Analytical Studies on the Variations of the Antarctic Ozone Layer

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ABSTRACT

The Antarctic ozone hole which was discovered in the mid 1980s has caused much attention from the scientists and politicians throughout the world.

For the formation of the Antarctic ozone hole, most scientists believe that the man-made chemical materials such as CFCs etc. are main cause. On the other hand, the electrochemistry-dynamics theory presented by Wei (Guang Ming Daily Dec. 11 ,1990) two years ago has also caused some attention.

In the paper the data of ozone, solar activity meteorology over Antarctica have been used for statistical analytical studies. Our results present some new evidence to support Wei's theory. However the influence of the human activities can never be slighted.

I. INTRODUCTION

In recent years the ozone depletion, especially the appearance of the ozone hole in the spring over Antarctica, has produced a heightened interest in the biological effect and the climatic effect of enhanced UVB radiation. Farman et al. (1985) reported firstly that the spring (especially October) total ozone at Hally Bay station (75°31′S, 26°44′W),on the coast of Antarctica, showed a progressive decrease amounting to about 50% between 1979 and 1984. The data from TOMS on the Satellite Nimbus-7 subsequently indicated that almost every springtime since 1979 the ozone hole have occurred over the entire Antarctic continent. Its developing process is shown in Fig.1.

The scientists and governments over many countries are extremely concerned with the ozone hole over Antarctica and the total ozone decrease over the globe.If the ozone layer is damaged, recovery of its original state would be very difficult and the consequence would be disastrous for the mankind.

So far the following several viewpoints are used to interpret the formation and the variation trend of the ozone hole over Antarctica. Anthropogenic activity viewpoint thinks that the main cause for the depletion of the total ozone should be the increasing chlorine in the atmosphere which results from the solution of the man-made chemical materials such as chlorofluorocarbons (CFCs etc.) produced by the refrigerant technology, by violet solar radiation. The appearance of the ozone hole might occur if the heterogeneous reactions proceeded rapidly on the surface of polar stratospheric clouds (PSCs) and at very low temperature environment of circumpolar vortices which are present in the Antarctic winter and spring. Atmospheric dynamics viewpoint suggests that after polar night when sunshine appears again over Antarctica in the earlier springtimes, the increasing diabatic heating by the sun makes the air move upward, and carries the air lower abundance of ozone in the troposphere into the stratosphere, resulting in the total ozone depletion. These viewpoints mentioned above have some limitations and the undefinition to explain the formation and the variation trend of the

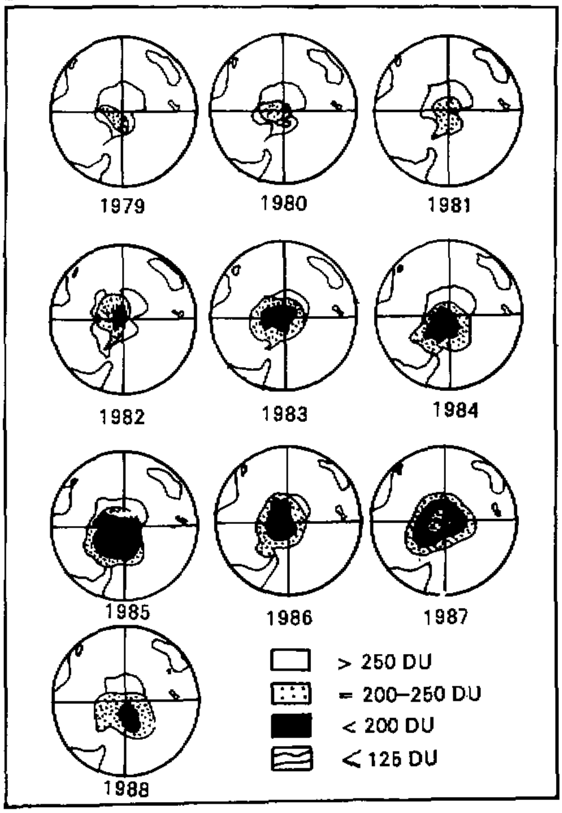

Fig.1. Interannual variations in the Antarctic total ozone amount depletion in October.

ozone hole. Anthropoqenic activity viewpoint can interpret the deepening process on the ozone hole but cannot interpret the shallowing procoss and the narrowing range on it especially the weakening process in 1988. Atmospheric dynamics viewpoint can only explain the natural seasonal phenomenon on the appearance of the ozone hole, but can not explain the deepening process on it year after year in the period 1979–1987. Two years ago Wei (1989, 1990) presented a new viewpoint on the formation of the Antarctic ozone hole and its trend. In his paper the relationships between the solar activities and a great amount of O_3 data have been analysed in more detail. He found that there are "sensitive areas" and "non–sensitive areas" existing in the total ozone responding to the influence of the 11–year solar cycle. Especially, the responses are stronger in the higher latitudes and the winter–spring period than those in the lower latitudes and the summer–autumn period. Accordingly, in addition to the Chapman process, which is the main one, there should be a secondary process for controlling the stratospheric ozone layer, especially in the polar areas. Therefore the basic idea of this theory is that, for the formation of the Antarctic ozone hole, the combinative action of the solar charged particles in the 11–year solar cycle and the Antarctic vortex is the prime cause; while the man–made chemical materials are the second. In essence, this is an electrochemistry–dynamics theory. It is called Wei–theory for short, This theory has made the prediction of the Antarctic ozone hole for the coming years. This prediction was preliminarily supported by the practical situation of the Antarctic ozone hole in the recent three years. Wei–theory is obtained on the basis of the analysis and the deduction using the long–term data of total ozone in the Northern Hemisphere. In this paper the correlation analysis was made in more detail based on the available data on the Antarctic total ozone [at Syowa station (69°00′S, 39°35′E) and South Pole station (89°59′S, 24°48′ W)] the circumpolar vortex and the corresponding solar radio activity etc. These furnish fresh evidence to Wei–theory. These results are the supplement and the development to Wei–theory.

II. THE CORRELATION ANALYSIS BETWEEN THE ANTARCTIC TOTAL OZONE AND THE SOLAR RADIO FLUX

Fig.2a and Fig.2b show mean monthly total ozone amounts at Syowa station for Feb. and Oct., 1966–1989 and at South Pole station for Feb. and Oct., 1962–1989 respectively. From Figs. 2a–2b it is seen that for Oct. the variations of the total ozone over Syowa station and South Pole station have obviously the quasi–11 year cycle. But for Feb. they have not quasi–11 year cycle. In addtion they have also the quasi–biennial oscillation for Oct.

The 10.7 cm solar radio flux (F 10.7 cm) is plotted in Fig.3 (Reinsel, et al 1987) and is generally used as indication of solar cycle activity. From Fig.3 it is seen that in this period they have two quasi–11 year cycles. In 1960s–1970s it is a general solar activity cycle and is a peak solar activity cycle in the 1970s–1980s.

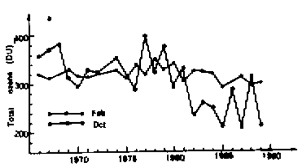

Fig.2a. Mean monthly total ozone amount at Syowa station from 1966–1989. ○ denotes October means ● denotes February means.

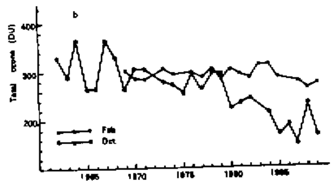

Fig.2b. Mean monthly total ozone amount at South Pole from 1962–1989. ○ denotes October means ● denotes February means.

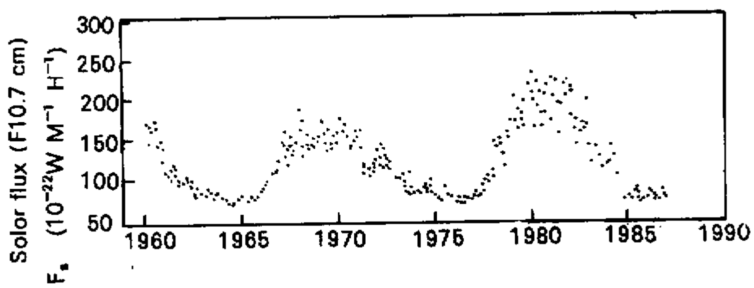

Fig.3. The variations of solar radio flux (F10.7 cm) with time.

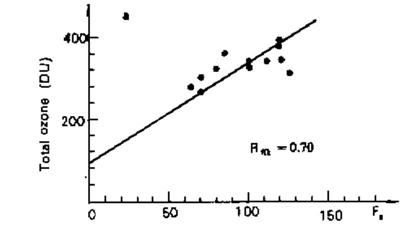

Fig.4a. Correlation between mean monthly total ozone amount and the solar radio flux (F10.7 cm) at Syowa station in October, 1965–1976.

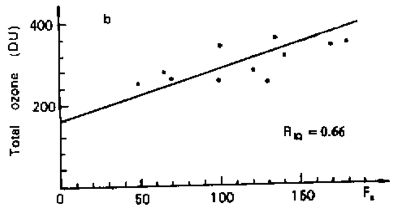

Fig.4b. Correlation between mean monthly total ozone amount and the solar raido flux (F10.7 cm) at Syowa station in October, 1976–1986.

To filter the quasi–biennial oscillation of total ozone variations the running average calculation is used in here. Since the effect of anthropogenic activity on total ozone appeared in later 1970s, we divided the time interval for calculating correlation into two stages, that is 1960s–1970s (before 1976) and 1970s–1980s (after 1976). This is also consistent with a general solar activity period and a peak solar activity period.

Fig.4a shows the correlation between mean monthly total ozone amount and the solar radio flux (F10.7 cm) at Syowa station in October, 1965–1976. The correlation coefficient $R_{f\Omega}$ is 0.70 and the statistic significance is better than 99% confidence level. Shown in Fig.4b is the correlation between them in October, 1976–1986. The correlation coefficient $R_{f\Omega}$ is 0.66 and the statistic significance is close to 99% confidence level. Fig.5a shows the correlation between mean monthly total ozone amount and the solar radio flux (F10.7 cm) at South Pole station in October, 1965–1976. The correlation coefficient $R_{f\Omega}$ is 0.73 and the statistic significance is better than 99% confidence level. Shown in Fig.5b is the correlation between them in October, 1976–1986. The correlation coefficient $R_{f\Omega}$ is 0.68 and the statistic signifi–cance is close to 99% confidence level.

Fig.6a shows the correlation between mean monthly total ozone and the solar radio flux (F10.7 cm) at Syowa station in February, 1965–1986. The correlation coefficient $R_{f\Omega}$ is only

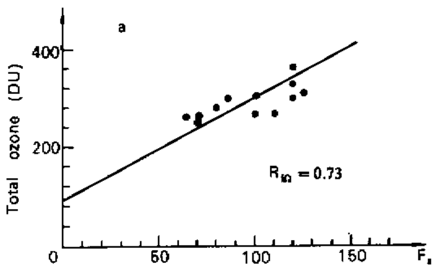

Fig.5a. Correlation between mean monthly total ozone amount and the solar raido flux (F10.7 cm) at South Pole in October, 1965–1976.

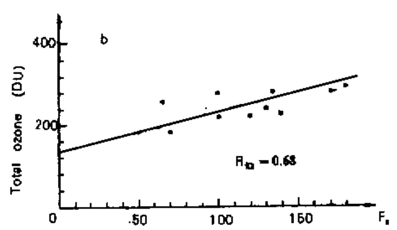

Fig.5b. Correlation between mean monthly total ozone amount and the solar radio flux (F10.7 cm) at South Pole in october, 1976–1986.

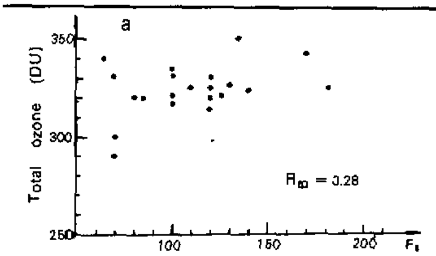

Fig.6a. Correlation between mean monthly total ozone amount and the solar radio flux (F10.7 cm) at Syowa station in February. 1965–1986.

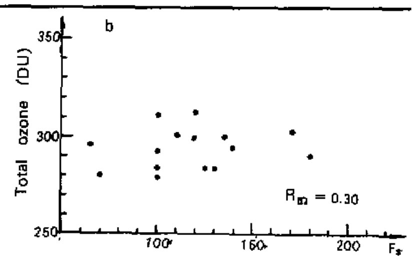

Fig.6b. Correlation between monthly total ozone amount and the solar radio flux (F10.7 cm) at South Pole in February. 1962–1986.

0.28. Fig. 6b shows the correlation between them at South Pole station in February, 1962–1986. The correlation coefficient $R_{/n}$ is only 0.30.

On the basis of the above mentioned analysis it is seen that the appearance and the variation trend of the ozone hole over Antarctica are obviously correlated to the solar radio flux with the quasi–11 year cycle i.e., the characteristics (range, intensity and variation trend) of the ozone hole are basically controlled by the charged particle current with the quasi–11 year period produced by the solar activity. Undoubtedly these furnish fresh evidence to the electrochemistry–dynamics theory on the formation and the variation of the ozone hole over Antarctica, supporting and developing this theory.

III. ADDITIONAL REMARKS: THE CIRCUMPOLAR VORTEX IS THE NECESSARY CONDITION IN THE FORMATION OF THE ANTARCTIC OZONE HOLE

It is well known that the Antarctic continent is the plateau covered with snow and ice throughout the year. It is a strong cold source on the earth in all seasons (Qu, 1990). In winter (Jun. – Aug.) the atmosphere over Antarctica hardly receives the solar radiation and cools by emission of longwave radiation. On the other hand, the activity of planetary wave from the Southern Hemisphere is weak which hardly transports heat momentum and mass from middle latitudes to polar region. The atmosphere is stable and forms a circumpolar vortex. This circumpolar vortex is the strongest until July–August (see Fig.7a–b) and is maintained to mid–spring.

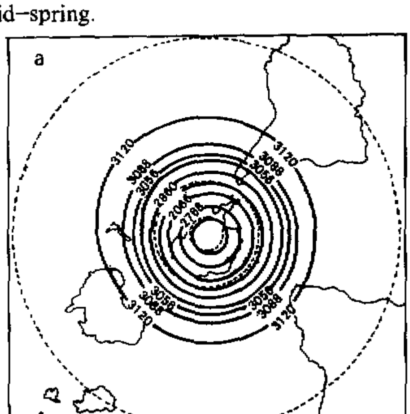

Fig.7a. Geopotential height field (in 10 gpm) for the Southern Hemisphere 10 hPa surface in August.

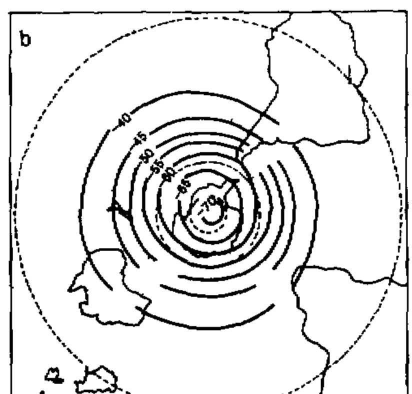

Fig.7b. Temperature field (in°C) for the Southern Hemisphere 10 hPa surface in august.

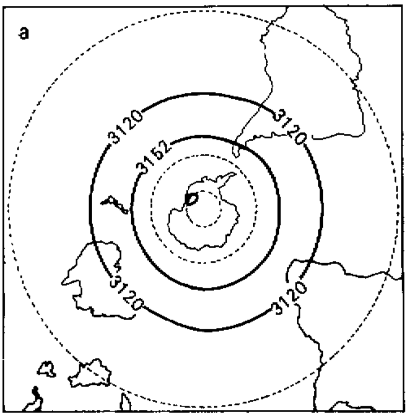

Fig.8a. Geopotential height field (in 10gpm) for the Southern Hemisphere 10 hPa surface in January.

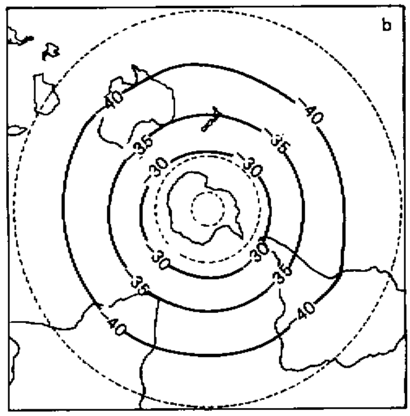

Fig.8b. Temperature field (in°C) for the Southern Hemisphere 10 hPa surface in January.

As the circumpolar vortex exists over Antarctica, on the one hand, it prevents the radial exchange and the ozone from lower latitudes is very difficult to enter the polar region to supplement the ozone. On the other hand, the ozone which was produced by the charged particle in the circumpolar vortex may be preserved. Furthermore the reaction reducing the ozone ($O+O_3 \rightarrow 2O_2$) does not stop at any time in the circumpolar vortex. Its comprehensive effect is that the ozone hole is formed in the circumpolar vortex in October, when the solar activity is in a weaker year, the ozone amount produced by the eletrochemistry process is less and the amount of the total ozone can be depleted, reaching its lower value. When the solar activity is in a stronger year, the ozone amount produced by the electrochemistry process is more and the amount of the total ozone can reach its higher value. Obviously the weakening and deepening of the ozone hole are correlated with the charged particle currert variations with the quasi−11 year by the solar activity.

The circumpolar vortex is broken down by the final warming resulting from the increasing planetary wave activity from the Southern Hemisphere and formed is the anticyclone with warm core (see Figs.8a−8b). Meantime the ozone radial exchange is strengthened, and the midlatitude air with high abundance of ozone flows rapidly into Antarctica, resulting in increase of total ozone and the ozone hole dispersing. At this time, the amount of the total ozone is not correlated with the quasi−11 year cycle by the solar activity (see Section II).

IV. MAIN CONCLUSIONS

(1) On the basis of the total ozone variation at Syowa station and South Pole station in the ozone hole and the solar radio flux (F10.7cm) variation at the same time, the correlation calculation shows: For Syowa station the correlation coefficient $R_{f\Omega}$ is 0.70 in Oct., 1965−1976 and 0.66 in Oct., 1976−1986. Their statistic significances are better than and close to 99% confidence level, respectively. For South Pole station the correlation coefficitnt $R_{f\Omega}$ is 0.73 in Oct., 1965−1976 and 0.68 in Oct., 1976−1986 Their statistic significances are better than and close to 99% confidence level, respectively. But in Feb. 1965−1986, the correlation coefficient $R_{f\Omega}$ is only 0.28 at Syowa station and 0.30 at South Pole station in Feb., 1962−1986. In addition, this paper also discusses that the circumpolar vortex is the necessary condition in the formation of the Antarctic ozone hole. These furnish fresh evidence to Wei−theory and are the supplement and development to it.

(2) The electrochemistry–dynamics theory may satisfactorily predict the future variation trend of the Antarctic ozone hole. Certainly this natural activity theory does not exclude the anthropogenic activity theory on the formation of the Antarctic ozone hole. Comparatively speaking, the natural activity is more important for the formation of the Antarctic ozone hole as compared with the anthropogenic activity. This theory can not only explain the deepening process of the Antarctic ozone hole with satisfaction but also explain the weakening process of it.

(3) To verify this theory in a deep–going, besides that the network for observational ozone is constructed at home, the total ozone and vertical distribution of ozone should be observed in Great Wall station and Zhong Shan station.

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