Stratospheric Temperature Trends

Our Evolving Understanding

and

Applications of GNSS-RO Observations

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ECMWF - ROM SAF Workshop on Applications of GPS-RO Observations

ECMWF, Reading, UK 16-18 June 2014

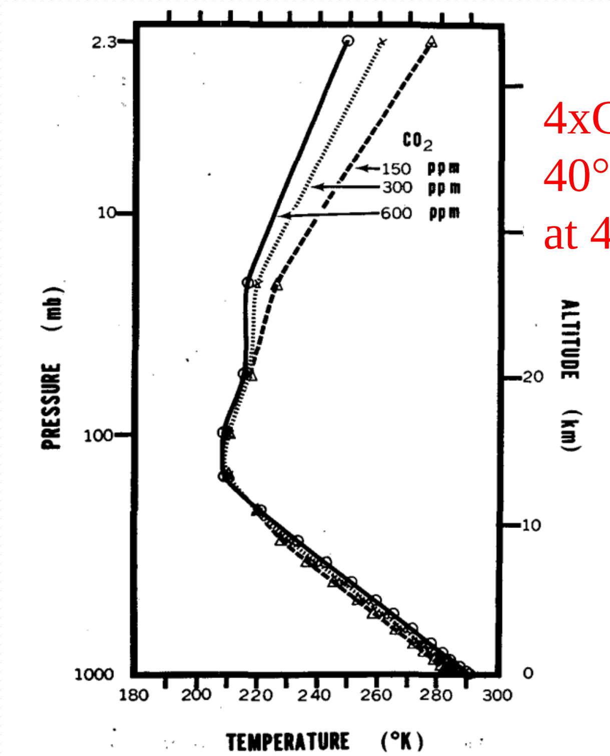
Objectives

- Review observed long-term stratospheric T changes
  - Radiosondes
  - Microwave Sounding Unit
  - Stratospheric Sounding Unit
  - Reanalyses
  - Not discussing GPS-RO. See Steiner et al. (2013), Ao et al. (2012), Ho et al. (2009, 2012), Leroy et al. (2008), Ringer and Healy (2008)2011, …
- Highlight areas of uncertainty, observational gaps
- Suggest questions for assessing value and limitations of RO observations

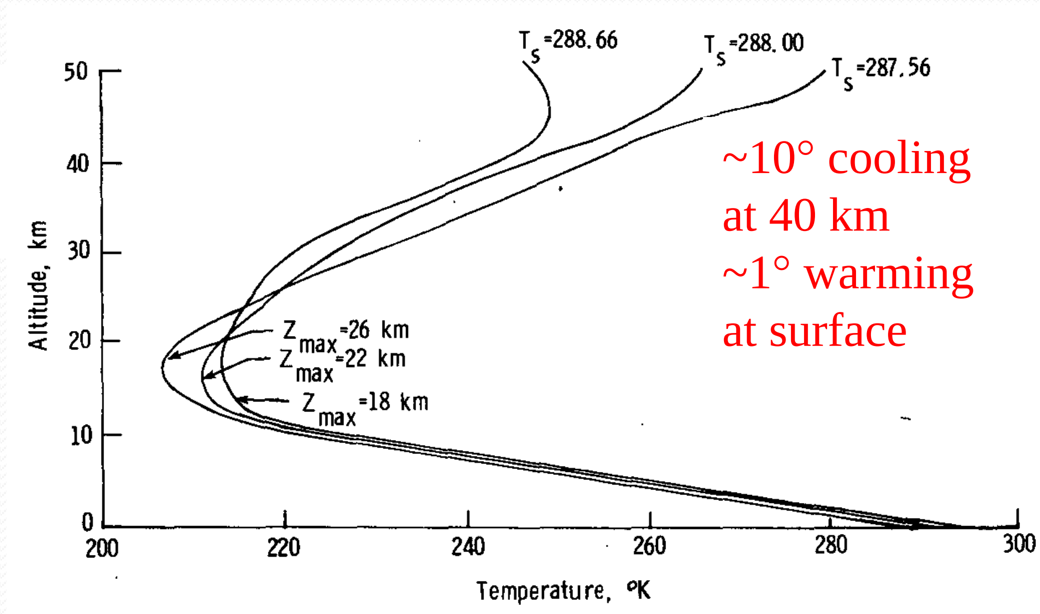
Why do we care about stratospheric temperature change?

- Detection and attribution of climate change
  - Greenhouse gases
  - Stratospheric ozone
- Understanding climate processes that are difficult to measure directly
  - Stratospheric water vapor (T changes at tropical tropopause)
  - Stratospheric circulation (latitudinal structure of T changes)

Models predict large stratospheric T changes



4xCO_2
40°cooling
at 40 km



~10° cooling
at 40 km
~1° warming
at surface

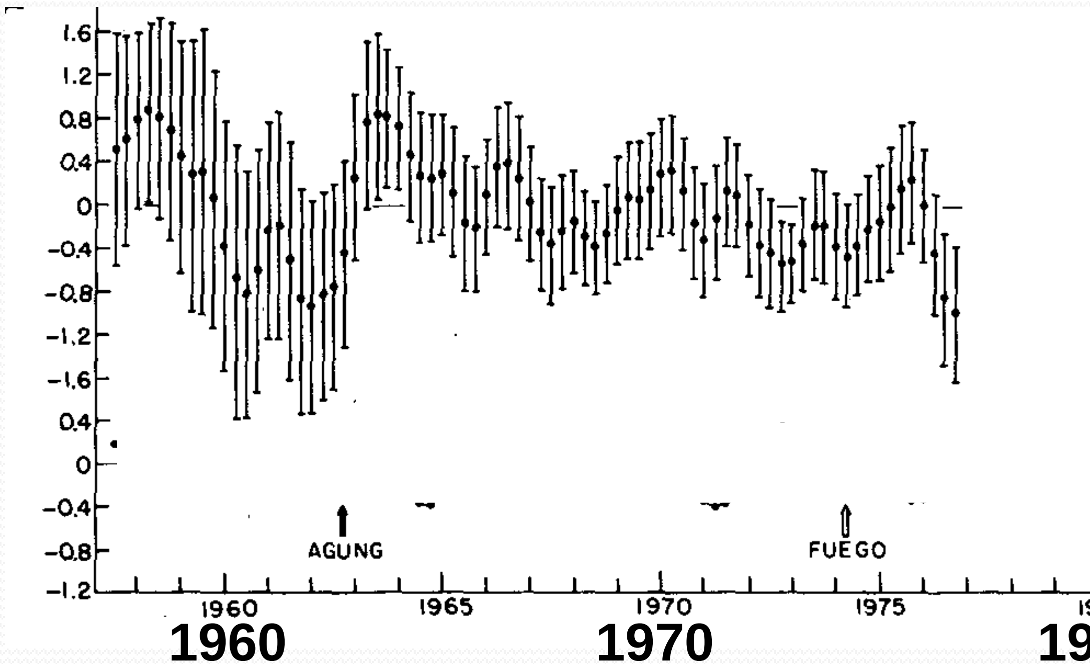
Manabe and Wetherald (JAS, 1967)

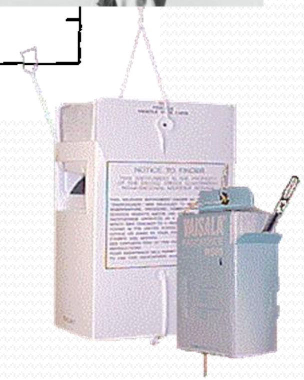
Increasing CO_2 cools stratosphere in 1-D radiative convective model

Ramanathan et al. (JAS, 1976)

O_3 depletion cools stratosphere in 1-D radiative convective model

Radiosondes: Long-term, legacy observations



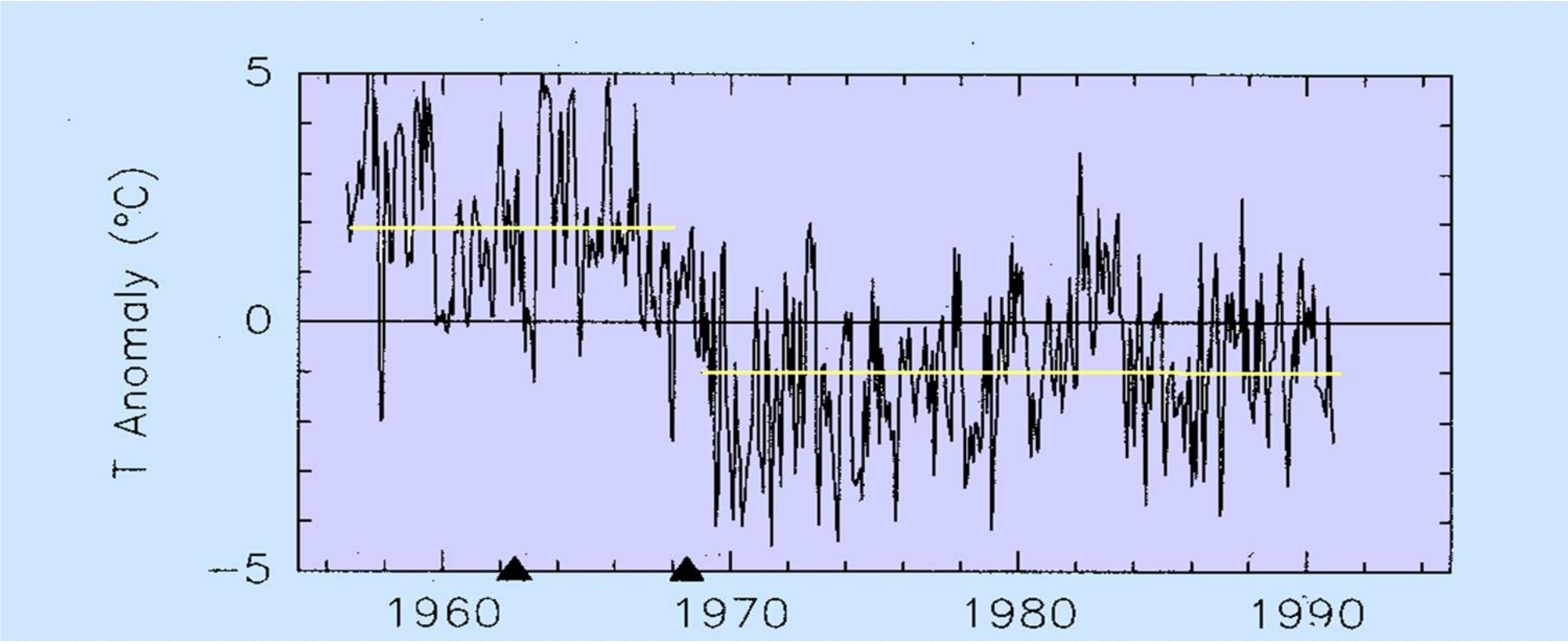


Global 100-30 hPa T Anomalies

Angell and Korshover (MWR, 1978)

- 42-station radiosonde network, 20-yr record
- Identified volcanic warming, QBO signal, ENSO signal, solar signal, cooling trend, sampling uncertainties

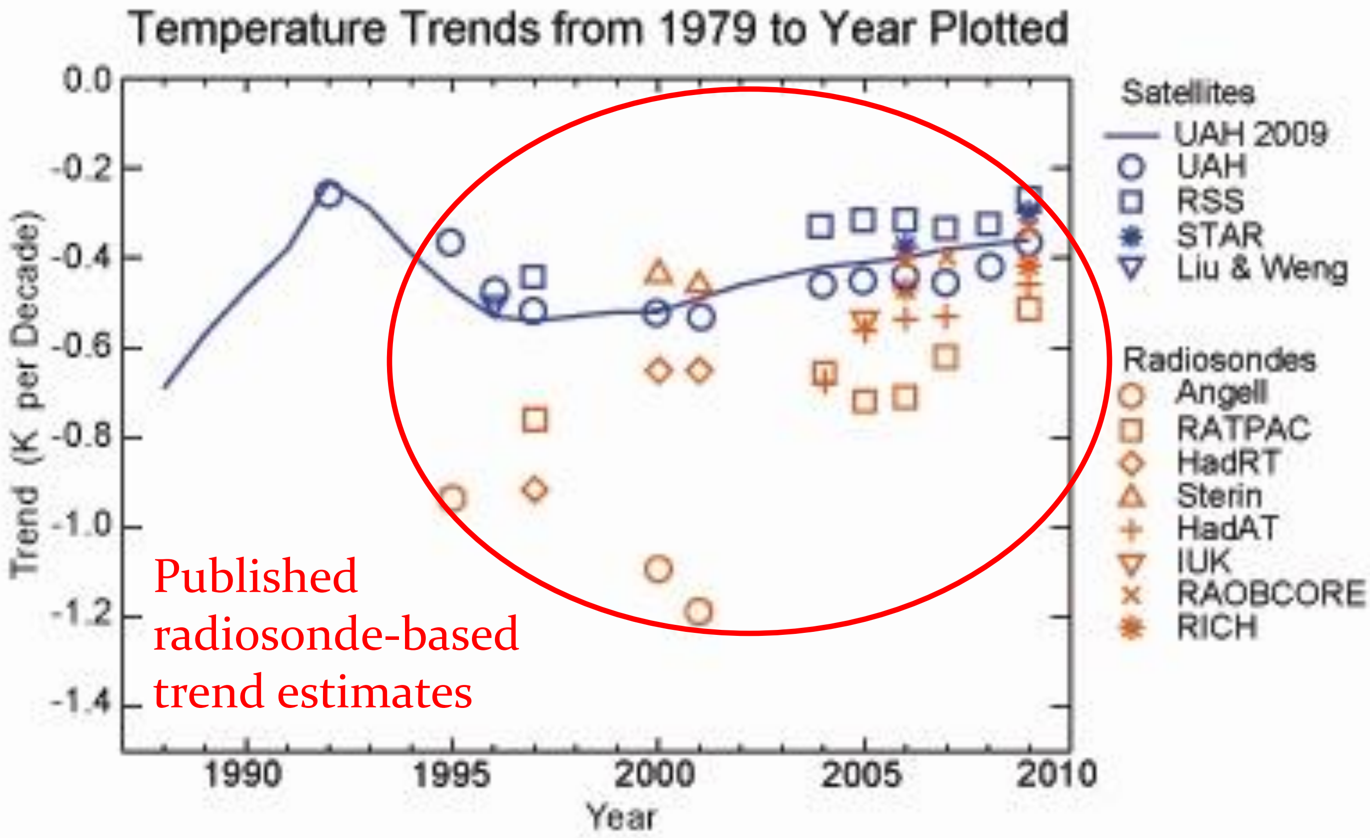
Time-varying biases in radiosonde data



- 100 mb monthly temperature anomalies at Bet Dagan, Israel
- 1968 change from French Metox to American VIZ radiosonde
- Spurious temperature decrease ~ 3 K

Gaffen (JGR, 1994)

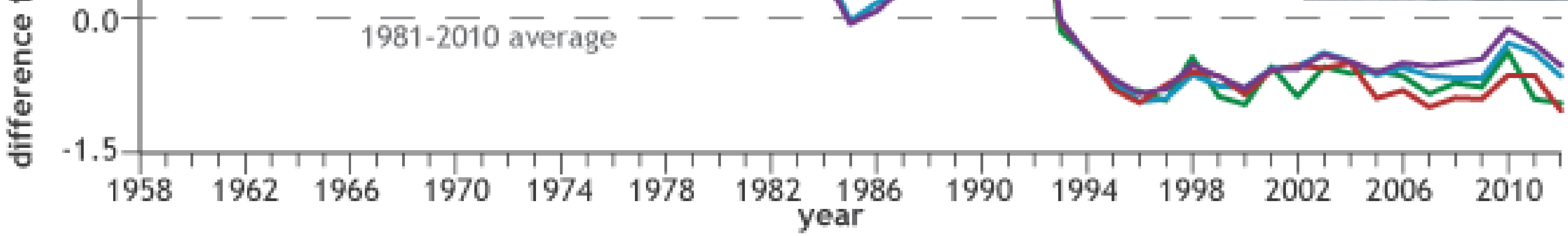
Stratospheric T trend uncertainties

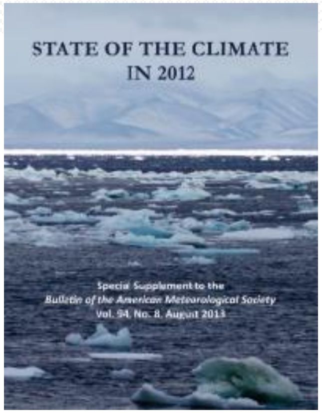


- All data points are PUBLISHED global lower-stratospheric trend estimates
- Cooling trends are order of magnitude larger than surface warming trend (~1K/century)
- Large spurious cooling in early radiosonde estimates
- Adjusted radiosonde data show less cooling
- Spread among trends comparable to trend magnitudes

Seidel et al. (WIREs Climate Change 2011)

Current radiosonde analyses

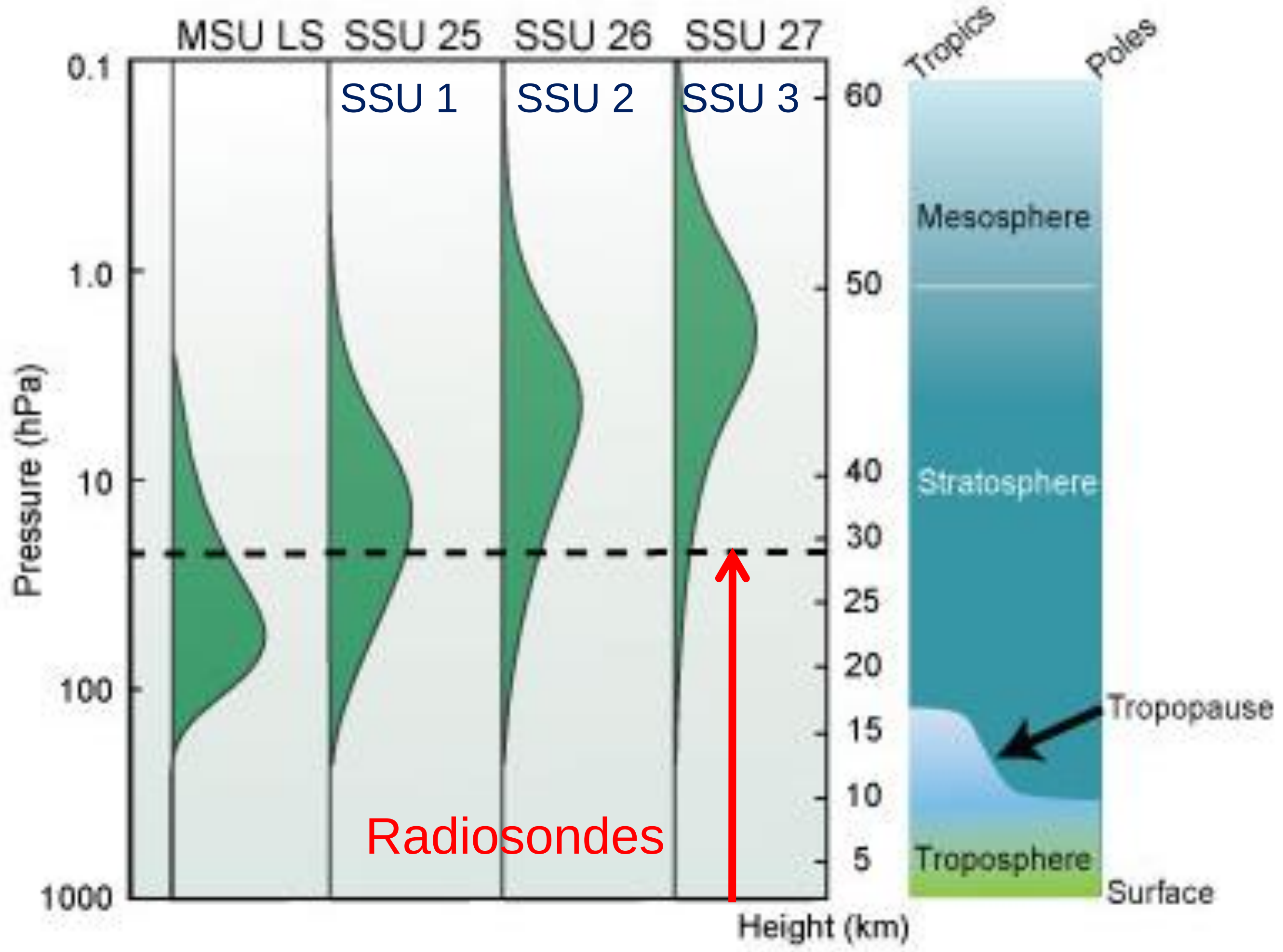




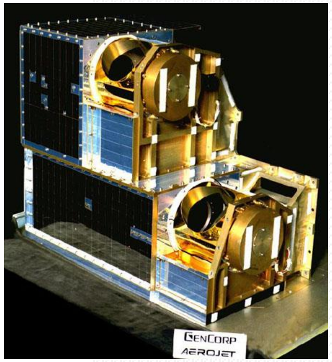
- 55-yr record … and continuing
- Time-varying biases removed by several teams
- Different approaches help quantify structural uncertainty
- ~ 1-2 K cooling since 1958; Little change since 1995

Bull. Amer. Meteor. Soc. supplement (2013)

20th century satellite observations

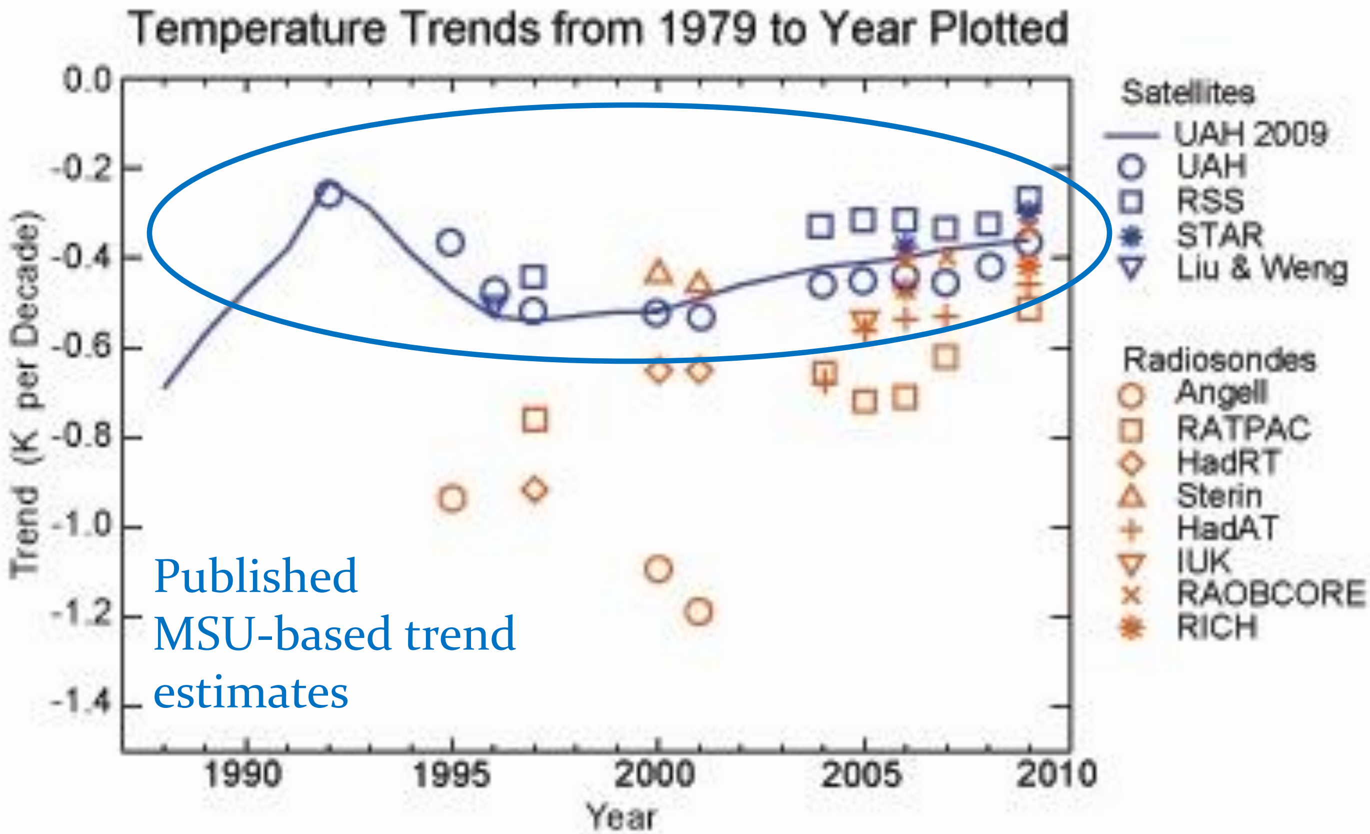


MSU



SSU

Stratospheric T trend uncertainties

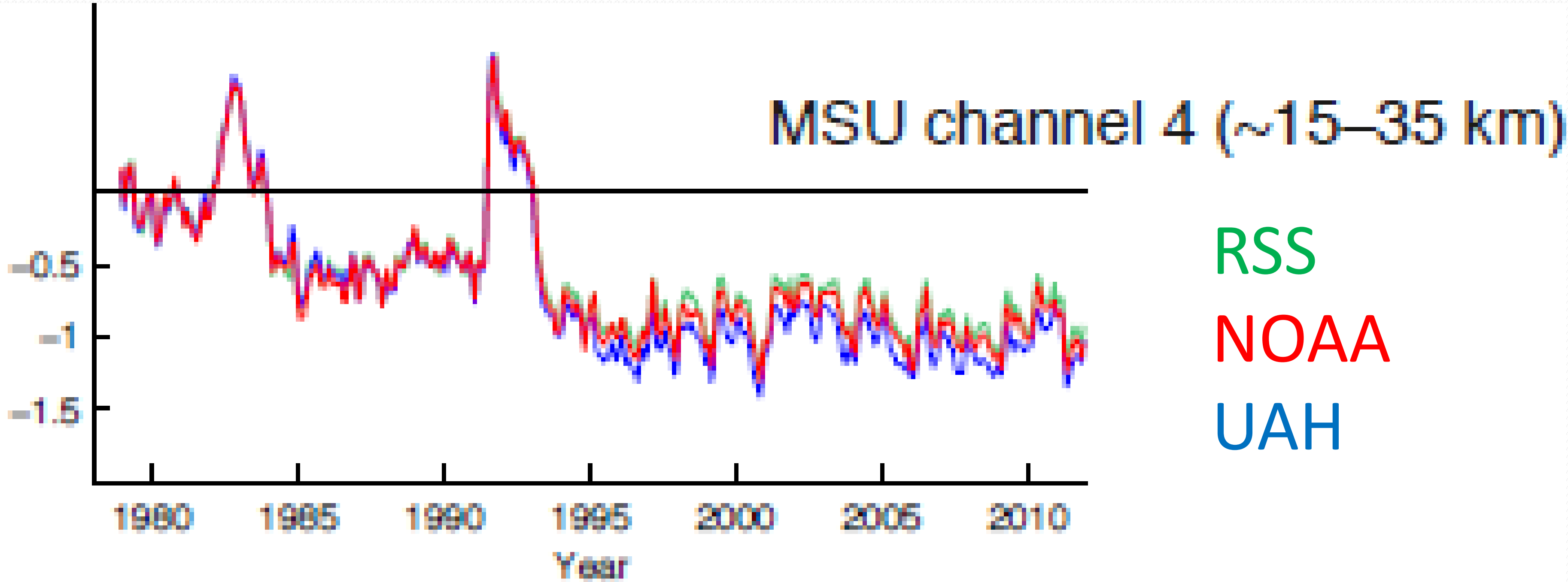


- MSU shows less cooling than radiosondes for the same periods
- Spread among trends comparable to trend magnitudes

Seidel et al. (WIREs Climate Change 2011)

Current MSU analyses

global T anomalies (K)

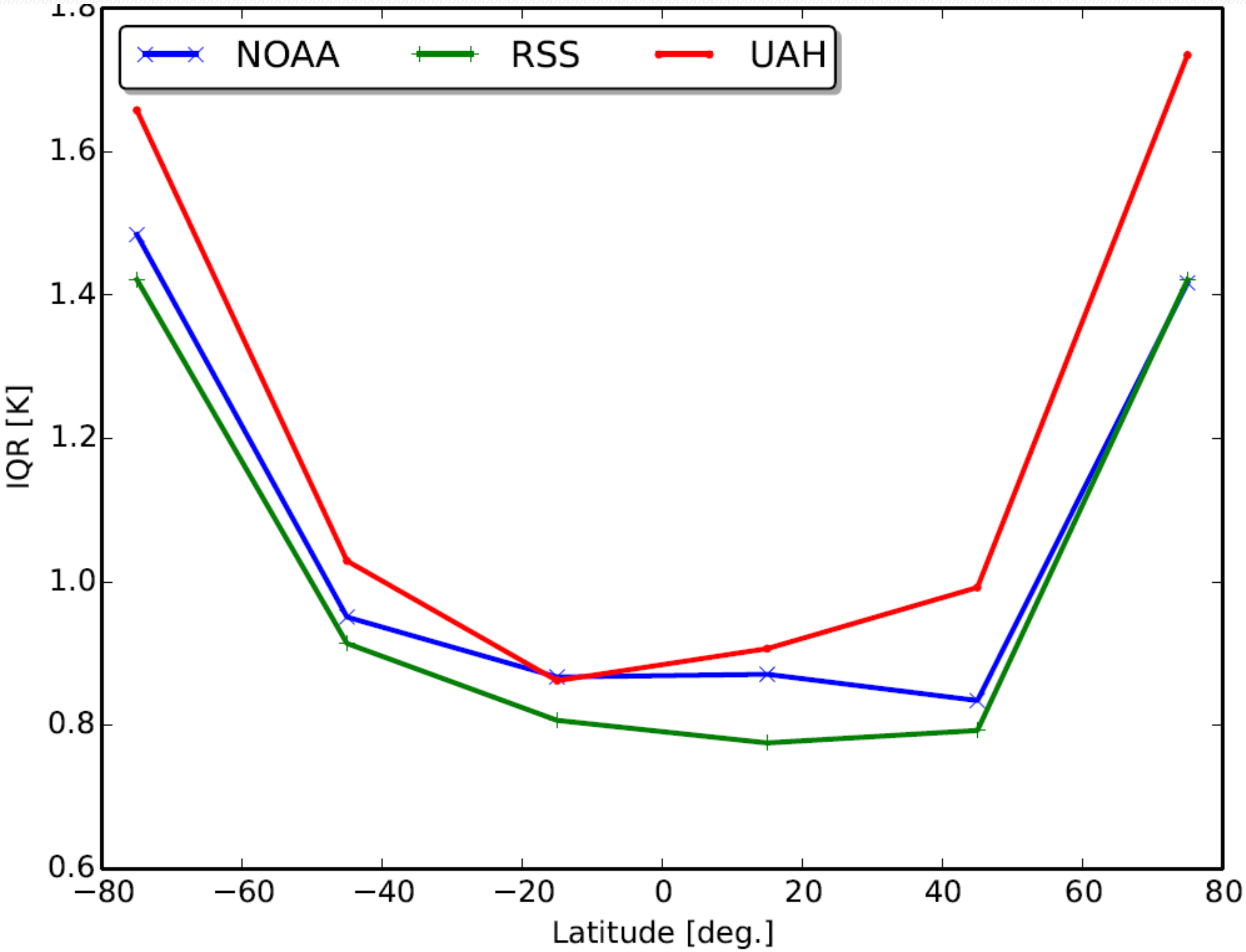


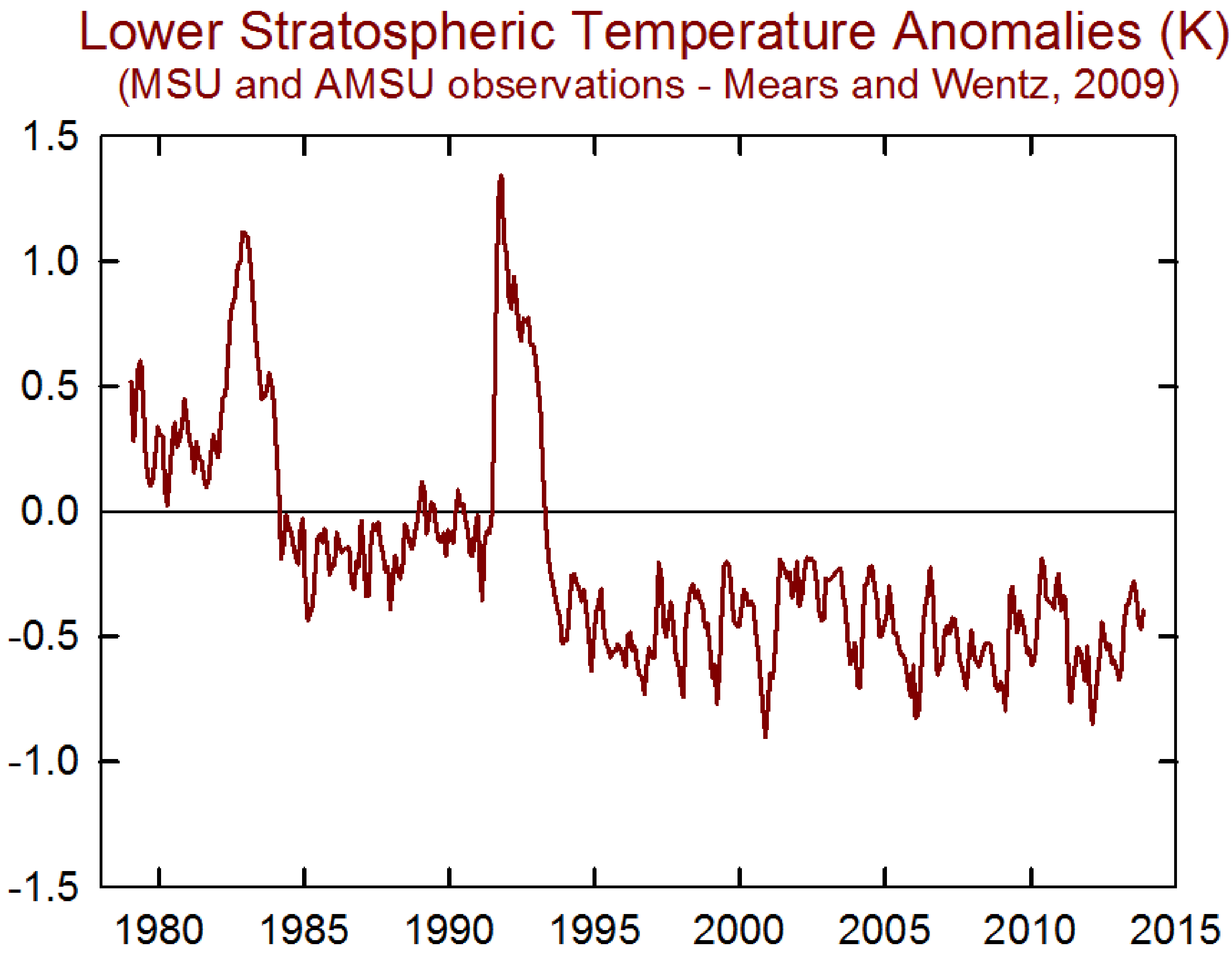
Thompson et al. (Nature 2012)

Comparison of MSU analyses

interquartile range of monthly zonal anomalies

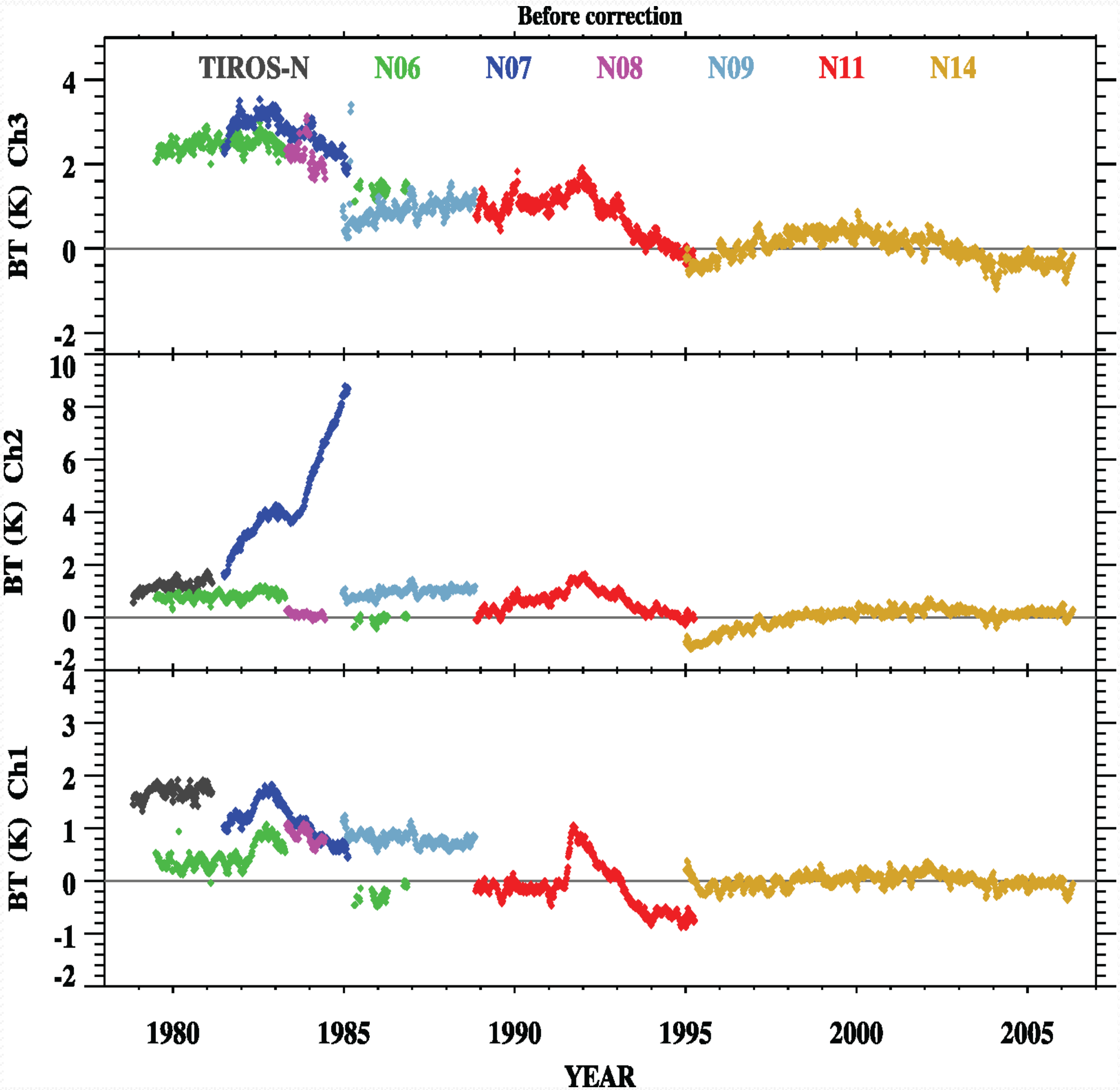
0.7	0.6	0.8	Global IQR(K)




Lower Stratospheric Temperature Anomalies (K)
(MSU and AMSU observations - Mears and Wentz, 2009)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1980
1985
1990
1995
2000
2005
2010
2015

Stratospheric Sounding Unit (SSU)

on NOAA Polar Orbiters 1979-2005

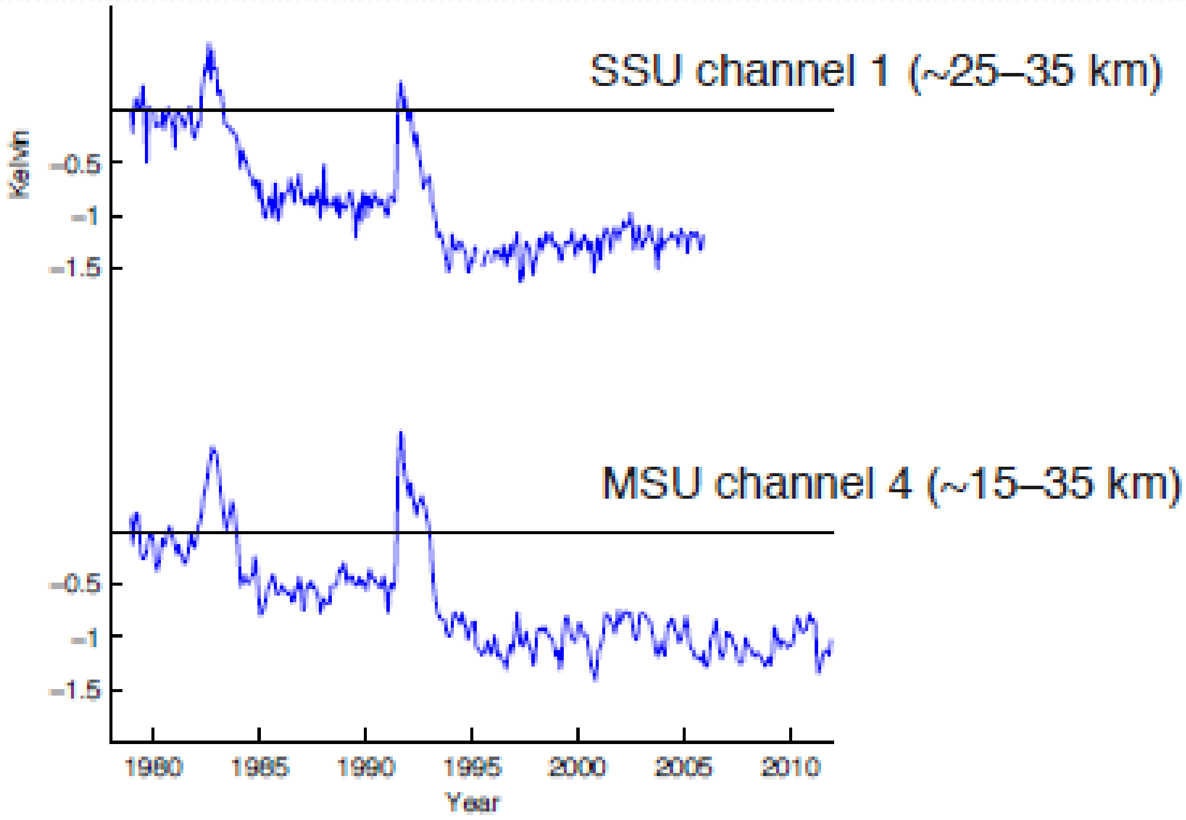


"Raw" brightness temperatures from multiple SSUs

SSU research in 21st century

- SSU record ends in 2005, but community remains interested in unique UKMO dataset
- Effect of atmospheric CO_2 increase on weighting function
  - Recognized (*WMO* 1988, *Brindley et al*. J. Climate 1999)
  - Reconsidered (*Shine et al*. GRL 2008)
  - Removed (*Randel et al*. JGR 2009)
- Concern about X channels (*Randel et al*. 2009) and vertical consistency (*Seidel et al*. 2011)
- NOAA creates second SSU dataset, different merging and adjustment methods (*Wang et al*. J. Climate 2012)
- Differences between datasets deemed a "mystery" (*Thompson et al*. Nature 2012)
- Re-examination by both NOAA and UKMO. New versions forthcoming.

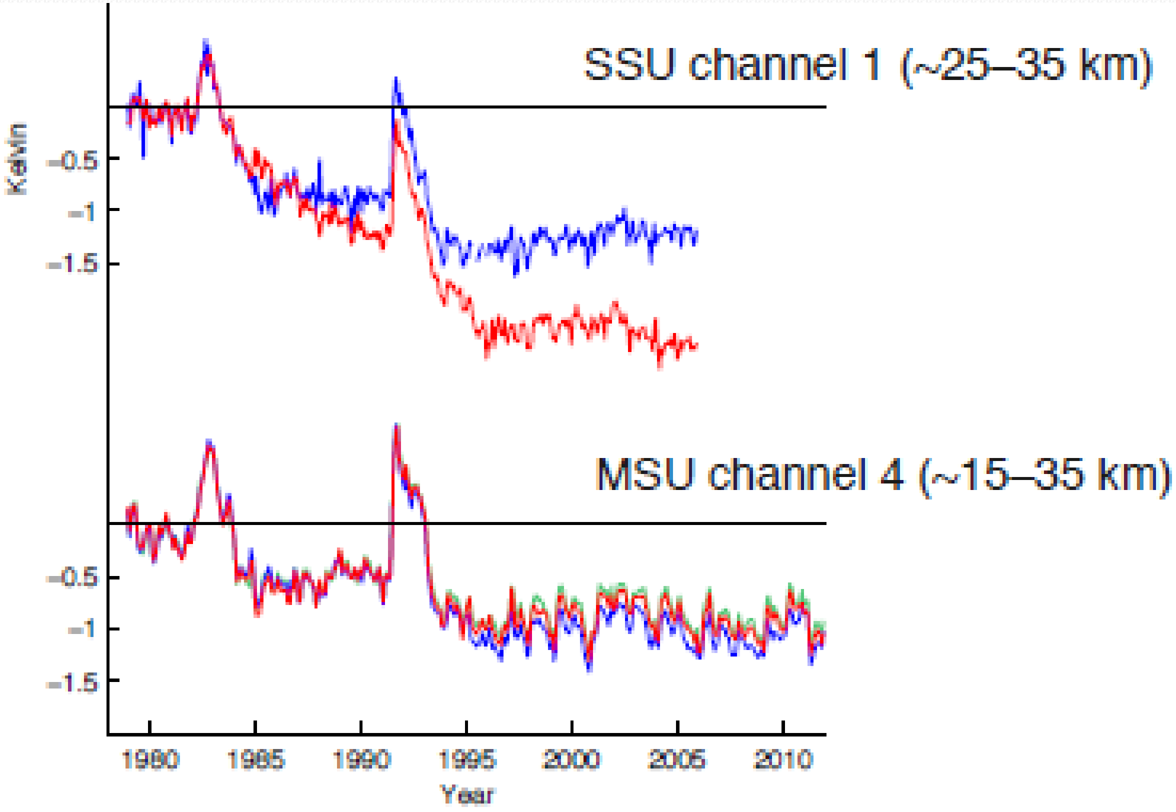
Lower Stratosphere: SSU and MSU



Met Office SSU Data

RSS MSU Data

Lower Stratosphere: SSU and MSU

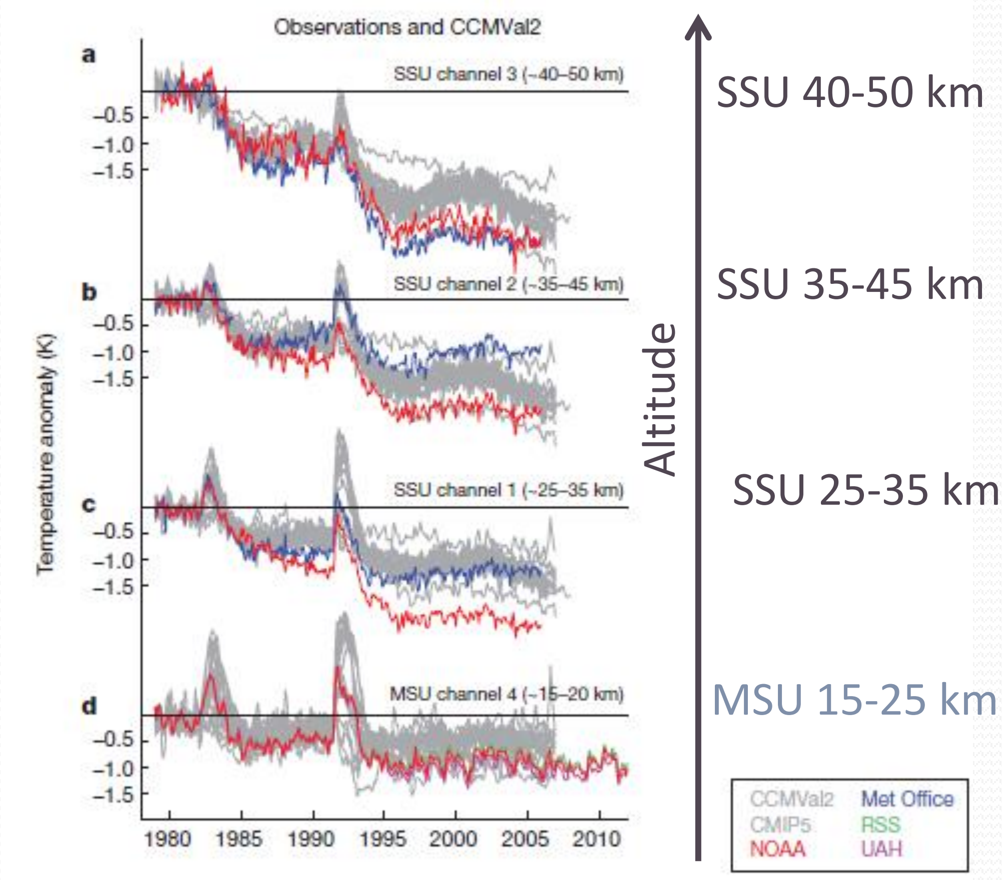


Met Office SSU Data
NOAA SSU Data

RSS MSU Data
NOAA MSU Data
UAH MSU Data

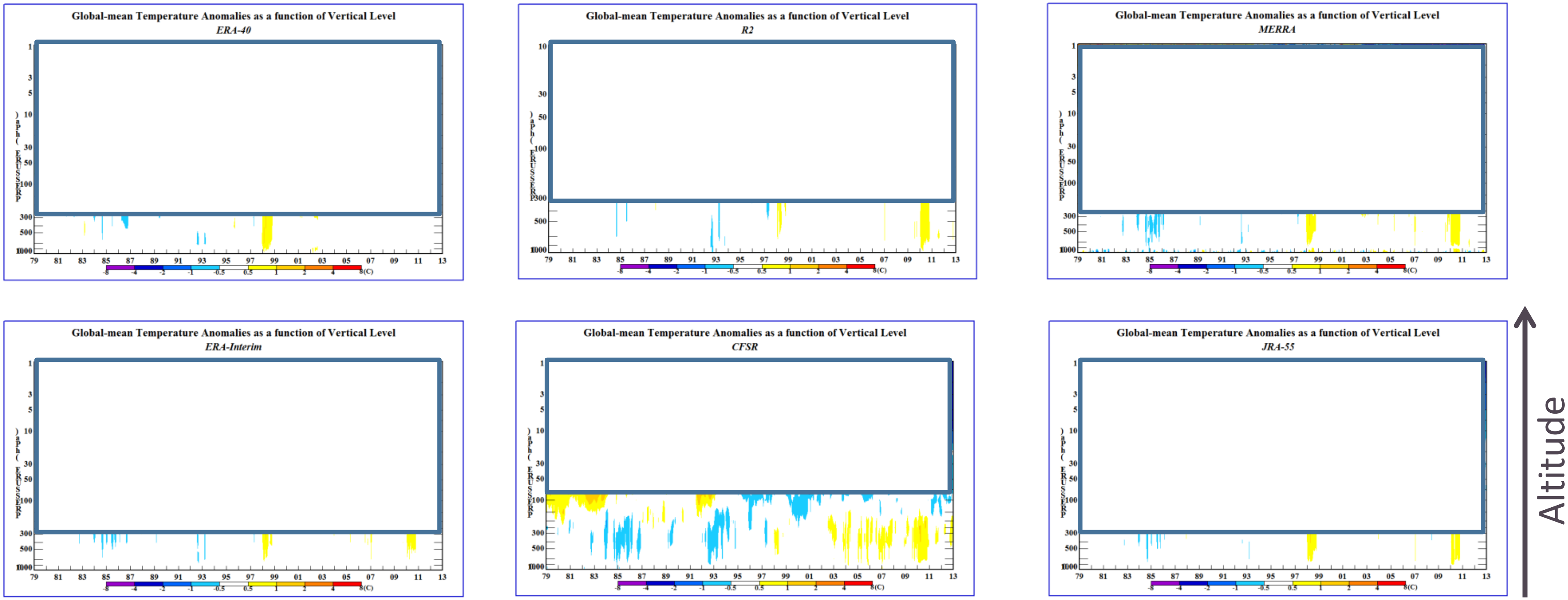
Comparing Models with SSU and MSU

Chemistry-Climate Models



- Differences between SSU versions inconsistent among 3 channels
- Volcanic warming greater in models than observed
- Differences between SSU versions, and with models, in long-term T change

Do reanalyses help?

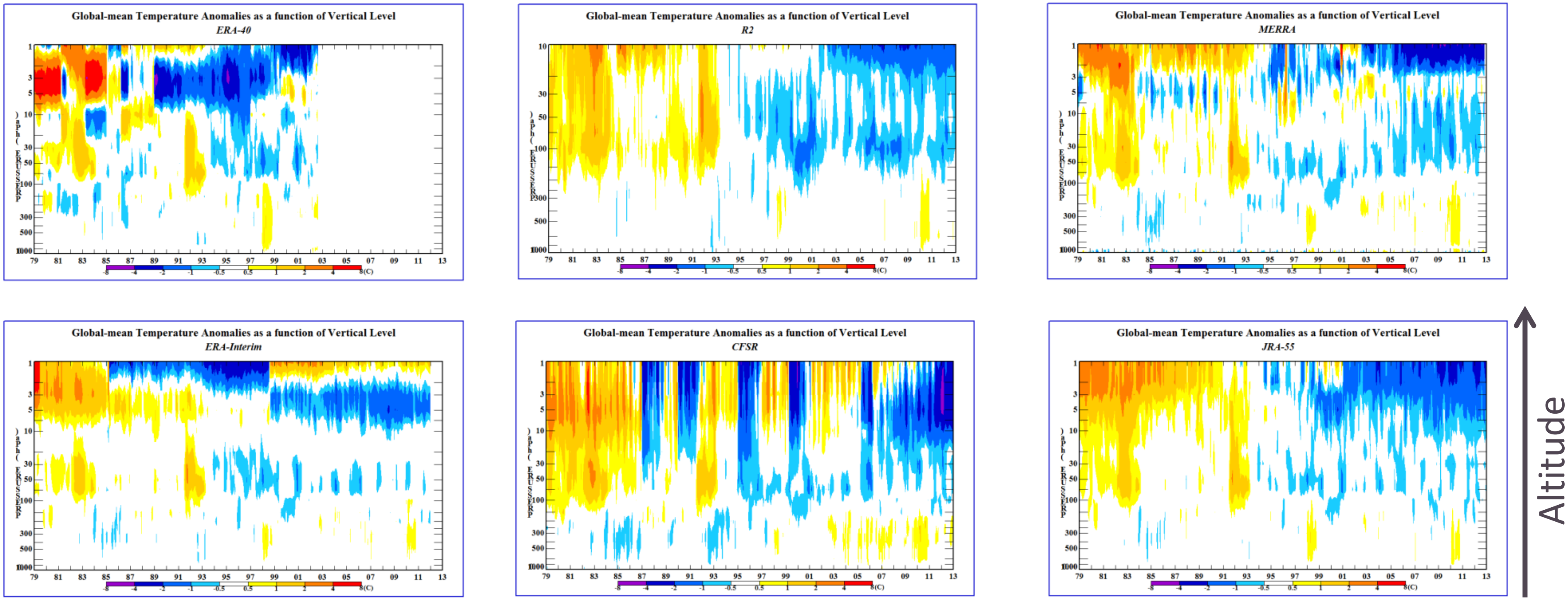


T Anomalies in 6 Reanalyses
1979 – 2012

Temperature scale: -8 to +8 K
1000 – 300 hPa

Figure courtesy of Craig Long
SPARC Analysis-Reanalysis Intercomparison Project

Do reanalyses help?



T Anomalies in 6 Reanalyses
1979 – 2012

Temperature scale: -8 to +8 K
1000 – top

Figure courtesy of Craig Long
SPARC Analysis-Reanalysis Intercomparison Project

Summary of Stratospheric T "Trends"

- Models have long predicted large stratospheric T changes.
  - Stratospheric T should remain a priority for climate change detection.
  - Discrepancies between models and obs need better explanations.
- Observations (and reanalyses) for detecting changes are not ideal.
  - Progress has been slow.
  - Large uncertainties remain and need to be better quantified.
  - **Lack of reference-quality observations a major problem.**
- Post-volcanic warming is the dominant signal in the lower stratosphere.
- Observations suggest long-term cooling, but
  - Cooling is not monotonic or linear
  - On global-average, there has been little change since 1995.

Questions about the potential value of GPS-RO to the climate observing system (response to 2008 COSMIC workshop at UCAR, Boulder)

1. *Comparability of data from different COSMIC satellites*
    - *Are claims of 0.02-0.05 K precision (surface – 30 km) realistic?*
2. *Comparability of CHAMP and COSMIC (and other?) GPS satellite systems*
3. *Reproducibility of refractivity results*
    - *Source of differences among 4 centers*
4. *Reproducibility of temperature results*
5. *Impact of assumptions on both refractivity and retrieved profiles*
    - *ionospheric structure, 1st guess tempreature and humidity profiles, …*
6. *Observed refractivity (or delay) vs. retrieved meteorological profiles*
    - *Potential value of refractivity as a benchmark climate variable*
7. *Profiling of the lower troposphere*
    - *(now I'd add the middle and upper stratosphere as concerns)*
8. *Impact of observations scattered across space and time*
    - *Suggested similar sampling of climate model runs to evaluate*
9. *Potential aliasing by water vapor changes in GPS-RO temperature time series*
10. *Water vapor retrievals*

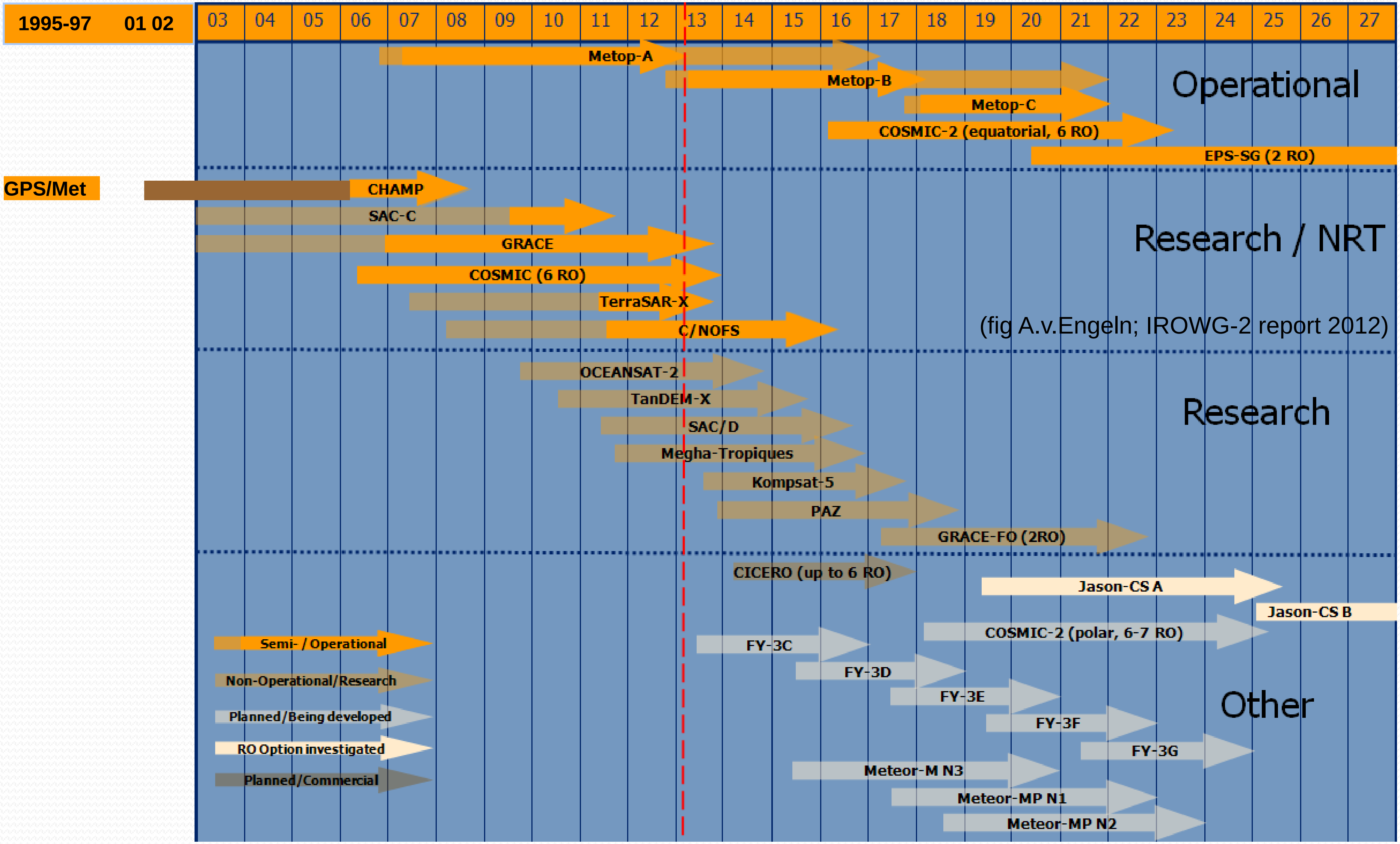
Current questions for climate applications of GPS RO

- Vertical domain of useful measurements
- Variables of most utility (refractivity, T_{dry} ?)
- Expected longevity of measurements
- Ground-based measurements needed to optimize long-term record. Possible coordination with GCOS Reference Upper Air Network (GRUAN)

Thank you!

GNSS radio occultation satellite missions: past, current, planned…

Figure courtesy of Andrea Steiner



SPARC T Trends Activity References

Ramaswamy, V., M.-L. Chanin, J. Angell, J. Barnett, D. Gaffen, M. Gelman, P. Kekhut, Y. Koshelkov, K. Labitzke, J.-J. R. Lin, A. O'Neill, J. Nash, W. Randel, R. Rood, K. Shine, M. Shiotani, and R. Swinbank, 2001: **Stratospheric temperature trends: Observations and model simulations.** *Rev. Geophys., 39, 71-122*.

Shine, K.P., M.S. Bourqui, P.M.de F. Forster, S.H.E. Hare, U. Langematz, P. Braesicke, V. Grewe, C. Schnadt, C.A. Smith, J.D. Haigh, J. Austin, N. Buchart, D. Shindell, W.J. Randel, T. Nagashima, R.W. Portman, S. Solomon, D.J. Seidel, J. Lanzante, S. Klein, V. Ramaswamy, M.D. Schwarzkopf, 2003: **A comparison of model-predicted trends in stratospheric temperatures.** *Quart. J. Royal. Meteor. Soc., 129, 1565-1588. doi: 10.1256/qj.02.186.*

Randel, W.J., K.P. Shine, J. Austin, J. Barnett, C. Claud, N.P. Gillett, P. Keckhut, U. Langematz, R. Lin, C. Long, C. Mears, A. Miller, J. Nash, D.J. Seidel, D.W.J. Thompson, F. Wu and S. Yoden, 2009: **An update of observed stratospheric temperature trends**. *J. Geophys. Res., 114, D02107, doi:10.1029/2008JD010421*.

Seidel, D.J., N.P. Gillett, J.R. Lanzante, K.P. Shine, P.W. Thorne 2011: **Stratospheric temperature trends: Our evolving understanding.** Wiley Interdisciplinary Reviews: Climate Change, 2, 592-616, DOI: 10.1002/wcc.125

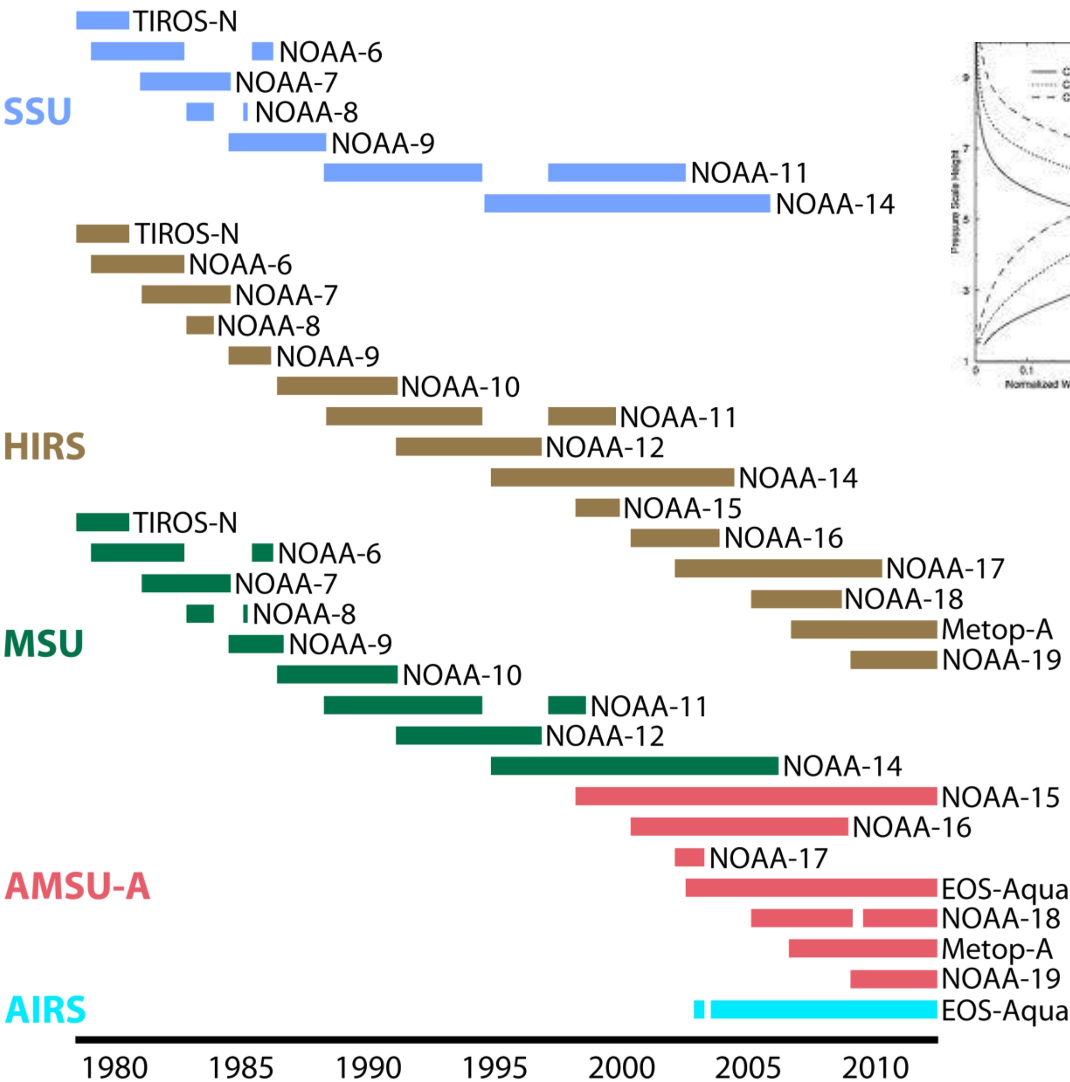
Thompson, D.W.J., D.J. Seidel, W.J. Randel, C.-Z. Zou, A. H. Butler, R. Lin, C. Long, C. Mears, A. Osso, 2012: **The mystery of recent stratospheric temperature trends**. Nature, 491,692-697, doi:10.1038/nature11579.

Other 21st C. Observations

	GNSS-RO	SABER	GOMOS
Principle	Refractivity-dependent time delay of radio transmission	Broadband radiometry; CO2 emissions	Chromatic refractivity; scintillation measurements
Altitude Range (km)	8-25	20-100	15-30
Vertical Resolution (m)	200	2000	200
Period of Obs.	~2006-present	2001-present	2002-2012
Maturity of analysis effort	High	low	low

GNSS-RO: Global Navigational Satellite System Radio Occultation
SABER: Sounding of the Atmosphere using Broadband Emission Radiometry (NASA)
GOMOS: Global Ozone Monitoring by Occultation of Stars (ESA)

21st C. Observations from Polar Orbiters



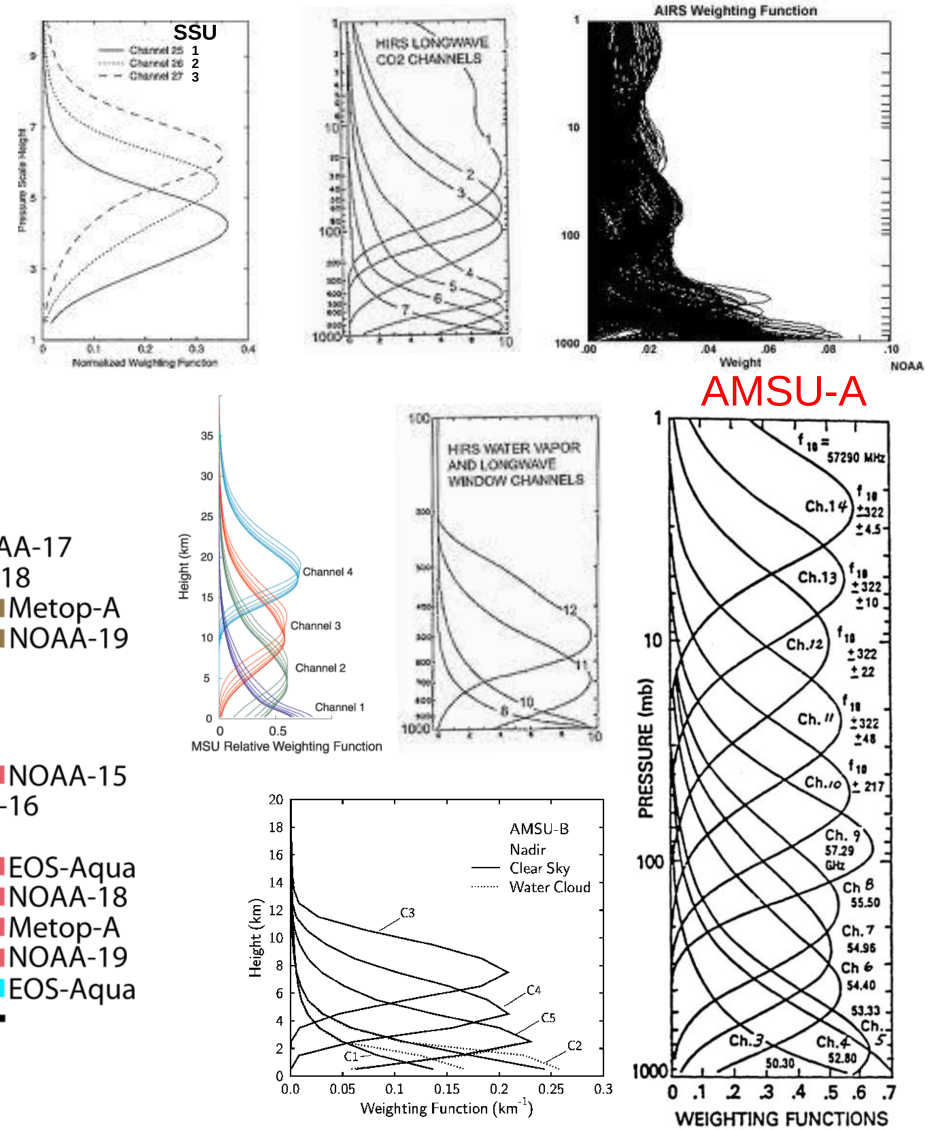
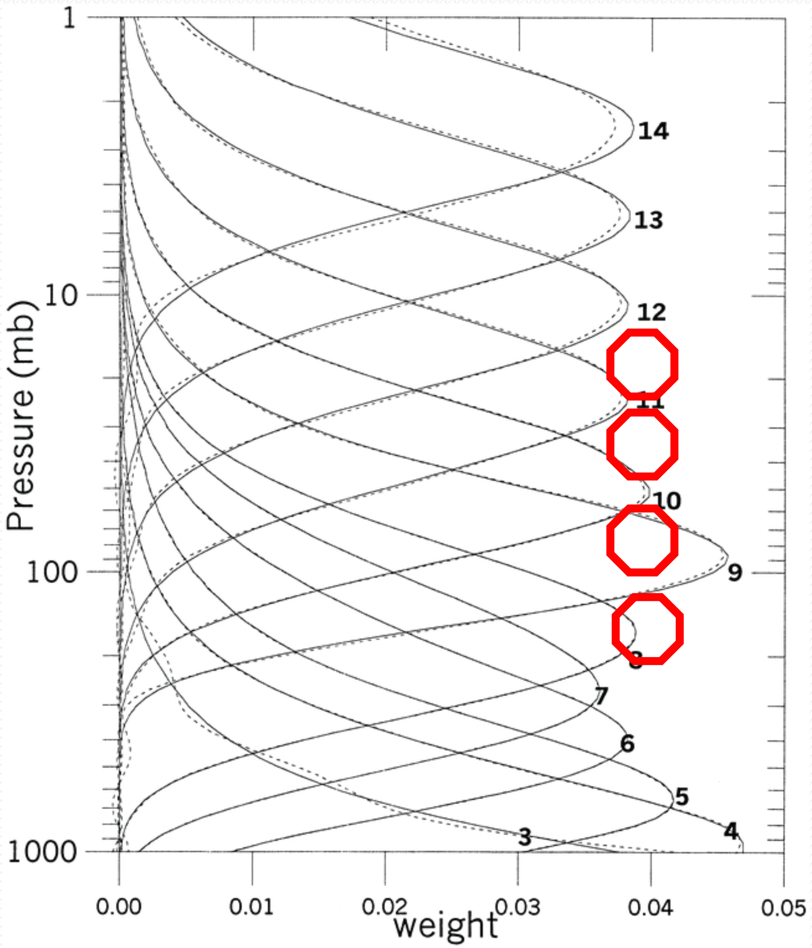


Figure courtesy of A. Simmons

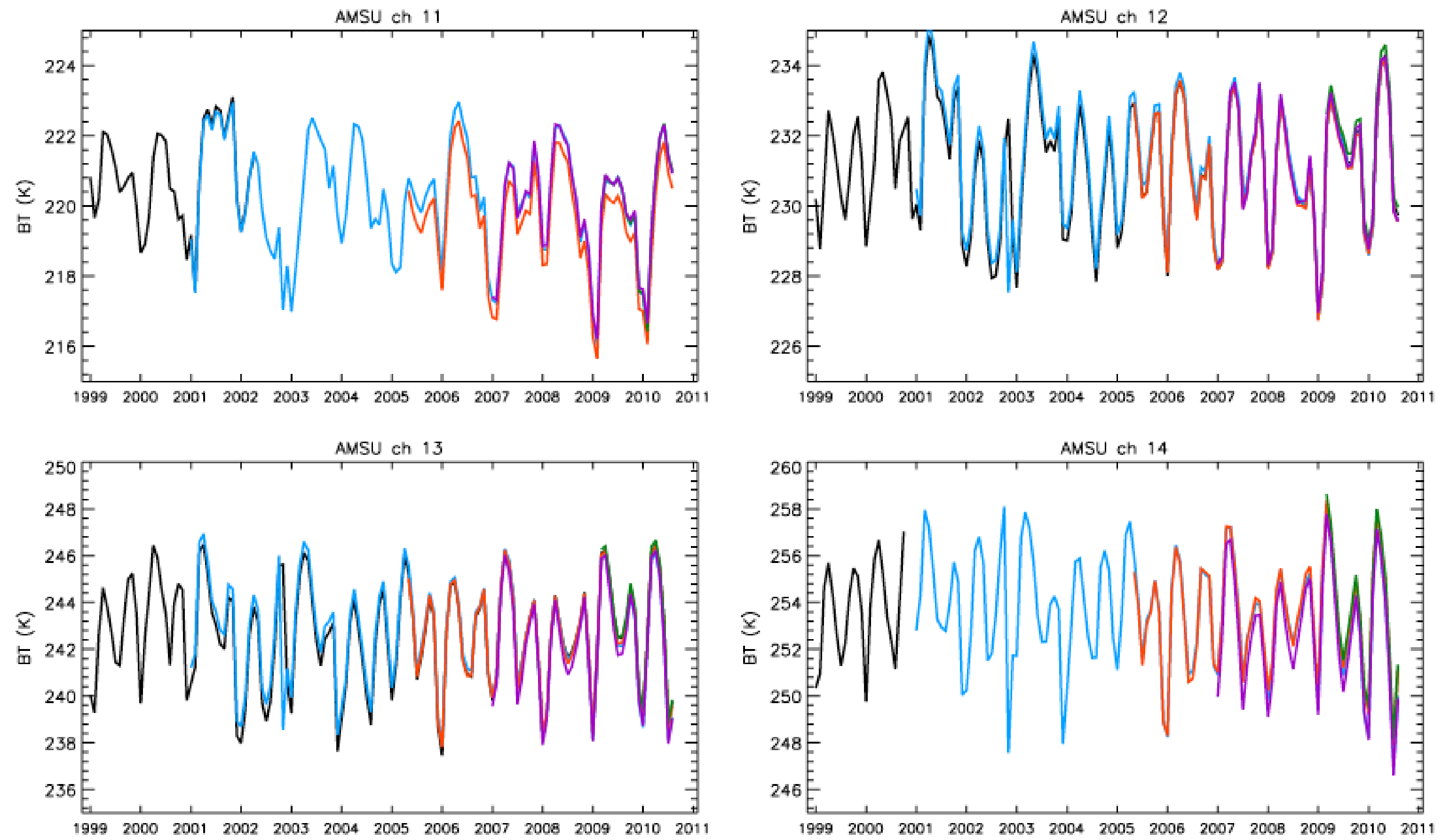
AMSU weighting functions



TIDE EFFECTS ON STRATOSPHERIC TEMPERATURE DERIVED FROM SUCCESSIVE ADVANCED MICROWAVE SOUNDING UNITS

Keckhut, P., B. M. Funatsu, C. Claud, and A. Hauchecorne, Quarterly Journal of the Royal Meteorological Society, 2014, doi: 10.1002/qj.2368

AMSU series from channels 11-14



NOAA 15 NOAA 16 NOAA 18 METOP A NOAA 19

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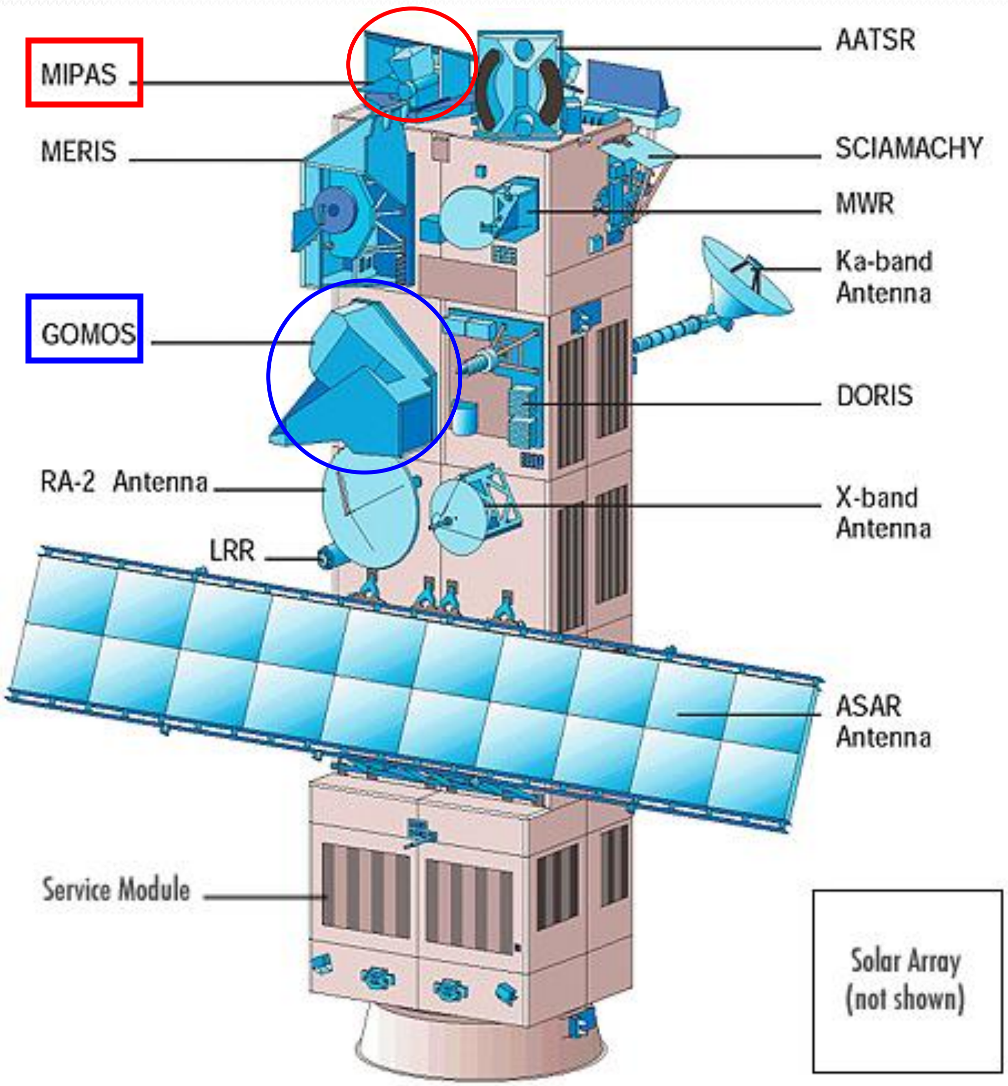
Viktoria Sofieva

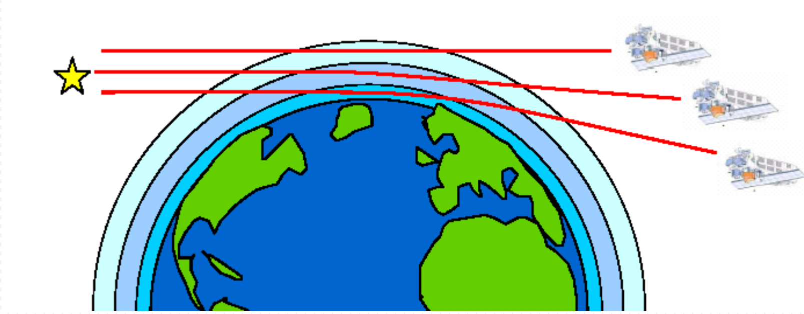
GOMOS temperature measurements: data updates



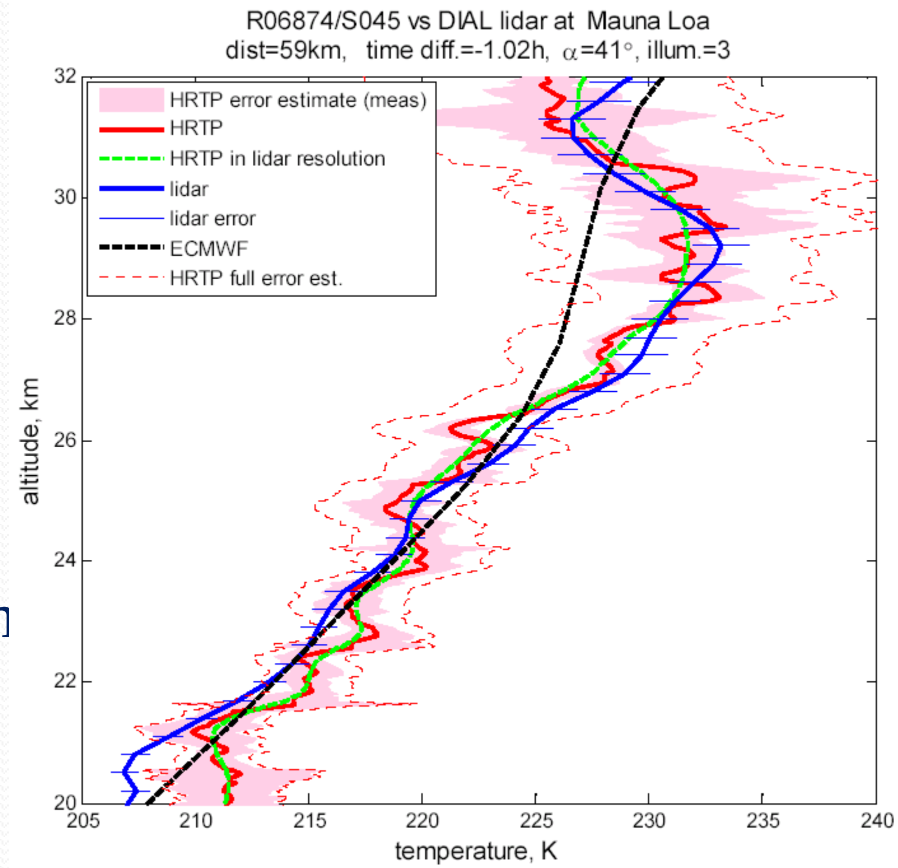
Envisat: 2002 - 2012

Viktoria Sofieva

High Resolution Temperature Profiles



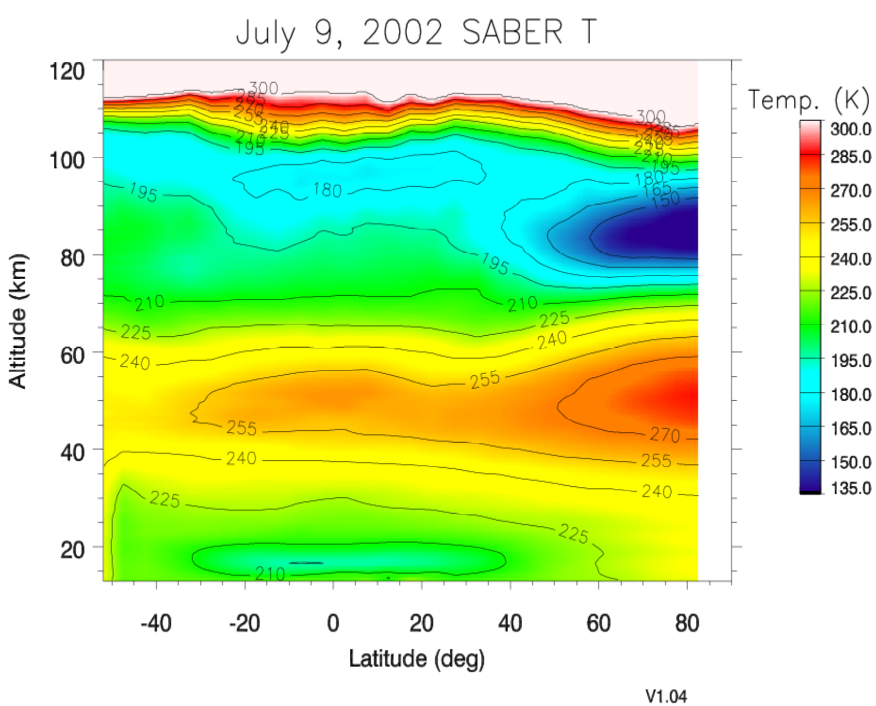
- Unique experiment
  - Based on chromatic refraction
  - Uses scintillation measurements by GOMOS fast photometers
- New reprocessed dataset (with IPF 6.0) is available and under validation
- Main parameters
  - vertical resolution ~200 m
  - precision ~1-2 K
  - Valid altitude range ~15-30 km

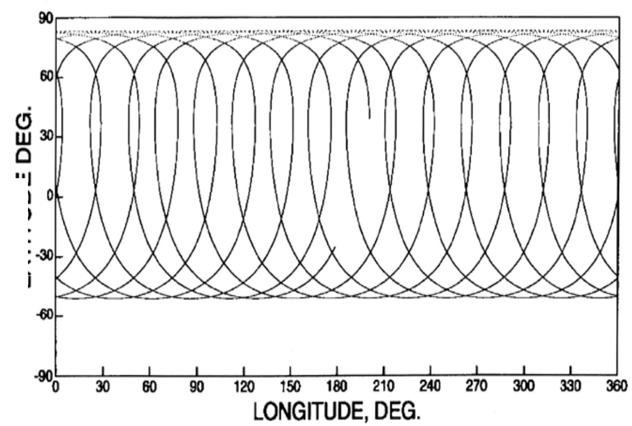


Bill Randel

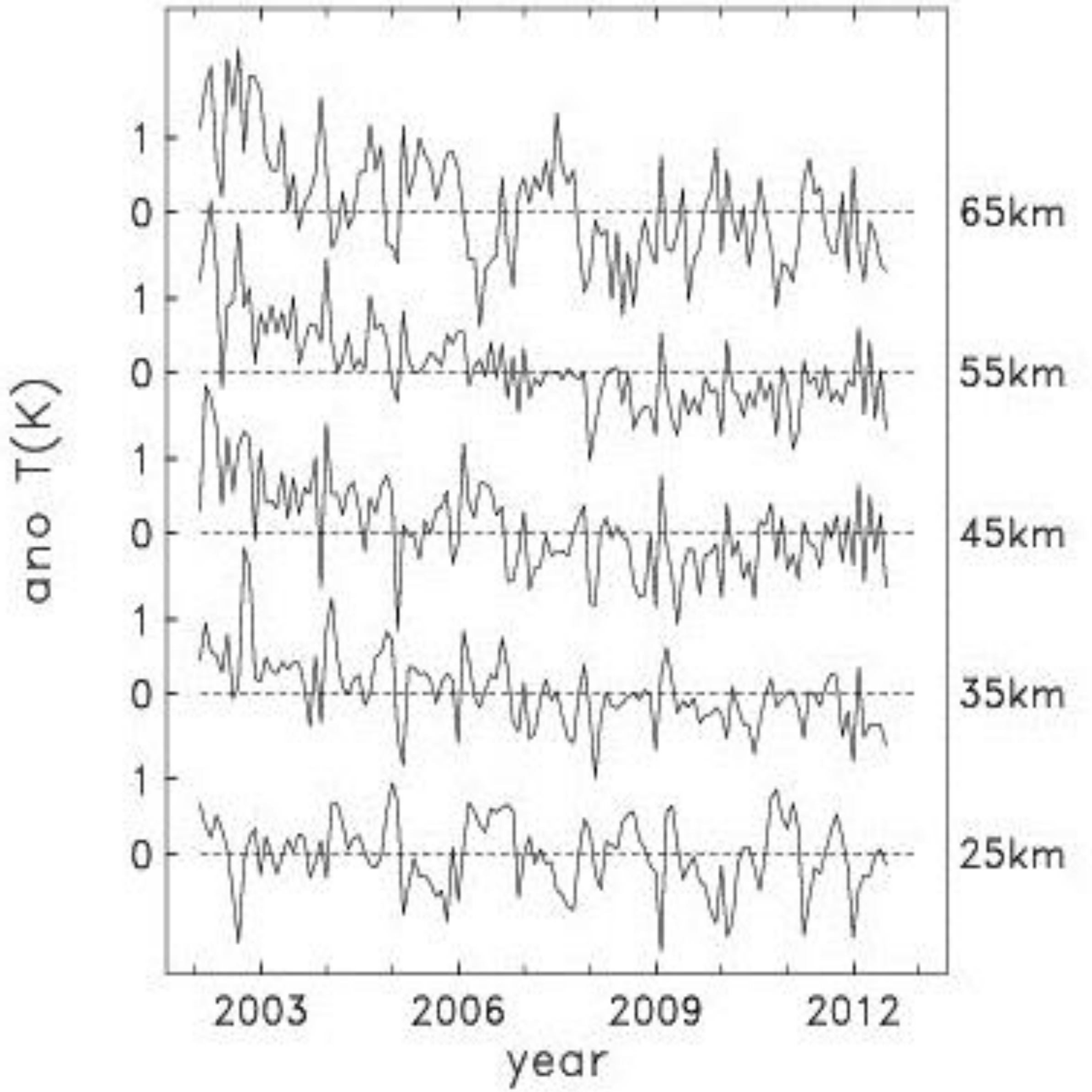
SABER data details

- Limb emission viewing geometry
- Broadband radiometry, T(p) derived from CO_2 emissions
- Data since late 2001
- Coverage: 50° S – 80° N / 80° S – 50° N (60-day yaw cycles)
- Altitudes ~20-100 km; Vertical resolution ~2 km





SABER T Anomalies (50^{o}N-S)



Unpublished data, courtesy of Bill Randel