPS5.6:2019.1; Schwärz et al. (2016), Angerer et al. (2017)

Vertically Resolved Trends – RO, RS 2002-2017

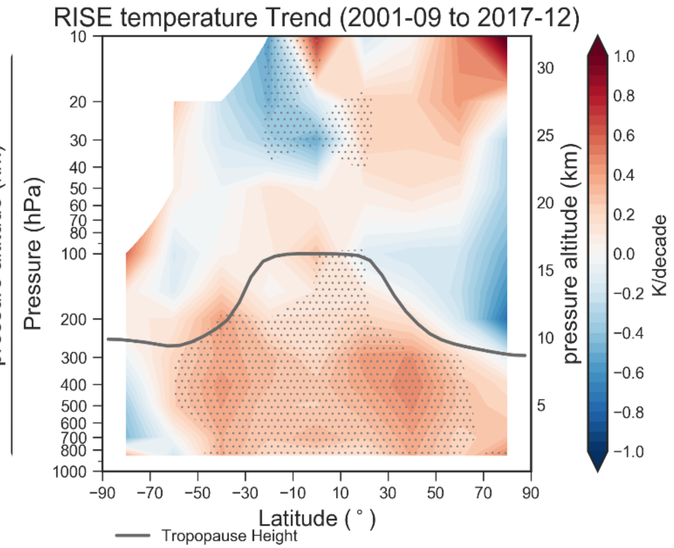
RO



RS Vaisala80/90/92



RISE



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

Thanks for funds to: esa asap FFG FWF