CHARACTERISTICS OF THE TEMPORAL-SPATIAL VARIATION IN ATMOSPHERIC OZONOSPHERE OVER THE NORTHERN HEMISPHERE DURING THE PERIOD OF 1963–1985

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ABSTRACT

The total ozone data of 113 ozone observational stations in the Northern Hemisphere (NH) spanning a period of 1963–1985 have been analysed in this paper. Some interesting results have been obtained, such as the temporal and spatial distribution, long-term trends, the harmonic analysis results, the relationship between the total ozone and solar activity, etc. Furthermore, by using the defined index G, the long-term changes of ozone meridional distribution patterns for the region of Europe-Asia (EA) have been approached particularly.

I. INTRODUCTION

It is known that ozone layer is a subsphere of the terrestrial atmosphere. Although it has a very small content in the free atmosphere, the ozonosphere has attracted more and more attentions to people in recent years (United Nations, 1985), and this is even more substantial since the late discovery of the so-called Antarctic ozone hole. This is because the ozone concentration can strongly influence the penetration of the solar UV radiation to the ground and then influence the equilibrium of terrestrial ecological environment. Now, some studies have indicated that the decrease in atmospheric ozone amount might alter the global climate evidently.

Because of the human activities, more and more chemical species enter the atmosphere from the earth's surface. Thus, the ozone layer might be seriously damaged by them, especially $CFCL_3$ and CF_2CL_2. Today, how to control the releasing of these species and the protecting of the ozonosphere have become very important.

On the basis of the data from ground-based observational network and satellite observations, London et al. (1976, 1978/1979) and Miller et al. (1980) extensively analysed the distribution and variation of total ozone within the scopes of hemisphere and globe respectively. In these studies they mainly dealt with the ozone change only before 1980's. Lately, Angell et al. (1979) and Oehlert (1986) also studied the global trends of ozone during 1958–1979 and 1964–1983 respectively, and noticed that the total ozone in the NH has had a decline trend since 1970's.

By using the long-term global ozone data (Canadian Department of the Environment), we have carefully analysed and compiled the "*Atlas of the Temporal-Spatial Variation of* Total Ozone over the NH" (Wei et al.). The time interval the Atlas covered is 1963–1985, almost containing two solar activity cycles—Cycle 20 and Cycle 21. The Atlas also provides six kinds of year-to-year or half-year-to-half-year ozone variation chart. In this paper, we use the Atlas data to study the characteristics of total ozone on: a) temporal and spatial distribution; b) the long-term trends. Both of them are the most interesting problems in this field at present.

II. MEAN STATE OF THE LONG-TERM OZONE VARIATION

Based on the grid point data (the grid interval is 10°) of total ozone from the Atlas, we can obtain an average NH distribution for the 23-year period,1963–1985 (see Figs.1a–b).

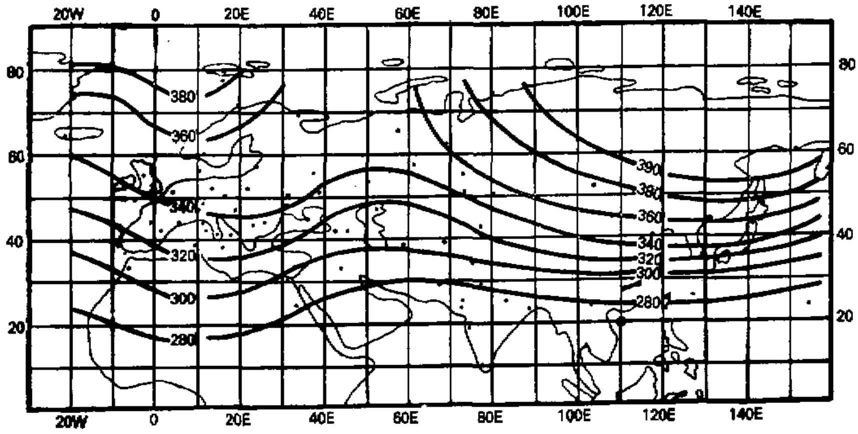

Fig. 1a. Average distribution of total ozone in the EA region (in Dobson unit) for the 23-Year period, 1963–1985.

It can be seen from Figs. 1a-b that

1) In the direction of longitude, the total-ozone distribution has a typical planetary wave structure with the wavenumber 3. That is, there are three prominent maximum centers (PMC) or deep ozone "troughs" located in the West Europe (WE), East Asia and North America (NA) respectively. In fact, they are quasi-steady and exist all the time, whether in winter/spring or in summer/fall. In addition, there are three low ozone concentration regions located in the East Europe, Atlantic and Pacific respectively, corresponding to the PMC. The results here roughly agree with those of London (Whitten et al., 1985) derived recently;

2) The locations of the PMC are just in correspondence with those of three westerly troughs of long waves at 500 hPa over the NH. This means that the sea-land distribution and atmospheric circulation have an important influence upon the ozone distribution. Another feature for PMC is that they differ from each other. In general, the PMC in WE is rather smaller and weaker than the others.

We can also obtain the mean ozone values for the 23-year period both in the EA and in the NA, from the grid point data. Considering the curtailing of parallel with latitude

ϕ, we introduce the area weighting factor $\cos\phi$ in our calculation of mean values for the two regions described above. As the sparseness of actual observation in polar and equatorial areas, the latitudinal range is chosen as 40° (30–70°N). Hence, the mean values for EA and NA are given as 339 Du and 340 Du respectively, both are about the same.

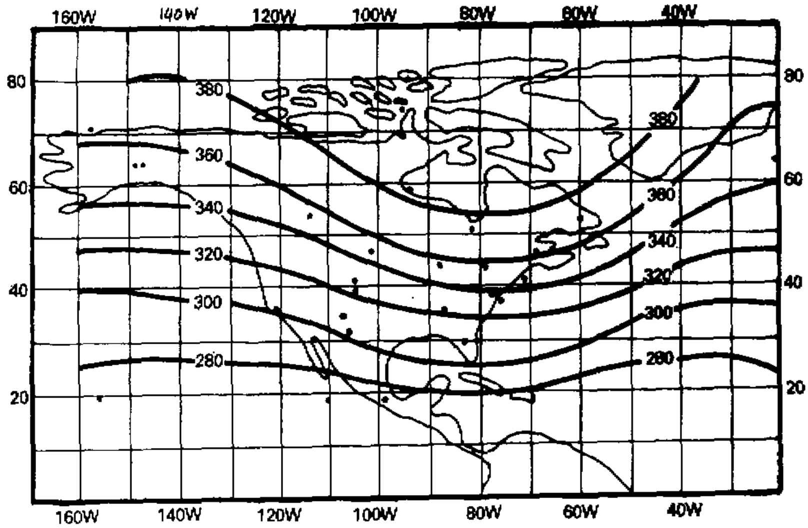

Fig. 1b. Same as Fig. 1a, except in the NA region.

III. LONG-TERM TRENDS IN TOTAL OZONE

Similarly, the year-to-year area-weighting mean values for the two regions of EA and NA can be used (shown in Fig. 2a) to study the long-term trends. From Fig. 2 the following points can be got:

1) During the period of 1964–1970, there was a trending increase in ozone concentration, and for EA this increase was even more substantial with respect to NA;

2) From 1970 to 1985, the ozone amount has a slow decreasing trend. On the average, the decreasing rates are: a) 1.7% from period 70–76 to period 77–82 for EA; b) 2.0% from period 77–82 to period 83–85 for EA; c) 0.3% from period 70–76 to period 77–82 for NA; d) 2.4% from period 77–82 to period 83–85 for NA.

The two points mentioned above are almost in agreement with the results of Kombyer et al. (1980), only our data have a longer time interval.

3) Furthermore, the total ozone concentration was relatively small in the period of 1964–1966, and then began to increase. By 1970 it had nearly reached its maximum, then entered a slow decline, and arrived at its minimum during 1976–1977. After that, the ozone amount shows a quick increase, and an additional peak in 1980. Finally it turned into a relatively-slow decline. It follows that the evolution illustrated above is just related to solar activity in the Cycle 20 and Cycle 21. So we can expect that the total ozone amount over the NH may rise again in 1987. In fact, as we compare the curve in Fig. 2a with that of solar activity index (SAI) shown in Fig. 2b, we can see a positive correlation between

the total ozone and SAI. The calculated correlation coefficient is +0.6 and the result for T-test is obvious.

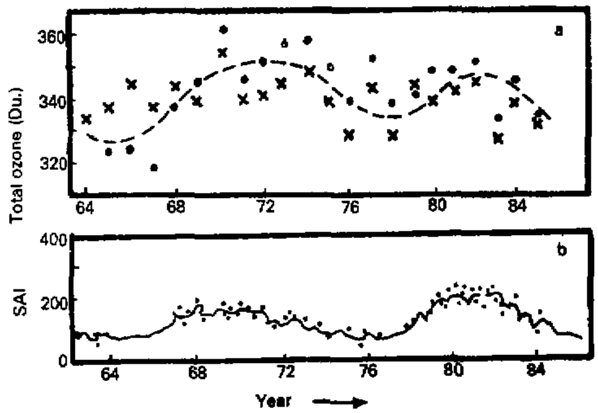

Fig. 2 Long-term trend (·—· EA region; *—* NA region) for variations of a) total ozone, b) SAI.

In general, the total ozone over the NH has decreased slowly since 1970's. This descending trend has become more evident since 1982. The fall trend can be seen for EA and NA, so it might be a common phenomenon for the entire NH.

IV. LATITUDE EFFECT AND LONGITUDE ANOMALIES

Based on the average-ozone data for every 10 degree latitude belt between 30°N and 70°N, the time-dependent variation of total ozone at these latitudes for EA and NA can be formed (see Fig. 3).

It is evident from the analysis in Fig. 3 that the total ozone variations for these latitudes are basically analogous to the general trend shown in Fig. 2. This is, the general trends including the peak in 1970 and the low values in 1978 and 1983 must be a common phenomenon for most of the NH.

But of course there are some latitudinal effects on ozone variations. First, the total ozone at high latitudes (HL) possesses not only higher concentration but also larger variation amplitude. Then, the fall trend of ozone since 1970's has been more obvious at HL and blurred with decreasing latitude.

The reasons why the total ozone possesses the latitude effects described above may be explained as follows: a) The carbon fluorides caused by human activities and its resolving product Cholorine can be transported from low latitude to HL, and then accumulated there. Thus they can destroy the ozone at HL(Wei et al.); b) The charged energetic particles reaching HL along the magnetic line of force of geomagnetic field can arrive at the mesosphere and stratosphere, especially in the maximum years of solar cycle. Then, more nitrides and hydrides induced by these particles can reduce the ozonosphere thickness at HL. According to the later mechanism, probably, we can explain the observational results in quasi-eleven periodicity for total ozone variation over the NH.

We know that the most important symbol to total ozone distribution is the PMC located at WE, NA and East Asia respectively, and these deep ozone "troughs" are much stronger in winter. So, we should discuss them in particular.

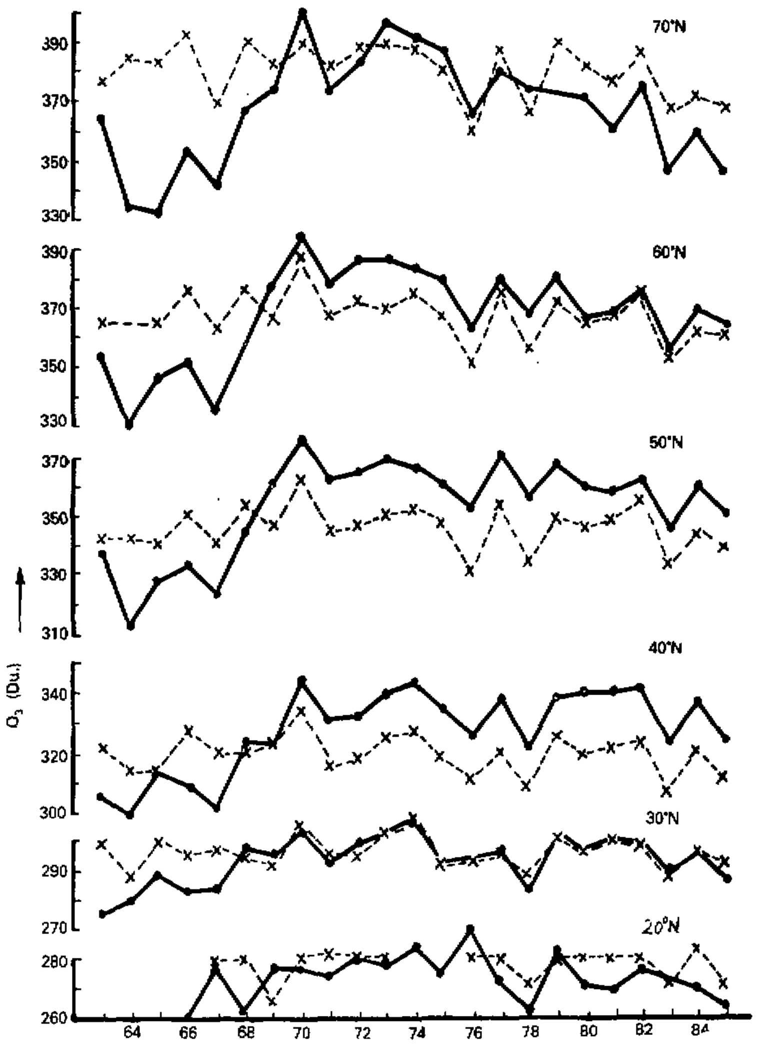

Fig. 3 The time-dependent variation of total ozone at all latitudes for EA(solid line) and NA (dashed line) respectively.

As for the time interval, we use the mean distribution data for winter/spring season given in the Atlas (Wei et al.), while the discussed horizontal range is divided into three subregions, as in Table 1, corresponding to the PMC shown in Fig. 1.

Table 1. Subregions Corresponding to the Three Deep Ozone Troughs over the NH

Name of Subregion	Relevant PMC	Latitude	Longitude
W	Deep Ozone Trough in WE	50–60°N	20°W–20°E
E	Deep Ozone Trough in East Asia	50–60°N	110°E–150°E
N	Deep Ozone Trough in NA	50–60°N	100°W–60°W

Hence, the mean values of total ozone associated with the three subregions in Table 1 can be called the intensity indexes of the ozone "troughs" in the East Asia, WE and NA respectively. We denoted them as I_E, I_W and I_N. Thus, we can obtain the averages of the indexes over the long-term:

$$\bar{I}_W=369\ \text{Du},\quad \bar{I}_E=439\ \text{Du},\quad \bar{I}_N=412\ \text{Du},$$

and their standard deviations are 12.4, 14.6, and 9.8 respectively. So it can be seen that among the PMC in the NH, the WE ozone "trough" is the weakest; the East Asia ozone "trough" is the strongest and has the largest variation amplitude, while the NA ozone "trough" is relatively stable. For this reason, we can often see from the Atlas (Wei et al.) that the ozone distribution over the NA is quite steady or quasipermanent, and the PMC in WE is so relatively obscure that it is almost smoothed down in the mean chart from the satellite observational results (Whitten et al., 1985) in recent years.

V. HARMONIC ANALYSIS RESULTS FOR OZONE VARIATION OVER THE NH

Figure 4 shows the results of spectrum analysis for EA and NA at different latitudes (30–60°N). The ordinate K refers to the standardized non-dimensional value of energy spectrum for the wave period representing the relative degree of importance for a period. The abscissa T is the periodicity and its unit is year. The main results are: a) the long-term variation of total ozone in the NH has four kinds of chief periods: 2-year, 4-year, 11-year and 22-year variation; b) the relative importance of these periods is different for different regions. In the EA Continent, the first and second chief periods are 11-year cycle and 22-year cycle, while in the NA region, the quasi-biennial variation seems to be a main harmonic component, although in this region the 11-year and 22-year periods can not be neglected; c) as the limitation of sample capacity, etc., the 22-year and 11-year cycles are difficult to resolve in our computation. So, the 22-year period is indefinite and requires more studies based on the much longer ozone observational data. Moreover, the lengths of these two periodicities are just corresponding with the quasi-11-year sunspot cycle and Hale Cycle; d) in the EA region, the QBO of total ozone is more obvious at low latitudes and its importance is decreasing with latitude. In addition, the length of the period for QBO can decrease with latitude (this "frequency-shift effect" exists in NA region, too.). Another interesting finding form Fig. 4 is that the QBO of total ozone in the NA can exist at HL. This is almost consistent with some recent studies, such as the results from satellite data analysis (Tolson, 1980); e) the total ozone variation also has the 4-year periodicity, especially for the NA. At lower latitudes there is ever 7-year cycle. All of these might have something to do with the action of the general circulation over the NA.

According to the synoptic classification system of the circulation process derived from the Antarctic-Arctic Institute of USSR (Zhang et al., 1983 (a).), when the second region (which contains the Pacific and NA) in the meridional circulation patterns, the circulation is defined as type M_1 or others. While the results of auto-correlation analysis and spectrum analysis for general circulation data over the NH during 1900–1968 pointed out that, the oscillation periods for M_1 in second region were 4-year and 7-year (Zhang et al., 1983 (b)). Furthermore, Hasebe(1980) analysed the global ozone data during 1962–1976 by means of optimum interpolation and pointed out that, the ozone variation had 4-year period which had some relations with the 4-year oscillation of temperature and eddy flux of sensible heat at 100 hPa in the region of HL. Therefore, the final analysis also proved that the ozone variation had a profound and underlying connection with the general circulation.

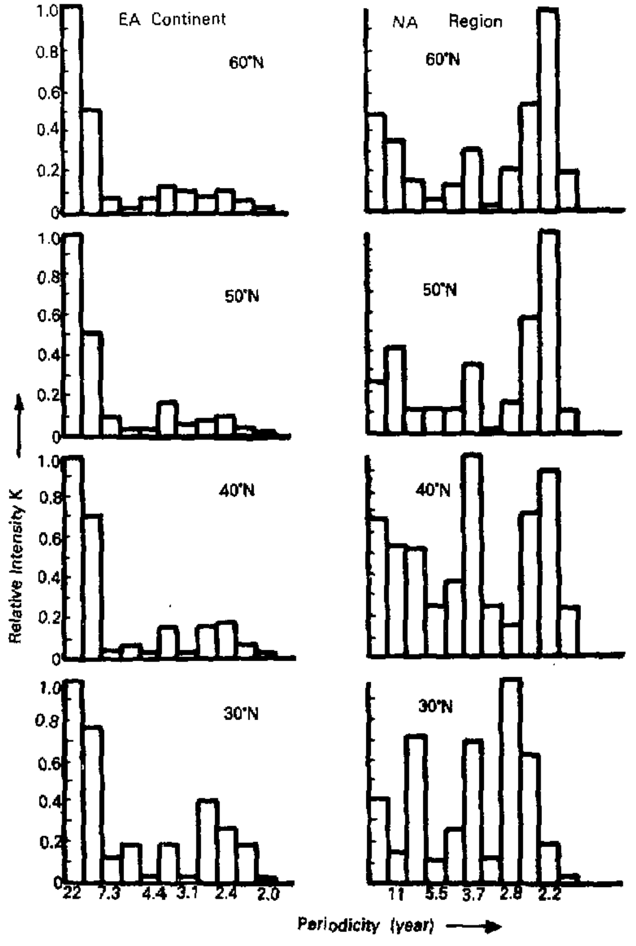

Fig. 4 The results of harmonic analysis for EA and NA at different latitudes.

VI. CONCLUDING REMARKS

1) The long-term mean values of atmospheric ozone at high latitudes in the NH provide a picture of quasi-3-wave distribution which is roughly in agreement with the results

of London et al. The study also indicates that the quasi-3-wave distribution exists in both half years, the winter/spring type and summer/fall type. But the total ozone amount of the former is much larger than that of the latter, and the contribution for this phenomenon is mainly from high latitudes.

2) Since 1970's, the atmospheric ozone variation in the NH has shown a slow decreasing trend to which some shorter waves are added. This trend is more obvious at high latitudes.

3) The results for this paper has supported the viewpoint that there is a positive correlation between the evolution of the terrestrial atmospheric total ozone and the solar cycle. And the total ozone variation lags behind the solar cycle in about one year.

4) Besides the 11-year cycle, the total ozone variation also possesses the periodic variation of QBO, which is more obvious at low latitudes in the EA and NA.

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