by various workers[6-8]. Remote sensing measurements made by satellite sensor SAM II starting in late 1978 show that more stratospheric clouds exist in both winter polar regions than had been realized earlier by visual sitings[8]. The PSCs are widely believed to be formed by condensation of nitric acid/water at extremely cold temperature in the winter polar vortex. In the ozone sounding of 28.9.1991, the lowest temperature reached was −80° C at 20 km as against −36° C at 20 km on 14.12.1991. It can be seen that this extreme cooling of the lower stratosphere is conducive to the development of the PSCs. It is, therefore, quite likely that the PSCs are partly responsible for the observed ozone depletion. However, the properties of the PSCs and the heterogeneous chemical processes involved in the ozone depletion are yet to be clearly understood.

The part played by atmospheric dynamics in the formation of the ozone hole has also to be looked into. It is clear that the strong circumpolar vortex during winter will prevent the poleward transport of ozone from lower latitudes. The only way atmospheric dynamics could play a part in the observed stratospheric depletion of ozone is by the upwelling of ozone-depleted tropospheric air into the lower stratosphere. On the contrary, available evidence suggests only weak but persistent downward motion in the lower stratosphere in September and October.

Conclusion

At the height of the ozone depletion over Dakshin Gangotri, Antarctica, during the spring of 1991, the major part of the depletion is centred around 20 km. The 'ozone hole' extends from 14 to 25 km and the ozone partial pressure within the hole drops to as low as 12 μmb. While ClO carried to the Antarctic stratosphere from the middle latitudes may account for nearly half of the depletion of ozone, the polar stratospheric clouds (PSCs) and the atmospheric dynamics are presumed to account for the rest of the depletion. There are considerable gaps in our understanding of the factors that lead to the formation and refilling of the 'ozone hole' and intensive research efforts are required before a clear picture of the 'ozone hole' and its implications could emerge.

1. Rowland, F. S. and Molina, M. J., *Rev. Geophys. Space Phys.*, 1975, **13**, 1.
2. Farman, J. C., Gardiner, B. G. and Shanklin, J. D., *Nature*, 1985, **315**, 207.
3. Sreedharan, C. R., Chopra, A. N. and Sharma, A. K., *Indian J. Radio Space Phys.*, 1986, **15**, 159.
4. Sreedharan, C. R., Sudhakar Rao, G. and Gulhane, P. M., *Indian J. Radio Space Phys.*, 1989, **18**, 188.
5. Molina, M. J., Tso, T. L., Molina, L. T. and Wang, F. C. Y., *Science*, 1987, **238**, 1253.
6. Solomon, S., Garcia, R. R., Rowland, F. S. and Wuebbles, D. J., *Nature*, 1986, **321**, 755.
7. Mc Elroy, M. B., Salawitch, R. J., Wofsy, S. C. and Logan J. A., *Nature*, 1986, **321**, 759.
8. Mc Cormick, M. P. and Trepte, C. R., *Geophys. Res. Lett.*, 1986, **13**, 1276.

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The first detection of Antarctic ozone hole

Shigeru Chubachi

Introduction

Since 1984 when ozone depletion in Antarctica was first reported[1], many scientists have been focussing on this interesting phenomenon. In this article, I present the way the ozone hole was discovered. I would also like to emphasize the importance of continuous geophysical observations.

Ozone hole today

I introduce the present state of the Antarctic ozone hole using the data from Syowa Station (69° S, 40° E). In Figure 1, year-to-year variations of the monthly means of total ozone amount at Syowa Station in January (*a*), September (*b*), and October (*c*) are shown. Figures 1 *b* and *c* clearly depict the Antarctic ozone hole increase. These figures show that the decrease in total ozone at Syowa Station started around 1982. Antarctic ozone decrease is not limited to spring but is also observed in summer.

Similar characteristics were obtained from the observations at other stations (Halley Bay, South Pole)[2,3] and from TOMS satellite data. The TOMS data derived from Nimbus 7 satellite measurements[4] shows that ozone characteristics found at Syowa Station were common to the Antarctic region.

Ozone layer over Antarctica

Now, I mention the history of ozone observations in the Antarctic. Ozone observations in Antarctica began in

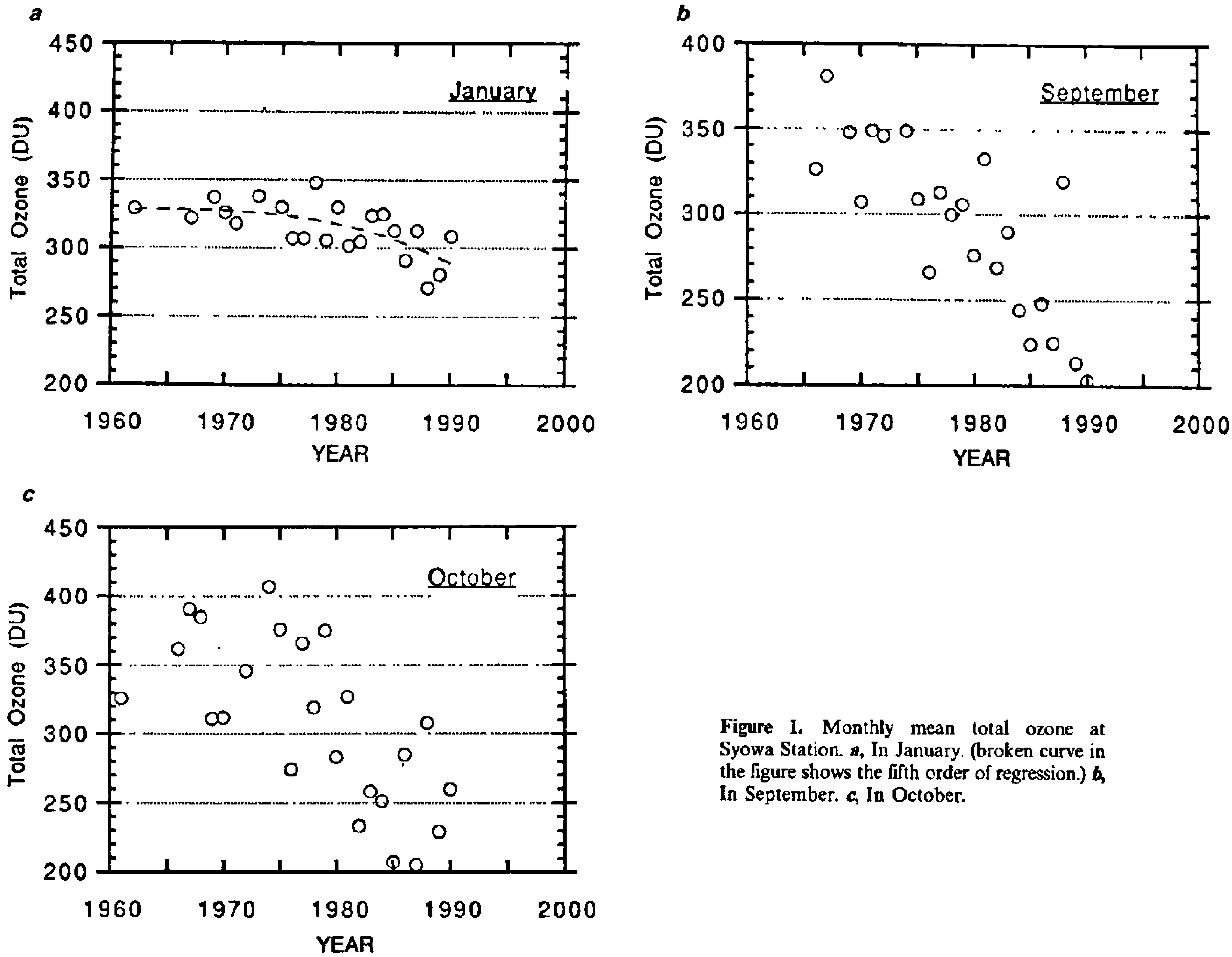

Figure 1. Monthly mean total ozone at Syowa Station. *a*, In January. (broken curve in the figure shows the fifth order of regression.) *b*, In September. *c*, In October.

1957 (International Geophysical Year) at five stations (Little America, Halley Bay, Dumont D'urville, Faraday, and Macquarie Island). However Little America and Dumont D'urville stopped ozone observations around 1960. The ozone observations at Syowa Station started in 1961 (ref. 5), Syowa Station was closed from 1962 to 1965. Then, Syowa station was reopened in 1966, and ozone observations were restarted[6]. Ozone observations have been carried out almost continuously since 1966. There are four other places in Antarctica where ozone observations have been carried out over such a long period. These are Halley Bay with the period of observations (1957–1991), South pole (1961–1991), Faraday (1957–1991) and Macquarie Island (1957–1991). Antarctic ozone hole was discovered as the result of the continuous ozone observations at these stations.

Attending Japan Antarctic Research Expedition (JARE)

In 1981, I visited Syowa Station as a member of the 23rd JARE. My mission was to carry out extensive ozone observations at Syowa Station. On November 14, we left Japan for Syowa Station. After two months we landed on Antarctica. My first task was to establish the seasonal changes of ozone at Syowa Station. The seasonal variations of total ozone were known except for the months from April through August[7]. There was almost no ozone data in these months, because of the difficulties of measuring ozone (low sun angle, severe weather).

I decided to solve these problems using moonlight ozone observations because standard sunlight observations are not possible to carry out during Antarctic winter due to lack of solar radiation. Lunar ozone observations had been already carried out in winter in 1969 at Syowa Station[8], but the number of observation days was small. We carried out the simultaneous observations of total ozone and its vertical profile through the year. We started the ozone observations in February. The observations of ozone were carried out in close cooperation with the meteorological team. Sunlight total ozone observations were carried out in February and in March. Moonlight ones were carried out from April through August. Lunar Dobson ozone measurements were valid if moon was larger than half and its elevation angle was larger than 20 degrees[9]. Due to these requirements, the number of days with moonlight observations was reduced by half. Moreover, we needed good weather, because we had to see the moon clearly to focus the moonlight into the instrument. These lunar Dobson observations were continued till September 4. The ordinary sunlight total ozone observations began that day.

Encounter with the ozone hole

It was during the night of 3–4 in September 1982 that surface temperature fell abruptly. Several persons were saying in the meteorological building at Syowa Station that a new record of the minimum temperature would be observed during that night. I checked the thermometer with them and around 5 o'clock we confirmed the new record (−45.7°C). This is the minimum record until 1991 September. At noon September 4, an abrupt ozone decrease was observed. I remember clearly the following discussion with R. Kajiwara (a member of the meteorological team), which took place on September 4 during dinner. He asked me 'Total ozone observed today is very small. What happened?' I answered 'Perhaps there is some trouble with the Dobson spectrophotometer. We have to start the check procedure of the Dobson spectrophotometer.' The check procedure detected no trouble with the instrument. When I look back to it now, this was the starting point of the Antarctic ozone hole search.

This value of total ozone on September 4 was very small compared to the one on the night just before and such a low ozone value had never been reported yet in that season at Syowa Station. We checked almost everything: instrument, observation time, and calculation procedure. At last, we concluded that there was no mistake in calculation and no trouble with the instrument. There was no way to solve that situation. We decided to continue the observations. Similar low ozone values were observed for fifty days (Figure 2), and recovery to normal situation was observed in October 28 with the sudden warming in the stratosphere. Until the end of January, observations were carried out satisfactorily.

Ozone Symposium at Greece in 1984

After coming back to Japan, we checked all the records of the observations at Syowa Station. The ozone values for that period were still low. No errors were found in the data, and we compared them to the ones observed at Syowa. The data from October to November showed similar values as the ones from Syowa. At this point, we were able to confirm that our observations were correct. Then, we decided to publish the data and to prepare a report.

We presented a paper at a domestic symposium of Polar Meteorology and Glaciology held at National Institute of Polar Research (December 1983). The paper of our results of ozone observations at Syowa Station (written in English) was published later in National Institute of Polar Research[10]. A similar paper was presented at the Quadrennial Ozone Symposium held in Greece (September 1984)[10] and at the MAP (Middle Atmosphere Program) symposium in Kyoto (Novermber 1984). However, there was no response to our paper. However this was not the end but the start of the story.

Meeting with B. Gardiner

In August 1985, during the IUGG meeting held at Hawaii, I had a chance to talk with Gardinar of the British Antarctic Survey. We talked about the state of the Base, and the method of the ozone observations. Then he asked me 'By the way, do you think there is something curious in Antarctic ozone?' I remembered my ozone data and answered 'Yes, it is decreasing rapidly.' Then he said 'I think so too. Only you and I know about the Antarctic ozone decrease.' He was the second author of the paper reporting the ozone decrease in Antarctica from Halley Bay ozone data[2].

Snowmass Meeting

In the period August–October 1987 'Airborne Antarctic Ozone Experiment' was carried out by National Aeronautics

Ozonesonde observation at Syowa Station.

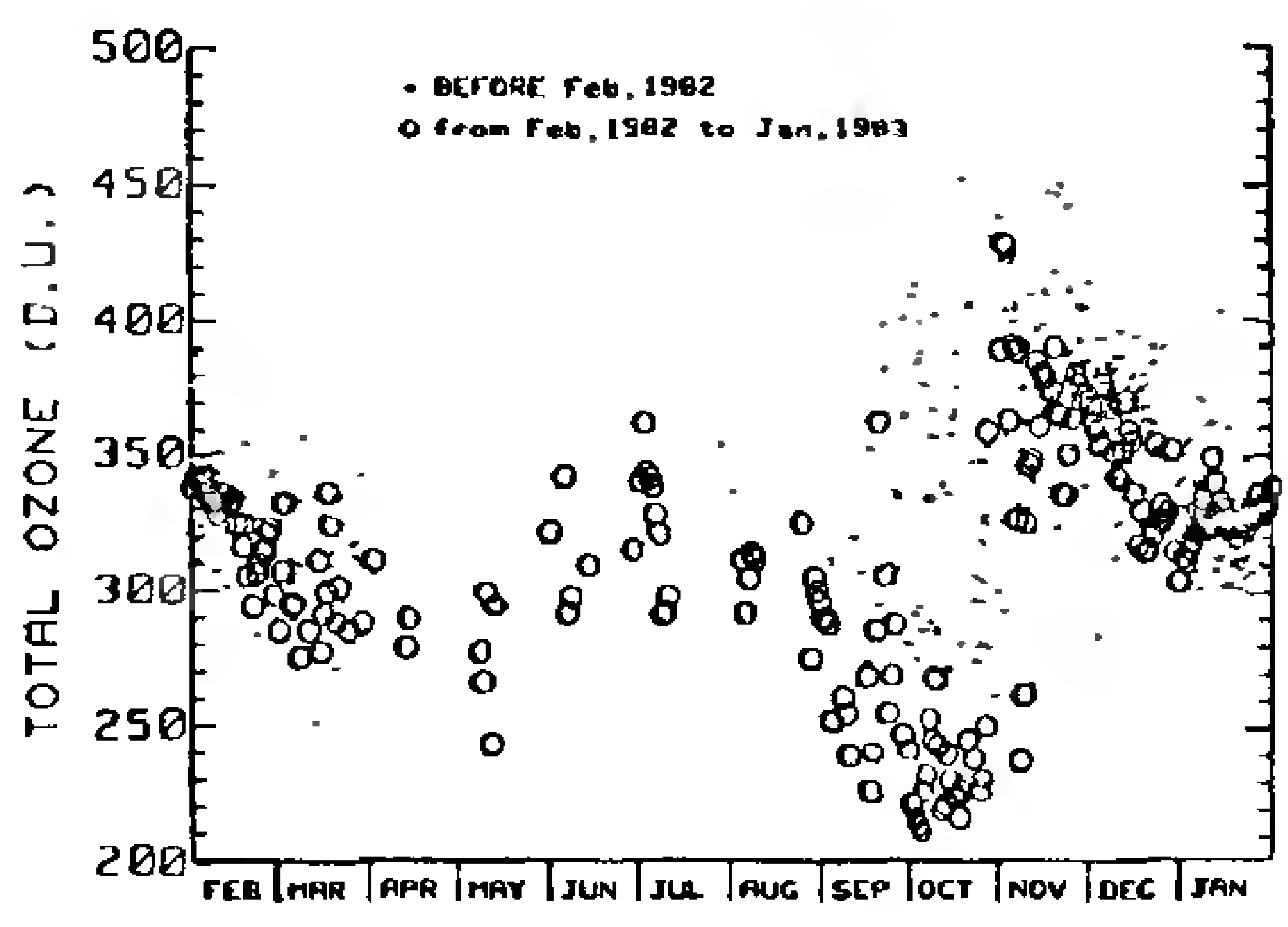

Figure 2. The daily representative of the total ozone amounts from February 1982 to January 1983 are shown superimposed on the ones from 1961 to January 1982. This figure shows that total ozone amounts from September to October in 1982 are lower than those measured during the same months in the former years.

and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA). The results of these observations were released at the workshop held in August 1988 at Snowmass in Colorado, USA. Upto this workshop, there were two hypotheses of the cause of the Antarctic ozone hole the first one being the chemical theory and the second one the dynamical theory. However, after this meeting, the chemical theory prevailed over the dynamical one.

Antarctic ozone research perspectives

Now it is clear that we have to monitor Antarctic ozone continually. It seems necessary to carry out not only ozone observations, but also monitoring of the other chemicals (especially CFCs). These will be very useful in explaining ozone variability in Antarctica. (It should be taken into account that the theory explaining the ozone hole needs to prove correct by comparing observed Antarctic ozone with the predicted one from this theory.) We think that this comparison will give new impetus to the study of Antarctic ozone changes. I hope that the new India Antarctic Station, Dakshin Gangotri (70° S, 12° E), will soon contribute to whole global efforts to monitor Antarctic ozone.

1. Chubachi, S., *Mem. Nat. Inst. Polar Res.*, Spec. Issue, 1984, **34**, 13–19
2. Farman, J. C., Gardiner, B. G. and Shanklin, J. D., *Nature*, 1985, **315**, 207–219.
3. Komhyr, W. D., Grass, R. D. and Leonard, R. K., *Geophys. Res. Lett.*, 1986, **13**, 1248–1251.
4. Stolarski, R S., Krueger, A. J., Schoeberl, M R., Peters, R. D, Newman, P. A. and Alpert, J C., *Nature*, 1986, **322**, 808–811.
5. Seino, Z., Saegusa, T., Suzuki, N. and Sakaguchi, T., General report of Meteorological Section in J.A R E.V., 1963, 1960–1962.
6. Shimizu, M., *JARE Sci. Rep., Ser. B.* (*Meteorol*), 1969, vol. 1, p. 38.
7. Sakai, S., *Nankyoku Shiryo* (*Antarctic Record*), 1979, **67**, 115–123.
8. Ishida, K., Suzuki, T. and Sakai, S., *Nankyoku Shiryo* (*Antarctic Record*), 1971, **39**, 32–38.
9. Chubachi, S., *Geophys. Res. Lett.*, 1988, **15**, 905–906.
10. Chubachi, S., in *Proceedings of the Quadrennial Ozone Symposium, Halkidiki, Greece* (eds. Zerefors, C. S. and Chazi, A.), Reidel Publishing Co., 1985.

Shigeru Chubachi is at the Meteorological Research Institute, 1–1 Nagamine, Tsukuba, Ibaraki, 305, Japan.