Variation Features of Total Atmospheric Ozone in Beijing and Kunming Based on Dobson and TOMS Data 1)

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ABSTRACT

About 20 years of Dobson and TOMS data are used to analyze the variation characteristics of total atmospheric ozone in Beijing (39.93°N, 116.40°E) and Kunming (25.02°N, 102.68°E). It is shown that: (1) the long-term change trends for 1979 (or 1980)–2000 period are −0.642 DU / year and −0.009 DU / year respectively in Beijing and Kunming, (2) there are strong intra-seasonal variations especially in wintertime, which are comparable to seasonal variations both in Beijing and Kunming, (3) the long-term trend deduced from shorter time period of record is significantly different from that for longer time period, both in Kunming and Beijing, (4) there are significant QBO signals both in Beijing (mid latitude) and Kunming (low latitude), (5) the inter-annual variations of atmospheric ozone in both stations are mainly composed of the long-term trend and QBO signals, and (6) our Dobson and TOMS measurements of total ozone are generally in good agreement.

Key words: Total atmospheric ozone, Seasonal variation, Trend, QBO

1. Introduction

Because of the significant influence of atmospheric ozone on human health and global environment, the change of atmospheric ozone has become one of the most important issues on which governments and common people focus.

Since the discovery of rapid ozone decreases in the springtime Antarctic ozone hole, a lot of researches have reported negative trend in ozone at mid latitudes based on short period of TOMS data. Stolarski et al. (1991) used 11.6 years and Hood & McCormack (1992) used 13.2 years of Nimbus 7 TOMS data to deduce the total ozone trends all over the world. Zhou et al. (1996) used 13 years of TOMS data to deduce the decreasing rate of ozone over China. Wei & Chen (1993) used an 11-year time period record of Dobson measurement to estimate the trends in Kunming and Beijing. It is always believed that long-term decreases in the total amount ozone (mainly in stratosphere) are mainly due to human activities, especially the release of chlorofluorocarbons into the atmosphere. Therefore, it is very useful to make accurate estimate of the long-term trend in total ozone. Trends deduced from such a short period of data may be caused by different kinds of reasons such as the impact of human activities, the natural oscillations with longer time scale or the influence of volcanic eruptions.

In this paper, we use a longer (21–22 years) Dobson record (some of the absent data in the record are added from TOMS data) to re-estimate the trend and to analyze other variation features of atmospheric ozone in Kunming and Beijing. In section 2, the ozone data

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sources are introduced and comparisons are made between Dobson data and TOMS data. In section 3, atmospheric ozone variation features are analyzed and their comparison are made between Kunming and Beijing. Conclusions are drawn in section 4.

2. Data sources and comparison between Dobson and TOMS data

Two stations (Beijing, 39.93°N, 116.40°E and Kunming, 25.02°N, 102.68°E) are selected in this paper, and two data sources are used. One is from the daily overpass data of the Nimbus 7 Total Ozone Mapping Spectrometer (Version 7) provided by NASA / Goddard Space Flight Center, with time coverage from November 1978 through April 1993. The other is from Dobson record at these two stations. The record of Dobson observation in Beijing covers the period of 22 years from January 1979 through December 2000 with absent periods: February through April 1987, September 1993, April 1994, and August and September 1996. The record in Kunming covers a 21-year period from January 1980 through December 2000 with absent periods: April through November 1987, March 1992, March through July 1993, January-February and December 1995, January through March 1996, and January through March 1997.

Two points should be noted here. One is that the Dobson record in Beijing is consisting of two parts: before 1994, the Dobson observation site is located at Xianghe (39.77°N, 117.00°E), which is about 68 km southeast to Beijing, and afterwards moved to Beijing. And the terrain between these two sites is very plain, so the short spatial distance has little influence on the total atmospheric ozone. Another point is that the whole Dobson measurements at both stations are re-processed. The daily value originally sent to World Ozone Ultraviolet Data Center (WOUDC) is the manually selected one among the whole measurements in one day, and now is the average of these measurements, being more reasonable, by using the global prevailing software (Dobson 3.01) coded special for Dobson. And since 1992, refined absorbing coefficients are used, which has improved the retrieval accuracy of the total atmospheric ozone.

Estimations of some of the absent data in Dobson record should be made and the TOMS data is a good candidate. In order to do this work, the consistency degree of the data with two different sources has to be determined at first. We select the coincident TOMS and Dobson data, 2835 pair samples for Kunming and 3734 pair samples for Beijing. Their respective statistical properties and relationships are given in Table 1. It can be seen that the two data sets both in Kunming and Beijing are in good consistency with the relative average error below 3% and the correlation coefficient above 0.93. The good consistency can also be seen in Fig. 1, giving the scatter plots of the TOMS and Dobson data.

Table 1. The statistical properties of TOMS and Dobson data and their relationship. (RMSE, root of mean square error)

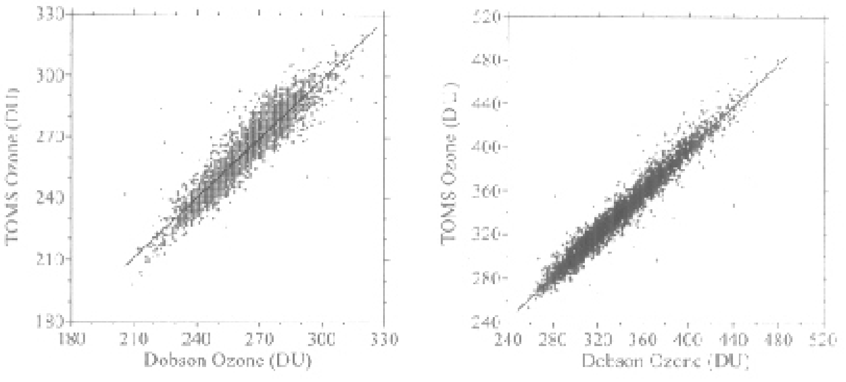
Station	Mean (DU) TOMS / Dobson	Variance root (DU) TOMS / Dobson	RMSE (DU)	Correlation coefficient	Number of samples
Beijing	340.7 / 339.4	38.9 / 38.9	8.40	97.7%	3734
Kunming	262.9 / 263.4	19.6 / 18.7	7.25	93.0%	2865

The relation between TOMS data and Dobson data can be expressed by the following formula:

$$\text{Kunming: TOMS} = 0.974589 \times \text{Dobson} + 6.16554, \tag{1a}$$

$$\text{Beijing: TOMS} = 0.976666 \times \text{Dobson} + 9.2777. \tag{1b}$$

Owing to the good consistency between TOMS data and Dobson data, some of the



(a) (b)

Fig. 1. Scatter plots of coincident Dobson and TOMS data in Kunming (a) and Beijing (b).

absent data in Dobson data from January 1979 (or 1980) through April 1993 can be estimated from TOMS based on the above relationship formula between them. Analyses below are based on the amended data.

3. Analysis of ozone variation features

In this section, we will analyze not only the seasonal variation features of atmospheric ozone, but also its interannual variability both in Kunming and Beijing, and make some comparison between these two stations.

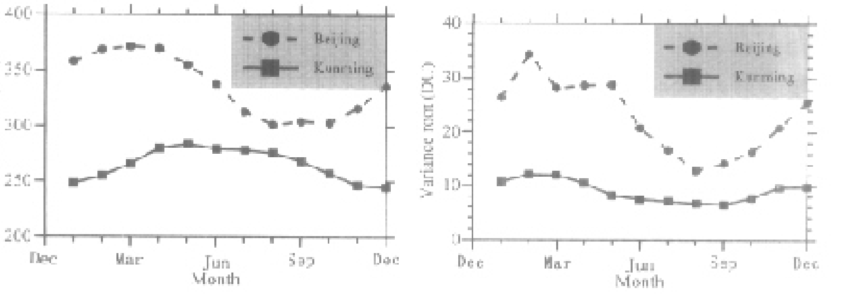
3.1 *Seasonal variation*

First, we analyze the seasonal variation of multi–year monthly mean ozone, and the variance in different seasons. These analyses are based on a time period of 21 years from 1980 through 2000 for Kunming and 22 years from 1979 through 2000 for Beijing. Atmospheric ozone has obvious seasonal variation both in Kunming and Beijing (Fig. 2a). In Kunming, the ozone amount is high in April through June, and low in November through January, with variation amplitude of about 38 DU. In Beijing, the oscillation amplitude is larger, about 70 DU, and the ozone amount is high in February through April and low in August through October. The seasonal variations in Kunming and Beijing are nearly 90 degree out of phase. It is in consistency with the analysis results from the SAGE II measurement data (Chen et al. 1995). The atmospheric ozone amount in Beijing is much larger than in Kunming, and even the lowest is above 300 DU in Beijing, while in Kunming the highest is below this value.

There are also obvious seasonal variations in the root of variance (RV) of daily atmospheric ozone in different months at both stations (Fig. 2b). In Beijing, RV is high from December through May (above 25 DU), and low from June through November (below 21 DU). In Kunming, though much lower than in Beijing, RV is high from November to April (above 9 DU), and low from May to October (below 8 DU). In Beijing, RV and monthly mean vary almost in the same phase, but the seasonal RV is about 90 degree of phase ahead in Kunming.

3.2 *Long–term trends*

The long–term trend in atmospheric ozone is most attractive. Not only the whole trends



(a) (b)

Fig. 2. Seasonal variation of multi-year monthly mean ozone (a) and root of variance (b).

but also trends in different seasons are analyzed here.

First, we analyze the whole trend, and the results are listed in Table 2. In Kunming, the whole trend of monthly mean over the 21-year time period from 1980 through 2000 is −0.009 DU / year (or −0.003%), and the trend of anomaly is −0.043 DU / year. In Beijing, the trend of monthly mean over the 22-year time period from 1979 through 2000 is −0.642 DU / year (or −0.189%), with −0.535 DU / year for anomaly. These results are significantly different from those of Wei and Chen (1993) and Zhou et al. (1996) from the data of shorter time periods. The whole trend of monthly mean over 1980 through 1991 is −0.299 DU / year (or −0.114%) in Kunming, and the trend over 1979 through 1991 is −1.186 DU / year (or −0.349%) in Beijing. Compared with the trends estimated from a longer time period, the trends estimated from shorter time period may be overestimated for the period 1979 to 1991. The long-term decrease of atmospheric ozone is always believed to be the result of human activities (although there are some disputes), but it is hard to say that the trend deduced from shorter time period is, to what extent, due to the result of human activities, or due to natural oscillations with long time scale.

Table 2. The linear trend of atmospheric ozone in different period of time (DU / year and in percentage)

Station	Monthly average		Anomaly of monthly average	
	1980 / 79−2000	1980 / 79−1991	1980 / 79−2000	1980 / 79−1991
Beijing	−0.642 (−0.189%)	−1 186 (−0.349%)	−0.535	−0.768
Kunming	−0.009 (−0.003%)	−0.299 (−0.114%)	−0.043	−0.221

Many researches show that the trends of atmospheric ozone vary with seasons. The results for Kunming and Beijing are shown in Fig. 3. In Kunming, the trends are negative from November through May, and positive from June through October, but they are very small in all seasons, none of which pass the significant statistical test (we adopt the method of significant test of linear trend by Santer et al. 2000). In Beijing, the trends are negative in all seasons, and only the trends in February through April are below −1.0 DU / year, which pass the significant statistical test (level 0.05).

3.3 *Long-term signal and QBO*

By removing the attribution of weather processes to the variability of atmospheric ozone,

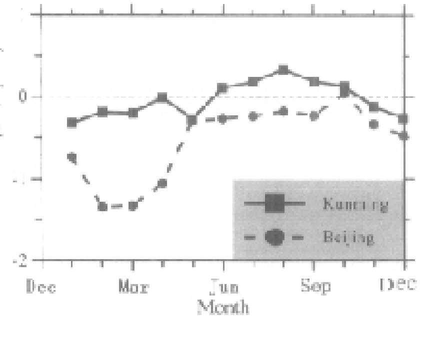


Fig. 3. Seasonal variation of trends of ozone over 1980 / 79 to 2000.

the variation of monthly mean is mainly composed of seasonal, quasi–biennial oscillation (QBO) and long–term signals (Shi et al. 1996). In order to separate the QBO and long–term signals, we apply singular spectrum analysis (SSA) to the anomaly series of monthly mean.

SSA has special features and greater flexibility when applied to the analysis of phenomena with long time scales and high sampling rates (the brief introduction of SSA is attached in Appendix). In contrast with standard spectral analysis in which the basis functions are given a priori, in SSA they are determined from the data themselves to form an orthogonal basis that is optimal in the statistical sense. Because oscillatory modes can be identified in the data, SSA is particularly helpful in isolating anharmonic oscillations with fluctuating amplitudes from noisy data (Keppenne and Ghil 1992). And the long–term change trend can also be identified (Vautard et al. 1992).

The SSA results of our ozone data are shown in Fig. 4. Both in Kunming and Beijing, the long–term trend and QBO signals are isolated. QBOs at both stations are nearly of the same phase. But their QBO amplitudes vary with time in different patterns. From the whole time period, the amplitudes change very little in Kunming, but in Beijing they are smaller before 1991 than after 1991. The long–term trend signal in Kunming seems to be composed of two about 10–year oscillations with three peaks in 1981, 1991 and 2000. In Beijing, the long–term signal first decreases rapidly in 1980, and then levels till a second rapid decrease occurs in 1991, and recovers partly in 1994. The second rapid decrease coincides with the volcanic eruption of Pinatubo (June, 1991 in Philippine), the strongest volcanic eruption in the 20th century. So we think that the second rapid decrease of atmospheric ozone in Beijing is due to the destruction of stratospheric ozone in mid latitudes by the aerosols produced by the Pinatubo eruption (Wei et al. 1994). The El Chichon eruption (April, 1982 in Mexico), which is the second strongest volcanic eruption in the 20th century seems to have little impact on the change of atmospheric ozone in Beijing. But in Kunming, the change of atmospheric ozone seems to be insensitive to the influence of both two volcanic eruptions. The fitting degree of the addition of long–term and QBO signal to the anomaly series is 57% for Kunming, and 59% for Beijing (according to formula A1). The interannual variation is mainly composed of these two signals.

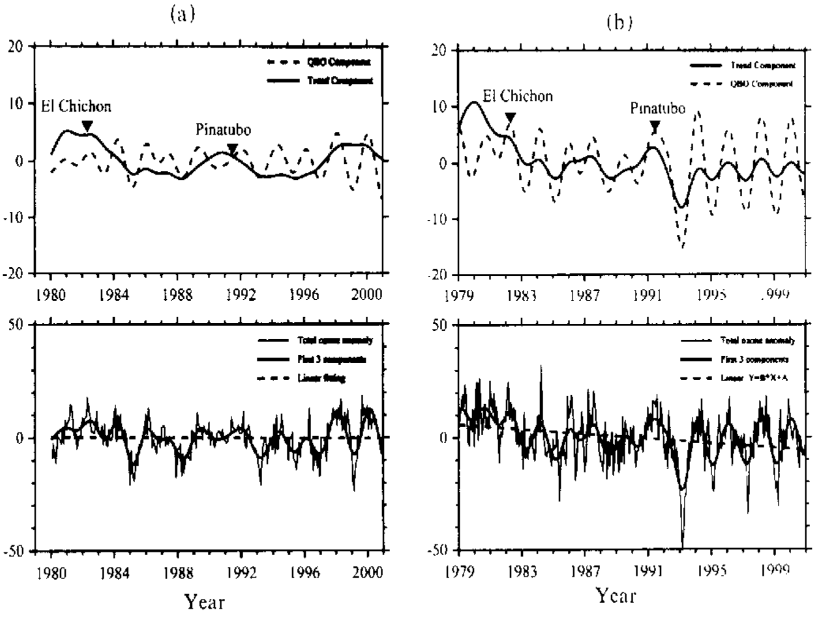


Fig. 4. Monthly anomaly series of atmospheric ozone and their reconstructed components in (a) Kunming and (b) Beijing. Above are the trend component (solid curve) and QBO components (dashed curve), and below are the anomaly series (thin) and the addition of trend component and QBO component (thick).

4. Conclusions

In this paper, a longer (21–22 years) Dobson records (some of the absent data in the record are estimated from TOMS data) are used to re–estimate the long–term trend and to analyze other variation features of atmospheric ozone in Kunming and Beijing, and some comparison are made between these two stations. The main results are summarized as follows:

(1) The long–term change trends for 1979 (or 1980)–2000 period are –0.642 DU / year and –0.009 DU / year respectively in Beijing and Kunming.

(2) There are strong intra–seasonal variations especially in wintertime, which are comparable to seasonal variations both in Beijing and Kunming.

(3) The long–term trend deduced from shorter time period of record is significantly different from that for longer time period, both in Kunming and Beijing.

(4) There are significant QBO signals both in Kunming (low latitude) and Beijing (mid latitude).

(5) The interannual variations of atmospheric ozone in both stations are mainly composed of the long–term trend and QBO signals.

(6) Generally, our Dobson and TOMS measurements of total ozone are in good agreement.

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APPENDIX

Brief Introduction of Singular Spectrum Analysis (SSA)

This appendix of SSA is modified from Keppenne and Ghil (1992).

Singular spectrum analysis (SSA) is algorithmically equivalent to the application of extended empirical orthogonal functions (EOF) to a univariate time series but has special features and greater flexibility when applied to the analysis of phenomena with longer time scales and higher sampling rates. Vautard et al. (1992) and Allen Smith (1996) provide reviews of SSA and Monte Carlo SSA and their applications to climate studies. For brevity, we here sketch the method based on its relation to spatial EOF analysis.

Spatial EOF (S–EOF) analysis expands the discrete field time series $x_{i,j}$ where the indices i and j refer to the spatial and temporal directions respectively – $i \in [1, M]$, $j \in [1, N]$ – into the sets of its eigenvectors (EOFs) and principal components (PCs). In SSA, the spatial direction is replaced by time lags, i.e., $x_{i,j} = x_{j+i}$, and M becomes the number of lags. The algebraic formula essentially remains the same.

In contrast with standard spectral analysis in which the basis functions are given a priori (e.g., the sines and cosines of Fourier analysis), in SSA they are determined from the data themselves to form an orthogonal basis that is optimal in the statistical sense. Oscillatory modes can be identified as pairs of nearly equal eignvalues, while their eigenfunctions and principal components have the same time scale of oscillation, as well as being nearly 90 deg out of phase. Because of this property, the method is particularly helpful for isolating anharmonic oscillations with fluctuating amplitudes from noisy data.

The part of the time series' variability corresponding to a given oscillation can be isolated by restricting the Karhuen–Loeve (K–L) expansion to the EOFs and PCs that have been identified as corresponding to that oscillation. The reconstructed components (RCs) carry the contributions of the individual EOFs and PCs to the variance of the time series. The fitting degree of the RCs to the time series can be calculated by the formula

$$r = 1 - \frac{\sum_i (R_i - x_i)^2}{\sum_i (x_i - \bar{x})^2}, \tag{A1}$$

where $\bar{x}$ is the mean of time series $\{x_i\}$, R_i is a reconstructed component.

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根据 Dobson 和 TOMS 资料分析北京和昆明大气臭氧总量变化特征

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摘 要 P4 A

用约 20 年 Dobson 和 TOMS 资料来分析北京(39.93°N, 116.40°E)和昆明(25.02°N, 102.68°E)两地大气臭氧总量的变化特征。结果表明：(1)在 1979–2000 年间北京大气臭氧长期变化趋势是-0.642 DU／年，而昆明在 1980–2000 年间的趋势是-0.009 DU／年；(2)北京和昆明两地大气臭氧都有很强的季节内变化(尤其冬季更强)，与季节性变化强度相当；(3)在北京和昆明，由记录较短的大气臭氧资料分析得到的长期变化趋势，与较长记录得到的结果有显著差异；(4)在北京(中纬度)和昆明(低纬度)大气臭氧都有显著的准两年振荡信号；(5)两个站点大气臭氧的年际变化主要由长期趋势项和准两年振荡信号组成；(6)Dobson 仪测量得到的臭氧总量与 TOMS 资料非常一致。

关键词： 大气臭氧，季节变化，趋势，准两年振荡