Journal of Atmospheric and Solar-Terrestrial Physics 138-139 (2016) 23–31

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Research paper

Effect of gravity waves on the tropopause temperature, height and water vapor in Tibet from COSMIC GPS Radio Occultation observations

Attaullah Khan [a,b], Shuanggen Jin [a,c,*]

[a] Key Laboratory of Planetary Sciences, Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Department of Geomatics Engineering, Bulent Ecevit University, Zonguldak 67100, Turkey

ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form
1 December 2015
Accepted 7 December 2015
Available online 8 December 2015

Keywords:
Tropopause
Gravity wave
GPS Radio Occultation
Tibet

ABSTRACT

The tropopause plays an important role in climate change, particularly in Tibet with complex topography and climate change system. In this paper, the temperature and height of the Cold Point Tropopause (CPT) in Tibet are obtained and investigated from COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) GPS Radio Occultation (RO) during June 2006–Feb 2014, which are compared with Lapse Rate Tropopause (LRT) from Atmospheric Infrared Sounder (AIRS/NASA). Furthermore, the impact of Gravity waves (GW) potential energy (E_p) on the CPT-Temperature, CPT-Height, and the variation of stratospheric water vapor with GW E_p variations are presented. Generally the coldest CPT temperature is in June–July–August (JJA) with −76.5 °C, resulting less water vapor into the stratosphere above the cold points. The temperature of the cold point increases up to −69 °C during the winter over the Tibetan Plateau (25–40°N, 70–100°E) that leads to increase in water vapor above the cold points (10 hPa). Mean vertical fluctuations of temperature are calculated as well as the mean gravity wave potential energy E_p for each month from June 2006 to Feb 2014. Monthly E_p is calculated at 5° × 5° grids between 17 km and 24 km in altitude for the Tibetan Plateau. The E_p raises from 1.83 J/Kg to 3.4 J/Kg from summer to winter with mean E_p of 2.5 J/Kg for the year. The results show that the gravity waves affect the CPT temperature and water vapor concentration in the stratosphere. Water vapor, CPT temperature and gravity wave (E_p) have good correlation with each other above the cold points, and water vapor increases with increasing E_p.

1. Introduction

Recently the upper troposphere and lower stratosphere (UTLS) received more attentions because of the important role in climate changes. The tropopause is the separating layer between the troposphere and the stratosphere. The annual cycle in tropopause temperature involves in the penetration of Hadley circulation cell into the lower stratosphere. The tropopause plays a massive role in the stratosphere–troposphere exchange and climate variability to allow/forbid different constituents to the stratosphere (Holton et al., 1995; Gettelman et al., 2011), particularly in Tibet with complex topography and climate change system (Liu and Zhang, 1998; Liu and Chen, 2000). The magnitude of stratospheric water vapor is strongly dependent on the tropopause temperature (TPT) (Rosenlof and Reid, 2008). The global warming study is mainly focused on CO_2 concentration, because water vapor is usually assumed to be balanced by the precipitation due to the short residence time in the troposphere. However the stratosphere water vapor concentration is changing with the time since the residence time of water vapor is longer than one year. Holton et al. (1995) and Mote and Coauthors (1996) showed that a small variation of water vapor (increase or decrease) in the stratosphere can significantly change the climate below by changing the global radiation budget. Therefore the tropopause was paid more attention in the recent epoch (Solomon et al., 2010; Gettelman et al., 2010). Annual cycle of the tropopause temperature and altitude is a significant feature that influences the climatic conditions of the region.

Study on the annual cycle of the tropical tropopause temperature suggests the significant role of vertically propagating Rossby and gravity waves (Garcia, 1987; Gray and Dunkerton, 1990; Haynes et al., 1991; Yulaeva et al., 1994; Holton et al., 1995). The Whole Atmosphere Community Climate Model (WACCM) higher simulation shows that warming effect around the tropopause is caused less by radiative effects, and more by warming effects from dynamical transport or convection (Wang et al., 2013). Theoretical, observational and modeling efforts clarify the sources

* Corresponding author at: Key Laboratory of Planetary Sciences, Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, PR China.
E-mail addresses: sgjin@shao.ac.cn, sgjin@beun.edu.tr (S. Jin).

http://dx.doi.org/10.1016/j.jastp.2015.12.001
1364-6826/

of gravity waves that are generated by meteorological events, such as typhoon, and convections propagating to the lower and upper stratosphere. De la Torre et al. (2004, 2006) observed important wave activities in the upper troposphere and lower stratosphere at mid-latitudes (30–40°S) above the Andes Range using temperature profiles retrieved from GPS Radio Occultation (GPS RO) between June 2001 and March 2003. Their results suggested that the major sources in this area were topography, jet-stream and convection. It was also illustrated that these sources were continually in action in this area, and different sources could act simultaneously. It should be noted that there are still some limitations and questions for the space-borne remote sensing technique, and the ground based observations and denser space observations are important to depict detailed characteristics of gravity waves in a local region.

Secondary gravity wave is generated by the breakdown of primary gravity wave in the lower stratosphere and transports water vapor to the stratosphere (Lane and Sharman, 2006). Water vapor in the stratosphere resides for a long time, more than one year and the stratospheric water vapor change should be considered as climate forcing not a simple response (Wang et al., 2009). When gravity waves break, it transports energy and momentum to the background and increases energy to the surrounding atmosphere. The role of gravity wave (GW) is very important to keep balance in atmospheric circulations by transporting energy and momentum to different altitudes. Gravity waves are more active in winter than in summer at lower stratosphere. The time and height variation of the wind velocity due to gravity waves showed a clear correlation with high relative humidity, observed by MU (Middle and Upper Atmosphere) radar (Murayama et al., 1994). Gravity wave generated in the troposphere propagates to the middle and upper atmosphere and transfers energy and momentum (Ern et al., 2013). Due to the low density of the air, the amplitude of the GW increases with higher amplitude at high altitude. Potential energy of GW related to the subtropical jet stream with some contribution of regional topography, calculated as mean wintertime E_p, exceeds 2.4 J kg^{-1} above the Himalayas and East China (Alexander et al., 2008). Most of the gravity wave's sources are positioned in the troposphere.

Previous studies showed that gravity waves transport not only energy and moment but also play a critical role in the global circulation and the temperature and constituent structures (i.e. water vapor, ozone concentrations and other chemical constituents) in the atmosphere (Moustaoui et al., 2004; Wang and Alexander, 2010). Therefore, the parameterization of gravity waves needs more improvements and high accuracy observations in wave propagation, amplitude and wavelength. In addition, a high spatial resolution instruments are required for a better study and reliable results, particularly in Tibet with lack of in-situ measurements. Nowadays, COSMIC Radio Occultation observations with six satellites provide unique global high-resolution temperature profiles, which can be used to study the characteristics of the gravity wave in lower atmosphere (e.g., Zeng et al., 2012; Faber et al., 2013; Jin et al., 2014). In this paper, the temperature and height of the Cold Point Tropopause (CPT) in Tibet are obtained and studied from denser COSMIC GPS Radio Occultation observations during June 2006–Feb 2014. Effects of gravity wave's potential energy on the CPT-Temperature, CPT-Height, and stratospheric water vapor are discussed. In Section 2, methods and observation data are introduced, and results are presented in Section 3. Finally conclusions are given in Section 4.

2. Data and methods

2.1. Observation data

The six FORMOSAT-3/COSMIC (Constellation Observing System for Meteorology, Ionosphere & Climate) satellites were launched in April 2006 by Taiwan/USA with final altitude of about 800 km. The orbital inclination of COSMIC satellites is 72°. COSMIC GPS Radio Occultation (RO) provides high resolution observations at Upper Troposphere and Lower Stratosphere (UTLS), which can be used to study the GW potential energy (E_p) in the stratosphere using the temperature profile.

COSMIC GPS RO observations from six satellites provide higher accuracy atmospheric and ionospheric products with up to 1500 to 2000 RO profiles per day. The variation of refractive index n along a GPS RO limb path in the Earth's atmosphere is dominated by the vertical density gradient. Since the refractivity decreases with the altitude generally, a negative sign is added in order to keep a positive bending angle. By inverting the equation through the Abelian transformation, the refractive index n can be written as a function of the bending angle a (Fjeldbo et al., 1971). In the neutral atmosphere, n is conveniently expressed in terms of refractivity defined as $N = (n - 1) \times 10^6$ through the relationship [Kursinski et al., 1997], which is related to the total pressure P and water vapor partial pressure Pw, temperature T, electron number density n_e, signal frequency f and liquid water content W, respectively. Therefore, using COSMIC GPS RO observations, the pressure, temperature and water vapor profiles in the troposphere and electron density profiles in the ionosphere are inversed (e.g., Anthes et al., 2008; Jin et al., 2011; Ho et al., 2010 and 2012; Jin et al., 2014). More information on COSMIC GPS RO products can be found at http://cdaac-www.cosmic.ucar.edu. The COSMIC RO has about 600 occultation per month over the Tibetan plateau (25–40°N, 70–100°E), which provide more atmospheric products over this area. The COSMIC Data Analysis and Archive Center (CDAAC) is responsible for processing the science data received from COSMIC satellites. Staten and Reichler (2008) examined that the COSMIC wet atmospheric temperature profile (wetPrf) has negligible difference with the dry one (atmPrf). In this study, the dry atmospheric temperature profile (atmPrf) is used from http://cdaac-www.cosmic.ucar.edu/cdaac. The temperature data (version 2010.2640) from June 2006 to Feb 2014 are used for the study on tropopause and gravity wave over the Tibetan Plateau.

Reanalysis data of Modern Era Retrospective-Analysis for Research and Applications (MERRA) (http://disc.sci.gsfc.nasa.gov/mdisc) and Atmospheric Infrared Sounder (AIRS) (http://airs.jpl.nasa.gov) are also used for water vapor. The MERRA is a NASA reanalysis using a modern satellite data and the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5), which focuses on historical analyses of the hydrological cycle (Rienecker et al., 2011). The AIRS is the first new generation operational remote sensors for upwelling atmospheric emission (Aumann et al., 2003). The AIRS is cross-track-scanning nadir sounders with a swath of ~1650 km wide. More than 2000 channels cover 3.71–4.61, 6.2–8.22, and 8.8–15.4 μm in infrared bands, and therefore the AIRS can sense atmospheric temperature, trace gases, water vapor, and surface temperature with very high accuracies.

2.2. Theory and method

COSMIC GPS radio occultation provides the information of neutral atmospheric parameters from near surface to altitude of 40 km. In this study the temperature profiles are used to observe the GW activities by neglecting the humidity effect (dry temperature profile). This profile is accurate with up to altitude of