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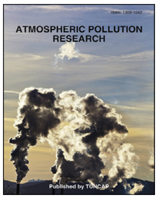

Stratospheric ozone change over the Tibetan Plateau

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ABSTRACT

We analyzed the total column ozone (TCO) from November 1978 to July 2016 over the Tibetan Plateau (TP) by using the Total Ozone Mapping Spectrometer (TOMS) and the Ozone Monitoring Instrument (OMI) data. Our results indicate that the trend of the TCO decreased from 1978 to 1993, but the decrease rate has slowed since 1996. Nevertheless, the TCO trend has increased gradually since 2003. We also found a low ozone concentration region in the southeast Tibetan Plateau with a minimum value of 260 DU. The maximum value of the TCO occurs in March and the minimum value occurs in October. By analyzing the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) ozone profile data, the height that ozone number density maximizes by season rank as follows: summer, autumn, spring, and winter. Ozone profiles change slightly in spring and autumn and change strongly in summer and winter. In the summer and autumn, ozone profiles tend oppositely to that in winter and spring, respectively. The appearance of low ozone event over the TP is confirmed and generally acted during the winter months (November, December and January). The value of the low ozone event is between 194 DU and 228 DU. Our results also show that the low ozone event has a decreased trend from 1978 to 2015.

1. Introduction

Ozone is a significant component of the atmosphere and has emerged to play an important role in the Earth's global climate change (Rajab et al., 2013). Peak ozone density is in the stratosphere at 20 km–25 km altitude. Since 1985, it has been decreasing in the stratosphere and southern mid-latitudes such that people began to pay attention to its depletion phenomena (Farman et al., 1985). The global average total column ozone concentration from 1997 to 2001 was nearly 3% below the ozone average values before 1980 (WMO, 2003). Global ozone in the upper stratosphere declined between 1979 and 1995, with the largest reduction between 10 and 15% near 40 km over mid-latitudes (WMO, 2007). Both ground and satellite observations show that near-global (60°S–60°N) column ozone has increased by around 1% ± 1.7% between 2000 and 2013 (WMO, 2014). Since 1995, researchers have discovered a low ozone event over the Tibetan Plateau (TP) and identified the connection between a low ozone event and the value of the Total Column Ozone (TCO) (Liu et al., 2010; Zhou and Luo, 1994, Zhou et al. 2006). Because of the special terrain of the TP, the important effects of thermodynamic and dynamic processes to the formation and development of global atmospheric circulation and ozone change are well documented (Guo et al., 2012). Therefore, ozone variation over the TP has also been investigated.

In the part of the characteristic of the TCO over the Tibet Plateau, most studies have focused on the mechanisms leading to the formation of the summer ozone valley and its inter-annual trend. Other studies have analyzed the seasonal variation and trend of TCO over the TP. Regarding the formation of the ozone valley, Zhou et al. (2006) mentioned that the mass exchange between troposphere and stratosphere over the TP affects the ozone valley. Tian et al. (2008) used the TOMS ozone data, the SAGE II zone profile, the European Centre for Medium-Range Weather Forecasts 40-year Re-Analysis reanalysis data (ECMWF ERA-40) and a 3-D chemistry-climate model (CCM) to study the formation of the ozone valley over the TP. This study indicated that the formation of the ozone valley is not only due to the thinness of the atmospheric column but also was related to the large-scale uplift and descent of isentropic surfaces. Liu et al. (2009a) pointed out that the formation of the ozone valley is mainly related to the Asian summer monsoon that can affect the wind transport of ozone-poor air masses.

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About the trend of the TCO, many studies have found the TCO trend to strongly decrease from 1980 to 1993 and to slightly increase since 1993 (Zou, 1996; Ye and Xu, 2003; Chehade et al., 2014). Liu et al. (2001) used a 2-D chemical model to simulate the TCO trend over the TP and showed that it decreased gradually from 1980 to 1993 and recovered gradually since 1995. These results also showed that the TCO has not recovered to the 1980 level. Zhou et al. (2006) confirmed that the TCO decreased from 1980 to 1993, reached its minimum value in 1993 then recovered since 1993. The global mean ozone trended significantly downward from early 1992 to the end of 1993 caused by the eruption of Mt. Pinatubo in June 1991 (McCormick et al., 1995). Guo et al. (2013) analyzed the TCO from 1979 to 2011 over East Asia and demonstrated the same trend. Zhou et al. (2013) found that the TCO over the TP had a larger downward trend from 1979 to 2010 and a weaker increasing trend from 2000 to 2010.

Low ozone events refer the decreases of total ozone that occur during winter over the TP. Zhou and Luo (1994) analyzed the ozone concentration by using TOMS data from 1979 to 1991 and initially found the low ozone event over the TP. Zou (1996) observed the low ozone events located at a large scale over the TP. Liu et al. (2001) summarized the reason for the low ozone event as related to the rapid decrease of the TCO in the lower stratosphere. By analyzing the TOMS ozone data during 1978–2000, Ye and Xu (2003) confirmed persistent low TCO over the TP and observed that an elevated heat source associated with thermally forced circulation can affect the formation of low ozone events. The low ozone event over the TP is caused by uplift of the local tropopause and the northward transport of tropical ozone poor air that is associated with an anomalous anticyclone in the upper troposphere (Liu et al., 2009a, 2010).

The analysis of ozone profile over the TP is used to investigate the dynamic transport between the troposphere and the stratosphere and the low ozone event over the TP. Chen et al. (2012) showed that dynamic transport is the primary factor to affect the ozone vertical distribution over the TP. Bian (2009) used ozone profiles and the TCO to analyze the formation of the ozone valley over the TP in summer.

In this study we used TCO data obtained from the TOMS (1978.11–2004.12) (without data from 1993.06 to 1996.06), the OMI (2005.01–2016.07) and the ozone profile from SCIAMACHY (2002.08–2012.04) to analyze the change of the TCO, ozone profile and the low ozone event from 1978 to 2015 over the TP.

2. Study area and data

The TP is located in western China, Central Asia. With an average elevation exceeding 4500 m, the TP is the highest and largest plateau in the world. The TP is surrounded by high elevation mountain ranges including the Himalayan range to the south and the Kunlun Range to the north. Because of the unique topography and geographical location, the TP has a significant effect on the atmospheric circulation and climate system in East Asia and the whole world (Zhang et al., 2014). Zhou et al. (2006) proposed that the TP is an important summer pathway through which air in the low troposphere can be transported into the stratosphere. The low content ozone and high content pollutants from the TP surroundings may converge upon the TP in summer, and be transported into the stratosphere, then diverged to the surroundings. Wang et al. (2008) used NCEP/NCAR reanalysis data to study seasonal variation of dynamic and thermal conditions over the TP. Results show that the dynamic over the TP strongly effects on the circulation in winter, following spring. This dynamic results in a deviated circulation over the TP with cyclonic circulations in the south and anticyclonic circulations in the north. They are both in the mid-low troposhere during winter. The cyclonic deflection circulation to the south becomes a typical summer cyclonic circulation pattern in June because of the northward shift of the westerly and total heating of TP. The summer thermal forcing is strongest and surrounds the TP with a cyclone deviation circulation. The winter mechanical forcing and the summer thermal forcing over the TP are significantly associated with the Indo-Burmese trough index. Owing to the topography, the TP also functions as a “high level heat source” to regulate the summer monsoon (Park et al., 2012). Our study area is 24°N to 42.5°N and 69°E to 104.5°E and just covers the TP.

The TCO data used in this study is from the Total Ozone Mapping Spectrometer (TOMS) and the Ozone Monitoring Instrument (OMI). Time periods of TOMS and OMI data are shown in Table 1. The TOMS instrument provides a long-term and continuous record of satellite-based observations and monitors the global and regional trends in total ozone column over the past 25 years. It is designed to provide global TCO estimates using back UV radiance in 313, 318, 331, 340, 360 and 380 nm wavelengths, and was carried on the Nimubus7 satellite from November 1978 to May 1993 (McPeters et al., 1996). After the failure of the Meteor-3 Spacecraft in December of 1994, the EP/TOMS instrument was mounted on the Earth Probe satellite launched on July 2, 1996 and measured both incoming solar energy and backscattered ultraviolet (UV) radiation (Mcpeters et al., 1998). The TCO TOMS data we used is version 8 of daily level 3 TCO gridded data (1.0° × 1.25°) provided by NASA (TOMS Science Team (), TOMS/Nimbus-7 Total Column Ozone Monthly L3 Global 1 × 1.25 deg Lat/Lon Grid, version 008, Greenbelt, MD, NASA Goddard Earth Science Data and Information Services Center, Accessed [Enter User Data Access Date at-http://disc.sci.gsfc.nasa.gov/datacollection/-TOMSN7L3mtoz_V008.html) (TOMS Science Team (), TOMS Earth-Probe Total Ozone (O3) Aerosol Index UV-Reflectivity UV-B Erythemal Irradiance Daily L3 Global 1 deg × 1.25 deg V008, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed [Data Access Date] http://disc.sci.gsfc.nasa.gov/datacollection/TOMSEP L3_008.html). The OMI, providing global coverage in one-day data with a resolution of 1.0° × 1.0°, is an ultraviolet/visible (UV/VIS) nadir solar backscatter spectrometer onboard the Aura satellite launched in July 2004 (Bak et al., 2013). The TCO data of the OMI/Aura Level-3 TCO Data Product used in this study are called OMTO3 (Bhartia (2012), OMI/Aura TOMS-Like Ozone, Aerosol Index, Cloud Radiance Fraction L3 1 day 1° × 1° V3, version 003, NASA Goddard Space Flight Center, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed [Enter User Data Access Date at] 10.5067/Aura/OMI/DATA3001).

The SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) is an ENVISAT satellite instrument with the wavelength range from ultraviolet (240 nm) to near infrared (2380 nm) and a moderate resolution (0.24–1.48 nm). It was launched in March 2002 (Burrows et al., 1995). The products of SCIAMACHY include nadir geo-located vertical column amounts of O_3, NO_2, OClO, SO_2, H_2CO, BrO, cloud, aerosol absorption indicator and stratospheric profiles of O_3, NO_2, BrO, H_2O, CO, CH_4, pressure and temperature. The dataset we used to study the TCO variation over the TP is the SCIAMACHY ozone profile product (V2.5) provided by the Institute of Environmental Physics, University of Bremen (http://www.iup.uni-bremen.de/~sciaproc/CDI/DATAAUTH/O3/). This product is an orbital data file and completes a global coverage scan every six days. For limb measurement, the geometrical spatial resolution is approximately 3 km vertically and typically 240 km horizontally across its track. In our study, the time-period of SCIAMACHY profile data is from August 2002 to April 2012.

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