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Trends and characteristics of total ozone and vertical profile in Kunming and Beijing, China*

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Abstract— This paper presents the trends of total ozone at Beijing and Kunming areas during the period of 1979 to 1989. The SBUV ozone vertical profile data and the periodic oscillation in upper ozone layers over Beijing area are also described. The results show that the variation of Beijing and Kunming per decade are about −5% and −1.5%, respectively.
Keywords: total ozone; ozone vertical profile; remote sensing; periodic oscillation.

1 Introduction

In the atmosphere, the ozone layer in the middle latitudes is only about 0.3 cm in thickness (300 Dobson units) in STP. However, it absorbs most of the solar UV radiation. Especially, the UV radiation shorter than 3000Å is cut off by it. Therefore, ozone layer has prevented the harmful rays and sheltered mankind and fauna as well as flora on earth.

Unfortunately, since the earlier 1970s, the total ozone has decreased. Especially, the Antarctic ozone hole which was discovered in mid 1980s has caused much attention from the scientists and politicians throughout the world.

Two stations for measuring atmospheric ozone have been set up in Beijing and Kunming of China since 1979. The seasonal variations and their total ozone trends have been discussed for about ten years data. Besides, because of big area of China, the year to year variations of the average total ozone over the most China have been shown with the analyses of ground-based ozone network data. Therefore, the first purpose of this paper is to understand what had happened to the toal ozone trends last 10—30 years over China.

The situation with regard to measurement of the ozone vertical profile is less satisfactory right now. Therefore, for the ozone trends in upper layers, unfortunately, the scientists understand still very poor today. In this paper, the SBUV ozone vertical

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profile data over Beijing have been used. Although SBVU data have the problem of the diffuser plate degrading, after corrected using the data of the ground remote sensing by Umkehr<C>, they do become available. Through careful analyses in detail, the results have increased our understanding about the trends and some physical characteristics for the upper layer ozone.

2 Trends of total ozone

The Beijing Ozone Station (Xianghe, 39° 41'N, 117° 00'E) was set up by the end of 1978 with Dobson instrument No. 75. Its data with very good quality and therefore it is one of the best stations in the world assessed by Bojkov *et al.* (Bojkov, 1988).

Fig.1 is the comparison between TOMS satellite data and Beijing data. Its standard deviation is only 2.1%. By the end of 1979, Kunming Ozone Station (25° 01'N, 102° 41'E) has also been set up with the instrument No.3, which was modernized. It has also got qualified data (Grass, 1989). In Fig.2, a and b show the long-term monthly mean total ozone variations for Beijing and Kunming respectively. Their seasonal oscillations are very clear.

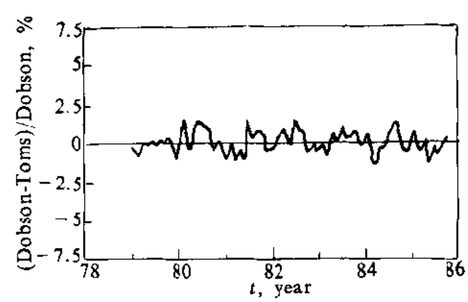


Fig.1 Monthly differences between ozone measured at Beijing and by TOMS (Bejkov, 1988)

The trends of them are calculated during this period with yearly mean values. They are about −5.0% and −1.5% for the both stations. It means that the ozone over the two areas are decreasing in general. However, in higher latitude the decreasing is much stronger than those in the lower latitude.

In addition to the above, we also analyzed the average total ozone trends since the earlier 1960s over China area, using grid values (10° × 10°) from the book written by Wei *et al.* (Wei, 1989) as shown in Fig.3. Besides, Fig.4 shows the annual average total ozone with time included some 1960s values in Beijing Station. From Fig.3, we can clearly see the total ozone decreasing trend since earlier 1970s. On the other hand, it is interesting to find out that in both this two figures, not only clearly show the QBO, but also show obvious lower total ozone happened around mid 1960s. This presents a very interesting and important phenomenon. Therefore, from more longer period, it seems that the low ozone in 1980s is still in the amplitude of natural oscillation at least in China.

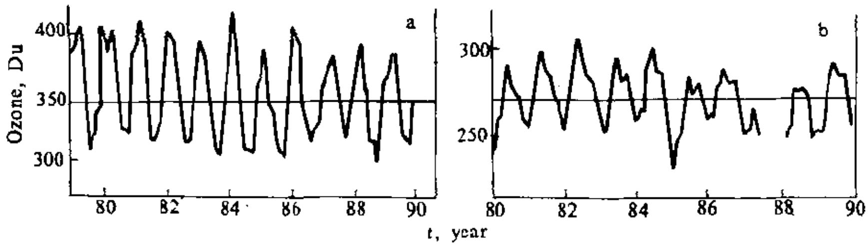
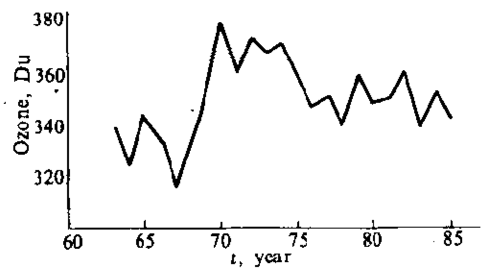


Fig.2 Monthly mean total ozone variations
a— Beijing b— Kunming



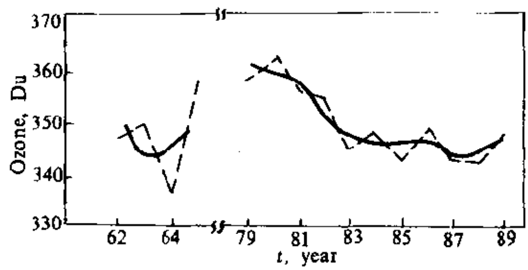


Fig.3 Long-term average total ozone variations of the area of 30-60°N, 90-140°E

Fig.4 Long-term annual average total ozone variation of Beijing Station included 1960s data

3 Trends and characteristics of the ozone vertical profile over Beijing

3.1 Corrections for SBUV data by Umkehr <C> measurements

The Umkehr method <C> was designed by Wei *et al.* (Wei, 1964) in earlier 1960s, which has been used in Beijing and Kunming for about 10 years. This method is a more objective one without using priori limitation conditions and has been proved with stable results (Wei, 1989). In Beijing Station, we have obtained more than 200 ozone vertical profiles from Umkehr <C> with good quality since 1979.

On the other hand, Dr. A. J. Miller kindly provided us the SBUV ozone vertical profile data over Beijing for the period of April, 1979 to October, 1986. Because of the degrading of the diffuser plate in the SBUV system, these data can not give the independent information about the long-term ozone verticl profile trends (WMO, 1989). However, through our comparative analyses and corrected by the Umkehr <C> data as mentioned below, the SBUV data are available and their results seem reasonable.

First of all, through calculations and transfer, we have made the unity of the layers and units between the two systems. The layers of 0−21 km, 21−28 km, 28−36 km, and above 36 km have been used in this paper. In each layer, the unit is Du. Fig. 5 shows the comparison at the same observational days for three layers of 21−28 km, 28−36 km and above 36 km before correction between the two systems. It can clearly see that (1) The peaks and valleies are very agreement with each other between the two curves. (2) Results of 21−28 km layer shows the peak values are higher than those of SBUV. This is due to that the Umkehr values are derived by solving two equations objectively and the SBUV data are smoothed in this layer by using priori conditions— ozone standard vertical profiles. (3) Fig 5a shows that the layer of above 36 km, before the later half of 1985, the variation patterns of the two curves are similar. However, there was a very strong downward drift of the SBUV data since the later half of 1985 due to the diffuser plate degrading responding the shorter wavelengths in SBUV system. The systematic differences between the two systems are due to the using of the different ozone absorption coefficients.

For correcting the SBUV data, the linear regression has been used to analyse the both data observed on the same days for obtaining the change rate in each layer. Because of the large drift mentioned above, the layer of above 36 km has been divided into two periods, i. e. April, 1979−September, 1985 (named A) and October, 1985−October, 1986 (named B), for analysing. The results are shown in Table 1.

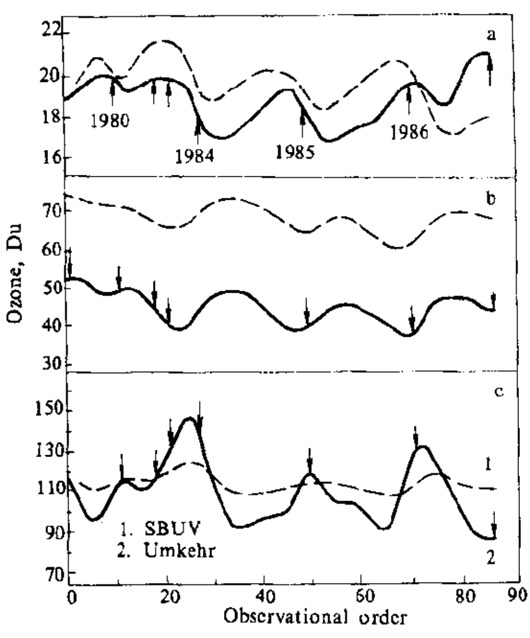


Fig.5 Comparisons of the SBUV data (running averaged and Umkehr <C> data (running averaged) before correction
a— layer of above 36km; b— layer of 28−36 km; c— layer of 21−28km

Table 1 The change rate of the Umkehr <C> and SBUV data

Layer	21−28 km	28−36 km	Above 36 km	
			A	B
Rate (SBUV)	-1.41×10^{-4}	-3.22×10^{-4}	-4.84×10^{-4}	-0.0123
Rate (Umkehr)	-4.17×10^{-4}	-2.12×10^{-4}	-3.74×10^{-4}	
Unit	Du/Day	Du/Day	Du/Day	

According to Table 1, using the Umkehr<C> change rate as a standard, the SBUV data have been corrected. The results are shown in Fig. 6. Comparing Fig. 5 and Fig.6, we can clearly find out that for the layers of 21−28 km and 28−36 km, the changes are not obvious. However, for the layer of above 36 km, the change is very marked, the correlation coefficients between the two curves are 0.18 and 0.79 before and after correction respectively.

3.2 The trends of ozone vertical profile in Beijing area

First, we obtained the correction coefficients by utilizing the change rate shown in Table 1. Therefore, the complete SBUV data of the upper three layers in Beijing area have been corrected. Their monthly mean value are shown as Fig.7a, 7b, 7c. Secondly, we using the total ozone data observed in Beijing Station as the standard, the corrected SBUV total ozone data in the same period have been obtained. Its monthly mean values are shown as Fig.7e. From Fig.7e minus Fig.7a, 7b, 7c, the monthly mean ozone values of layer of 0−21 km are calculated show as Fig. 7d. According to this figure, for filtering the seasonal variations, the annual mean values for each layer have been done. Then, the trends of the ozone vertical profile in Beijing area during the period of

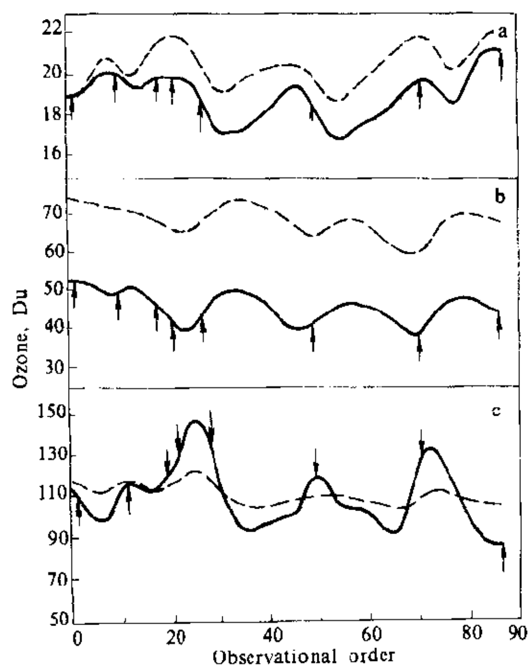


Fig.6 Comparisons of the SBUV data (running averaged) and Umkehr <C> data (running averaged) after correction (a— layer of above 36 km; b— layer of 28−36 km; c— layer of 21−28 km)

1979 − 1986 are obtained as shown in Table 2.

Table 2 Trends of the ozone vertical profile over Beijing area (1979 − 1986)

	Total	0 − 21km	21 − 28km	28 − 36km	Above 36km	Units
Mean value	312.1	109.5	115.2	66.5	20.9	Du
Decreasing (8 years)	16.5	5.9	5.0	4.5	1.8	Du
Relative change	− 5.3	− 5.3	− 4.4	− 6.8	− 8.5	%

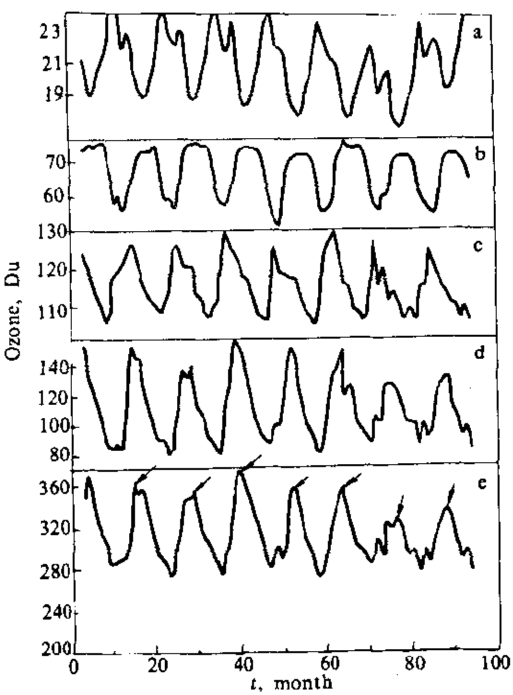


Fig.7 Monthly total ozone and monthly mean ozone in different layers from SBUV data after correction

From Table 2 we can see: (1) The total ozone trend during the period of 1979 to 1986 from the SBUV data is basically agreement with that from the ground data. (2) In the upper layers of 28 − 36 km and above 36 km, the relative change in 8 years are a little bit larger than those below 28 km. Anyway, the difference of the relative change between upper and lower layer is not as big as theoretical expected. (WMO, 1988). (3) The absolute decreasing ozone amount in lower layers is much more important than that in the upper layers.

3.3 Some characteristics in upper ozone layer over Beijing area

Fig. 7 shows some interesting characteristics of the seasonal variation with different phases. For more clear, the monthly values in 8 years have been averaged and obtained the average seasonal variations for different layers as shown in Fig.8. Ozone in layer of 0 − 21 km, its seasonal variation is complete the same with that of the total ozone. For the layer of 21 − 28 km, the pattern is also similar although its maximum is a little bit advanced. The most interesting thing is that the phases of the seasonal variations in layers of 28－36 km and above 36 km are complete opposite. For the layer of 28－36 km, its maximum is happened around June. But for the layer of above 36 km, this month is just its minimum happened.

WMO Report No. 11 (WMO, 1981) gave a figure which is very similar to Fig. 8 below 36 km. However, it did not give the information above 36 km. This means that the Fig.8 is reliable and it gives more complete pattern about the characteristics of the seasonal variations of the ozone vertical profile.

As for the quantitative explanation for Fig.8 is complex. It might be related to photochemistry, dynamics and the atmospheric state. Therefore, we should study it in more detail in the future.

In the layer of above 36 km, there are oscillations with the period of quasi-27 days and quasi-10 days in the winter-half-year are find out by the spectrum analysis. However, in the summer-half-year, these oscillations do not clearly appear.

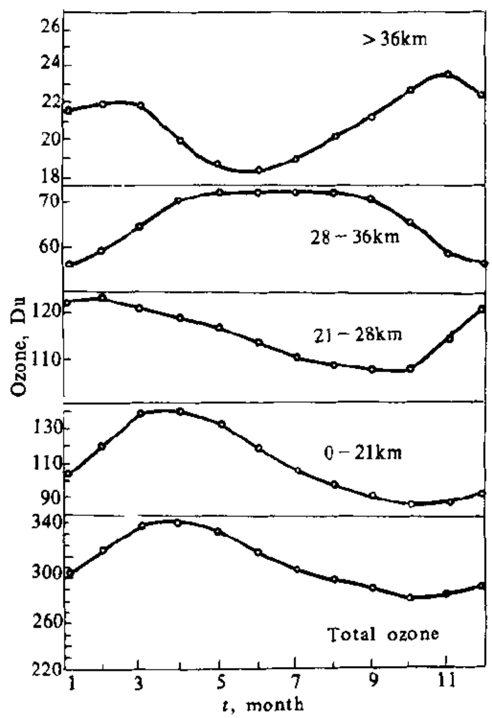


Fig.8 The seasonal variations of total ozone and the ozone vertical profile from SBUV data after correction

4 Conclusions

In both Beijing and Kunming areas, the total ozone presented negative trends during the period of 1979－1987 with about －5% and －1.5% respectively. These include the influences of solar cycle and Q. B. O. and so on.

If in consideration of longer period include 1960s, the total ozone decreasing in 1980s in still in the natural oscillation range at least in China.

With the corrected SBUV data, the trends of the ozone vertical profile over Beijing area have been done. The trends of the upper level (above 28 km) is a little bit larger than that of the lower level (below 28 km) with the values of about

-7% to -8% and about -5% respectively. The difference between the two levels is not as big as the theoretical expected.

Present a more complete pattern of the ozone seasonal variation of the ozone vertical profile. Besides, oscillations with the period of quasi-27 days and quasi-10 days have been found in the layer of above 36 km in the winter-half-year.

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