Study on the Trace Species in the Stratosphere and Their Impact on Climate

CHEN Yuejuan* (陈月娟), ZHOU Renjun (周任君), SHI Chunhua (施存华), and BI Yun (毕云)

School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026

(Received 19 April 2006; revised 30 August 2006)

ABSTRACT

The trace gases (O$_3$, HCl, CH$_4$, H$_2$O, NO, NO$_2$) in the stratosphere play an important role, not only in the photochemical processes in which the ozone layer destroyed, but also in the radiative processes. In this paper, we review the works on the distribution and variation of the trace gases in the stratosphere and their impact on climate, which have been carried out at the University of Science and Technology of China in the recent 20 years. The Halogen Occultation Experiment (HALOE) data were used to analyse the distribution and variation of the mixing ratio of these trace gases and the temperature trends in the stratosphere in the most recent decades. And the reanalyzed National Centers of Environmental Prediction (NCEP)/NCA1R data were also used to give the temperature trends and compared with the results from HALOE data. Numerical simulations were also carried out to study the impact of ozone depletion on the global climate. In this review, the distributions of the trace gases, especially those over the Qinghai-Xizang Plateau, are discussed, and the variations and trends for the trace gases in various levels in the stratosphere have been given for the most recent decade. The temperature variation and the cooling trend obtained from HALOE data in the middle and lower stratosphere for the last 13 years are significant, which agree well with the results from NCEP/NCAR data. While the temperature trend in the upper stratosphere in this period do not seem to have much cooling. The numerical simulations show that either the Antarctic ozone hole or the ozone valley over Qinghai-Xizang Plateau affect not only the temperature and circulation in the stratosphere, but also the temperature, pressure and wind fields in the troposphere, then lead to the global climate change.

Key words: stratosphere, trace gases, global climate


1. Introduction

The long-term observational records showed the substantial changes of stratospheric temperature during the past four decades, which lead to the changes of the circulation in the stratosphere and effect on the global climate system through the interaction between the stratosphere and the troposphere. Stratospheric temperature change occurs as a result of both natural and anthropogenic factors. The latter includes the variation in the greenhouse gases and ozone depletion. The simulations based on the known changes in species' concentration indicate that the depletion of lower stratospheric ozone is the major radiative factor accounting for the 1979-1990 cooling trend in the global, annual-mean lower stratosphere, with a substantially lesser contribution by the well-mixed greenhouse gases. In the middle and upper stratosphere, both well-mixed greenhouse gases and ozone changes contribute in an important manner to the cooling (Ramaswamy et al., 2001). The uncertainties in the simulations are due to the uncertainties of the changes in stratospheric ozone, water vapor, greenhouse gases, and aerosols. In order to predict the future evolution of the stratosphere and estimate the effects of stratospheric changes on global climate, it is important to get more information of the distribution and variation in stratospheric trace gases, and develop global models for simulating the influence of the stratospheric changes on the global climate system.

Over the past three decades, more attention has been paid to the observation and study on stratospheric ozone trends, since ozone has profound effects on human health and the climate, and ozone can be destroyed because of emission by the supersonic transport in the stratosphere and the release of chlorofluoro-
romethanes in the troposphere. As earlier as in the 1970s, the measurements not only for ozone in the stratosphere but also for the chemical species which are important in ozone chemistry were reported by individual nations (WMO, 1982). The Antarctic ozone hole was discovered in 1985 (Farman et al., 1985) and discussed theoretically by Solomon (1990). Evidence shows that the increased concentration of chlorine in the presence of aerosols and particles leads to reactions that will cause Antarctic ozone depletion. Further analyses of satellite and ground-based Dobson data have shown ozone declines over the period 1960–1988 of 3% to 5% in the Northern Hemisphere (30°–64°N) during winter months, and in summertime ozone decreased about 3% in the Northern Hemisphere temperate zone in 1980s (Russell III et al., 1993). The changes of ozone occurring in the middle-latitudes, especially in the summertime, are not completely understood. In order to provide critical data for study of the ozone distribution and those processes which affect ozone levels, the Halogen Oscillation Experiment (HALOE) was launched onboard the Upper Atmospheric Research Satellite (UARS) spacecraft in 1991 (Russell III et al., 1993), and it has continuing measurements to present time and provides near global coverage of the data. The long-time record and near-global coverage of these data allows the opportunity to derive global, seasonal cycle data set representative of climatological structure.

Methane (CH₄) and water vapor (H₂O) are important not only in ozone chemical process but also in the radiative process. The knowledge about changes in water vapor at the upper troposphere and lower stratosphere is of great importance because strong alterations in radiative forcing can result from small absolute changes in water vapor at these levels (IPCC, 2001). New analysis of balloon and satellite observations of stratospheric water vapor indicate that stratospheric water vapor above 18 km shows an increase of about 1%/year for the period 1880–2000 but with a slowing of the positive trend after 1996 (IPCC, 2001). Recently assessed increases in lower stratospheric water vapor mixing ratio over the last few decades are likely to have caused a decrease in stratospheric temperature by an amount comparable to that produced by ozone decreases (IPCC, 2001; Forster and Shine, 1999; Smith et al., 2001). Therefore, the data sets of O₃, CH₄ and H₂O provided by HALOE observation are valuable for input to radiative schemes and improve the model simulation of stratospheric temperature. Since 1993, great numbers of journal articles have been published to describe scientific results from HALOE observation (e.g., Luo et al., 1993; Tuck et al., 1993; Webster et al., 1994; Crutzen et al., 1995; Schoebert et al., 1996; Remsberg et al., 1996). When the longer observational data were obtained, HALOE data were used to investigate the quasi-biennial oscillation (QBO) of the trace gases in the stratosphere. The QBO signals in the HALOE-observed mixing ratio of O₃, HCl, HF, CH₄, H₂O, NO, NO₂ were presented by Luo et al. (1997). The seasonal cycles and QBO variation in CH₄ and H₂O were studied by Randel et al. (1998), and the quasi-biennial and subbiennial variation of O₃, CH₄ and H₂O were analyzed by Dunkerton (2001).

At that time in China, considerable attention has also been paid to the measurement and study in the middle atmosphere, a series of observations and studies have been done for the ozone and aerosols in the stratosphere (Lu and Wang, 1994; Wang, 1997). One of the most important findings was the ozone valley over Qinghai-Xizang Plateau in summer (Zhou and Luo, 1994). Since China is located at the east of Asia continent with the highest topography Qinghai-Xizang Plateau, the distribution and variation of the trace gases over China would have some specific characteristics. Since there is a lack of stratospheric observations on the other trace gases in China at that time, we know less about the abundance, distribution and variation of those trace gases over China in the stratosphere. In order to get more information about the trace gases, since 1998, our group (a group in the University of Science and Technology of China) started to use HALOE data to investigate the distribution and variation of ozone, HCl, CH₄, H₂O, NO and NO₂ over the Northern Hemisphere and China (in particularly over the Qinghai-Xizang Plateau), and study the QBO of the trace gases, especially the vertical structures of the QBO for O₃, NO, NO₂ and HCl and the QBO signals over extratropical region. Besides, the HALOE observed temperature are also used to analyze the temperature trend, especially in the middle and upper stratosphere, and compared with the variation of the trace gases. After the discovery of the Antarctic ozone hole, many works have been done to investigate the physical mechanisms producing this dramatic springtime ozone decrease (Solomon et al., 1987; Brune et al., 1989) and Solomon, 1990). Besides the simulations using two-dimensional models for assessing the impact of changes in the chemical composition of the atmosphere on the ozone layer (Isaksen and Soreide, 1986; Chipperfield and Pyle, 1988), some of the three-dimensional models have been applied to study the response of the thermal structure to high-latitude ozone depletion. Using the National Center for Atmospheric Research (NCAR)