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Seasonal variation in the vertical distribution of ozone over *Dakshin Gangotri*, Antarctica

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सार — 1987 का दक्षिण गंगोत्री अंटार्टिका का ओजोन परिज्ञापन प्रस्तुत है। अंटार्टिका का दो शिखर रेखाचित्र पर ओजोन का उर्ध्वाधर वितरण का चित्रण एक 200-150 और दूसरा 50 हैक्टापास्कल (एच. पी. ए.) तक हैं। शीतकाल के अंत-वसंत के प्रारंभ में ऊपरी शिखर काफी हद तक कम होता हैं। क्षोम मण्डल का ओजोन कम रहता है और लगभग पूरे वर्षभर स्थिर रहता है।

ABSTRACT. Ozone soundings made from *Dakshin Gangotri*, Antarctica during 1987 are presented. The vertical distribution of ozone over Antarctica is characterised by a double peak profile, one around 200-150 hPa and the other around 50 hPa. During late winter-early spring the upper peak is considerably depleted. Tropospheric ozone remains low and nearly constant throughout the year.

Key words — Antarctic ozone hole, seasonal variation, vertical distribution, tropospheric ozone.

1. Introduction

Ozone, although present only in trace amount, is an important constituent of the atmosphere since it is a strong absorber of the biologically harmful ultraviolet radiation from the sun. It also plays a vital role in the radiation balance of the atmosphere particularly in the stratosphere. Most of the ozone in the atmosphere is concentrated in the middle stratosphere from about 15 to 30 km and acts as a protective shield against the solar ultraviolet radiation. In recent years there is increasing evidence to suggest that the ozone concentration in the atmosphere is decreasing. Though the exact cause of this depletion is still not clearly understood, man-made chemical pollutants are suspected to play an important role in this depletion process. Satellite data collected since 1978 indicate an average global ozone loss of about 5 per cent during the past nine years (Rowland 1987). To compound the matter further, it has been discovered that a substantial decrease (ozone hole) in the amount of ozone occurs over Antarctica during spring time. This is causing worldwide concern to the scientists and public alike, necessitating continuous monitoring of ozone concentration around the globe in general, and over Antarctica, in particular. The first Indian attempt to obtain ozone soundings over Antarctica was made successfully during the second Indian Scientific Expedition to Antactica (Sreedharan *et al*. 1986). However, it was only during the sixth Scientific Expedition in 1986-87 that India commenced a regular ozone observational programme.

2. Sounding programme

The sounding programme during 1986-87 was split into two parts, namely, 'summer' soundings during January-March for inter-comparison of data with other Antarctic stations *Novolazarevskaya* (Soviet Union) and *Showa* (Japan), and 'spring' soundings from August to November for studying the ozone depletion and subsequent recovery. A few soundings were also taken in the intervening period from April to July and later in December. Thus, a total of 30 ozone soundings were made at *Dakshin Gangotri* using the Indian ozonesonde.

3. Results

The ozone soundings are listed in Table 1 and the ozone profiles are depicted in Fig. 1. These profiles have not been adjusted for total ozone since there were no simultaneous total ozone observations in the area. This aspect should be kept in mind while interpreting the data presented in this paper. In Fig. 1, the vertical line immediately to the left of the base of the profile denotes the zero partial pressure of ozone. Successive vertical lines to the right of the zero line indicate increasing ozone partial pressure in units of 50 μhPa.

The results of 'summer' soundings have been published by Faruqui *et al*. (1988). Vertical distribution of ozone over *Dakshin Gangotri* is characterised by a double peaked profile, both peaks occuring above the tropopause which is around 300 hPa. Within the troposphere the concentration of ozone is low (20-40μ hPa) and nearly constant throughout the year, the variation with height is also insignificant. However, in the stratosphere the concentration of ozone shows marked changes with height and with season. Above the tropopause level the concentration of ozone increases rapidly upto the level of about 200 to 150 hPa (first peak) reaching a value of 50-60 μhPa. Further up, the concentration either remains constant or decreases slightly up to 100 hPa. Thereafter, there is a sharp and marked increase in the

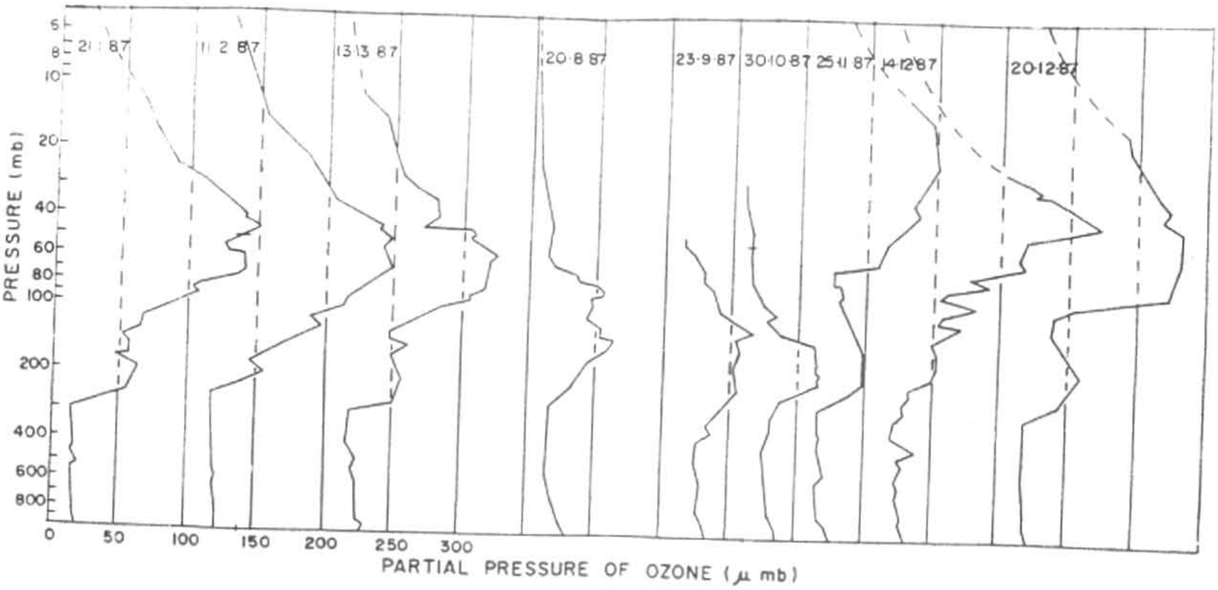

Fig. 1. Ozone soundings from *Dakshin Gangotri* (1987)

TABLE 1

Ozonesonde data of *Dakshin Gangotri* for 1987

Date of ascent (1987)	Terminate pressure (hPa)	Ozone max pressure (hPa)	Ozone partial pressure (μhPa)	Tropopause		Surface ozone (μhPa)
				Height (hPa)	Temp. (°C)	
17 January	13.0	67.6	129.1	—	—	Signal missing
21 January	11.2	47.0	149.1	300	—53.0	20.0
28 January	16.5	67.0	131.6	278	—50.3	22.9
11 February	6.8	67.0	148.1	245	—57.0	22.8
13 March	12.2	59.0	125.5	295	—53.6	29.5
18 March	16.3	115.0 (I); 73.4(II)	129.6(I); 121.5(II)	310	—53.1	25.2
5 August	45.0	153.0	88.8	260	—68.5	—
20 August	8.0	137.0(I); 85.8(II)	62.7(I); 56.3(II)	—	—	28.9
19 September	63.5	155.0	60.9	203	—59.2	36.0
23 September	47.0	125.0	66.0	330	—63.7	33.0
9 October	55.5	138.0	51.2	330	—58.0	29.6
30 October	29.5	210.0	67.1	335	—51.8	36.8
6 November	51.0	128.0	46.9	—	—	23.9
25 November	11.0	22.0	102.3	270	—58.4	28.4
4 December	23.0	39.0	174.4	210	—59.0	32.2
20 December	8.0	41.0	135.0	288	—52.5	26.0

concentration (second peak), the value reaching a maximum partial pressure of 130-150 μ hPa at the level of 70 to 40 hPa corresponding to a height of 18-21 km. The concentration then decreases continuously. Sreedharan *et al.* (1986) have also reported similar observations.

3.1. *Seasonal variation*

Based on the annual temperature variation at *Dakshin Gangotri*, it can be said that there are two main seasons in Antarctica, namely, a relatively short and mild summer covering November, December and January months and a long and severe winter from April to August. The transition periods between these two seasons namely, February-March and September-October are short and constitute autumn and spring respectively. High ozone soundings have been obtained between second half of November and March, reaching up to 8 hPa level. Whereas, during the period from August to mid-November except one sounding on 20 August, balloons burst prematurely between 60 hPa and 30 hPa levels. In the absence of data above this level, it is not possible to comment on the vertical distribution of ozone above 50 hPa during these months. However, seasonal changes in the vertical profile up to about 50 hPa is clearly discernible from the soundings. From the data presented in Table 1 and the ozone profiles depicted in Fig. 1, it can be seen that the lower stratospheric ozone content over Antarctica is maximum during late summer and early autumn (Jan and Feb months) while it is minimum during late winter and early spring—the lowest values occurring in October. During summer, the maximum concentration of 130-150 μhPa, occurs at a height of 18-21 km, *i.e.*, between 70 hPa and 40 hPa. The decrease in the ozone content starts towards the end of February or beginning of March and continues up to October. Between August and mid-November the decline in the ozone amount in the 150 hPa to 50 hPa layer as compared to the summer values is evident a d is substantial. Ozone sounding taken on 20 August 1987 which reached 8 hPa level shows the first peak of (60μ hPa) at 150 hPa as with the soundings of previous months. But the ozone concentration further aloft showed negligible increase and then decreased continuously; rapidly in a thin layer (from 80 hPa to 60 hPa) and gradually thereafter. Ozone profiles of 23 September 1987 and 30 October 1987 also show similar trend. Ozone values during August-September-October months in the 50 hPa to 20 hPa layer have ranged from 10 μ hPa to 15μ hPa. Thus, in 1987, which is considered as the year in which the Antarctic ozone hole was most dramatically manifested both by its pole-centred symmetrical pattern (Krueger *et al.* 1989) and depth of depletion, ozone losses over *Dakshin Gangotri* reached 90% at 20 km height during October fiom the peak values in January. United States scientists have also reported that total ozone losses in the depleted region above Antarctica reached 50% in October 1987 with losses in the 15-20 km altitude range soaring to 95% (Anonymous 1988). Ozonesonde measurements at Showa (69°00′ S, 39°35′ E —Japanese station) have also showed that ozone depletion is most striking in the altitudinal region of 10-25km, during spring (Kondoh *et al.* 1987). It, therefore, appears that the first peak remains unaffected though it gets lifted slightly while the magnitude of the second which is the main peak is greatly decreased during late winter and early spring.

The ozone concentration starts increasing by about middle of November and attains highest value by the beginning of January. It is interesting to note that the depletion in ozone amount occurs gradually over a long time but its recovery takes place rapidly in 4-6 weeks.

4. Discussion

The vertical and temporal variations in ozone concentration over *Dakshin Gangotri* present contrasting features between the troposphere and the stratosphere in respect of this element. The tropospheric ozone content is low and nearly constant throughout the year. Also, the variation with height is insignificant. In contrast to this the stratospheric ozone concentration shows marked changes with height and with season. London (1985) in his discussion on the observed distribution of atmospheric ozone and its variations mentions that observed ozone concentration is nearly constant in the troposphere but increases with height in the lower stratophere to a maximum that depends on latitude and season. Above the level of maximum, the concentration decreases almost exponentially with height through the middle and upper stratosphere and lower mesosphere. The results obtained by the authors are in conformity with the earlier findings.

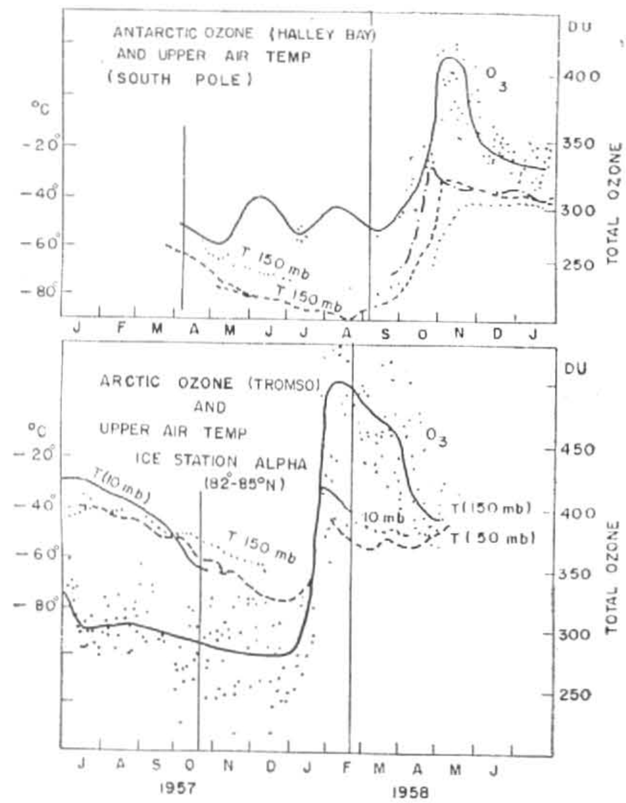

Fig. 2. Ozone and stratospheric temperature over the Antarctic and Arctic (Ramanathan 1964)

The low content of tropospheric ozone and its relative constancy with seasons can be attributed to the near absence of its photochemical production and destruction in the troposphere. The source and sink region of ozone being the stratosphere, the magnitudes of ozone transported from the stratosphere into the troposphere and that destroyed at the ground are very small.

Substantial decrease in the stratospheric ozone levels over Antarctica during winter and spring seasons after a summer time high is well established. Even in the Arctic region the seasonal variation in ozone amount is similar. As early as Ramanathan (1964) from a comparative study of ozone observations taken during the International Geophysical Year, 1957-58 in both the hemispheres (Fig. 2) has shown that both the polar regions register a seasonal loss in ozone. Seasonal (winter) decrease in ozone to the tune of 6% over Arosa, Switzerland has been demonstrated (Rowland 1987). The explanation for the seasonal loss appears to lie in the ozone chemistry. Ozone formation essentially requires sunlight (ultraviolet radiation) which decreases rapidly both in duration and intensity once the 24-hour sunlight period is over. It stops completely during the continuous dark period in the peak winter. When the sun appears again new synthesis begins and the ozone level marginally increases. Transport of ozone rich midlatitude air through the stratospheric circulation also occurs around the same time since the polar vortex dissipates with the onset of summer Hence, there is a sudden increase in ozone concentration. The sharp rise in ozone values occur earlier (by about 2 months) in the Arctic than in the Antarctic (Fig. 2) possibly because the Antarctic polar vortex remains stronger, preventing meriodonial exchange of airmass for a longer duration. In fact, in the southern hemisphere the stratospheric circulation generally goes only as far as about 60° S latitude for most of the year as against the stratospheric air circulating all the way to the north pole in the northern hemisphere. Hence, over the Antarctic, the ozone level peaks at about 380 Dobson units while it reaches about 450 Dobson units over the Arctic.

The recent discovery of a 'hole' in the ozone layer over Antarctica in the early spring is causing lot of concern not because the ozone amount decreases from its peak value in summer months, since this is a seasonal feature as explained earlier, but because the extent of depletion has increased in recent years. For example, at the British Antarctic station, Halley Bay, almost 40 per cent less ozone was recorded in 1985 than was routinely observed 20 years earlier (Rowland 1987). A second reason for concern is the sudden deepening of the 'hole' at a time (September-October) when actually the ozone concentration should start increasing in view of the reappearance of sunlight as can be seen in Fig. 2. This means that a fundamental change in the pattern of seasonal variation in ozone amount appears to have occurred between 1957-1958 and 1985. This accelerated depletion is now believed by most workers to be related to the presence of chemical pollutants such as chloroflurocarbons (CFC's). The mechanisms of ozone destruction by the CFC's have been explained in detail by several authors (Rowland 1987 and Stolarski 1988). Infact aircraft expeditions in 1986 and 1987 have shown conclusively that chlorine chemistry is the primary cause of the ozone hole (Solomon and Schoeberl 1988). It would appear that these mechanisms are operating in the Antarctic atmosphere.

5. Conclusion

Vertical distribution of ozone over Antarctica is characterised by a double peak profile, both of which occur in the stratosphere. The tropospheric ozone is low and nearly constant throughout the year. While the lower peak of ozone (200-150 hPa) remains unaffected, the upper peak at 50 hPa is drastically thinned out in the late winter-early spring (September-October) period.

The seasonal variation in the vertical distribution of ozone over Antarctica shows a summer time high around 50 hPa, starts decreasing in autumn, stabilizes at a certain low value in winter, then at the end of winter and the beginning of spring dips steeply and finally rises sharply in late spring eventually reaching peak level in summer.

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