Atmospheric Research 193 (2017) 1–9

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Distribution and trends of the cold-point tropopause over China from 1979 to 2014 based on radiosonde dataset

Chaoli Tang[a,b,c], Xuebin Li[a], Jianyu Li[a], Congming Dai[a], Luofeng Deng[d], Heli Wei[a,b,*]

[a] Key Laboratory of Atmospheric Composition and Optical Radiation, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Hefei 230031, China
[b] University of Science and Technology of China, Hefei 230026, China
[c] Anhui University of Science and Technology, Huainan 232001, China
[d] Beijing Institute of Tracking and Telecommunications Technology, Beijing 100094, China

ARTICLE INFO

Keywords:
Cold-point tropopause
Cold-point temperature
Long-term trends
Change rate
Radiosonde dataset
China

ABSTRACT

The variation trends of the cold-point tropopause (CPT) are presented using radiosonde observations from 77 stations over China during 1979–2014. The latitude regions over China from 18°N to 53°N are divided into 7 latitude zones with every 5° intervals, and the spatial areas of 18°N–53°N, 75°E–135°E are divided into 27 lattices with 5° × 10° grids. The annual-mean values of height-of-CPT (H-CPT) and temperature-of-CPT (T-CPT) are then calculated by all the available samples within each latitude and longitude bin. By using the least squares regression method, it is found that the H-CPT increases with the rate of 273 m/decade, and overall the significant cooling rate of − 0.70 K/decade for the T-CPT over the whole of China. Then, the trends and latitude distribution of H-CPT and T-CPT for each latitude zone are analyzed. The difference of H-CPT among latitude distribution characteristic is reducing year by year, and the difference of T-CPT is enlarging. The H-CPT displays a rising trend between 28°N–53°N latitude region with the positive change rates, and it has decline trend between 18°N–28°N latitude region with the negative change rates. The change rates of T-CPT are negative values for all latitude zones. At last, the nonuniform latitudinal and longitudinal distribution of long-term trends of H-CPT and T-CPT are first presented for each spatial cell.

1. Introduction

The exchange of air mass, water vapor, trace gas and energy between the troposphere and the stratosphere occurs in the tropopause (Zhou et al., 2001a; Gettelman et al., 2011; Homeyer et al., 2014; Seidel et al., 2016). Long-term trends in the structure of the tropopause region are of scientific importance as the tropopause structure impacts the general circulation of the atmosphere. One aspect of the tropopause that is of particular interest for water vapor transport is the cold-point tropopause (CPT) (Randel et al., 2004; Pao et al., 2009; Kim and Alexander, 2015). The CPT is the position of the coldest temperature in the vertical temperature profile between troposphere and stratosphere, which is one of the most basic structural features of the Earth's atmosphere (Xie et al., 2014; Kumar et al., 2015).

The variation of tropopause structure is closely linked to climate change, and thus is a potentially important indicator of the global climate change (Fueglistaler et al., 2009; Li et al., 2016). Owing to its extreme sensitivity to climate variability and climate change, CPT has attracted wide research interests. Randel et al. (2000) studied the interannual variability of the tropical tropopause through regression analyses to isolate the spatial structure of interannual variations in both radiosonde data and the National Centers for Environmental Prediction (NCEP) reanalyses over 1957–1997. Santer et al. (2003) examined the changes in tropopause height base on the NCEP and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalyses data. Schmidt et al. (2008) and Ratnam et al. (2005, 2013) investigated the structure and variability of the tropopause using radio occultation measurements by CHAMP/GPS (CHAllenging Mini satellite Payload/ Global Positioning System). The growing evidence from a variety of data sources (such as radiosonde data, reanalysis products, GPS radio occultation and so on) has suggested that the height of the CPT (H-CPT) has increased (Austin and Reichler, 2008; Schmidt et al., 2008; Kim et al., 2013) and the tropical temperature-of-CPT (T-CPT) has experienced a cooling trend in the last decades (Randel et al., 2000; Zhou et al., 2001b; Feng et al., 2012), which is closely associated with tropospheric warming and stratospheric cooling.

China is vast in territory with the climate varying from subarctic to subtropical, The analysis of the temporal and spatial variations of the regional climate in China is important to the study of the global climate change. Especially in the southwest of China, the Qinghai-Tibet Plateau

* Corresponding author at: Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, P. O. Box 1125, Hefei, Anhui 230031, China.
E-mail address: hlwei@aiofm.ac.cn (H. Wei).

http://dx.doi.org/10.1016/j.atmosres.2017.04.008
Received 8 December 2016; Received in revised form 17 February 2017; Accepted 3 April 2017
Available online 04 April 2017
0169-8095/

is the world's highest and largest plateau. The Qinghai-Tibet Plateau has its own unique climate characteristics and its effects on climate is worthy of study (Tobo et al., 2007; Fu et al., 2009; Xu et al., 2013). Therefore, actual knowledge about the long-term trends of the CPT over China region will be useful to the researches of climate change.

In this study, the CPT is determined using the sounding temperature profiles. Radiosonde data is by far the most directly atmospheric sounding data and its time spans decades. Through processing 36-year radiosonde data series derived from the version 2 of the Integrated Global Radiosonde Archive (IGRA2) (Durre, 2016), we analyze the CPT trends over China for the period of 1979–2014 by seasons, latitudes and longitudes. Section 2 outlines the radiosonde data source and the methods of data processing and analysis. Section 3 describes the long-term trends and spatial variation of the CPT over China. The brief discussions and concluding remarks are given in Section 4.

2. Data and methodologies

2.1. Data source

The new beta release of version 2 of the Integrated Global Radiosonde Archive (IGRA2), which has replaced IGRA1 as NCDC's baseline upper-air dataset, was available to the public (Durre, 2016). Compared to IGRA1, IGRA2 has more soundings and longer records (Durre, 2016). Quality control algorithms have been applied to remove gross errors. The quality assurance procedures can be grouped into seven general categories: fundamental "sanity" checks, checks on the plausibility and temporal consistency of surface elevation, internal consistency checks, checks for the repetition of values, climatologically based checks, checks on the vertical and temporal consistency of temperature, and data completeness checks (Durre et al., 2006, 2008).

The IGRA2-derived sounding dataset was adopted in this investigation. There are 2,783,403 sounding profiles from 144 stations over China region in the IGRA2-derived dataset from 1956 to 2014.

2.2. The methods for CPT data processing

In order to study the long-term variation trends of CPT over China, the H-CPT and T-CPT are firstly identified with each sounding profile based on the definition of CPT. The T-CPT is the minimum temperature determined from each sounding profile. The H-CPT is the minimum height corresponding to the T-CPT.

To remove possible incorrect CPTs in the sounding profiles, quality controls for T-CPT are carried out with each sounding profile. Firstly, any sounding profile with the maximum height lower than 18 km is ignored due to the insufficient height range of the sounding balloon for CPT identification. Secondly, the sounding profile is ignored when the maximum height of sounding profile equal to the H-CPT for it is an ineffective record. Finally, the remaining H-CPT and T-CPT meeting the requirements are saved for the following analysis.

Fig. 1a and b shows the number of stations and distribution of available profiles over China region for each year from 1956 to 2014 in IGRA2-derived dataset. The original station and profile numbers are shown as black triangle, and the numbers after quality control processing are shown as red star. As can be seen from Fig. 1a and b, before 1978, the available stations and sounding profiles were relatively sparse in China. After 1978, the number of sounding station is generally more than 85 for each year, and the corresponding number of sounding profiles is basically more than 50,000 for each year.

Based on the above analysis, 77 stations (hereafter S77) with continuous sounding measurements without interruption during the period of 1978.12 to 2014.11 are selected to analyze the variation trend of CPT, as shown in Fig. 1c. In the following studies, we take 1978.12–1979.11 as 1979 (winter, spring, summer, autumn), 1979.12–1980.11 as 1980 (winter, spring, summer, autumn), and so on. The purpose of this division is to analyze the impact of seasonal variation on the CPT.

A total of 1,709,051 sounding profiles is available after the quality control for the S77 during the period of 1979 to 2014. According to the literatures (Anthes et al., 2008; Son et al., 2011; Xian and Fu, 2015), in order to reduce the noises and to increase the statistical significance, three times standard deviation threshold is adopted to remove the possible abnormal values in H-CPT and T-CPT derived from 1,709,051 soundings. With statistical analysis, the average value of H-CPT of 1,709,051 soundings is 16.32 km, and the corresponding three times standard deviation is 8.37 km. The average value of T-CPT of 1,709,051 soundings is 204.46 K, and the corresponding three times standard deviation is 22.94 K. According to the judgment of three times standard deviation, the values of H-CPT lower than 7.95 km (or higher than 24.69 km) are identified as abnormal value, and the values of T-CPT lower than 181.52 K (or greater than 227.40 K) are identified as abnormal value. A total of 5355 sounding profiles are removed, and approximately 99.7% of 1,709,051 soundings are identified as normal values.

At last, a total of 1,703,696 sounding profiles is adopted in the following investigations for S77.

2.3. The methodologies for CPT data analyzing

In order to investigate the seasonal variation trends of CPT properties, we define 4 seasons as: Spring from March to May, Summer from June to August, Autumn from September to November, and Winter from December to February in coming year. For the investigation of the latitude distribution of long-term trends of the CPT properties, we divided the latitude regions over China from 18°N to 53°N into 7 latitude zones with the interval of 5°, as shown in Fig. 1c. The average of H-CPT (T-CPT) for each latitude zone is calculated by the H-CPT (T-CPT) of sounding profiles of all stations within the latitude zone. For the investigations of the spatial structure of the long-term trends of the CPT properties, we divided the areas of 18°N–53°N, 75°E–135°E into 27 lattice using 5° × 10° grids to ensure each grid cell contains at least one viable station. Each cell is signed with the digital number on the top right corner in each grid in Fig. 1c. The average of H-CPT (T-CPT) for each grid cell is calculated by the H-CPT (T-CPT) of sounding profiles of all stations within the grid cell.

In this study, firstly, the annual and seasonal means of H-CPT (T-CPT) over the whole of China region are calculated by averaging over all 27 grid cells. And the trend of H-CPT (T-CPT) over the whole of China region is fitted by the least squares method. Then, similar treatments are done for each latitude zone to derive the latitudinal distribution characteristics of the annual and seasonal means of H-CPT (T-CPT) and their trends, and are done for each grid cell to derive the spatial (latitude-longitude) distribution of the trend of the annual-mean H-CPT (T-CPT).

3. Results

3.1. Average trends of the CPT over China from 1979 to 2014

The average of height and temperature of CPT in the whole of China region is calculated by the corresponding average of 27 grid cells. By using the least squares regression method, the long-term evolution trends of H-CPT (T-CPT) are obtained.

Fig. 2a and b shows the annual-mean trends over the whole of China for height and temperature of CPT during 1979–2014. Fig. 2a presents a significant increase in H-CPT over the whole of China ranging from 15,258 m to 16,558 m during 1979–2014, yielding a net rise of 273 m/decade over the 36 years. Fig. 2b presents a significant decrease in T-CPT over the whole of China ranging from 207.4 K to 204.5 K during 1979–2014, yielding a net cooling of −0.70 K/decade over the 36 years.

Fig. 2c and d shows the seasonal-mean trends for height and