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Advances in Space Research 48 (2011) 2016–2022

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Long term variability of total ozone yearly minima and maxima in the latitudinal belt from 20°N to 60°N derived from the merged satellite data in the period 1979–2008

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Received 25 November 2010; received in revised form 18 July 2011; accepted 20 July 2011
Available online 27 July 2011

Abstract

This paper deals with the behavior of the annual cycle of total ozone (ACO3) and its amplitude ($O3_{AMP}$) in the latitudinal belt from 20°N to 60°N. The prominent feature of the $O3_{AMP}$ spatial pattern is the sharp maximum over the north-east coast of Asia. The spatial correlation of $O3_{AMP}$ with its highest/lowest value varies with location: in the middle latitudes it correlates predominantly with the values of annual maxima of total ozone, while in the lower latitudes, there is a strong negative correlation with the values of ACO3 minima. Regarding temporal evolution of $O3_{AMP}$ we detected distinct negative trend in the period of 1979–1995 which is caused by stronger negative trend of maxima than the negative trend of minima in ACO3. In the period 1995–2008 we found the positive trend of ACO3 in most regions due to stronger positive trend of maxima than that of minima in ACO3 in the middle latitudes (especially over the central and northern Europe and the north-east Asia). In the lower latitudes a weak negative trend of $O3_{AMP}$ was identified and linked to weaker positive trend of maxima than positive trend of minima in ACO3. The behavior of the temporal trends was linked to the changes in Brewer–Dobson circulation and to the trends of tropopause pressure.

Keywords: Annual cycle; Total ozone; Trends in annual cycle; Long-term trends

1. Introduction

Ozone is an important trace gas in the atmosphere. Chapman (1930) hypothesized that UV radiation plays a crucial role in ozone photochemistry. The atomic oxygen is formed by dissociation of oxygen by solar photons. It is very reactive and thus quickly combines with the molecular oxygen to form ozone. Ozone absorbs UV radiation and protects the life on the Earth. Ozone is destroyed not only by absorption of UV radiation but also by reactions with chlorine, bromine, hydrogen and nitrogen in the atmosphere (e.g. Mohanakumar, 2008).

The first studies concerning the influence of halocarbons on total ozone appeared in the first half of the 1970s (Molina and Rowland, 1974; Stolarski and Cicerone, 1974). The authors pointed out that the man-made ozone depleting substances (ODS) in the atmosphere could destroy ozone layer. In the late 1980s, a decreasing trend of total ozone was observed even in the middle latitudes of both hemispheres (Rowland et al., 1988). Similar results were obtained by Bialek (2006) who found the negative trend of total ozone to be strongest in winter/spring and weakest in autumn for period 1980–2003. This negative trend was related to increasing of ODS in the atmosphere. In 1985, the ozone hole over Antarctic region was discovered

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doi:10.1016/j.asr.2011.07.010

(Farman et al., 1985) as the strongest manifestation of influence of ODS on ozone layer. This discovery led to the international effort which resulted in the Montreal Protocol in 1987 with amendments in the following years. In the mid-1990s a turnaround of trend in total ozone was observed in the northern middle latitudes. This change has a dynamical origin because ODS in the stratosphere peaked in the late 1990s, not in the mid-1990s (Dhomse et al., 2006). Due to this change a simple linear trend of total ozone is not proper from the mid-1990s. A piecewise linear trend is proposed to be used (Reinsel et al., 2002). Krzyścin (2011) compared classical regression model, piecewise regression model and flexible trend model and he concluded that all models give significant positive trend in the period 1996–2008 for the total ozone averaged over the globe in boreal winter.

The annual cycle is a major component of the global ozone variation. In the middle latitudes we observe a maximum of the annual cycle in late winter/early spring and a minimum in summer/fall. This annual cycle is substantially affected by the Brewer–Dobson circulation which transports ozone from the tropics to high latitudes. The Brewer–Dobson circulation is stronger in the winter hemisphere than in the summer one.

This paper deals with the spatial distribution of annual cycle of total ozone in latitudinal belt from 20°N to 60°N, the dependence of annual cycle on its annual extremes, temporal trends of annual cycle of total ozone and its components and possible links of the detected trends to changes of temperature at 100 hPa and tropopause pressure. We look for change in trends of annual cycle of total ozone and its components in the mid-1990s. Section 2 treats the data and method, Section 3 gives the main results, Section 4 provides the discussion of the results and Section 5 summarizes the conclusions.

2. Data and method

Monthly averages of total ozone are taken from the TEMIS datasets at http://www.temis.nl/protocols/O3global.html. More about the TEMIS datasets can be found in van der A et al. (2010). Monthly means of total ozone in the period 1978–2008 are available in this database but we took into account only period 1979–2008 because the regular satellite observations of total ozone started in October 1978 and we wanted to have observations of total ozone in each month of the year. The TEMIS ozone data are available in regularly positioned grid points, spaced 1.5° in longitude and 1° in latitude. Maximum (minimum) in the annual cycle was computed as maximum (minimum) from monthly means of total ozone from the given year and amplitude of annual cycle was determined as difference between these two extremes.

This paper is done in the framework of cooperation between the Czech and Chinese Academy of Sciences and thus we are predominantly interested in distribution and trends of the amplitude of the annual cycle of total ozone (ACO3) over Europe and the territory of China. Since the latitude of the southernmost point of continental China is about 20°N and the latitude of northernmost point is about 53°N, we select a belt bounded by 20°N and 60°N. We did not want to apply any artificial borders, so we performed the analysis for the whole range of longitudes.

In order to identify trends in the values of annual cycle extremes piecewise linear regression was employed with the breakpoint in 1995 reflecting the change in the total ozone trend in the mid-1990s. This procedure was performed not only for annual cycle of total ozone but also for its yearly maxima and minima as well as for maxima and minima of two potential covariates: temperature in the 100 hPa level and pressure at the tropopause, both of which were obtained in the 2.5 to 2.5° horizontal resolution from the NCEP/NCAR reanalysis dataset (Kalnay et al., 1996). The trend estimation procedure was carried out individually for each grid point.

3. Results

The geographic distribution of the amplitude of annual cycle of total ozone ($O3_{AMP}$) in the latitudinal belt from 20°N to 60°N is shown in Fig. 1a. The lowest values of $O3_{AMP}$ occur in the subtropics (about 40–60 D.U.). There is an increase towards higher latitudes where the amplitude typically exceeds 100 D.U. with strong longitudinal variation. The highest values are observed poleward of 45°N near 150°E (Okhotsk Sea region). In this maximum $O3_{AMP}$ reaches more than 140 D.U. compared to the minimum at the same latitude over the northern Atlantic ocean (less than 100 D.U.).

The amounts of ozone in the maximum of ACO3 ($O3_{MAX}$) are shown in Fig. 1b. The observed pattern strongly resembles that of Fig. 1a, i.e., the behavior of $O3_{AMP}$ is similar to behavior of ACO3 maximum. The lowest values of $O3_{MAX}$ are observed in low latitudes (about 300 D.U.), and they increase towards the pole as well as well as their longitudinal variations. The global maximum is found at about 55°N and 150°E (460 D.U.). The most profound longitudinal variations of $O3_{MAX}$ (about 80 D.U.) are detected along 55°N with the highest values observed near the Okhotsk Sea and the lowest ones over continental Europe and Asia and eastern Atlantic.

The lowest amounts of ozone in the ACO3 minima ($O3_{MIN}$) are again observed in subtropical regions (Fig. 1c). There is an increase with latitude but not so strong as in the case of $O3_{MAX}$. The Okhotsk Sea maximum is less pronounced, broader and shifted eastward. The maximum over Canada (55°N, 70°W) is better visible in the values of minima in ACO3 than in the case of its maxima.

Pearson correlation coefficient has been computed to quantify the strength of the link between $O3_{AMP}$ and values of its maxima and minima at each latitude (Fig. 2). The correlation between $O3_{AMP}$ and $O3_{MAX}$ is positive for all latitudes, within the range from 0.4 at 20°N to more than 0.9 north of approximately 40°N. The correlation is