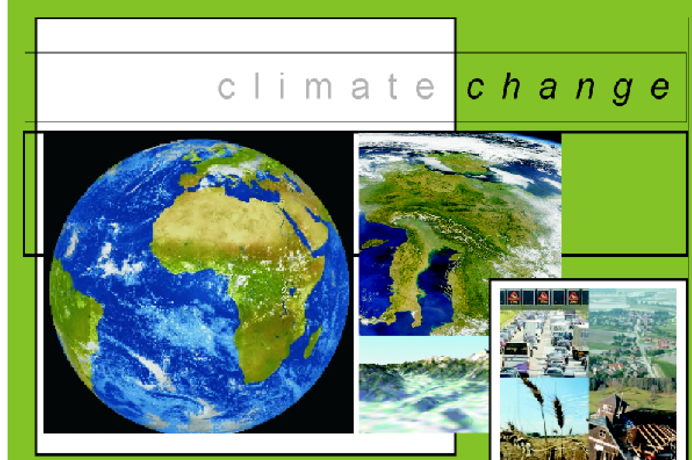
Seven Years of Tropical Tropopause Climatologies from CHAMP RO Measurements Compared to ECMWF and NCEP Analyses and Other RO Missions



Der Wissenschaftsfonds.

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A R S C l i S y s

Introduction

The Radio Occultation (RO) method is an active limb sounding technique (see also poster 00432, Borsche et al.). A signal from a GPS (Global Positioning System) satellite is recorded on a satellite in low Earth orbit and penetrates increasingly or decreasingly denser atmospheric layers, depending on the relative motion of the satellites. In this way the ray is slowed down and bent resulting in "atmospheric phase delays". RO measurements are especially suited for climate change studies by providing a combination of: 1) long-term stability, 2) global coverage, 3) virtually all-weather capability during day and night (L-band signals), 4) high vertical resolution (0.5 km–1.5 km), and 5) high accuracy ($\Delta T < 1$ K).

Data

For this study, RO data of five different satellites were analyzed: CHAMP measurements from September 2001 to February 2008, however, with missing data in July 2006; SAC-C measurements from August 2001 to January 2002 and from April 2002 to September 2002; GRACE measurements of July 2006; and measurements from the six-satellite mission FORMOSAT-3/COSMIC (F3C) from August 2006 to February 2008 of flight model one (FM-1) and from August 2006 to April 2007 of flight model four (FM-4). Atmospheric phase delays of all RO measurements were provided by the University Corporation of Atmospheric Research (UCAR), Boulder, USA, except for the GRACE data which were provided by the GeoForschungsZentrum (GFZ), Potsdam, Germany.

All RO data were very recently re-processed at the Wegener Center with the EGOPS software tool at version 5.4, which converts the atmospheric phase delays to temperature profiles. On these single profiles, tropopause temperature using the lapse rate definition of the World Meteorological Organisation were calculated. In addition, the altitude of the lapse rate tropopause temperature was determined as well as the cold point tropopause temperature and altitude. All four tropopause parameters were averaged temporally on a monthly basis and spatially within the tropical region (±15°N/S).

As reference data we, firstly, used operational analyses of the European Centre for Medium-Range Weather Forecasts (ECMWF). All four tropopause parameters were computed for single ECMWF profiles which were spatially and temporally collocated to CHAMP RO measurements. Secondly, we used the tropopause lapse rate temperature of the reanalyses as provided by the National Centers for Environmental Prediction (NCEP).

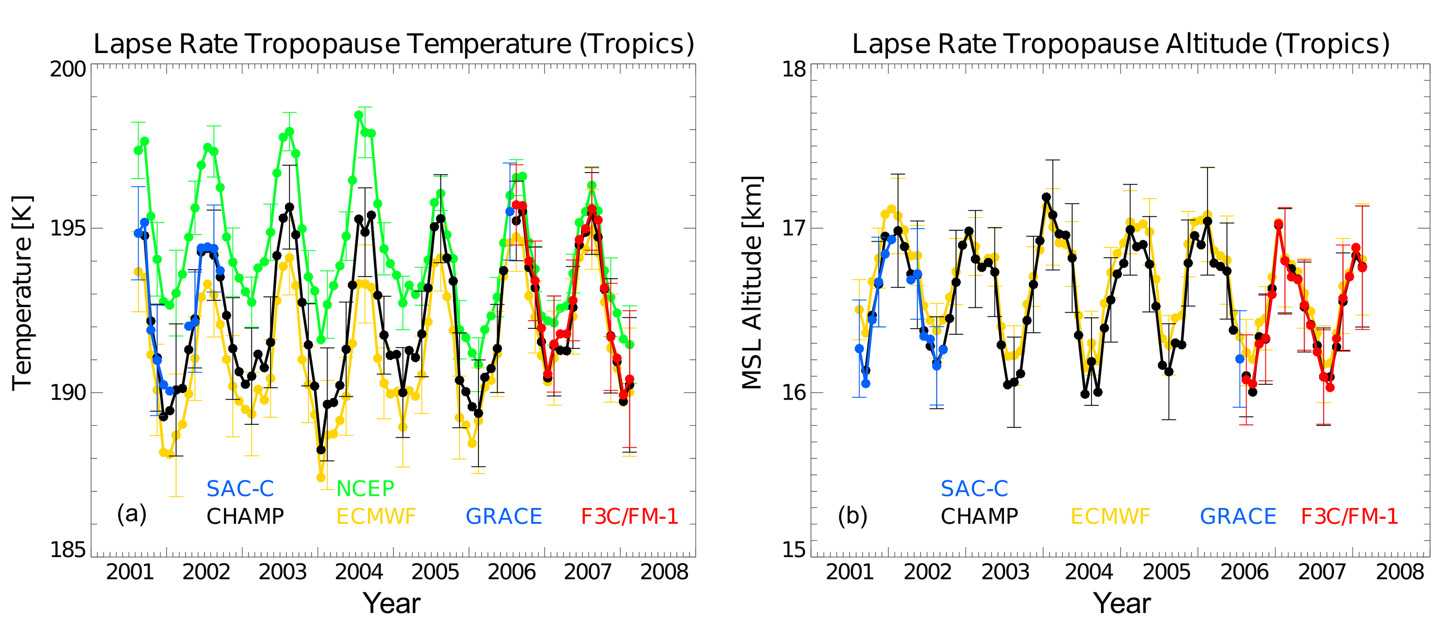
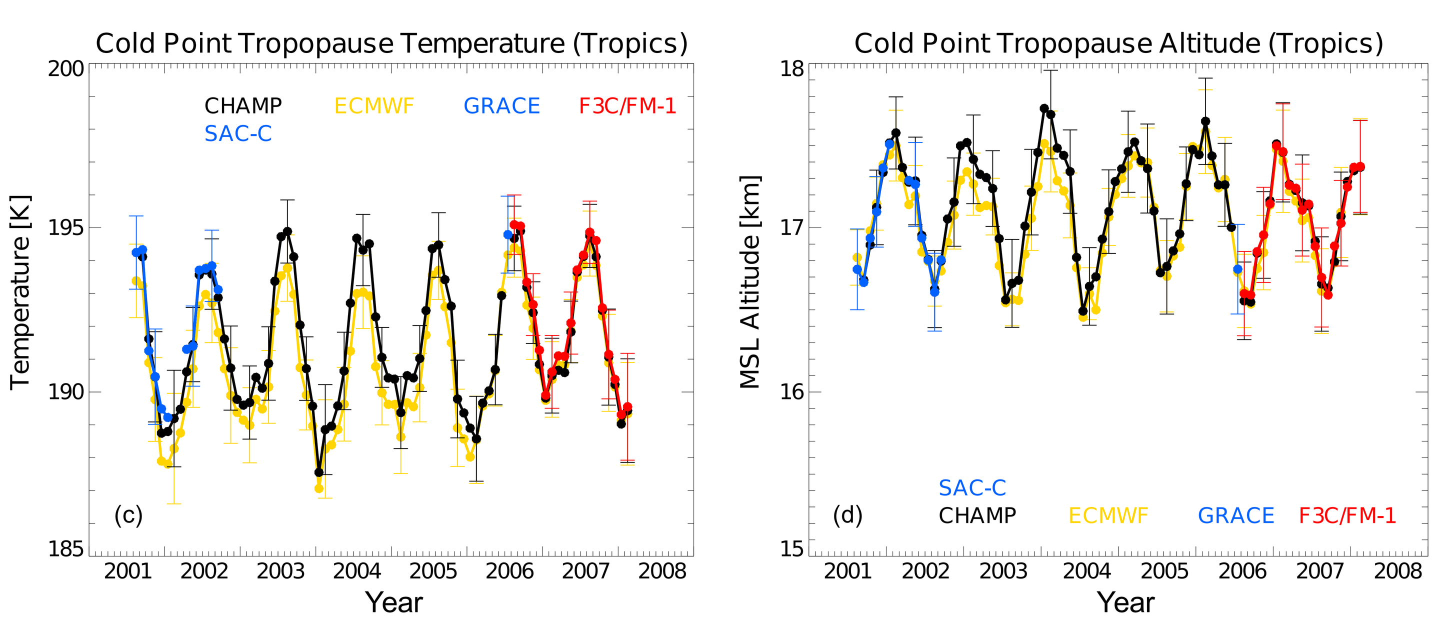


Figure 1 (top row): (a) Temporal evolution of monthly mean tropical (±15°N/S) laps rate tropopause (LRT) temperature for CHAMP (black), SAC-C (blue), GRACE (blue, July 2006), and FORMOSAT-3/COSMIC flight model one (F3C/FM-1) (red) RO data. LRT temperature as provided by NCEP reanalyses (green) and calculated from ECMWF profiles (yellow) were included as reference. (b) Temporal evolution of monthly mean tropical LRT altitude. (c) and (d) The same as for (a) and (b) but for cold point tropopause (CPT) temperature and altitude, respectively.



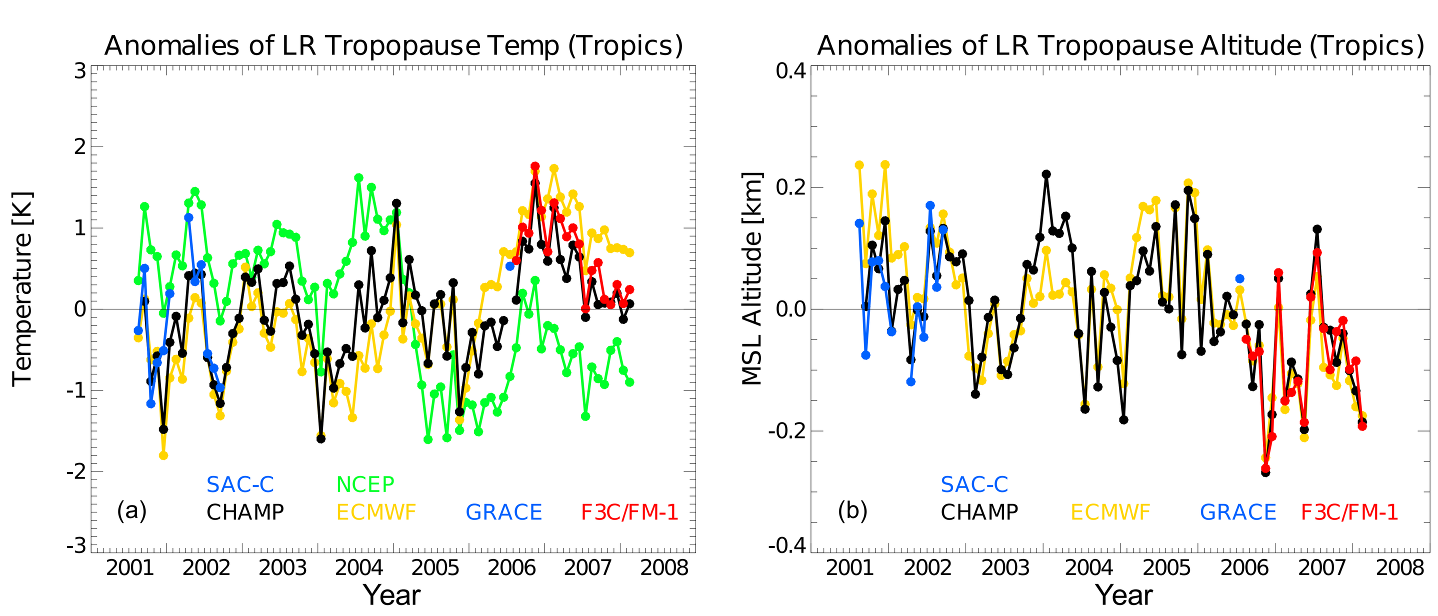
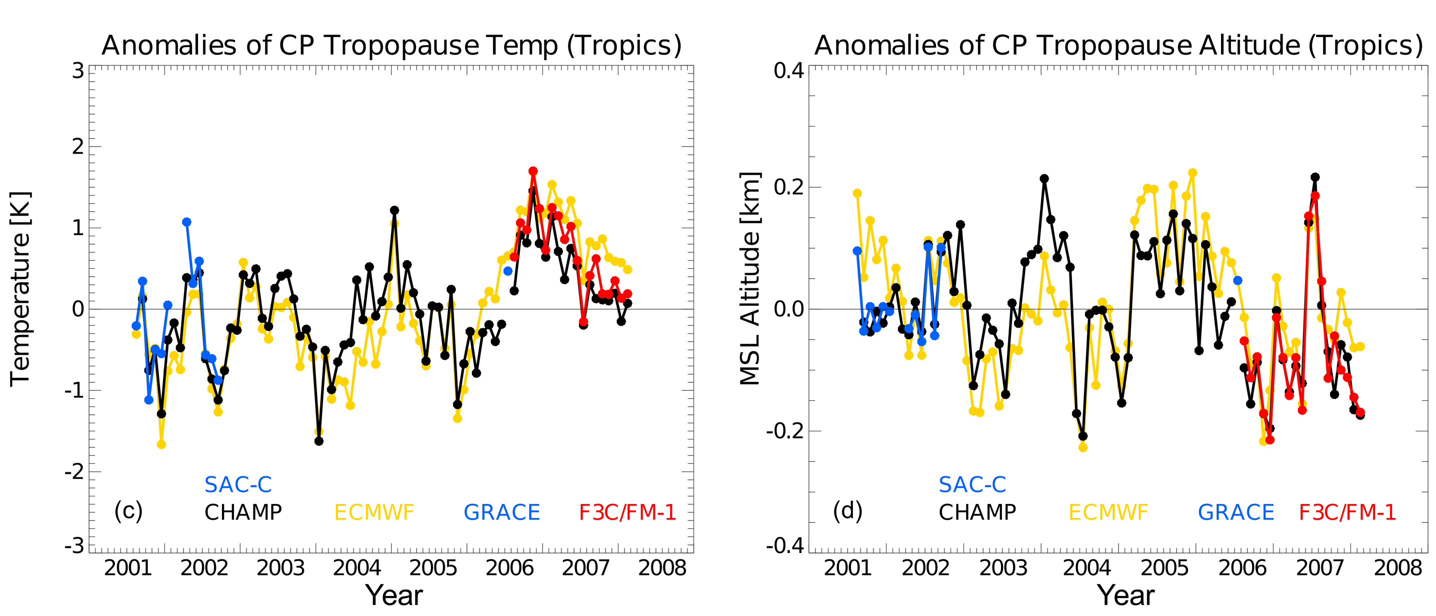


Figure 2 (second row): Deseasonalized anomalies of LRT temperature (a) and altitude (b) as well as CPT temperature (c) and altitude (d) for CHAMP (black), SAC-C (blue), GRACE (blue, July 2006), F3C/FM-1 (red), NCEP reanalyses (green), and ECMWF (yellow). The seasonal cycle was removed based on the time period 2002 to 2007 and was performed for every data set separately, except for F3C/FM-1 and SAC-C for which the CHAMP seasonal cycle was taken.



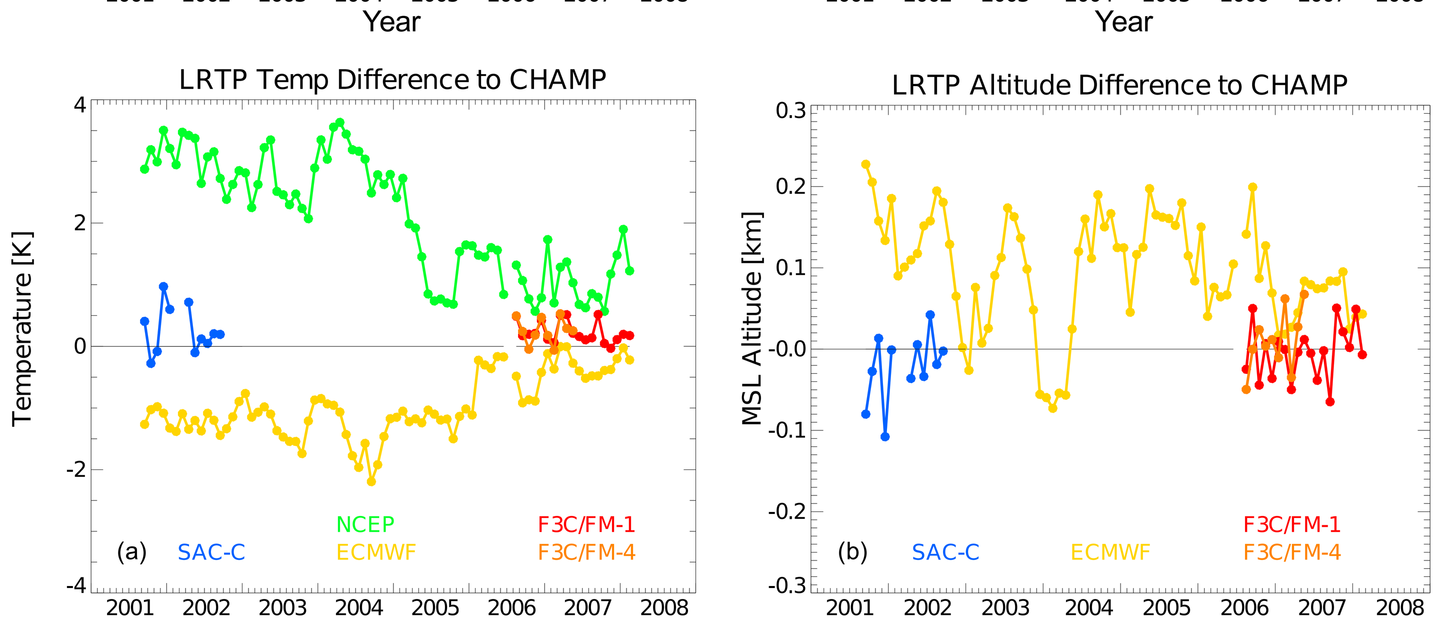
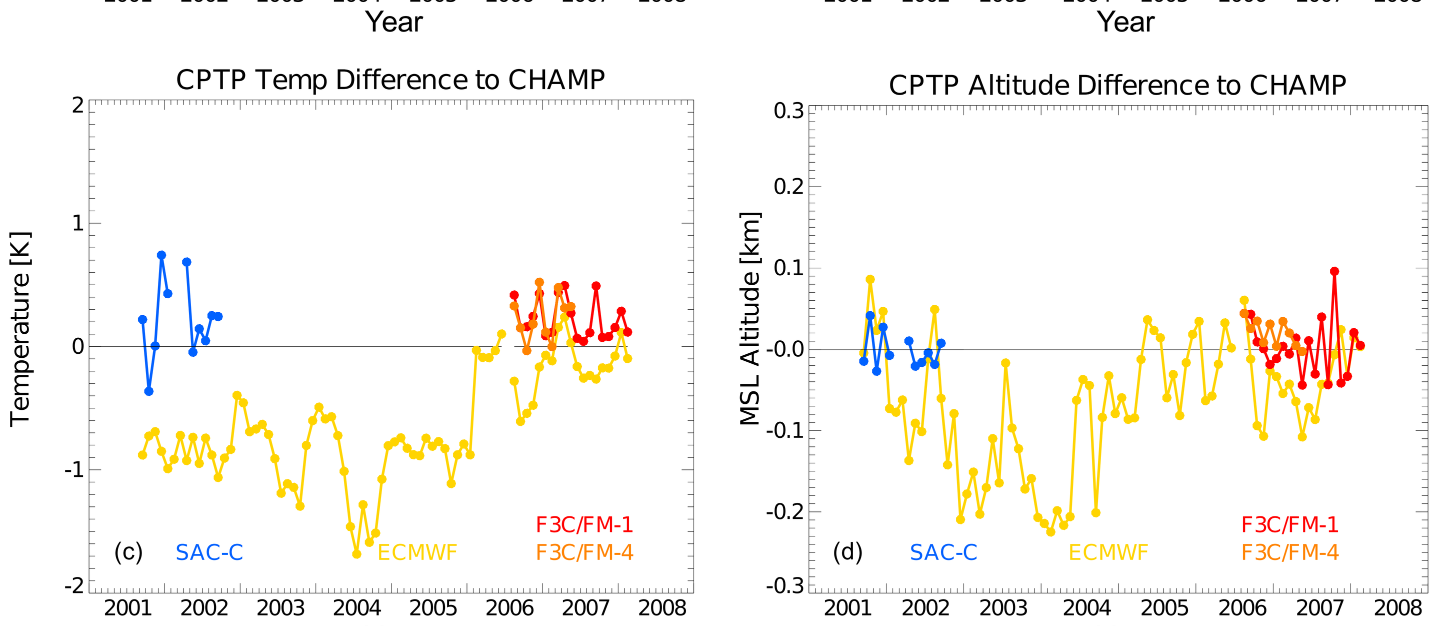


Figure 3 (third row): Monthly mean tropical differences relative to CHAMP for LRT temperature (a) and altitude (b) as well as CPT temperature (c) and altitude (d) for SAC-C (blue), F3C/FM-1 (red), F3C/FM-4 (orange), NCEP (green), and ECMWF (yellow). RO measurements of different satellites compare very well, whereas ECMWF temperature differences relative to CHAMP are distinctly negative and NCEP differences positive. Note the difference of the y-axis of LRT compared to CPT temperature.



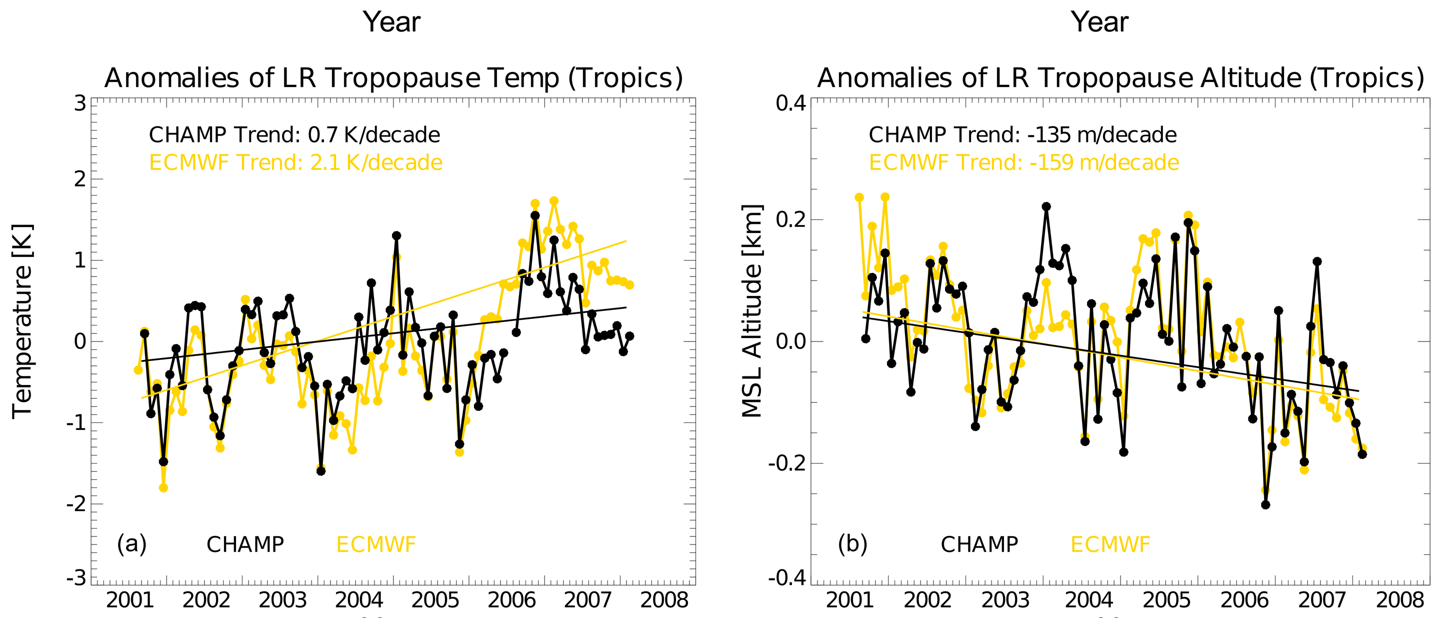
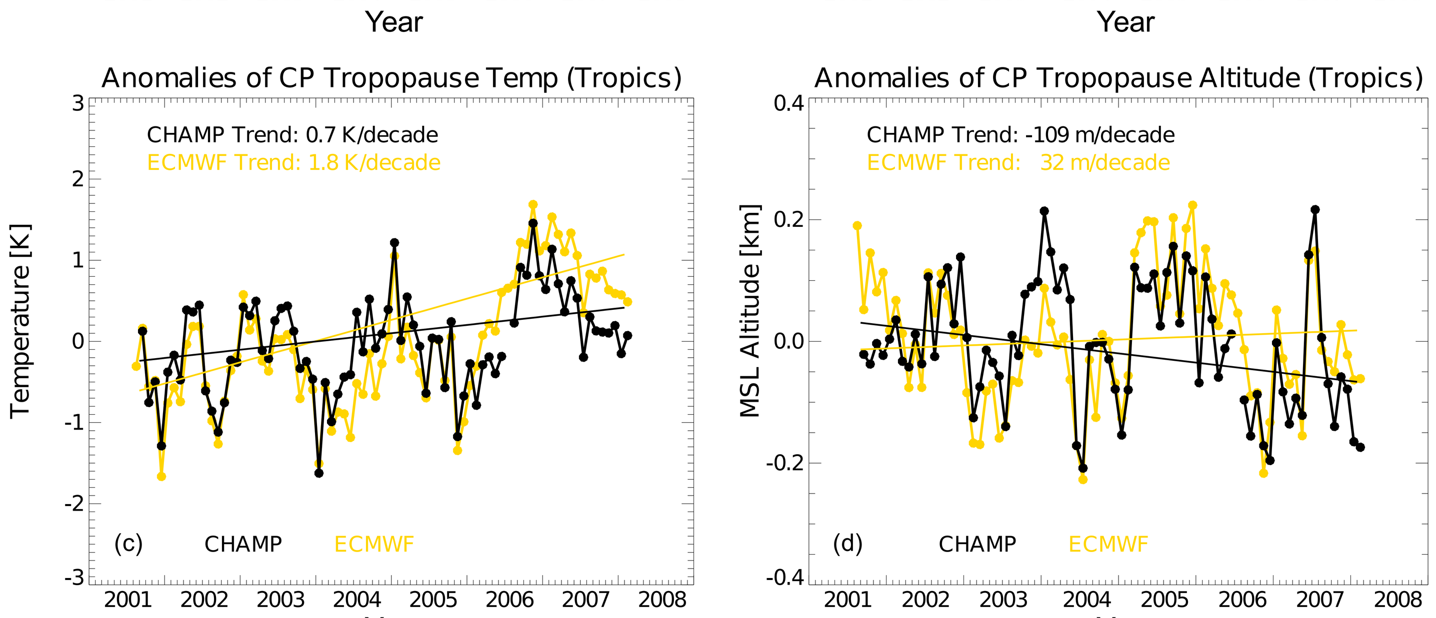


Figure 4 (bottom row): LRT temperature (a) and altitude (b) as well as CPT temperature (c) and altitude (d) anomalies of CHAMP (black) and ECMWF (yellow). A linear trend estimation is superimposed, which is based on the time period 2002 to 2007. LRT temperature trend estimation for CHAMP results in an increase of 0.7 K/decade whereas LRT altitude decreases by -135 m/decade.



Results and Discussion

The evolution of lapse rate tropopause (LRT) and cold point tropopause (CPT) temperature, as shown in **Fig. 1a** and **Fig. 1c**, respectively, exhibit a pronounced annual cycle. They exhibit an amplitude of about 3 K with maxima in summer and minima in winter. The annual cycle of LRT and CPT altitude (**Fig. 1b** and **Fig. 1d**, respectively) is opposite to that of temperature and exhibits an amplitude of around 0.5 km. Deseasonalized anomalies, as shown in **Fig 2**, were calculated for each data set and are based on the time period 2002 to 2007. Because of their short time periods, SAC-C and F3C tropopause anomalies were calculated based on the CHAMP seasonal average. **Fig. 3** shows differences of all data relative to CHAMP. Differences relative to CHAMP were calculated for all tropopause parameters for SAC-C, F3C/FM-1, F3C/FM-4, ECMWF, and NCEP data. Differences are very small for all RO satellites implying good agreement between the different measurements. On average, SAC-C LRT temperature is 0.25 K, F3C/FM-1 0.23 K, and F3C/FM-4 0.25 K warmer than CHAMP. On the contrary, the reference data, exhibit much larger differences compared to CHAMP of about +3 K for NCEP LRT temperature and of about -1.5 K for ECMWF. LRT and CPT ECMWF altitude relative to CHAMP exhibit high variability and amount to 96 m ±69 m and -69 m ±77 m, respectively, whereas SAC-C and F3C altitude differences amount to less than 20 m with a standard deviation of less than ±40 m. **Fig. 4** shows CHAMP and ECMWF LRT and CPT temperature and altitude anomalies with a trend estimate superimposed. Trends were estimated with a linear fit of the data for the time period 2002 to 2007, which is only a short time period of six years. From our analysis, the ECMWF LRT and CPT temperature trends amount to 2.1 K/decade and 1.8 K/decade, respectively, whereas the CHAMP trends amount to only 0.71 K/decade and 0.7 K/decade, respectively. This trend difference is mainly explained by an ECMWF model enhancement in early 2006 which resulted in tropopause temperature anomalies to suddenly decrease significantly. CHAMP LRT and CPT altitude trends are negative and amount to -135 m/decade and -109 m/decade, respectively.

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