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OZONE OBSERVATIONS AT SYOWA STATION FROM FEBRUARY 1987 TO JANUARY 1988

Susumu KANETO[1*], Akira YAMAMOTO[1**], Hiroyuki OGIHARA[1***], Hidetoshi SUGAWARA[1****] and Takashi YAMANOUCHI[2]

[1]*Japan Meteorological Agency, Antarctic Office, 3–4, Otemachi 1-chome, Chiyoda-ku, Tokyo 100*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Procedures and results of ozone observations at Syowa Station, East Antarctica, during the period from February 1987 to January 1988 are reported. The annual change of total ozone observed by a Dobson spectrophotometer shows remarkable depression in early October. The depression rate was about 50% of the normal value. The vertical distribution of ozone by chemical ozone sonde revealed that the total ozone depression results mainly from ozone decrease in the lower stratosphere.

1. Introduction

At Syowa Station (69°00′S, 39°35′E), observations of total ozone were started in 1961 and those of vertical distribution in 1966. The results of each year have already been reported by each Japanese Antarctic Research Expedition wintering meteorological team as data reports called "Antarctic Meteorological Data" published by the Japan Meteorological Agency (JMA). These data have also been reported to the WODC (World Ozone Data Center, Atmospheric Environment Service, Canada). Recently, the "Ozone Hole" phenomenon in the Antarctic spring has been found by CHUBACHI (1984), FARMAN *et al.* (1985) and STOLARSKI *et al.* (1986).

In order to clarify the "Ozone Hole" phenomenon, extensive observations of ozone were carried out, namely, total ozone observations including moonlight observations in the Antarctic winter and ozone sondes.

2. Observations

2.1. Total ozone

A Dobson spectrophotometer was used to observe total ozone. Some checks were done through the wintering period, with acceptable results.

At a high latitude ozone observatory, total ozone observation using sunlight becomes erroneous or impossible in winter because of low solar elevation angle or no

Present affiliation: * Sapporo District Meteorological Observatory, JMA.
** Observations Division, JMA.
*** Aerological Observatory, JMA.
**** Wakkanai Local Meteorological Observatory, JMA.

Table 1. Total ozone observations from February 1987 to January 1988.

Year Month	1987 2	3	4	5	6	7	8	9	10	11	12	1988 1
				Number of days or nights of observation								
Sun AD	27	28	15	—	—	—	3	27	30	30	31	31
Sun CD	—	—	6	—	—	—	11	22	20	19	1	—
Moon	—	5	4	14	12	12	13	10	6	2	—	—
				Total ozone data in m atm-cm								
Mean	311	302	312	262	290	284	266	224	204	255	320	306
Maximum	349	333	342	297	318	301	292	277	305	403	368	327
Minimum	281	267	275	226	266	267	237	174	153	195	220	276

sun light. We used three methods to obtain continuous data including winter: the first is the normal method using AD pair wavelengths on direct sun or zenith sky, the second is CD pair on direct sun to extend sunlight observation period and the third is AD pair on focused moon to obtain data in sun-less wintertime.

Data limitations and some comparisons are shown in Appendix. The differences of sun CD pair and moon AD pair from sun AD pair observations are about 1% and 5%, respectively. Table 1 shows the monthly number of total ozone observations, and monthly mean, maximum and minimum values from representative daily data.

2.2. *Vertical distribution of ozone*

Thirty-one ozone sondes of electro-chemical type (KI solution, platinum and carbon electrode) were launched by rubber balloon and vertical distributions of ozone were measured except for 2 erroneous flights. The ozone sonde results were calibrated by multiplying by the Dobson ratio. The Dobson ratio was calculated from sonde total ozone and Dobson total ozone. The sonde total ozone was determined by direct observation from the surface to about 30 km and the residual ozone on the assumption that the mixing ratios of ozone above that level are constant. Observational error of the ozone sonde can be checked using the Dobson ratio and residual ozone. Table 2 shows the date, Dobson total, Dobson ratio and balloon burst height

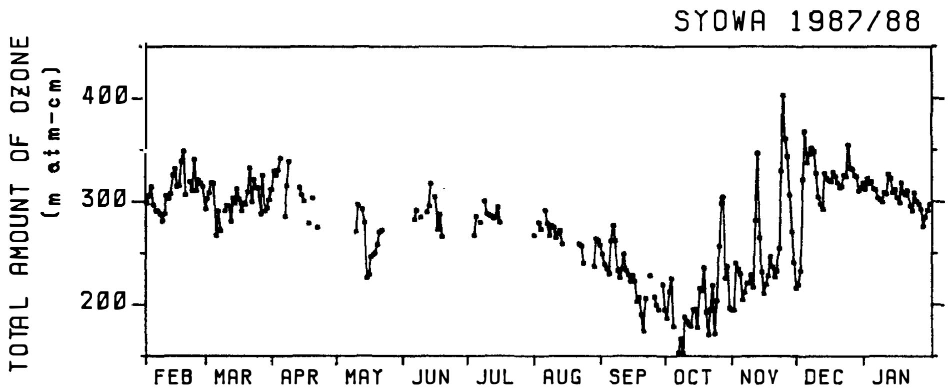
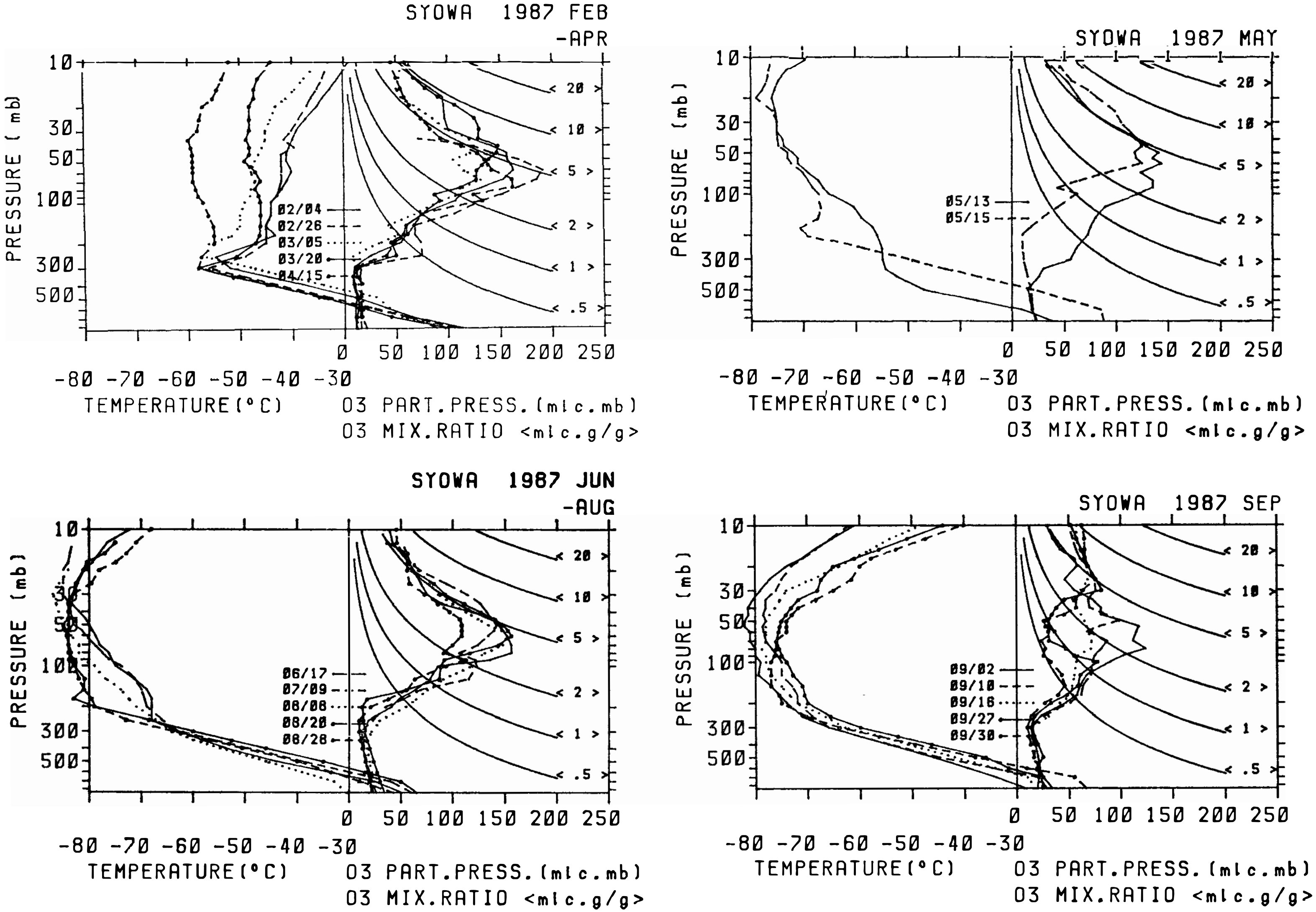


Fig. 1. Total ozone by Dobson spectrophotometer from February 1987 to January 1988.

Table 2. Ozone vertical distribution observations from February 1987 to January 1988.

Year Month	Ozone sonde Date (Total ozone, Dobson ratio, BB pressure)	Short Umkehr method Date (Total ozone)		
1987 2	04PM (303, 1.14, 8.3)			
	26PM (313, 1.30, 38.6*)			
3	05PM (264, 0.92, 8.2)			
	20PM (311, 0.90, 6.6)			
4	15AM (301, 0.88, 5.8)			
5	13AM (286, 0.94, 7.8)			
	15PM (233, 0.94, 7.5)			
6	12AM (294, ** , 6.9)			
	17AM (275, 0.89, 6.5)			
7	09PM (286, 0.87, 12.1)			
8	08PM (277, 0.97, 16.4)			
	20PM (259, 1.16, 11.5*)			
	28PM (237, 0.82, 9.1)			
9	02PM (233, 0.97, 8.3)	18PM (204)		
	10AM (237, 0.92, 8.4)	19AM (190)		
	16AM (225, 0.95, 5.9)	20PM (177)		
	27AM (199, 1.01, 7.3)	30AM (193)		
	30AM (196, 0.97, 5.6)			
10	07AM (167, 1.02, 8.0)	01AM (189)	15PM (180)	
	10AM (189, 0.96, 7.6)	07PM (167)	31PM (195)	
	15AM (182, 1.17, 28.0)	08AM (160)		
	22PM (211, 0.91, 5.5)	08PM (158)		
	28PM (226, 1.23, 4.9)	12PM (184)		
11	02PM (243, 0.84, 4.3)	02PM (243)	19AM (238)	
	06AM (212, ** , 5.4)	03AM (235)	19PM (224)	
	11PM (337, 0.92, 4.4)	06PM (213)	29AM (250)	
	16PM (222, 0.93, 5.2)	12PM (313)	29PM (228)	
	25PM (362, 1.07, 11.4*)	13AM (256)		
12	02PM (239, 1.05, 6.2)	01PM (221)	02PM (253)	
	16AM (313, 1.17, 10.3)	02AM (229)		
1988 1	20PM (312, 1.09, 5.6)	11AM (310)	20PM (311)	31AM (295)
		12PM (324)	21AM (307)	31PM (297)
		19PM (320)	29PM (288)	
		20AM (307)	30PM (295)	

Total ozone in m atm-cm.
Dobson ratio = Dobson total/Sonde total.
BB pressure denotes balloon burst pressure in mb.
* Analysis was stopped at this pressure because of erroneous data.
** Electronic ozone reaction current is abnormal.


SYOWA 1987 FEB -APR
02/04
02/26
03/05
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SYOWA 1987 SEP
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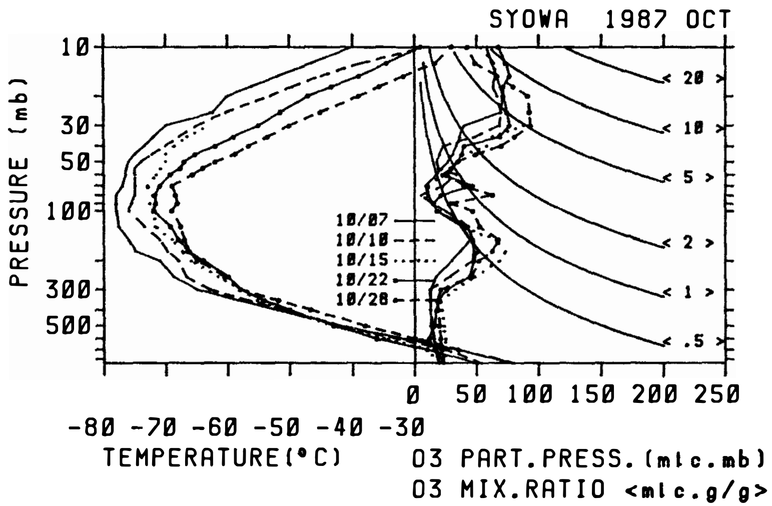

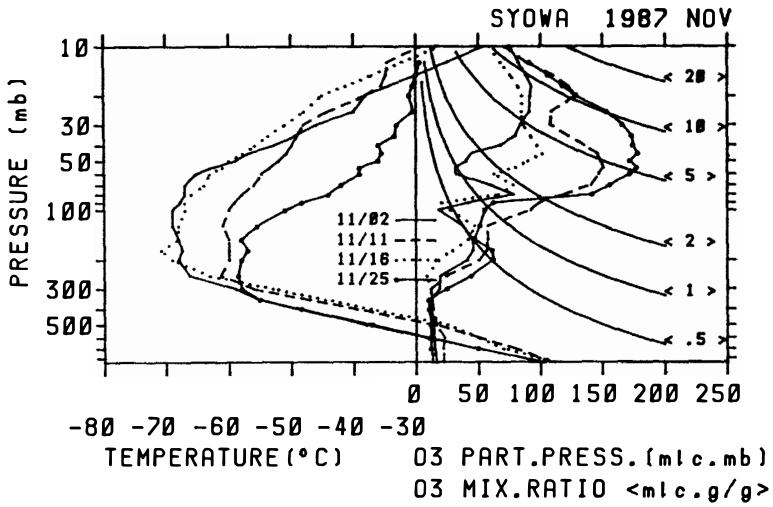

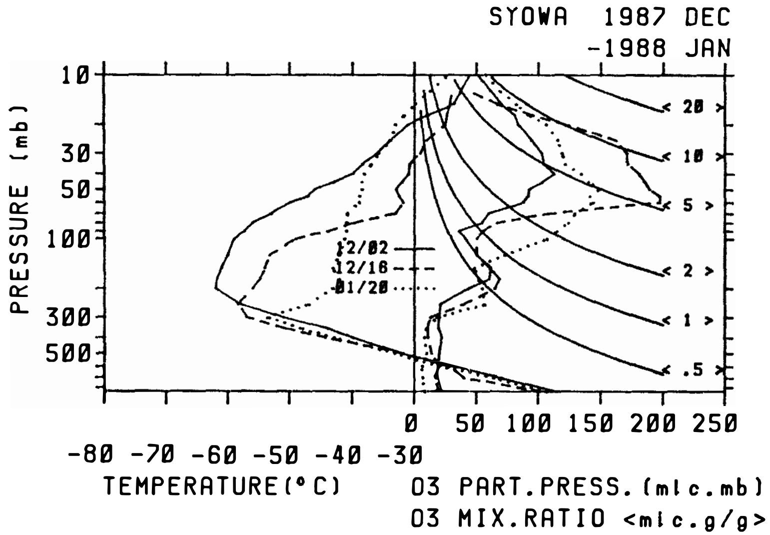

Fig. 2. Ozone sonde results from February 1987 to January 1988.

of each observation. From Table 2, the average Dobson ratio is 1.00 and 2/3 of the observations are within 1.0 ± 0.1. These results agree with those from Japanese sonde reported by TIAO *et al.* (1986). Most of the sondes rose to over 20 mb (25 km); 2/3 of the observations reached 10 mb (30 km). At 10 mb the residual ozone amount is about 1/5 of the total ozone.

On the other hand, by using a spectrophotometer, we can estimate the vertical distribution of ozone by what is called "short Umkehr" observations. However, its vertical resolution is about 5 km and the method has a limitation of observing period because the observation is done while the sun elevation angle is 1 to 10 degrees and the zenith sky must be clear throughout the observation. Thirty-three series of observations were done from September 1987 to January 1988. Some data of the period from September to December, when the vertical distribution of ozone is different from normal, are not so good compared with the sonde soundings (refer Appendix). Table 2 includes the date and Dobson total of each short Umkehr observation.

3. Results and Discussion

Figure 1 shows the annual change of total ozone using daily representative data from February 1987 to January 1988. For February through April, the total amount of ozone maintained the value of about 310 m atm-cm. From April to July the level fell to 280 m atm-cm. During these periods, small fluctuations of total ozone were observed, especially in the middle of May. In August the decreasing tendency was accelerated and in early October the lowest value of 153 m atm-cm was recorded. This is the minimum value recorded at Syowa Station from the start of ozone observation in 1961, about 50% of the normal value between 1961–1980 given by JAPAN METEOROLOGICAL AGENCY (1984). From the end of October to early December, total ozone fluctuated between 200 and 400 m atm-cm levels. Similar fluctuations of total ozone were observed at Syowa Station previously when the "Ozone Hole" did not exist (JAPAN METEOROLOGICAL AGENCY, 1984). In mid-December it returned to the 300 m atm-cm level.

Figure 2 shows the vertical profile of ozone partial pressure and temperature observed by ozone sonde. From February to August, ozone partial pressure profiles remained in a one-peak pattern. In September, the peak value decreased untile the peak disappeared. IWASAKA (1986) reported on the descending motion of the Antarctic stratospheric aerosol layer in winter of 1983 but in September and October, it seems to ascend. From Fig. 2, the ozone-poor layer in September seems to subside from the 27 th to the 30 th. In October, subsidence is seen at the upper edge of the layer but a small peak appears in the lower half. In 1983 the lowest value of total ozone in October was about 220 m atm-cm; the value was not so small as in 1987. In November and December, according to the large fluctuations of total ozone seen in Fig. 1, the vertical profiles of ozone partial pressure varied in the lower stratosphere. In January, the profile again became unimodal.

Figure 3 shows layer mean ozone partial pressure from ozone sonde observations. The layer thickness is about 4 km in winter and 5 km in summer. Layers 0–1 (0–9

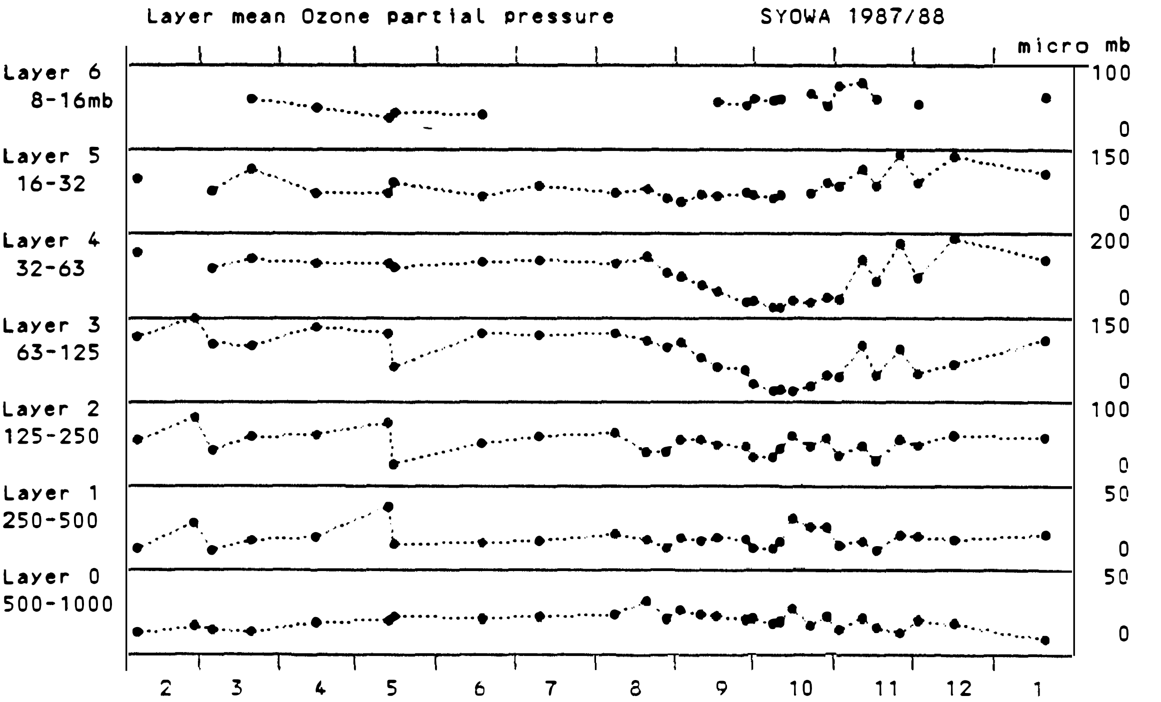

Fig. 3. Layer mean ozone partial pressure by ozone sonde from February 1987 to January 1988.

km) are in the troposphere and layers 3–6 (14–32 km) in the lower stratosphere. Layer 2 (9–14 km) spans the upper troposphere and lower stratosphere. In layer 0 (0–5 km), an ozone partial pressure maximum appears in the austral winter. This agrees with the surface ozone observation by CHUBACHI (1985). In layers 1 and 2 (5–14 km), ozone partial pressure is almost constant but in March and May large fluctuations are seen. In layers 3 and 4 (14–23 km), ozone partial pressure is constant from February to August except for March and May fluctuations in layer 3 (14–18 km). It decreased from the end of August, reaching 1/5 of the summer level in mid-October. But in layers 5 and 6 (23–32 km), ozone partial pressure was constant from February to October. Fluctuations are seen in November in all layers above layer 3 (14–32 km) corresponding to the total ozone fluctuations in Fig. 1.

CHUBACHI and KONDOH (1986) have reported the relation between total ozone and stratospheric temperature at Syowa Station by using monthly mean data of 15 years. From September to March, the correlations are positive; the relations in other months were not shown because of data shortage. Figure 4 shows the relation between total ozone and stratospheric 30 mb temperature by ozone sondes on a daily basis from February 1987 through January 1988. In Fig. 4, the relation can be separated into three categories. From February to July the relation is positive and linear except for March 5 and May 15. From August to September the relation turns negative. From October to January the relation again becomes positive. The daily data from February 1987 to January 1988 do not always agree with the monthly mean result.

To consider the seasonal change of total ozone, the tropopause pressure (*i. e.* stratospheric thickness) is one of the most important elements. At the mid-latitudes,

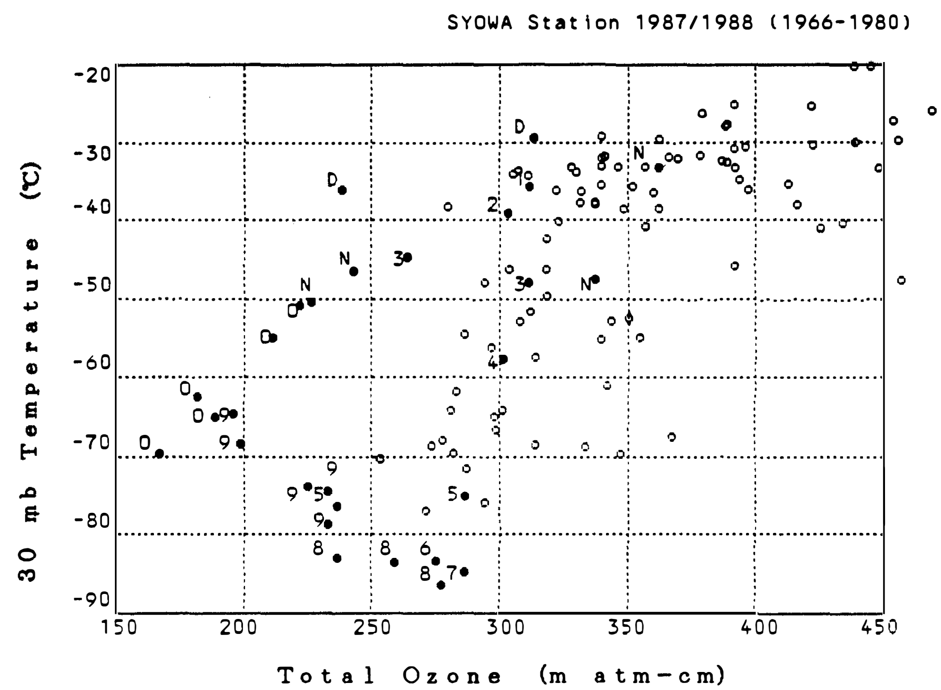

Fig. 4. Total ozone and 30 mb temperature relation. Data are designated by the month of 1987 or 1988 (1: January 1988, 2: February 1987, . . . O: October, N: November, D: December 1987). Other data in 1966–1980 are only plotted by open circles.

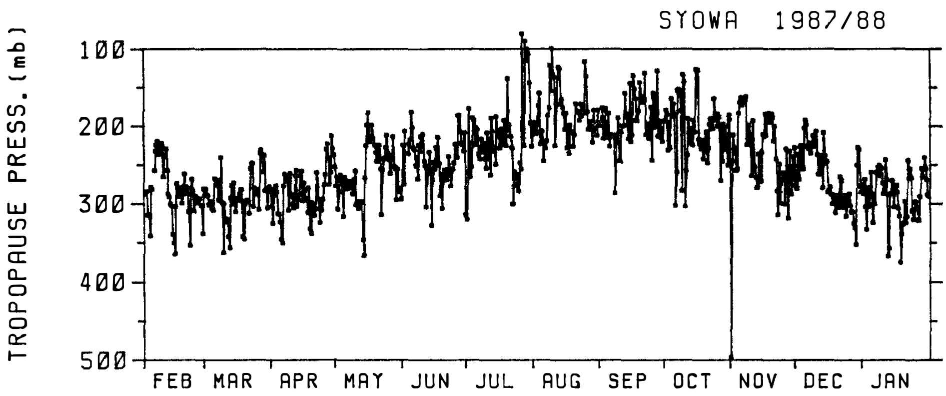

Fig. 5. Tropopause pressure by routine radiosonde from February 1987 to January 1988.

in winter the polar tropopause exists at about 300 mb, while in summer the tropical tropopause does at about 100 mb. In winter the photochemical production of ozone becomes small and the dynamical transport becomes important for total ozone change because ozone lifetime is considered to be very long (nearly 1 year in the 300 to 10 mb layer). Thus, in winter, the stratosphere can store much ozone that is brought from the equatorial region by large scale stratospheric circulation. Actually, in the mid-latitudes, a total ozone maximum appears at the end of winter (*e.g.*, IWASAKI and KANETO, 1984).

In the polar region, the tropopauses are polar throughout the year. Figure 5 shows the tropopause pressure observed twice daily by routine radiosondes at Syowa

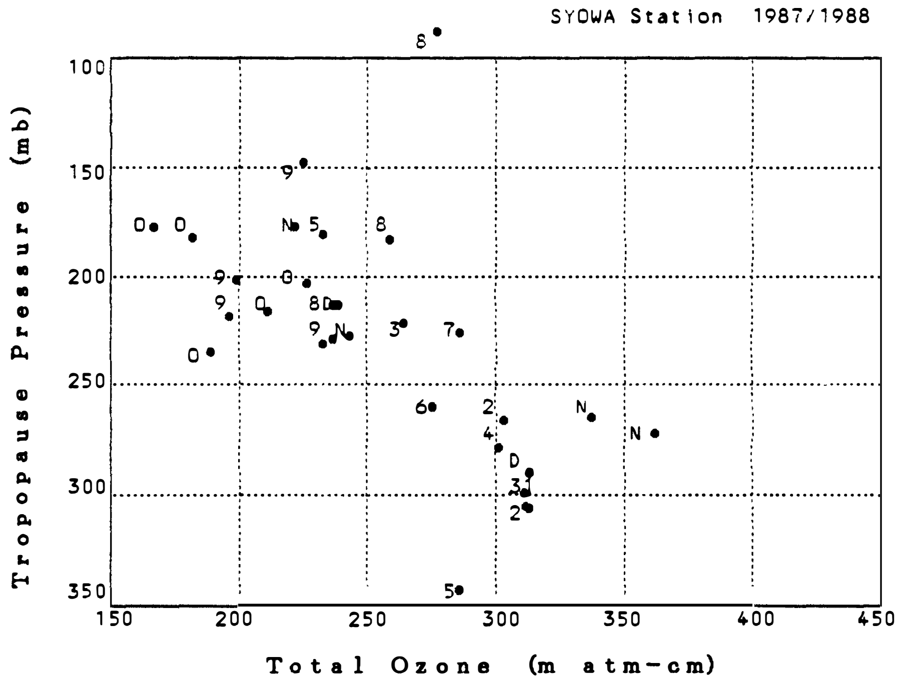

Fig. 6. Total ozone and tropopause pressure relation from February 1987 to January 1988.

Station from February 1987 to January 1988. The definition of the tropopause here is the operational one determined by the WORLD METEOROLOGICAL ORGANIZATION (1983), and is not always adequate for the polar region, especially in winter, when the stratosphere becomes cool and the boundary of the troposphere is not clear. But here, we use it as a first order estimation. The seasonal change is small but in the Antarctic summer the tropopause pressure is about 300 mb and in winter it decreases to about 200 mb. Namely, the stratosphere is thicker in summer than in winter in contrast with the mid-latitudes. The tendency is consistent with the appearance of total ozone maximum in summer as seen in Fig. 1. These results agree with the analysis by SCHUBERT and MUNTEANU (1988).

Figure 6 shows the relation between total ozone and tropopause pressure by ozone sonde. The correlation is positive except for the period from August to October when the relation is not clear. The positive correlation between total ozone and tropopause pressure is the same in the mid-latitudes, but at Syowa Station there is no change of tropopause type.

In Fig. 1, short period fluctuations of total ozone are seen, especially in May and November. In May, from ozone sonde results in Fig. 2, the tropopause pressure changes from 350 mb on May 13 to 180 mb on May 15 in correspondence to the total ozone change from 286 to 233 m atm-cm. At the same time, the tropospheric temperature changed greatly although the stratospheric temperature remained almost unchanged. This tropospheric temperature variation may be the result of tropospheric air mass alternation because the air mass cannot transform so much in two days. In November, total ozone fluctuations correspond to those of tropopause pressure as seen in Fig. 6. But the variation of ozone vertical profiles in November is different from that of May as seen in Fig. 2. In November, the tropospheric temperature fluctuation is not so large as in May but stratospheric temperature changed greatly in the 30–200 mb layer. In that period, the polar night jet in the upper stratosphere becomes weak and the meander of the jet becomes large. The stratospheric temperature fluctuations in November may be mainly caused by stratospheric air mass alternation resulting from the change of seasonal conditions.

4. Summary

At Syowa Station, East Antarctica, extensive ozone observations were carried out from February 1987 to January 1988 in order to clarify the "Ozone Hole" phenomenon.

The annual change of total amount of ozone measured by a Dobson spectrophotometer shows a minimum in early October. The value is about 50% of the monthly normal.

Vertical distributions of ozone measured by electro-chemical ozone sondes revealed that the total ozone depression in August to October occurred mainly as a result of the ozone decrease in the restricted layer of the lower stratosphere between 14 and 23 km. In this period, the relations between total ozone and stratospheric temperature, and between that and tropopause pressure, were different from other periods.

It is shown that there were short period fluctuations of total ozone in May and November of 1987. Those were discussed mainly in terms of the dynamical air mass alternations of troposphere and stratosphere.

Acknowledgments

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Appendix

A.1. Limit of total ozone observation

In Operations Handbook—Ozone Observations (KOMHYR, 1980), the limit of total ozone observation using AD pair wavelengths is $1.15<\mu<3.0$ and CD pair is $2.4<\mu<3.5$, where μ is the ratio of optical path length through the ozone layer to the vertical path length. We tried to observe at high μ and determine a limiting value of μ at which useful data can be obtained. Figure A shows our results of these observations: (a) direct sun AD pair, (b) direct sun CD pair, and (c) focused moon AD pair. Ordinarily there exists a critical μ limit where the observed total ozone value abruptly decreases. The limits decided from Figure A are shown in Table A.

A.2. Accuracy of observed total ozone value

In these three types of total ozone observation in Table A, direct sun AD pair observation is most reliable, so we simultaneously observed direct sun AD pairs and

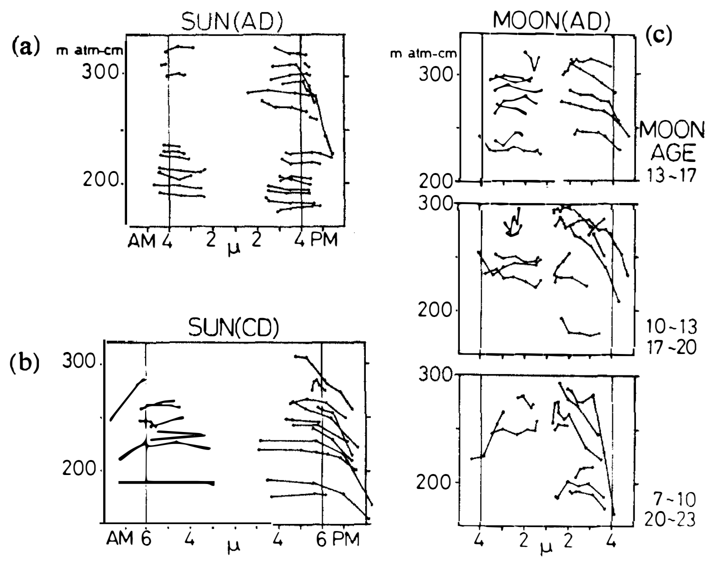

Fig. A. Total ozone change with μ. (a) Sequences of direct sun AD pair wavelengths observations. (b) Same as (a) but for direct sun CD pair. (c) Same as (a) but for focused moon AD pair.

Table A. Limits of total ozone observations.

Observation type	Upper limit of μ
Direct sun or zenith sky AD	4.0
Direct sun CD	6.0
Focused moon AD	3.0~4.0*

* In focused moon observations, the upper limit of μ changes with the moon age.

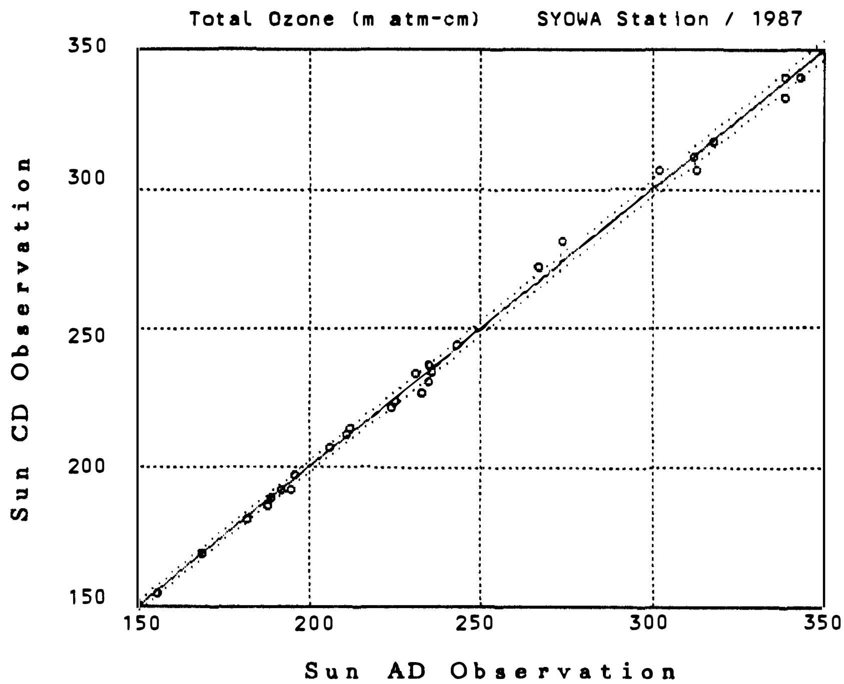

Fig. B. Comparisons of total ozone with sun AD pair and sun CD pair. Dotted lines denote 1% difference of sun CD from sun AD value.

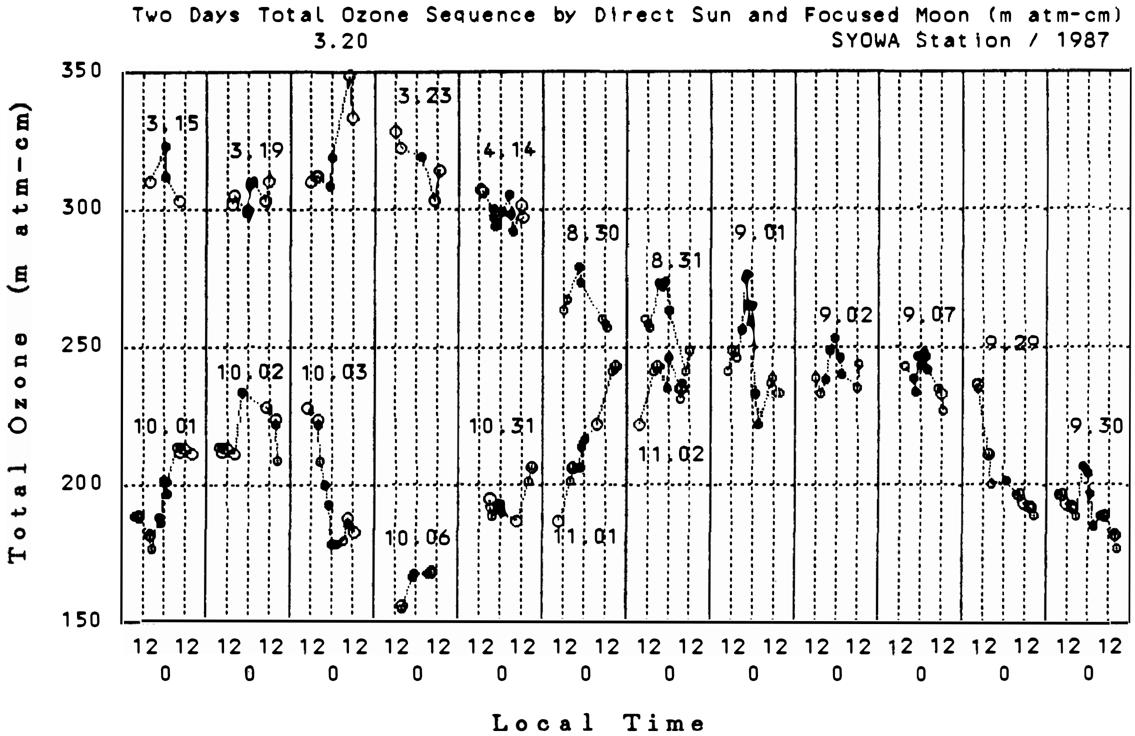

Fig. C. Two-day sequences of total ozone by direct sun and focused moon observations. Sun AD: large open circle, sun CD: small open circle and moon: closed circle. The first date is designated by month and day.

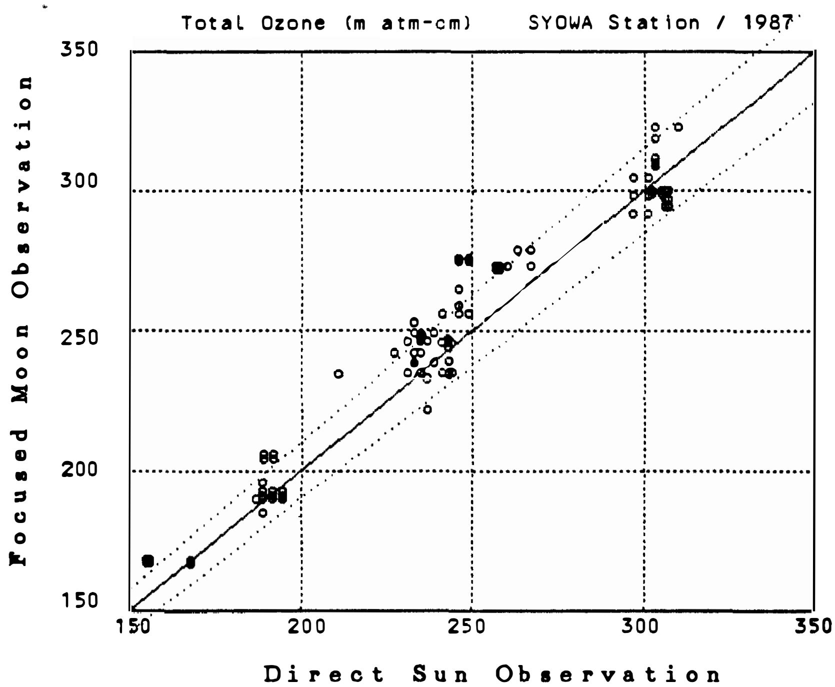

Fig. D. Comparisons of total ozone measured by direct sun and focused moon observations having time lapse of less than 9 hours. Dotted lines denote 5% difference of focused moon from direct sun value.

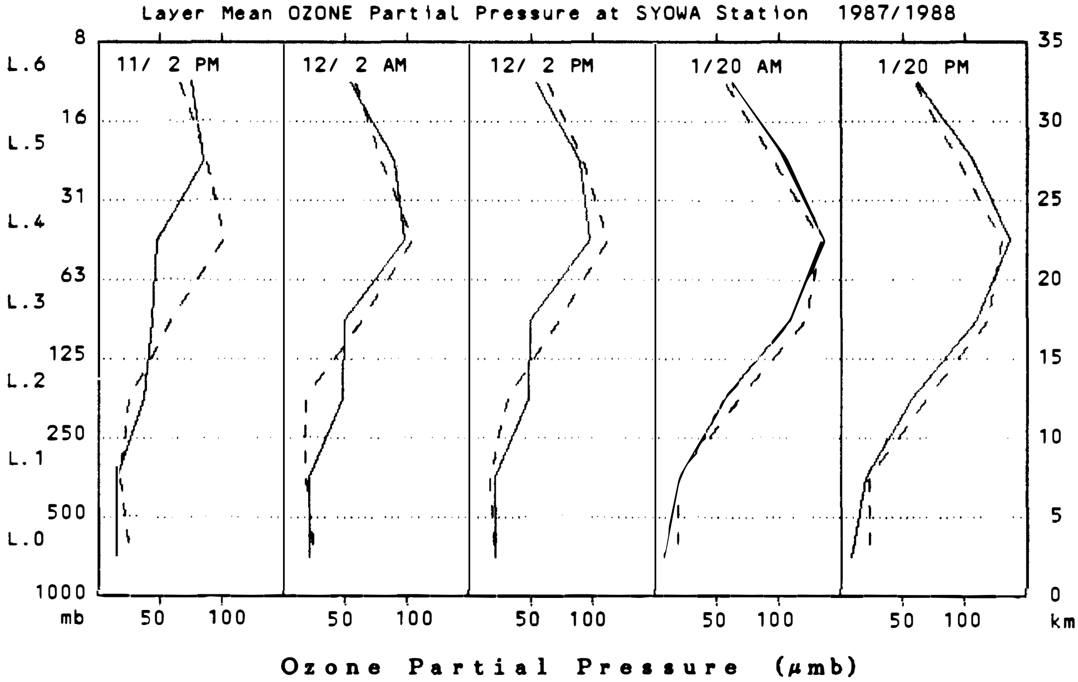

Fig. E. Layer mean ozone partial pressure by ozone sonde (solid line) and by Dobson spectrophotometer of short Umkehr method (broken line).

CD pairs. Figure B shows the result that the differences of CD pairs from AD pairs are about 1% of standard AD values.

It is not possible to carry out simultaneous observation using direct sun and focused moon. Figure C shows sequences of those observations in two days. In general, the data are smoothly connected, but in August and September total ozone by focused moon is always larger than that by direct sun just before and after the observation by moon. Figure D shows the relation of sun and moon data that are selected such that the time lapse of those observations is less than 9 hours. The differences between focused moon observations and direct sun observations are about 5% of the sun data, but near 250 m atm-cm the difference reaches +10% because of August and September data. While observational conditions were constant through the period, it is not clear whether these results give the seasonal characteristics of diurnal variation of total ozone or not. These results agree with the results reported by ISHIDA *et al.* (1971) and by CHUBACHI and KAJIWARA (1988).

A.3. Comparison of sonde sounding and short Umkehr method

Raw data of short Umkehr observations were sent to WODC. We received the analyzed data except in the period when the total ozone is less than 200 m atm-cm.

Comparisons of sonde sounding and short Umkehr method observed on the same day are shown in Fig. E. The large differences are seen at layer 4 of November 2 PM and Layer 2 of December 2 AM. These differences show the difficulties of short Umkehr method analysis when the vertical ozone profile is different from the computational standard.

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