Tropical Tropopause Characteristics from CHAMP

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Summary. In this paper an overview of the temperature structure in the tropical upper troposphere and lower stratosphere (UTLS) region is given using Global Positioning System (GPS) radio occultation (RO) data from the German CHAMP (CHAllenging Minisatellite Payload) satellite mission. Several climatologies for tropopause parameters based on radiosonde data and model analyzes have been published in recent years. Both the data sources suffer either to less global coverage or low vertical resolution. This fault can be overcome by the GPS RO technique due to its global coverage, high vertical resolution, all-weather viewing, and long-term stability. CHAMP RO data are available since 2001 with up to 200 high resolution temperature profiles per day. Using CHAMP RO data during May 2001-September 2003, the structure and variability of the tropical tropopause is presented.

Key words: CHAMP, GPS, radio occultation, tropopause, UTLS region, GFZ Potsdam

1 Introduction

The tropopause separates the troposphere and stratosphere which have fundamental different characteristics, for example, chemical composition and static stability. Thus, the identification of the tropopause is of importance for describing climate variability and change, and for understanding the troposphere-stratosphere exchange [1, 2]. According to the World Meteorological Organization (WMO), the tropopause is defined as the lowest level at which the temperature lapse-rate is less than 2 K/km and the lapse-rate average between this level and the next 2 km does not exceed 2 K/km [3]. This is the so-called lapse-rate tropopause (LRT). Beside this definition in the tropics the potential temperature and the minimum temperature in a vertical temperature profile (cold-point) is used to locate the tropical tropopause.

In the past, several studies have been performed leading to tropopause climatologies from different data sources [4, 5, 6]. The most important data source for the determination of tropopause parameters are radiosonde data whereas model analyzes (ECMWF or NCEP) suffer from low vertical resolution and attendant biases. Despite of good vertical resolution of radiosonde measurements, a global coverage is impossible. On the other hand, investigations of long-term radiosonde data have to take into account for the inhomogeneous time series due to sensor changes. This effect can be overcome by the

GPS RO technique with its (1) high vertical resolution (less than 1 km), (2) long-term stability, (3) all-weather capability, and (4) global coverage [7, 8, 9].

The proof-of-concept GPS RO experiment GPS/MET (GPS/Meteorology) performed between 1995 and 1997 has demonstrated for the first time the potential of GPS-based limb sounding from LEO satellites for deriving atmospheric temperature and water vapor profiles [8]. Further missions with radio occultation experiments followed (Øersted, SAC-C, and CHAMP), but the German geoscience satellite CHAMP is the only one measuring continuously atmospheric profiles in an operational manner since mid-2001 [10, 11].

First investigations of the thermal structure and variability in the tropical UTLS region based on GPS RO measurements were performed by [12, 13] on the basis of the GPS/MET data from 1995-1997 with focus to the so-called 'prime-times' (June-July 1995, December-February 1996/97) [9]. First applications of CHAMP RO data to the UTLS region with a 1-year data set were published in [14]. Here we present a thermal tropical tropopause statistics based on GPS RO measurements aboard CHAMP for the May 2001-September 2003 period.

2 The tropical tropopause

2.1 Validation

The temperature in the UTLS region derived from CHAMP is in excellent agreement with radiosonde measurements serving as an independent data source for CHAMP RO data validation. As shown by [15], the temperature bias between CHAMP and radiosonde data is less than 0.5 K between 300-30 hPa for more than 10,000 RO that meet the condition that the radiosonde was launched within a distance of less than 300 km and with a time delay less than 3 hours from the CHAMP measurement.

2.2 Time-averaged and spatial structure

Averaged tropopause statistics were computed from individual high-resolution CHAMP temperature profiles. For the identification of the LRT, the WMO definition for the thermal tropopause was used [3]. In addition to the LRT parameters, the cold-point tropopause (CPT) characteristics and the 100-hPa level features are also included here. The tropical tropopause has not a sharp boundary. As discussed, e.g., in [5, 16, 17] a tropical transition layer (TTL) is introduced in which the interaction of convection, the stratospheric wave driven circulation and horizontal transport processes determine the troposphere-stratosphere exchange. [17] suggest that the CPT forms the upper boundary of the TTL. The 100-hPa level that has also been used for the identification of the tropical tropopause can only serve as a proxy. On the

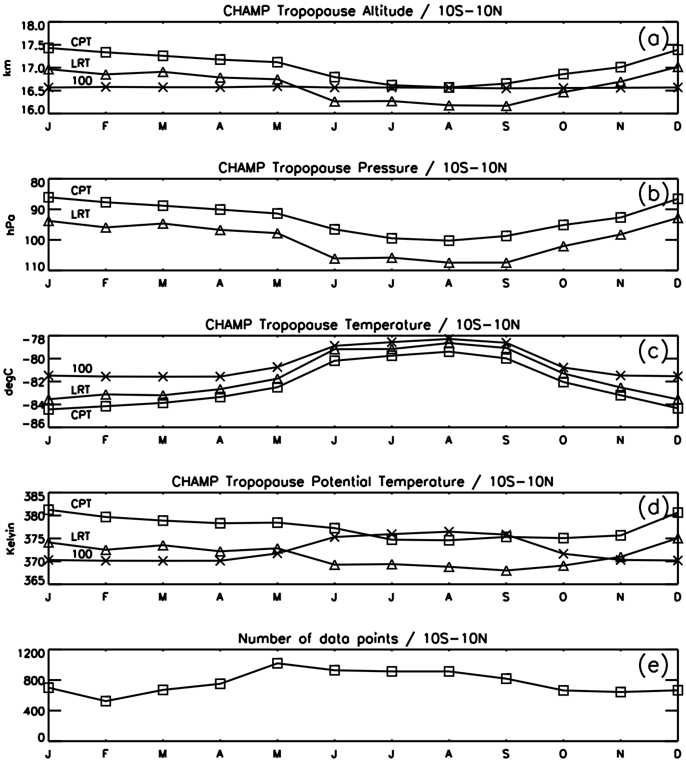

Fig. 1. Monthly means of CHAMP tropical tropopause parameters for the period May 2001-September 2003 (LRT: lapse-rate tropopause, CPT: cold-point tropopause, 100: 100-hPa level).

basis of the individual CHAMP RO measurements monthly averages of the tropopause parameters were calculated.

Fig. 1 shows the monthly-average tropopause parameters for the equatorial zone (10S-10N). The tropopause is highest and coldest during the northern hemisphere winter months, and lowest and warmest during the northern summer. A discussion of this annual cycle can be found in, e.g., [18, 19]. In the CHAMP data the LRT altitude has its maximum at 17.0 km in December and January and the minimum in August and September (16.2 km). During all months the CPT is about 300-500 m higher than the LRT. The 100-hPa level is at 16.6 km all time long. In the northern hemisphere winter the 100-hPa level is in the troposphere and during the southern hemisphere winter months it is located in the stratosphere. Fig. 1b shows the annual cycle of LRT and CPT pressure supporting the interpretation for LRT and CPT altitude: minimum of LRT pressure in December-January (93-95 hPa) and maximum in August-September (107 hPa). The CPT pressure is about 5-10 hPa lower than the LRT pressure. Fig. 1c shows annual and zonal tropopause temperature values from CHAMP RO data. In the equatorial zone the tropopause temperature is lowest in the northern hemispheric winter months and highest during northern summer. Monthly averaged CPT temperatures reaching -84°C in December-January and increasing to -79°C in August. LRT values are about 1 K higher than CPT temperatures. The potential temperature is an important value because the tropical tropopause corresponds to an isentropic surface with a potential temperature of on average about 380 K [1]. Typical values of potential temperature in the equatorial zone found in the CHAMP RO measurements are between 368-374 K for LRT and 374-381 K for the CPT. The number of CHAMP RO temperature profiles that are the basis for these investigations can be found in (Fig. 1e).

The spatial structure of the tropical LRT derived from CHAMP RO measurements for the northern hemispheric winter months is shown in Fig. 2. The highest LRT altitudes during December-February are >17 km in the tropical western Pacific region and over South America. A smaller maximum altitude is located over Central Africa and the western Indian Ocean (Fig.

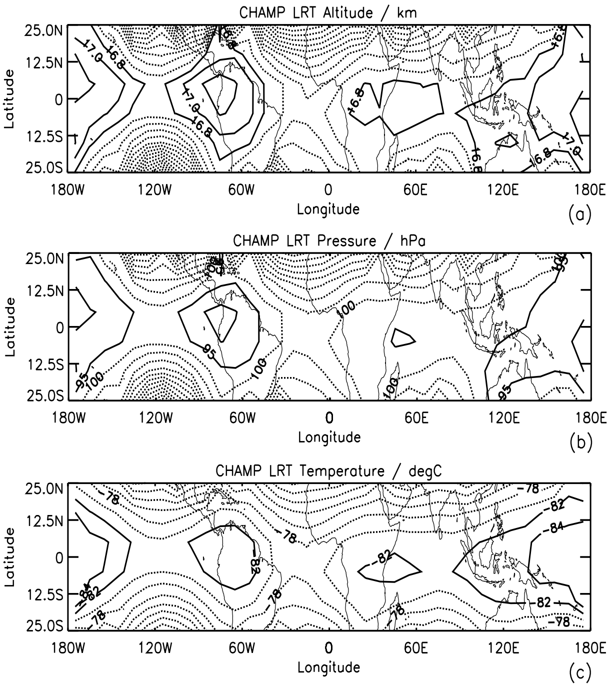

Fig. 2. LRT altitude (a), pressure (b), and temperature (c) for the northern hemisphere winter months (December-February). Contour intervals are (a) 0.2 km, and values above 16.8 km are plotted with solid lines; (b) 5 hPa, and values below 95 hPa are plotted with solid lines; (c) 2 K, and values below -82°C are plotted with solid lines.

2a). The associated pressure patterns are shown in Fig. 2b. The coldest LRT temperatures (Fig. 2c) are less than -82°C correlated with the maximum LRT altitudes. During the northern hemisphere summer (not shown here) the area of highest tropopause (>17 km) is moving northward to the south-Asian monsoon region. The temperature in that region is less than -80°C as also in the western Pacific area but here with LRT altitudes reaching only 16.2-16.4 km.

The basis for the contour plots in Fig. 2 are mean tropopause parameters representing an area of ±5° in latitude and longitude. The 6 latitudes (25°S, 15°S, 5°S, 5°N, 15°N, and 25°N) and 35 longitudes (175°W, 165°W, 155°W, ... , 155°E, 165°E, and 175°E) are the centers of the bins. Each of this areas contain on average about 40 CHAMP measurements. Thus, already this single satellite constellation leads to a global coverage of the tropical region for seasonal plots of climate parameters where no interpolation is necessary. With increasing numbers of RO experiments in the next future the spatial information density (not only in the UTLS region) of atmospheric climate change parameters will increase rapidly.

3 Conclusions

Tropical tropopause parameters on the basis of CHAMP RO measurements for the period May 2001-September 2003 have been discussed. Because of accuracy, high vertical resolution, and globally distributed temperature data in the tropopause region the relatively new RO technique is suitable for global monitoring of the UTLS as an important part of the atmosphere. Changes in tropopause parameters can be used for the detection of climate change as already shown by [2]. The CHAMP RO experiment generates the first long-term RO data set, other satellite missions will follow (GRACE, TerraSAR-X, METOP, COSMIC) establishing the RO technique for global temperature monitoring in the UTLS region.

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