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A multi-year comparison of lower stratospheric temperatures from CHAMP radio occultation with MSU/AMSU records

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*Thanks for
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Outline

- Motivation and Context
- Study Design
- Data Sets
- Method
- Results
- Conclusions

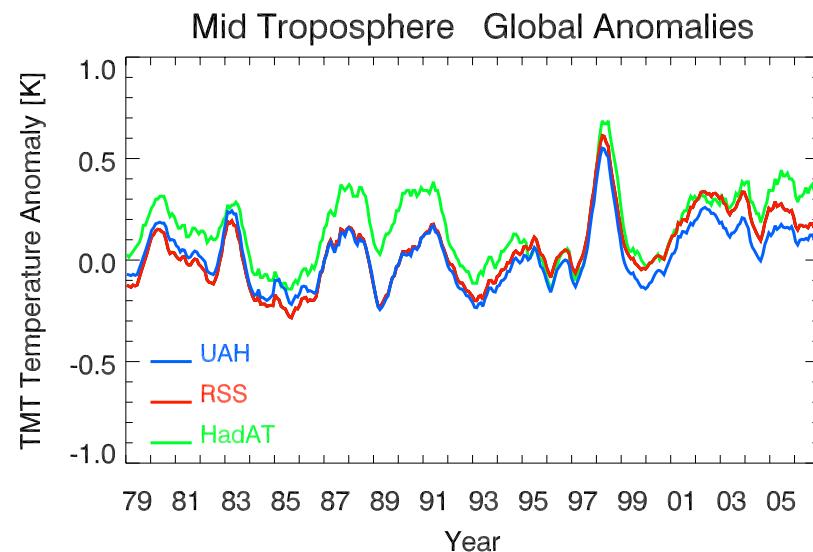
Reference/details:

Steiner, A.K., G. Kirchengast, M. Borsche, U. Foelsche, and T. Schoengassner,
A multi-year comparison of lower stratospheric temperatures from CHAMP radio
occultation data with MSU/AMSU records,
J. Geophys. Res., 112, in press, doi: 10.1029/2006JD008283, 2007.

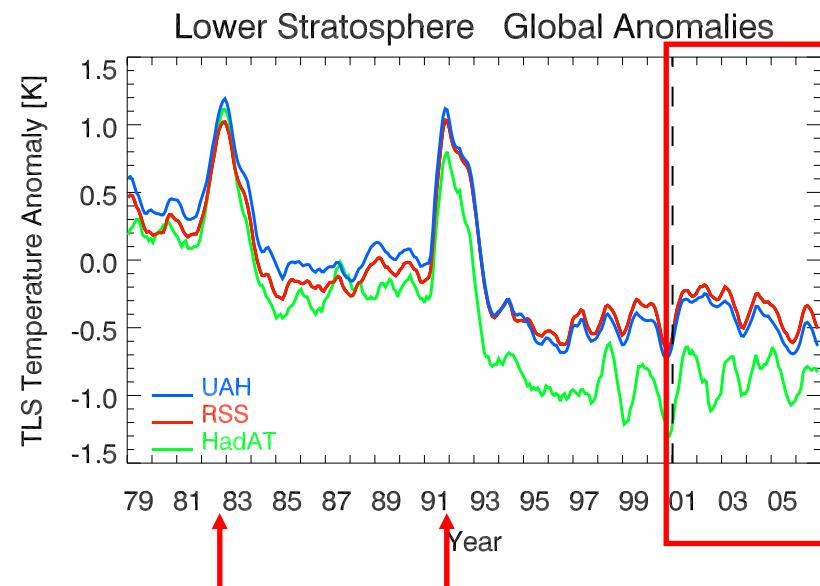


Motivation and Context (1)

Temperatures in the Troposphere and Stratosphere



Tropospheric Warming
(MSU/AMSU TMT(T2) channel)



Stratospheric Cooling
(MSU/AMSU TLS(T4) channel)

Reference: Karl, T. R., S. J. Hassol, C. D. Miller, and W. L. Murray (Eds.) (2006),
Temperature trends in the lower atmosphere: Steps for understanding and reconciling differences, A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.



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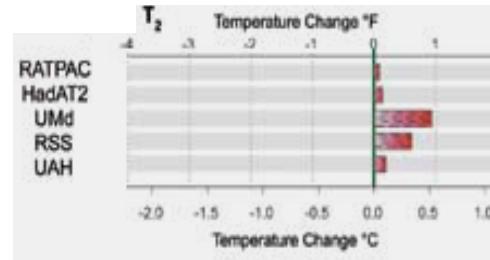


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Motivation and Context (2)

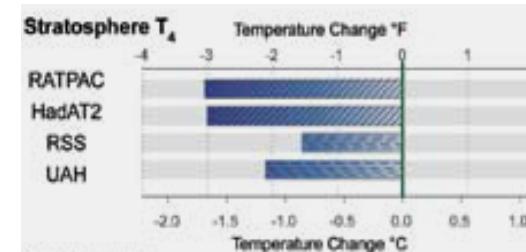
Temperatures in the Troposphere and Stratosphere

Tropospheric Warming
(MSU/AMSU TMT(T2) channel)



T2 [K]	Trend 1979–2004	T4 [K]
0.1	Radiosondes	-1.5
0.15	UAH	-1.1
0.3	RSS	-0.8
0.45	UMd	

Stratospheric Cooling
(MSU/AMSU TLS(T4) channel)



„In fact, new types of more accurate data such as temperature and moisture profiles from GPS RO measurements are already available, although as yet, few efforts have been made to analyze them.“

[Karl et al., 2006]



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Study Design

- Calculation of synthetic MSU/AMSU temperature of the Lower Stratosphere (TLS) from GPS radio occultation data
- Comparison to MSU/AMSU and Radiosonde TLS temperatures, and TLS temperatures from ECMWF analyses
- Period 2001 – 2006 (all-data overlap Sep 2001–Dec 2006)
- Regions:
 - Global (70°S–70°N)
 - Tropics (20°S–20°N)
 - NH Extratropics (30°N–70°N)
 - SH Extratropics (30°S–70°S)



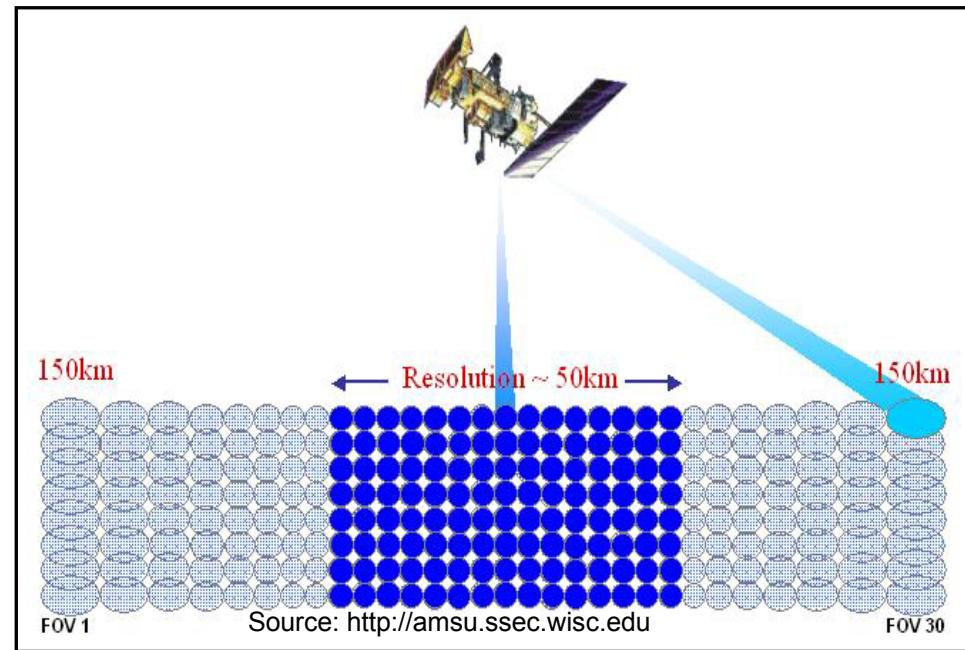
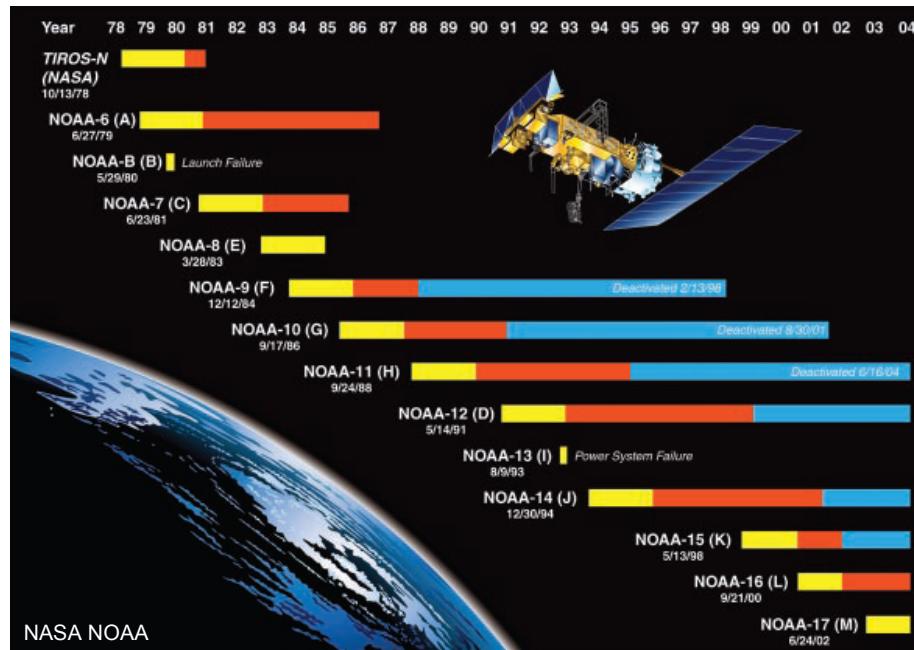
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Data Sets (1) – Measurement Principles

(Advanced) Microwave Sounding Unit (AMSU/MSU) on NOAA satellites



Passive microwave sensor

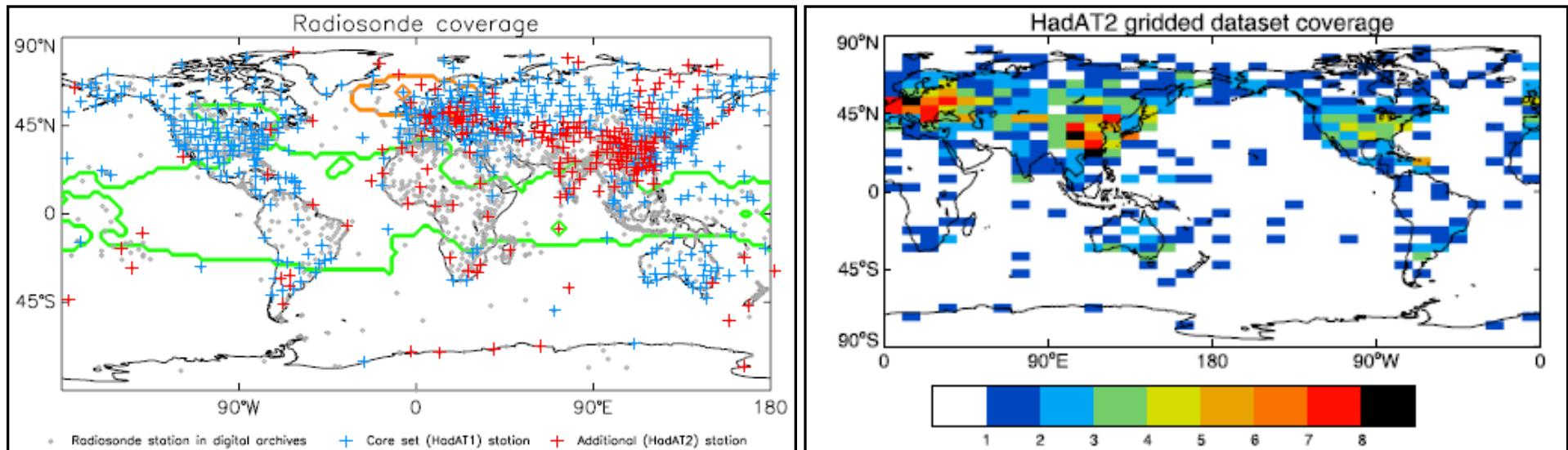
- measures Earth's microwave emissions using the 50–60 GHz oxygen absorption line.
- provision of layer average brightness temperatures
- inter-calibration & correction procedures for diurnal drift, orbital decay, inter-satellite biases are addressed differently by different groups. “*There is no objective way to specify the optimal correction procedure and a degree of subjectivity is inevitably introduced*” (Thorne et al., BAMS, 2005)
- Based on the same raw data, different measures derived by different construction methodologies.



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Data Sets (2) – Measurement Principles

Radiosonde measurements HadAT (Hadley Center/MetOffice, UK)



- grossly consistent station records, stations biased to continental NH
- daytime biases from solar heating of the temperature sensor, greatest impact at stratospheric levels
- main source of data discontinuity: time-varying biases, different data adjustments and processing methods, changes in stations and in instrumentation type with persistent residual cooling bias at tropical stations and in night-time measurements [Karl et al., CCSP Rep., 2006].
- discrepancies between MSU/AMSU and radiosonde observations

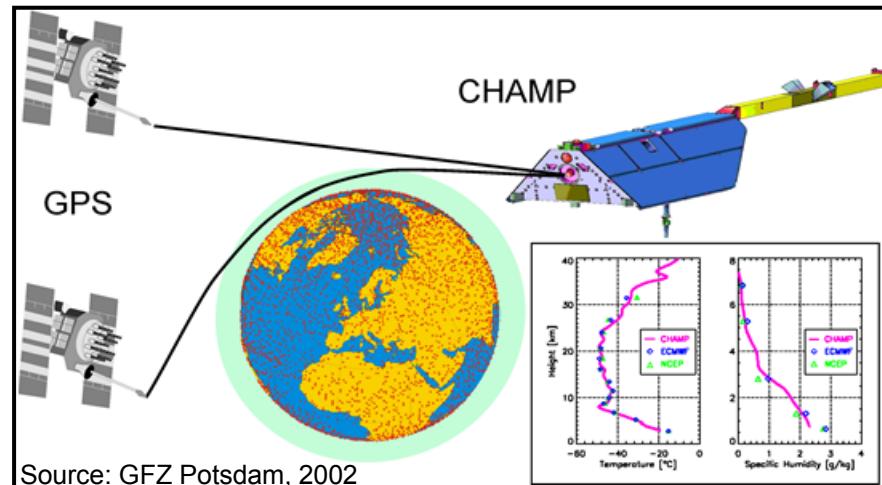


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Data Sets (3) – Measurement Principles

Radio Occultation (RO)



GPS radio occultation:

- an active limb sounding method
- uses radio signals from a GPS satellite, which are received onboard the CHAMP satellite.
- The relative motion of the satellites provides a near-vertical scan through the atmosphere.



Data Sets (4) – Data Characteristics

- RO temperature climatologies:- retrieved at Wegener Center/University of Graz
 - based on orbital data and phase delay measurements from
 - **CHAMP** and **GRACE** provided by GFZ Potsdam, Germany, and
 - **SAC-C** and **COSMIC** provided by UCAR/CDAAC, Boulder, CO
- ECMWF analyses: used as a reference analysis dataset (best available global atm. analysis)
- MSU/AMSU brightness temperatures: University of Alabama, Huntsville (**UAH**)
Remote Sensing Systems (**RSS**), Santa Rosa, CA
- HadAT2 radiosonde data: Hadley Centre/Met Office, UK, synth. MSU temperature anomalies

Data Set Characteristics				
Data Set	Version	Horizontal Resolution	Time Period <i>monthly data</i>	Basic Sampling <i>per day globally</i>
CHAMP RO			09/2001–12/2006	~ 150 profiles
SAC-C RO			06/2002–08/2002	~ 150 profiles
GRACE RO			06/2006	~ 150 profiles
COSMIC RO	CCR v2.3	10° zonal means	12/2006	~ 200 profiles (2 satellites used)
ECMWF	T42L60 T42L91	10° zonal means	09/2001–01/2006 02/2006–12/2006	~ 8,000 grid points, 4 times/day
MSU/AMSU	RSS v2.1	2.5° lat x 2.5° lon	11/1978–12/2005	~ 30,000 TLS observations
	UAH v5.1	2.5° lat x 2.5° lon	12/1978–12/2006	
HadAT2 MSU	HadAT2	5° zonal means	01/1958–12/2006	1–2 soundings/day, 676 stations

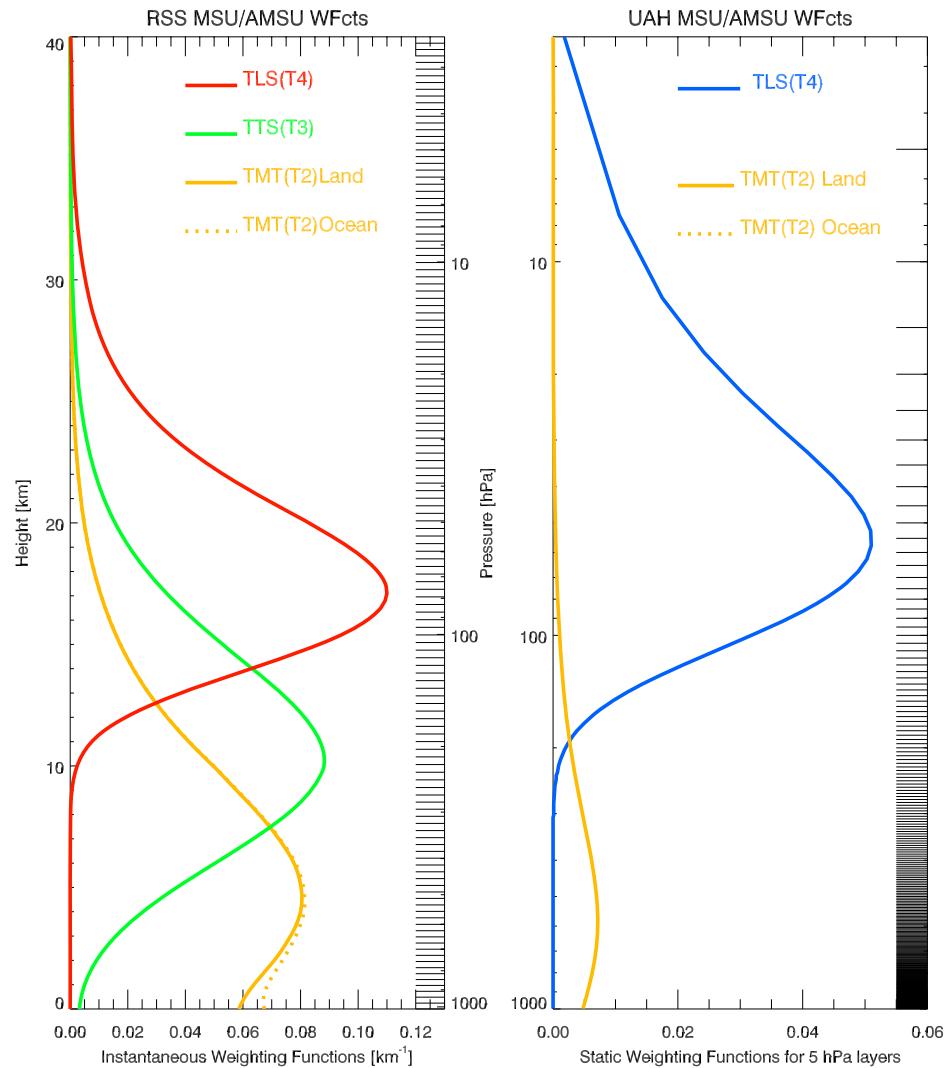


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Method (1) MSU/AMSU Global Weighting Functions



Temperature Lower Stratosphere TLS/T4
(Temperature Tropo/Stratosphere TTS/T3)
Temperature Middle Troposphere TMT/T2

RSS (left)

Instantaneous weighting functions
as function of height [km]

UAH (right)

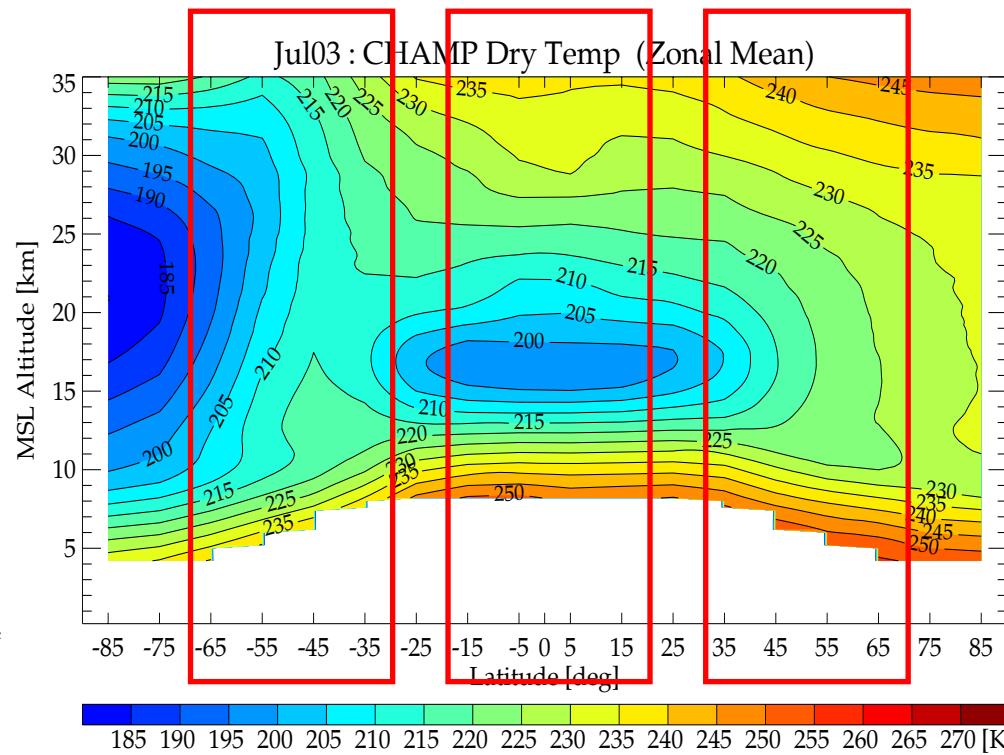
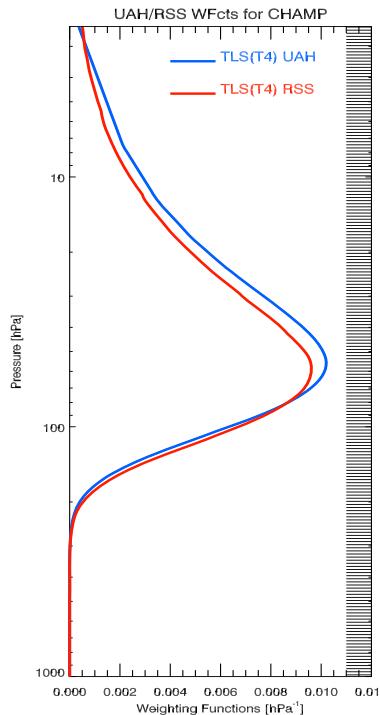
Mean static weighting functions
for 5 hPa layers



Method (2) Calculation of synthetic RO TLS Temperatures

- Interpolation of weighting functions wf_i to RO pressure levels p_i
- Calculation of synthetic MSU temperatures T_{MSU}
- using UAH and RSS weighting functions, then
- averaging the two TLS temperatures ($\Delta T \sim 0.1 \text{ K}$)

$$T_{MSU} = \frac{\sum_{i=1}^N T_i(p_i) * wf_i}{\sum_{i=1}^N wf_i}$$



Regions

Global (70°S - 70°N)
Tropics (20°S - 20°N)
Extratropics
NH (30°N - 70°N)
SH (30°S - 70°S)



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Method (3) Radiative Transfer Model RTTOV

RTTOV_8.5 radiative transfer model [Saunders et al., 2006] alternatively applied to test the validity of our approach

Differences between using a global weighting function versus using a Radiative Transfer Model for MSU4:

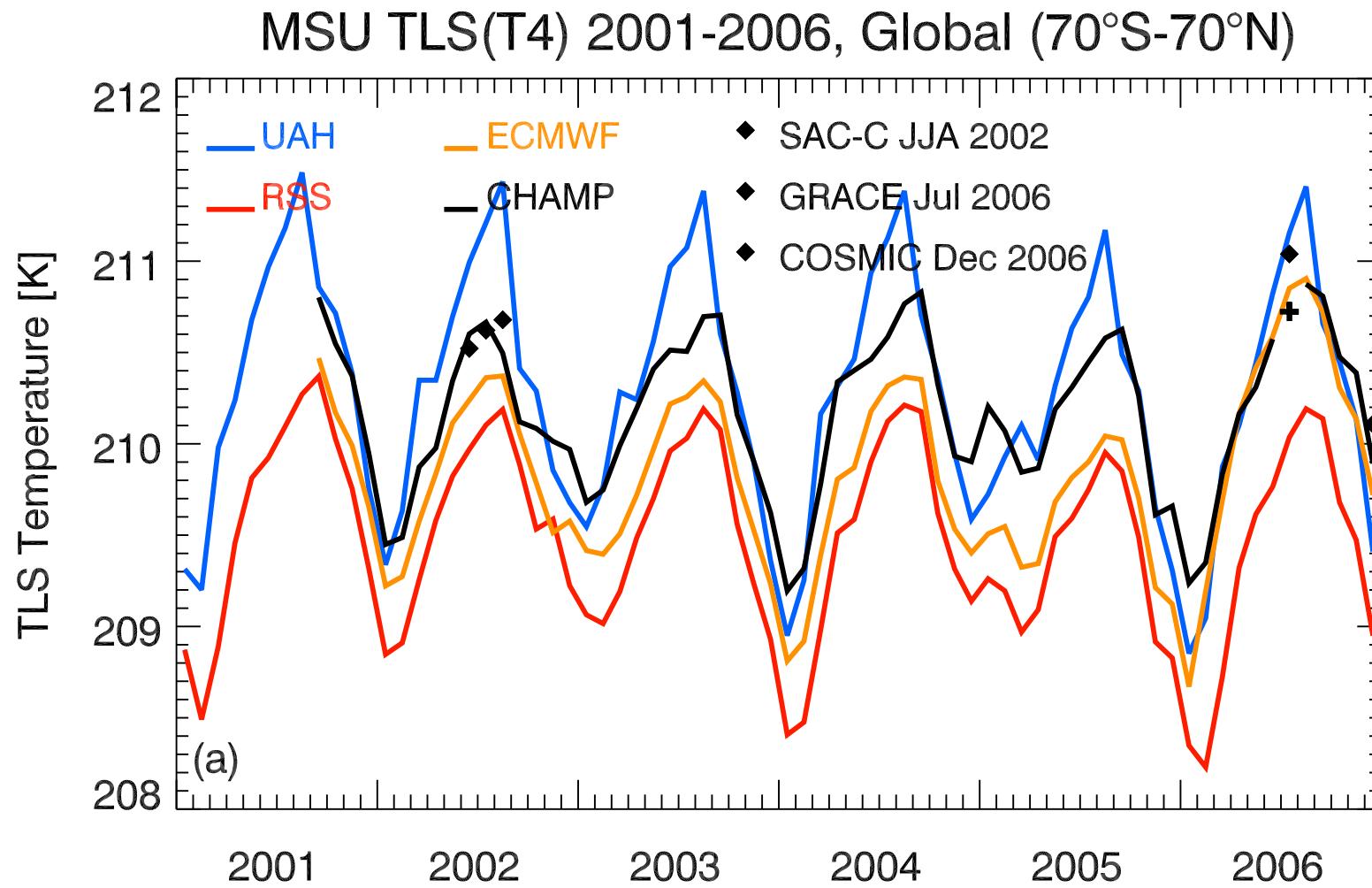
- for TLS absolute temperature on average < 0.2 K (individual maxima of monthly values ~0.3 K) for all four regions. This is within the MSU4 and AMSU9 bias estimates of Christy et al., JAOT, 2003.
- for TLS temperature anomalies the difference is < 0.1 K for all four regions
- In terms of TLS trend differences – negligible drift over time
<0.01 K/decade globally
<0.02 K/decade hemispheric scale
- Results are consistent with Santer et al., JGR, 1999; 2000 that using a radiative transfer model or a suitable global weighting function for computing TLS temperatures yields negligible difference for global and large-scale zonal means.



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Results (1) TLS Absolute Temperatures – Global and Tropics





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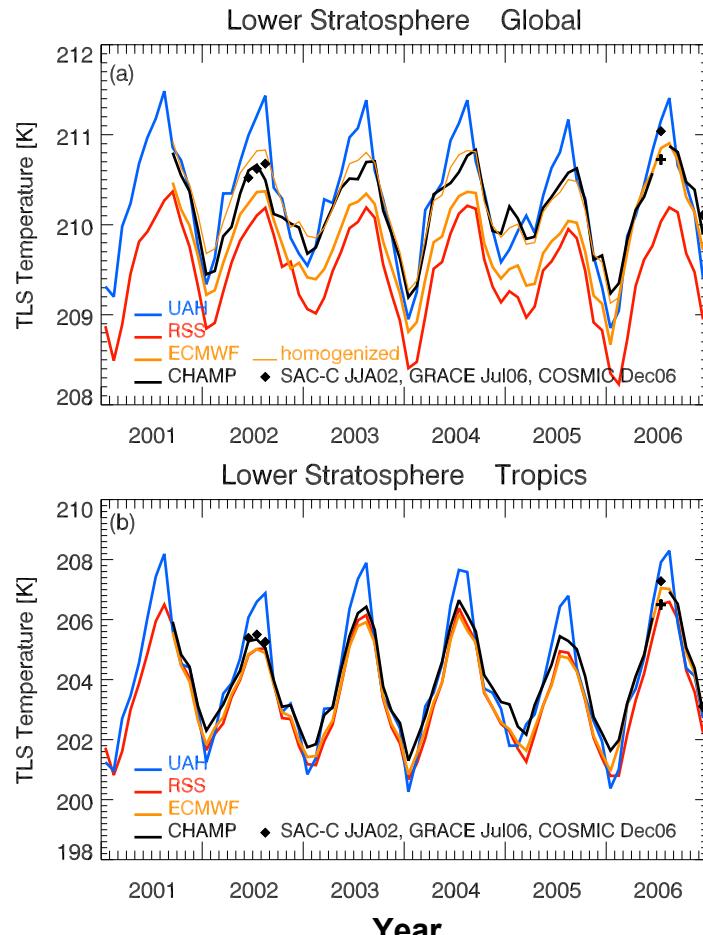


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Results (1)

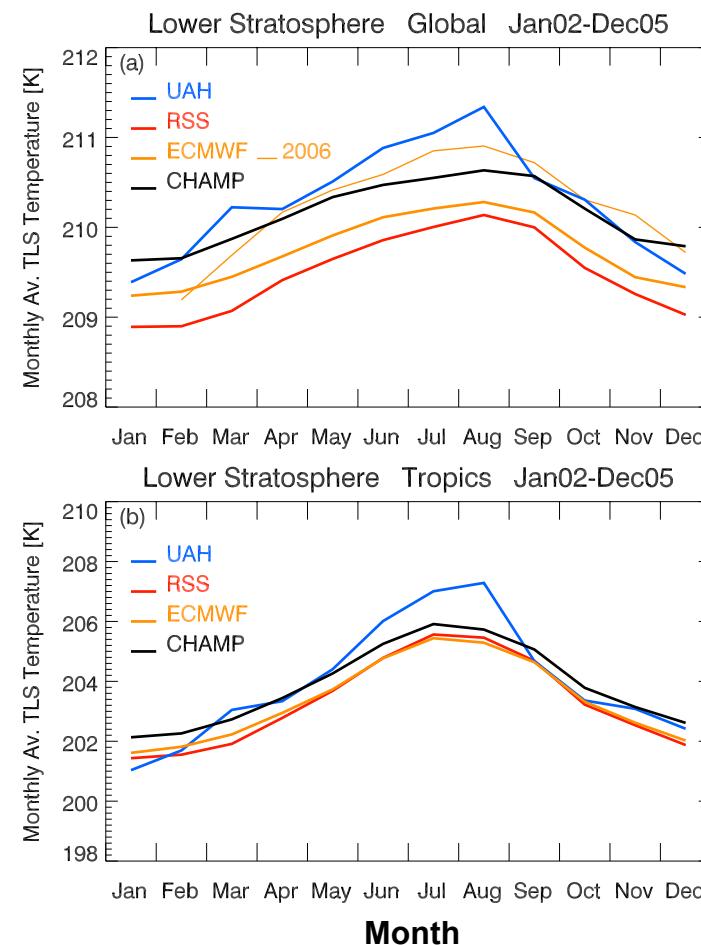
TLS Absolute Temperatures – Global and Tropics

TLS absolute temperatures



Global:
UAH-CHAMP 0.11 K (± 0.31 K)
RSS-CHAMP -0.69 K (± 0.16 K)

Monthly means over 2002-2005



references for temperature anomalies



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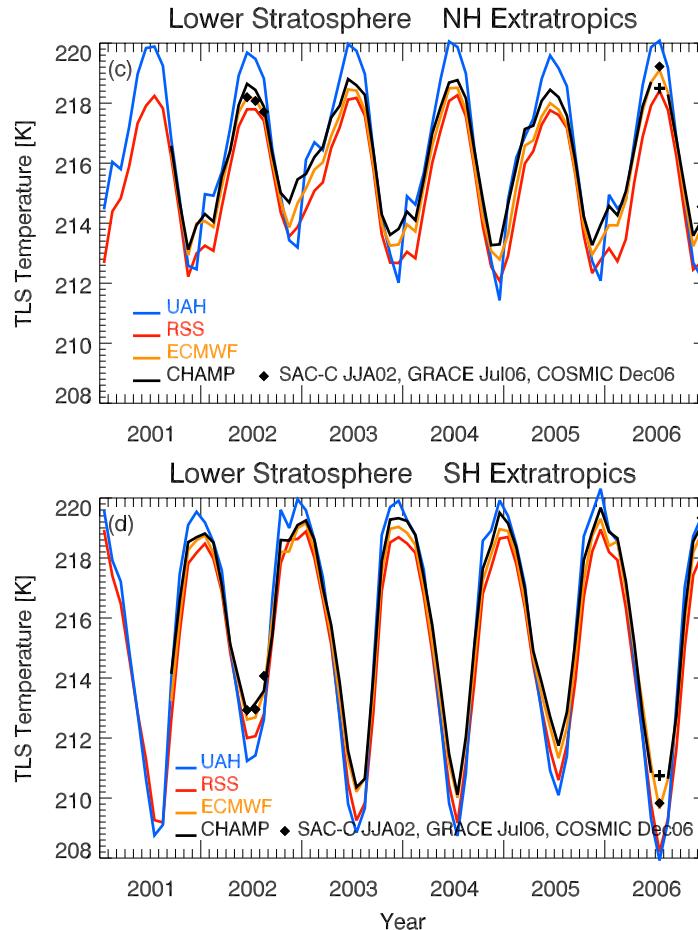


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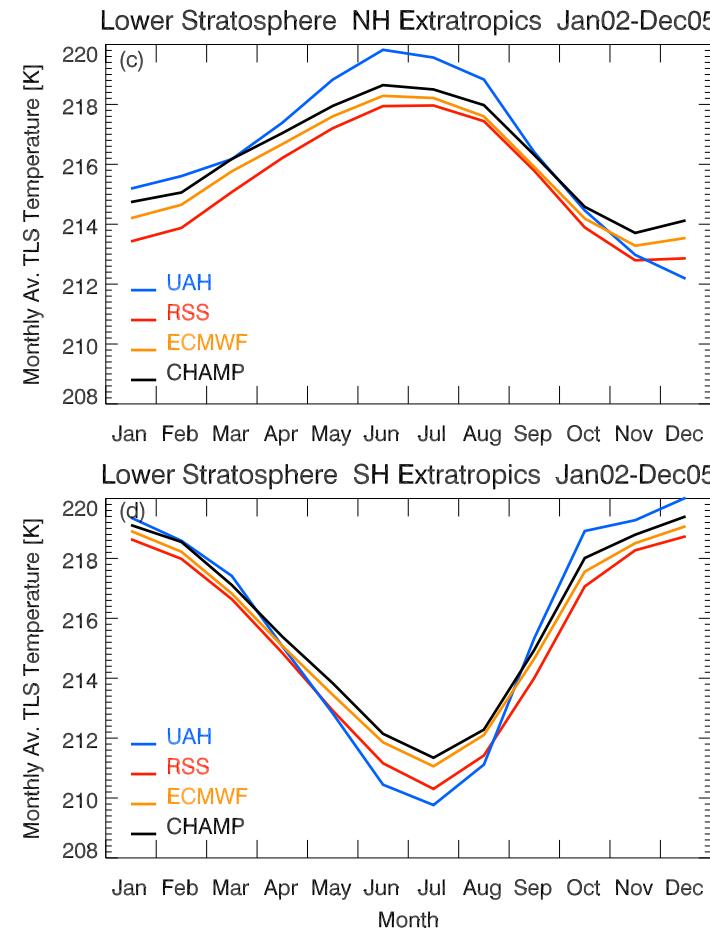
Results (2)

TLS Absolute Temperatures – NH/SH Extratropics

TLS absolute temperatures



Monthly means over 2002-2005



references for temperature anomalies



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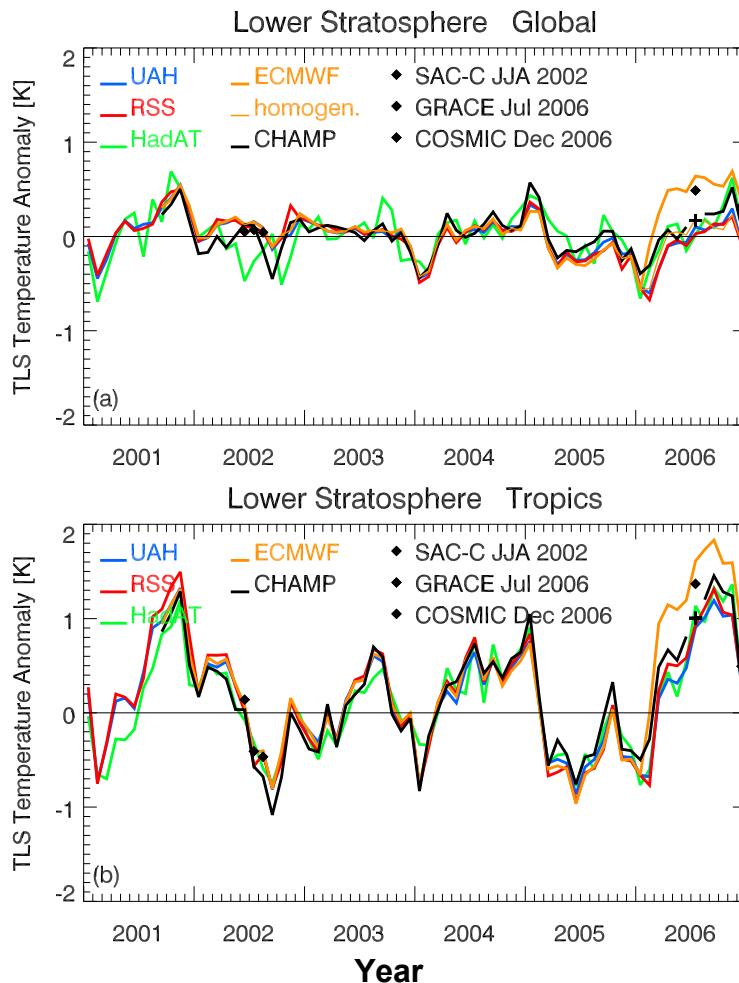


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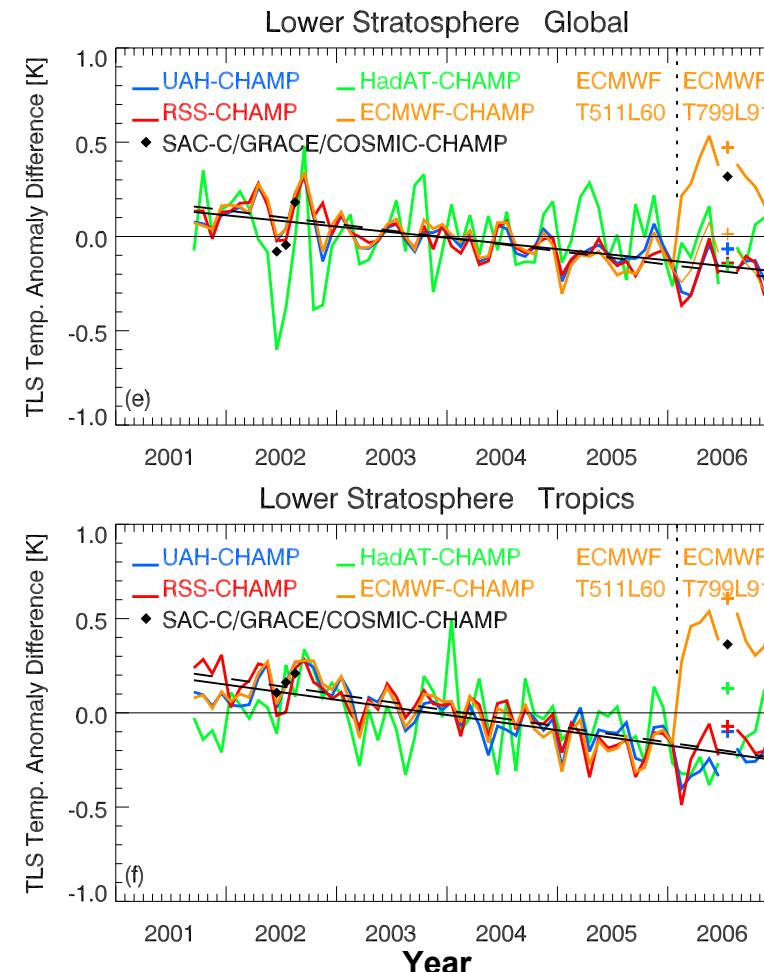
Results (3)

TLS Temperature Anomalies – Global and Tropics

TLS temperature anomalies



TLS temperature anomaly differences





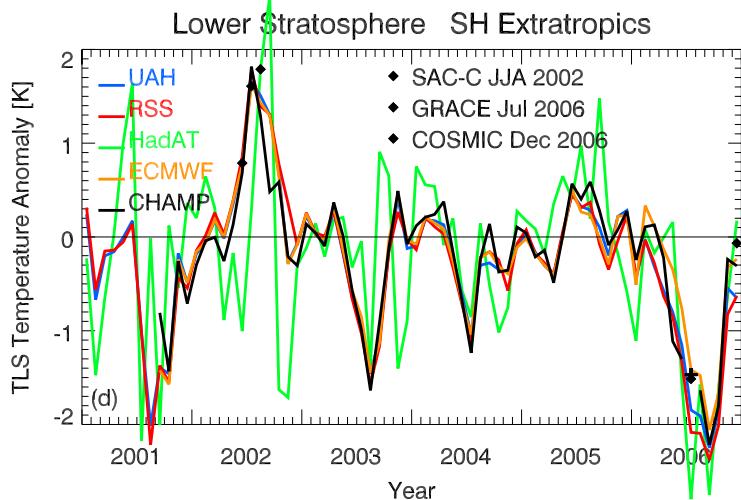
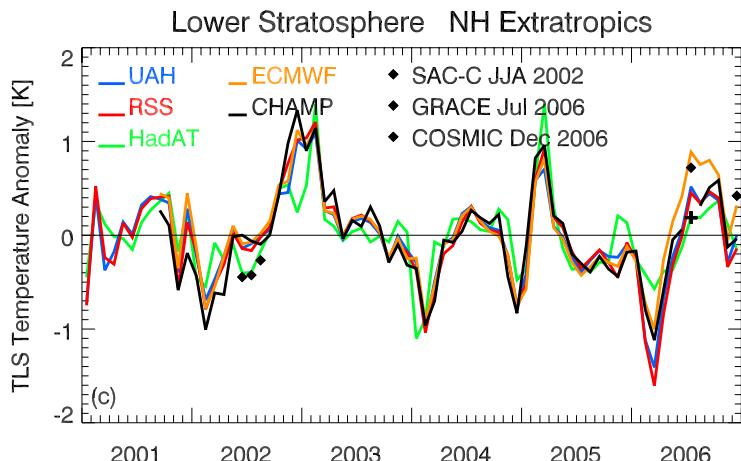
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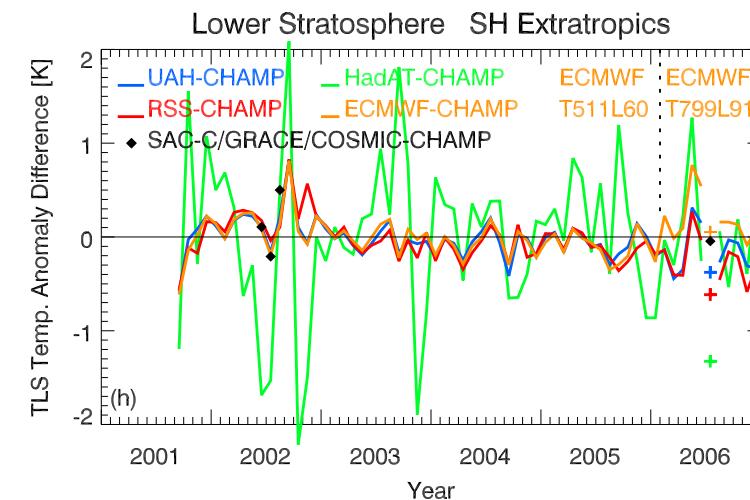
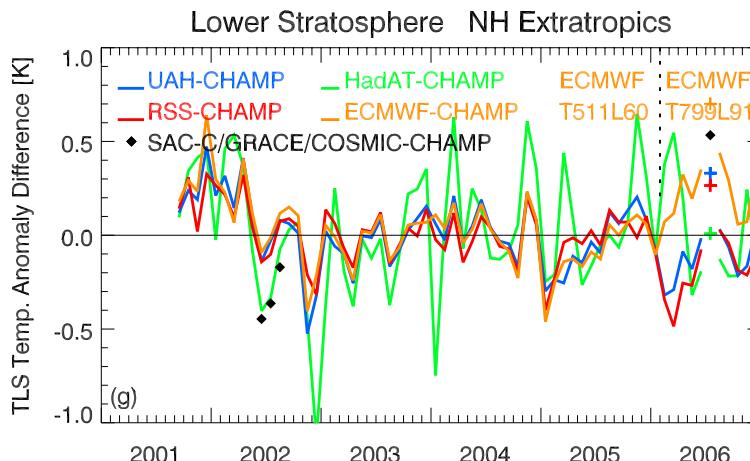


Results (4) TLS Temperature Anomalies – NH/SH Extratropics

TLS temperature anomalies



TLS temperature anomaly differences





Results (5) Temperature Anomaly Differences – Discussion

TLS Temperature Anomaly Difference			
Data Sets	RMS [K]	Trend [K/5yrs]	RMSdet [K]
<i>GLOBAL</i>			
UAH–CHAMP	0.13	-0.30**	0.08
RSS–CHAMP	0.14	-0.36**	0.08
<i>TROPICS</i>			
UAH–CHAMP	0.16	-0.40**	0.10
RSS–CHAMP	0.17	-0.42**	0.10

** significant at > 95% confidence level

2001–2006 TLS Trends: HadAT2 and CHAMP coincide well, UAH and RSS show a statistically significant cooling trend difference to CHAMP globally and in the tropics.

Check:

Contribution of known error sources of RO data and
the related TLS computation procedure to 5-year TLS trend differences



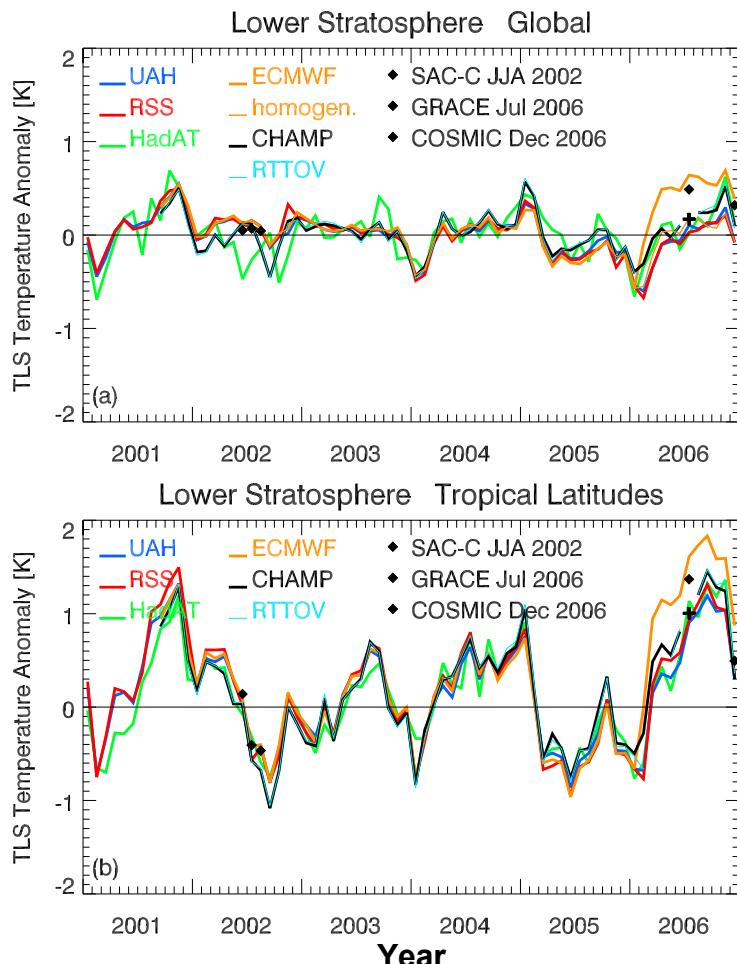
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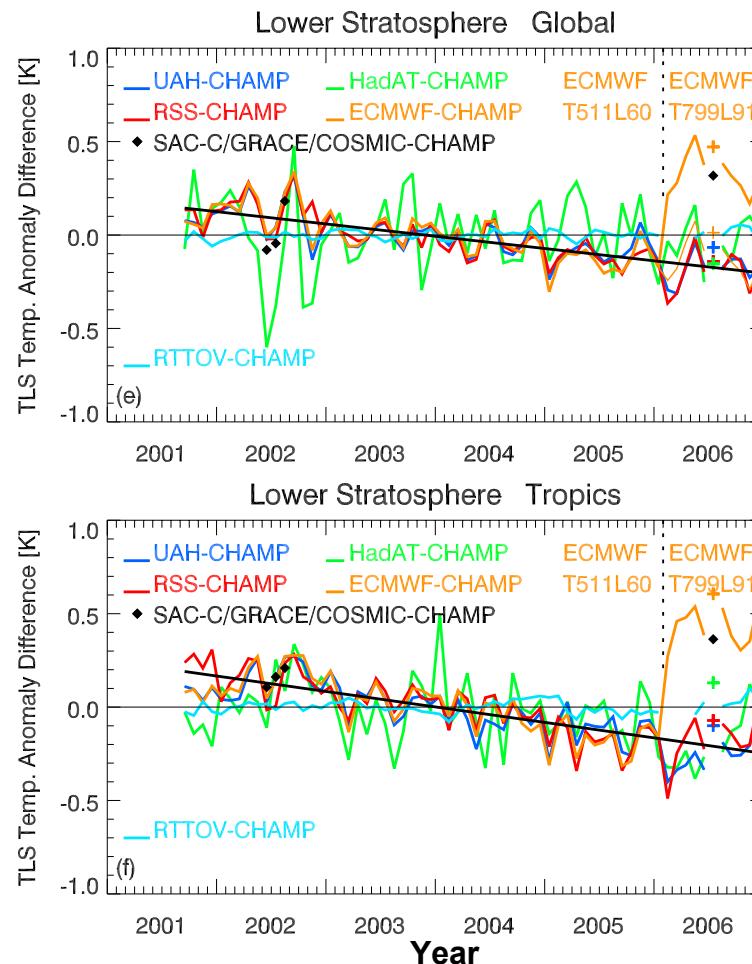


Results (6) TLS Temperature Anomalies – Global and Tropics

TLS temperature anomalies



TLS temperature anomaly differences



WFCTS vs RTTOV: for TLS temperature anomalies the difference is < 0.1 K for all regions



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Results (7) Contribution of known error sources

Sensitivity check of high altitude “initialization”:

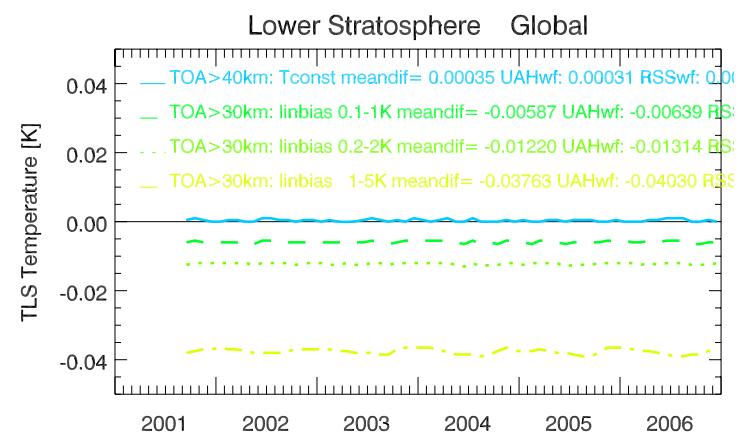
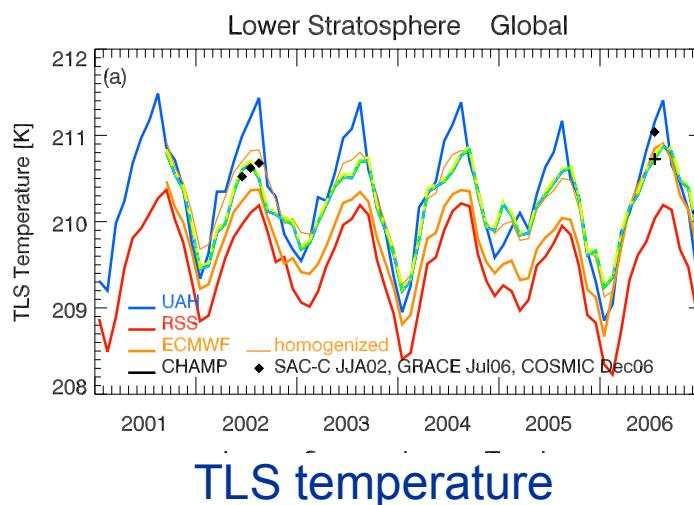
>40 km T = constant → Terror = 0.0003

30–40 km linear bias in T of 0.1–1 K → Terror = ~5/1000 K

30–40 km linear bias in T of 0.2–2 K → Terror = ~1/100 K

30–40 km linear bias in T of 1–5 K → Terror = ~4/100 K

→ high altitude initialization drifts <0.02 K/5yrs





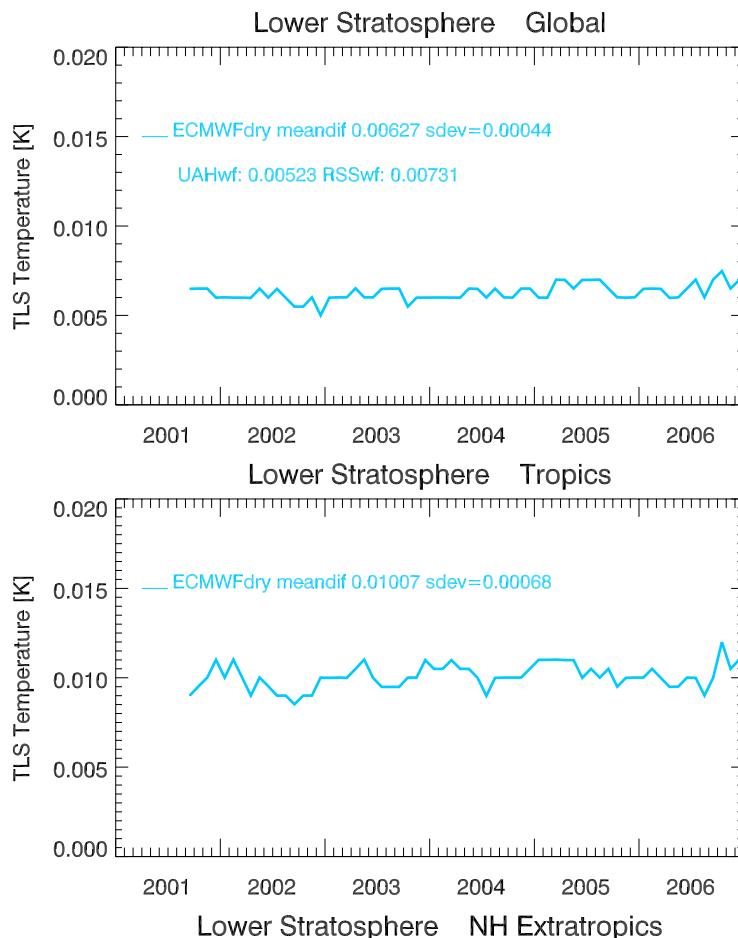
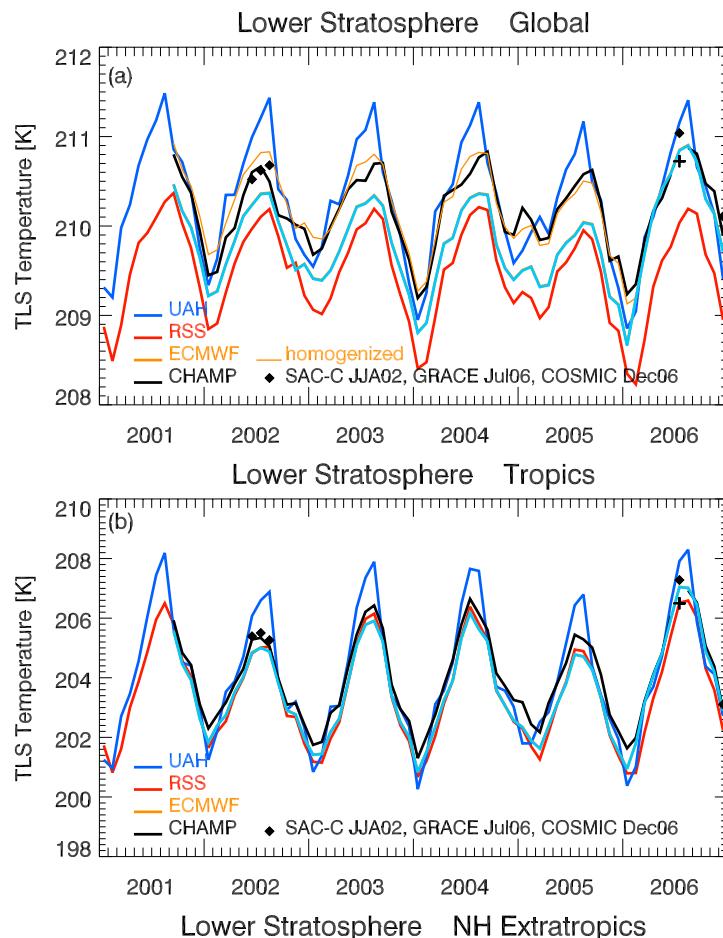
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Results (8) Contribution of known error sources

Dry/physical temperature difference < 0.02 K/5yrs





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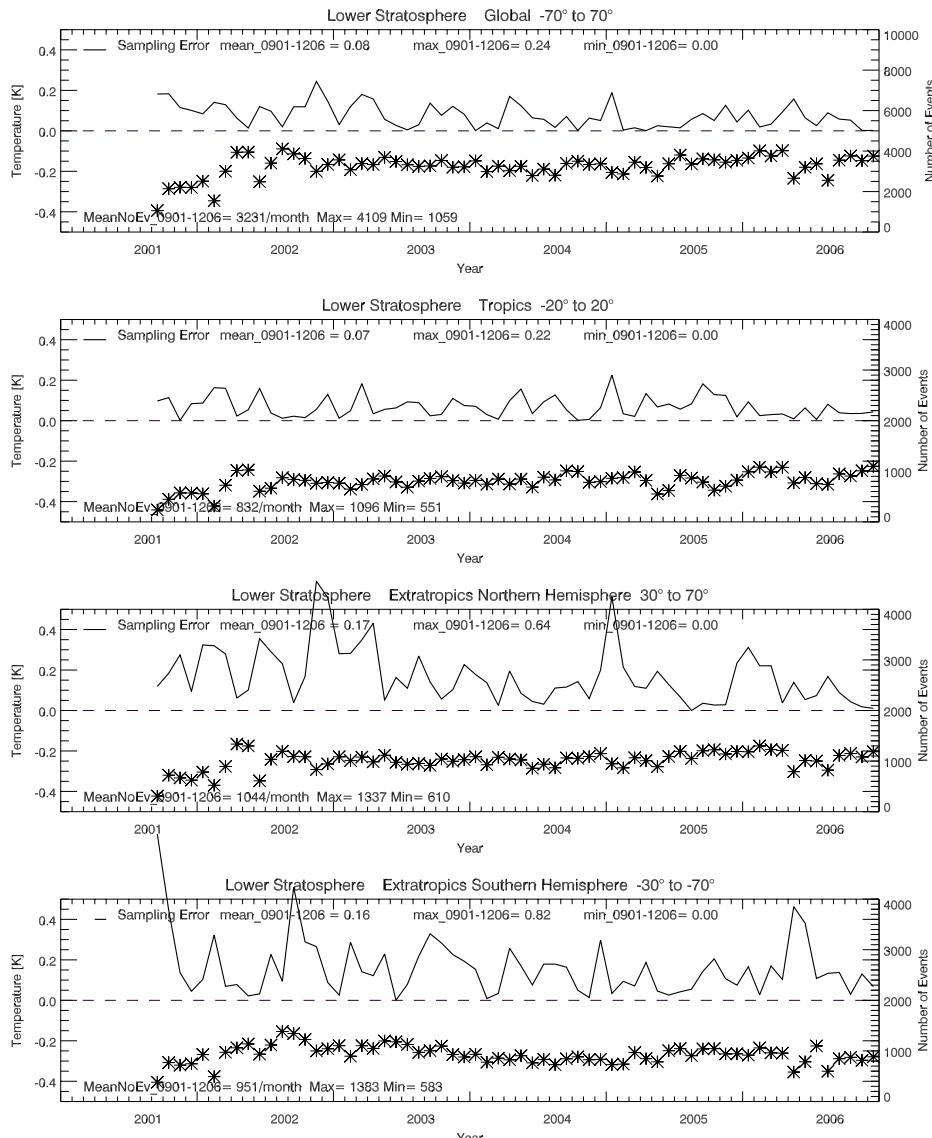


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Results (9) Contribution of known error sources

Mean sampling error

mean sampling error drift < 0.02 K/5yrs





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Results (10)

Temperature Anomaly Differences – Discussion

Contribution of known error sources of RO data and the related TLS computation procedure to 5-year TLS trend differences:

- high-altitude initialization bias drifts < 0.02 K/5yrs
- dry/physical temperature difference < 0.02 K/5yrs
- mean sampling error drift < 0.02 K/5yrs
- weighting function vs radiative transfer model < 0.01 K/5yrs

About one order of magnitude smaller than the detected trend differences.



Conclusions

- *TLS Absolute Temperature*: Global offsets relative to CHAMP 0.11 K (± 0.31 K) for UAH and -0.69 K (± 0.16 K) for RSS. ECMWF TLS agrees best with RSS until Jan07, then closely follows CHAMP due to improvement in ECMWF resolution.
- *TLS Temperature Anomalies*: Overall very good agreement of CHAMP anomalies with UAH, RSS, ECMWF anomalies for intra-annual variability (RMS difference < 0.1 K globally, 0.1 K tropics, < 0.25 K extratropics). HadAT2 anomalies show larger intra-annual variability differences (about a factor of two globally).
- *2001–2006 TLS Trends*: HadAT2 and CHAMP coincide well, UAH and RSS show a statistically significant cooling trend difference to CHAMP globally (-0.30 to -0.36 K/5yrs) and in the tropics (-0.40 to -0.42 K/5yrs). The contribution of known error sources regarding the RO data and related TLS computation is about an order of magnitude smaller. Further search for error sources needed.
- *SAC-C, GRACE, and COSMIC*: TLS temperatures closely match CHAMP temperatures (within the sampling error range of < 0.3 K), despite very different orbits and different instruments and raw processing chains (GFZ and UCAR), indicating the homogeneity and consistency of RO datasets.