THE OZONE HOLE AS OBSERVED AT THE BRAZILIAN ANTARCTIC STATION IN 1992

V.W.J.H. Kirchhoff, F.R. da Silva, and R.A. Barreira
Instituto Nacional de Pesquisas Espaciais, INPE, C.P. 515
12201-970 São José dos Campos-SP, Brasil

ABSTRACT

Stratospheric ozone measurements were made at the Brazilian Antarctic station Ferraz, near the Antarctic Peninsula, during 1992 using ECC ozone sondes launched on balloons. The technique has been used extensively before in the Brazilian tropics, for measurements of tropospheric and stratospheric ozone. This work is part of the Brazilian CIRM PROANTAR Program, with logistic support of the Brazilian Air Force and Navy. The measurement period extended from March to November 1992. A total of 43 ozonesondes were sucessfully launched. The ozone layer over Ferraz was observed with and without ozone depletions. Ozone is observed to be depleted at several heights, not only near the peak of the layer (22 km), but also at levels in the lower stratosphere, where depletion may be quite severe. The Antarctic ozone hole was observed on several occasions during August, September, and October, when the partial pressure of ozone was reduced by about 50% near the layer peak, in general, but being much larger in some cases. The hole condition was in general quite variable. In the lower stratosphere, around 15 km, intense ozone reductions were observed on several soundings, when the ozone partial pressure practically vanished.

INTRODUCTION

This paper describes ozone measurements at the Brazilian Antarctic Station Comandante Ferraz, with emphasis on the formation of the 1992 ozone hole.

The ozone hole is essentially an Antarctic phenomenon, as described by Stolarski (1988), for example. The role of conventional chemistry and polar stratospheric clouds on heterogeneous chemistry producing ozone depletions is described in Hamill and Toon (1991). Low latitude ozone perturbations may occur as well, as consequences of the main Antarctic ozone depletion (Thompson, 1991; Prather and Jaffe, 1990; Prather et al., 1990; Kirchhoff et al., 1994) and therefore low latitude ozone monitoring (Sahai et al., 1987; Kane, 1991) remains an important complement to Antarctic observations. The recent trends study of Stolarski et al.(1992) shows that there is a consistent negative trend in low latitude ozone, but the equatorial region is still unaffected.

The Brazilian Antarctic station was created in 1982-83, with the organization of the Brazilian

Antarctic Program, known as the CIRM PROANTAR Program, with logistic support of the Brazilian Air Force and Navy. The objective of this program is to carry out scientific projects to study the Antarctic region. Research with an interest in Atmospheric Chemistry started in 1984, with ozone concentration measurements near the ground (Kirchhoff and Pereira, 1986). Further measurements of atmospheric constituents have used the same technique as described, for example, in Kirchhoff and Rasmussen (1990).

The Brazilian Antarctic station is located on King George Island (62.1° S, 58.4° W), which is part of the South Shetland island agglomerate near the Antarctic Peninsula, and separated from it by the Bransfield straight, as shown in **Fig. 1**. The Chilean station Frei, also on King George Island, offers the facility of an aircraft landing strip, where Hercules C-130 can land under good weather conditions. Generally, at least two steps are necessary to reach the Antarctic station from Brazil. The usual starting airport is Rio de Janeiro, with the first landing at Pelotas, Brazil, and the second in Punta Arenas, Chile.

The 1992 ozone soundings obtained at the Brazilian Antarctic station are the result of lengthy planning and preparations, which started at least three years before. During the summer period of 1991, January and February, in situ training and preparation for the winter period took place at the station. The 1992 period of measurements started in March and lasted until November. During the measurement period at the Antarctic station, ozone measurements were also made at Punta Arenas, Chile, where a Brewer spectrophotometer was installed in June of 1992 (Kirchhoff et al., 1993).

MEASUREMENT TECHNIQUE

The measurement technique used in Antarctica to observe the vertical ozone profile is the same used before in the study of other environments, having been used extensively in the tropics, for example by Kirchhoff et al., (1991) and elsewhere by Oltmans and Komhyr (1976, 1986). The ozonesonde is of the ECC (Electrochemical Concentration Cell) type, described by Komhyr (1969), and Komhyr and Harris (1971). It uses iodine and iodide redox cells, where two electrodes made of platinum are immersed in neutral buffered iodide solution of different concentrations in the cathode and anode. This allows the appearance of a small voltage difference between the electrodes, which creates a small current flow when air containing ozone flows into the cathode. This current is directly proportional to the partial pressure of ozone. Balloons of 2000 grams allow the sonde to make in situ measurements as it ascends in the atmosphere. The sounding equipment uses a modern phase shift automatic directional ground antenna that receives radiosonde and ozonesonde signals at 1680 MHz. The sondes use digital transmission. The major difficulty to launch a sonde in Antarctica is dealing with the strong surface winds that are common at the Brazilian station, resulting in very long ranges of about 100-150 km, by the time the balloon is at 15-20 km. For some of our 1992 launches, the sondes reached maximum range before the balloon could approach its maximum height, so a few profiles are incomplete, showing data only below the peak ozone concentration. For a complete profile, the sondes can make about 60 observations per km, including temperature, pressure, relative humidity, temperature of the sensor, battery voltage, and ozone. For a sounding height of about 25 km, this represents the collection of about 9000 data points. Kirchhoff and Marinho (1992) describe tropospheric ozone measurements at the station.

RESULTS AND DISCUSSION

Table 1 shows all soundings made in 1992 at the Brazilian Antarctic station Comandante Ferraz, and describes a total of 43 ozone profiles, obtained between March 27 and November 4. The Table indicates dates and launch times as well as burst altitude in hecto Pascal. Also shown, as short notes, in the last column of Table 1, are some of the observed features of the ozone layer. As mentioned before, some of the profiles are incomplete, as shown in the features' column by the letter **I**, for example; other notations (shorts) are explained at the bottom of Table 1. These characteristics will be discussed later.

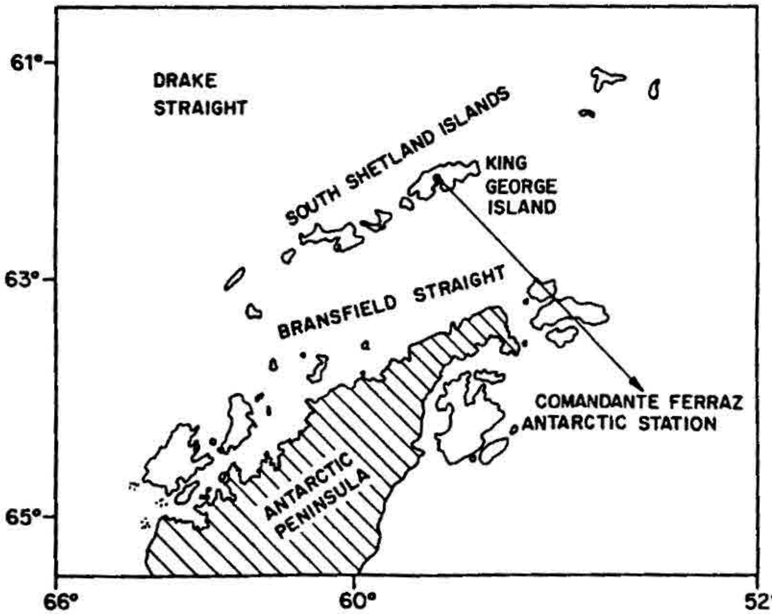

Figure 1 - The map of the Antarctic Peninsula (hatched) shows the South Shetland islands, with King George island and the Brazilian Antarctic station.

Table 1 - Ozonesonde launches from Ferraz station in 1992.

#	DATE	JULIAN DAY #	LAUNCH TIME (hr:min,Z)	BURST HEIGHT(hPa)	TEMPERATURE(°C) lowest 100 hPa	OZONE LAYER FEATURES
1	27 MAR	87	18:20	105.2	-50 -50	I (Incomplete), TP(Tropopause peak)
2	28 MAR	88	18:20	82.6	-60 -56	I, TP
3	04 APR	95	21:00	17.2	-63 -54	TP, Secondary Base Peak (SBP)
4	21 APR	112	19:24	22.4	-62 -60	Broad Major Peak (BMP)
5	11 MAY	132	19:18	46.2	-72 -66	I, TP, Early hole?
6	13 MAY	134	16:33	23.5	-76 -66	BMP
7	10 JUN	162	15:02	14.9	-70 -62	Divided peak
8	20 JUN	172	14:34	64.9	-76 -70	I, SBP
9	29 JUN	181	19:16	115.5	-66 -66	I, SBP
10	07 JUL	189	15:20	35.4	-74 -64	I
11	13 JUL	195	17:25	500.0		I
12	19 JUL	202	16:25	49.2	-79 -75	I, SBP
13	28 JUL	210	15:29	25.3	-80 -67	SBP, Divided major peak
14	05 AUG	218	15:31	149.6		I
15	07 AUG	220	15:58	51.2	-81 -77	I, SBP
16	11 AUG	224	15:34	51.1	-69 -66	I
17	13 AUG	226	19:58	76.6	-75 -73	I, TP
18	16 AUG	229	18:33	59.3	-78 -73	I, TP, SBP
19	18 AUG	231	18:48	98.2	-79 -79	I, TP
20	22 AUG	235	20:46	131.2		I
21	23 AUG	236	18:46	22.9	-81 -72	TP, major peak small
22	25 AUG	238	16:34	9.1	-77 -72	SBP, BMP
23	30 AUG	243	20:11	39.7	-85 -77	I, TP
24	04 SEP	248	15:34	9.7	-79 -73	Severe hole
25	06 SEP	250	16:59	42.9	-80 -75	SBP, no major peak ?
26	10 SEP	254	19:08	16.7	-80 -72	Normal layer ?
27	15 SEP	259	14:53	10.8	-72 -67	Control layer
28	25 SEP	269	19:20	17.3	-77 -75	Severe hole, TP, LSH
29	29 SEP	273	15:52	30.4	-70 -64	I, TP, Lower Stratosphere Hole (LSH)
30	03 OCT	277	21:36	52.3	-76 -75	Severe hole, LSH
31	08 OCT	282	20:27	09.3	-76 -74	Strong upper drop, TP, LSH
32	10 OCT	284	20:30	28.2	-73 -64	Strong upper drop
33	12 OCT	286	18:37	09.05	-69 -64	Lower Stratospheric Hole (LSH), TP
34	14 OCT	288	15:49	32.3	-64 -63	LSH, TP
35	15 OCT	289	13:39	24.6	-64 -59	LSH, TP, Divided major peak
36	16 OCT	290	19:43	41.8	-63 -61	LSH
37	18 OCT	292	16:49	67.3	-75 -71	I, LSH
38	19 OCT	293	18:32	10.7	-74 -72	TP, major peak destroyed
39	20 OCT	294	19:21	29.1	-76 -75	Severe hole
40	27 OCT	301	17:28	08.6	-59 -47	LSH, saturated above
41	30 OCT	304	18:20	09.7	-66 -59	LSH, saturated above
42	02 NOV	307	17:21	141.3		I
43	04 NOV	309	17:55	09.3	-56 -52	TP, Recovered, except at peak ?

I, incomplete when burst occurs below main peak; **TP**, Tropopause Peak; **LSV**, Lower Stratosphere Valley; **BMP**, Broad Major Peak; **LSH**, Lower Stratosphere Hole; **SBP**, Secondary Base Peak

Table 2 is a list of soundings made in the Summer period of 1991. The main purpose was to train personnel, and obtain a few ozone profiles measured well outside the ozone hole period, for later comparison with ozone hole conditions. Eleven ozone profiles were obtained in the January-February 1991 period. The last column describes again the major features of each profile, using some of the same short notation as in Table 1.

Table 2 - Ozonesonde launches from Ferraz station in 1991.

#	DATE	LAUNCH TIME (hr:min, Z)	BURST HEIGHT (hPa)	OZONE LAYER FEATURES
1	21 JAN	18:00	08.5	TP, Upper Ozone dip (UOD)
2	22 JAN	17:00	10.0	TP,Dip in Main Peak (DMP), UOD
3	23 JAN	18:34	08.8	TP, DMP, UOD
4	25 JAN	17:03	08.9	TP, very thin major peak
5	26 JAN	17:00	11.0	TP, Divided major peak, UOD
6	31 JAN	11:30	09.5	Divided major peak, UOD
7	02 FEB	11:04	42.0	I, TP
8	03 FEB	13:42	08.3	Divided major peak, UOD
9	05 FEB	12:09	10.1	Divided major peak, UOD
10	06 FEB	11:25	10.2	Divided major peak, UOD
11	07 FEB	11:44	12.0	Divided major peak, UOD

CHOOSING A CONTROL LAYER

In order to compare the different ozone profiles obtained, and so be able to see small differences, from one profile to another, it is necessary to choose one of the measured profiles as a "control" layer. This choice is to some extent arbitrary, but some general features are desirable. On the other hand, since the purpose of the control layer is only a qualitative comparison, its choice is not critical. The control profile, or layer, should be as close as possible to the **typical** ozone layer (or profile) observed over the Brazilian Antarctic station. In principle, this layer should occur during a period when there is no ozone depletion under way, for example in January. Looking at the profiles obtained in 1991, it becomes clear that the ozone profile obtained January 21 fits best the above requirements to become the control layer of this study. Its upper limit is at 30 km, and all the other features of the profile seem to match the above desired characteristics.

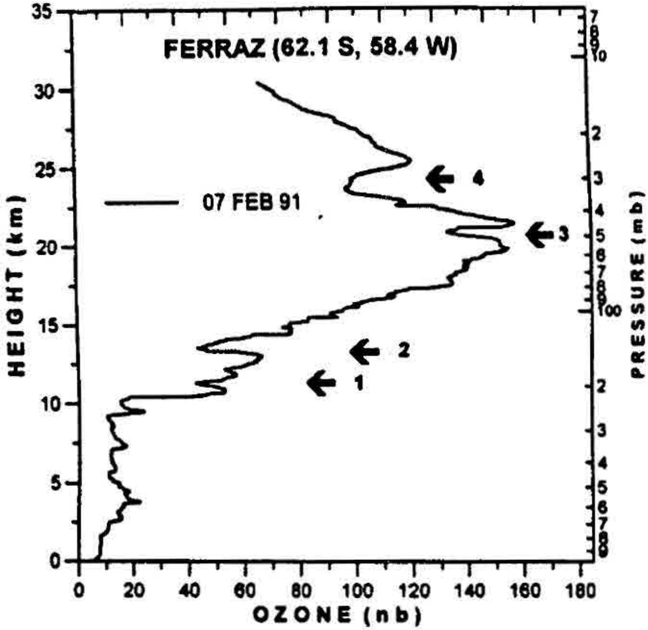

Figure 2 - Ozone profile observed on February 07, 1991, at the Brazilian Antarctic station Comandante Ferraz. The arrows point at features of the ozone layer discussed in the text.

Fig. 2 shows some of the interesting profile features for the 1991 set, and includes characteristics pointed by arrows; an ozone enhancement right after the tropopause, shown by arrow 1, an ozone decrease immediately following the previous ozone peak, pointed at by arrow 2, a dip shown by arrow 3, and yet another dip, higher up at the upper portion of the layer, shown by arrow 4. All these features are present in most of the eleven profiles obtained in 1991. Their persistence over the time period of the observations demonstrate the stability of the ozone layer over the Brazilian Antarctic station. The day to day variability of the 11 profiles obtained in 1991 is relatively small. **Fig. 3** shows the comparison for February 6. Most of the profile features have been preserved from January 21, including the tropopause peak at about 10 km height (TP in Table 1 and 2), the valley after the tropopause peak, in the lower stratosphere at a height of about 12-14 km (where most of the ozone destruction will occur during springtime), and the smaller dips, decreases in the ozone layer, that can be seen (barely in these examples, but consistent and more pronounced on the other profiles) near the major peak, at about 22 km, and above the major peak, at about 24-26 km.

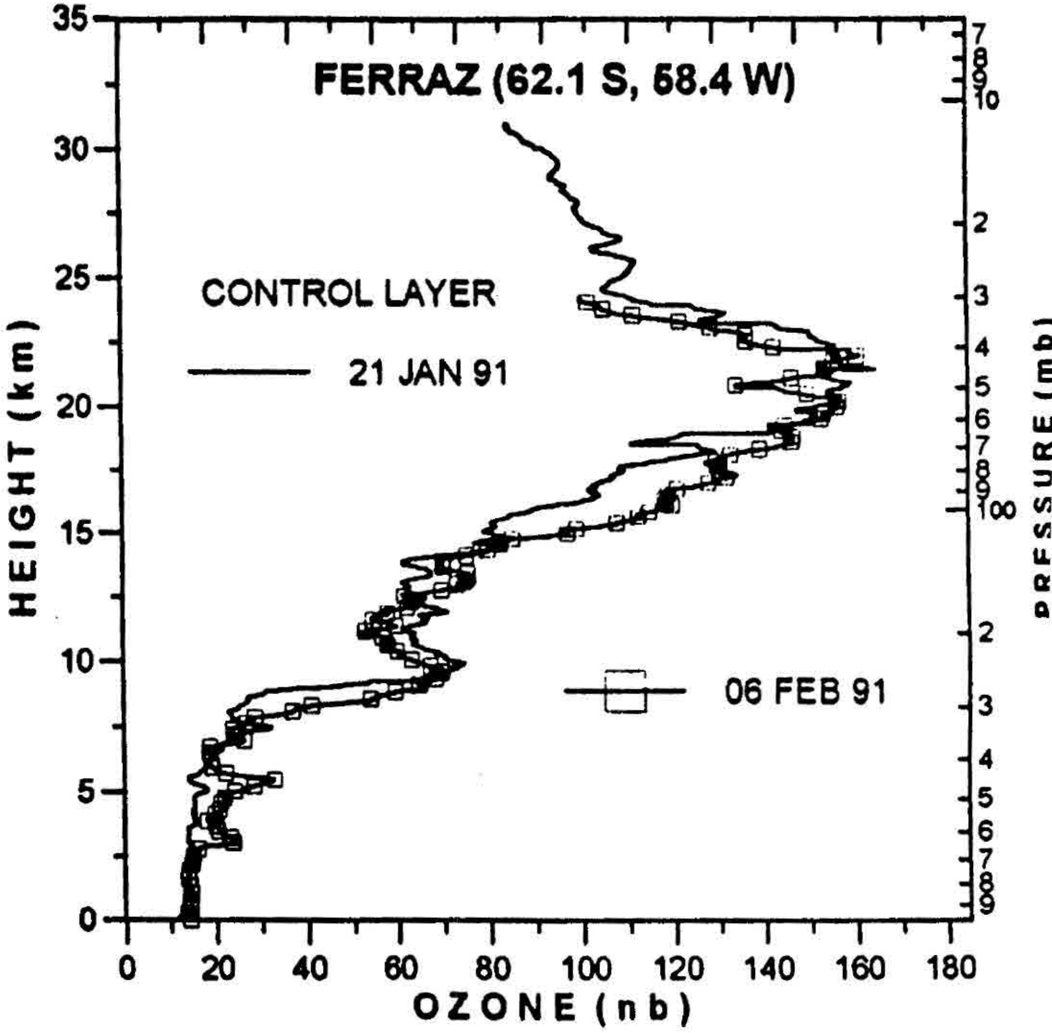

Figure 3 - Comparison of the profile of February 06, 1991, with the control layer of January 21, 1991.

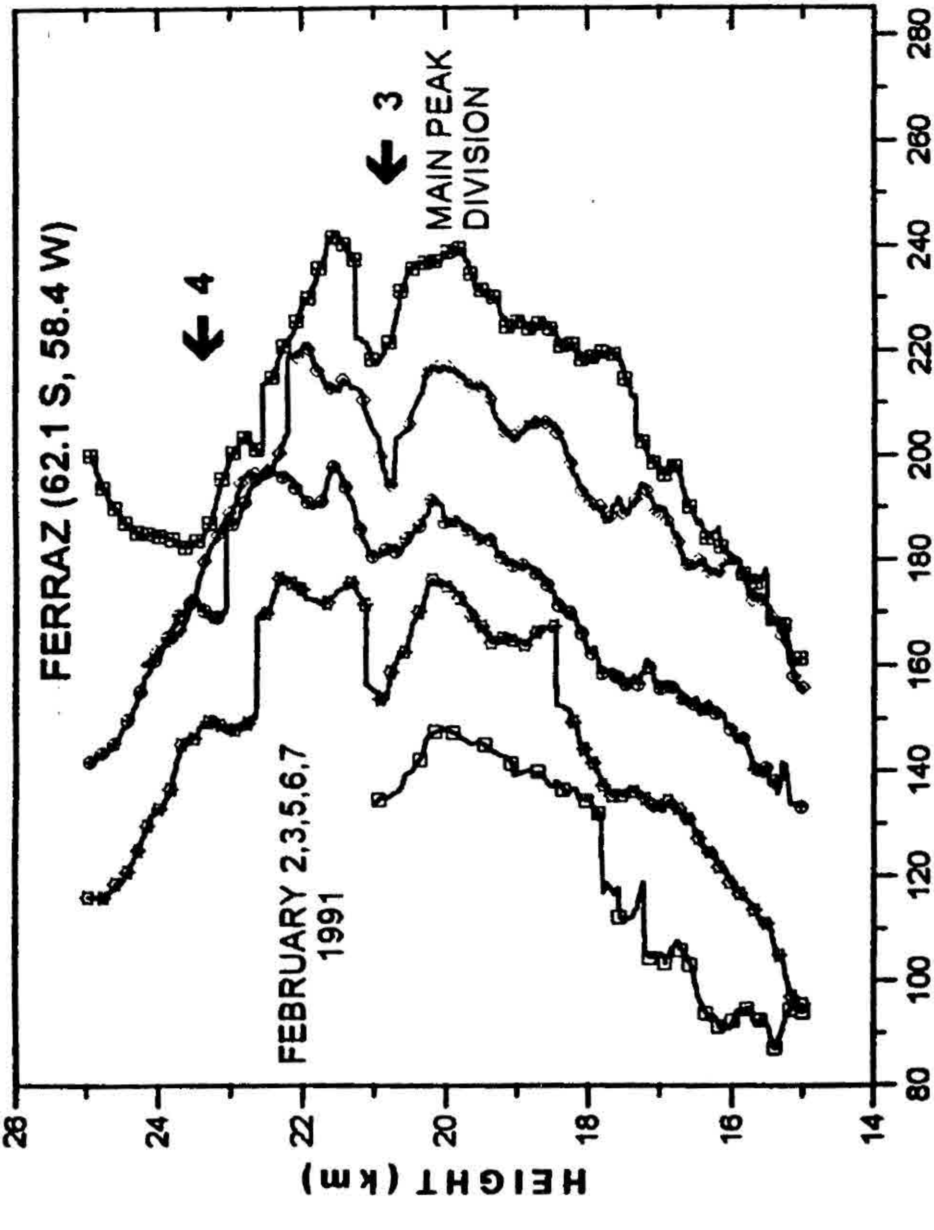

Figure 4 - Several ozone profiles obtained in February 1991 show persistent features in the layer. The profiles are shifted by about 15 nb to avoid superposition.

The ozone dip, or small decrease present at the major ozone peak, is shown in **Fig. 4** for 5 of the 1991 profiles to emphasize the stability of the stratospheric layer in this time period. Again the arrows point to the features 3 and 4, as in the previous Figure. Note that the ozone profiles in **Fig. 4** are shifted in order to avoid superposition. It can be seen that the ozone dip, or main peak division as it is called in **Fig. 4**, is very similar on the five occasions shown, covering a period of five days (February 2 to February 7).

GENERAL OZONE PROFILE VARIATION IN 1992

Kirchhoff and Marinho (1992) described some of the tropospheric ozone characteristics at the Brazilian Antarctic station, therefore only stratospheric features are discussed here. The measurement period includes profiles in the ozone hole period and before it. There is no ozonesonde information after the hole period, that is, when the ozone profile became completely recovered, around late November. The available ozonesonde data are therefore characteristic for a pre-hole and hole period of 1992.

The month of transition between the no-hole to the hole condition seems to be July. Data available from the Antarctic region over the last decade show that the ozone column content in August has been somewhat smaller (15% typically) in comparison to the pre-hole averages. Late July and the beginning of August represent a period of minimum temperatures in the lower stratosphere. In the case of the ozonesoundings over the Brazilian Antarctic station, the temperatures observed at 100 hPa, for example, decrease from March to late July-August, when they reach a minimum of about -83 C, and increase again from September onwards. **Fig 5** shows the observed temperatures at 100 hPa, and the lowest temperatures of the layer for 1992.

THE PRE-HOLE PERIOD

The two March profiles, unfortunately, did not reach much above 15-16 km, so there is no information for the upper layer. In the lower stratosphere the profile seems to be normal. The two April profiles already show lower ozone concentrations in the lower stratosphere, nearly 50% less ozone at about 14 km, than the control layer. The major peaks are also reduced from about 160 to 130 nb (nanobars). The two May profiles seem to follow the April profiles. For May 11 the low ozone values correlate well with the very low temperature observed in the stratosphere (Table 1 and Fig. 5).

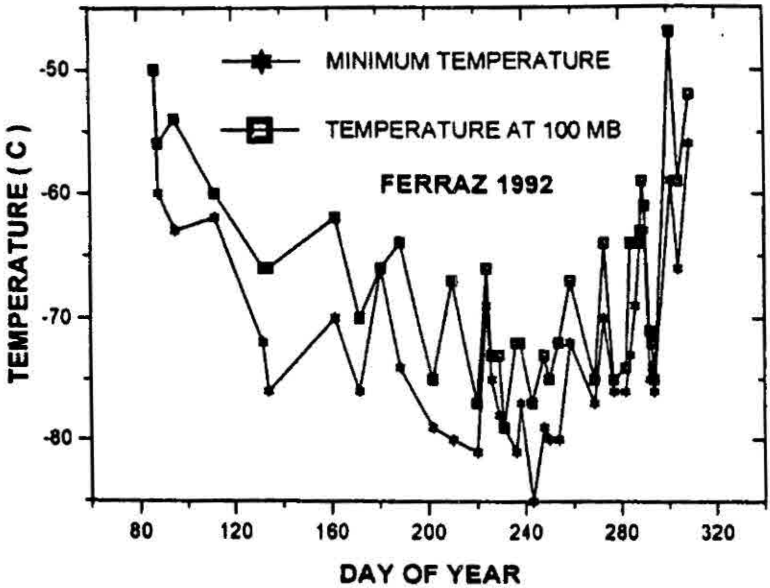

Figure 5 - Temperature variation at 100 mb and lowest temperature of the profile plotted as a function of day number.

June had three profiles. One of them showed peak ozone of about 140 nb, but the largest difference from previous profiles occurred in the lower stratosphere. The ozone concentration near 15 km was equal to the control layer value, and on the other two profiles, the concentrations near 15 km are considerably larger than those of the control layer. This seems to have been an anomaly. July, with four profiles, seems to be a continuation from June, with almost equal ozone concentrations near the major peak, and equal or larger ozone concentrations near 15 km.

August had 10 (incomplete) profiles. In early August the upper part of the layer is not well described, and the lower stratosphere values seem to be rather close to the control layer values. It is at the end of August that a sharp transition seems to start, with ozone decreases relative to the control layer that are more significant at the higher altitudes (August 23, 25, and 30).

THE HOLE PERIOD

Satellite data from the TOVS (Tirus Operational Vertical Sounder) instrument, operated by NOAA (National Oceanic and Atmospheric Administration), show that the first sign of the ozone hole formation does not occur at or near the South Pole, as one might expect, but appears instead near the Antarctic Peninsula, over the Palmer archipelago (NOAA, 1992). The TOVS total ozone map of August 31, 1992, shows a small spot of very low total ozone, between about 160 and 190 DU, at (63° S, 60° W). This is coincidentally very close to the location of the Brazilian Antarctic station. At this time period, the largest total ozone spots can be seen between 30° and 60° S. By September 7 the ozone hole was well developed over the Pole, where it presented the lowest total ozone values, showing an elongated geometry reaching out over the 60° meridian where it started at the end of August. This elongated form of the Antarctic ozone hole persisted apparently until October 5 when it reached the extreme of the South American Continent. It is interesting to mention that a Brewer spectrophotometer installed at Punta Arenas (a city of eighty thousand inhabitants) Chile, since June 1992 (Kirchhoff et al., 1993) registered the lowest ozone column amount on October 5. As shown by the satellite data of TOMS (Total Ozone Mapping Spectrometer) and TOVS instruments, this was the day when the ozone hole polar area had its maximum extension towards the Southern Hemisphere tip. The Punta Arenas instrument observed only 190 Dobson Units (DU) on this day, while the September average (the lowest monthly average of the year) was 306 DU.

During the September and October ozonesoundings, the ozone hole was clearly identified on several occasions above the Brazilian Antarctic station. The first clear examples of severe ozone concentration reductions in the whole layer were seen on September 4, shown in **Fig. 6**. Near 15 km, there is a significant reduction, nearly 50 %, which is also the case for heights near and above the major ozone peak. Satellite data and ground based information from Antarctic sations show that 1992 had an early beginning of the ozone hole. Marambio, Syowa, and South Pole show ozone partial pressures of about 70 nb when normal values are 120 nb during the second half of August. The temperatures in the stratosphere over the Brazilian Antarctic station were the lowest of the year, as noted already.

The early September period of the ozone hole formation was followed by a period that was rather normal, except at heights above the main ozone peak, where the ozone disappeared. This can be seen quite well in the September 15 sounding, shown in **Fig. 7**. Up to heights of 22 km the layer is very similar to the control layer. It is only above the peak that the ozone concentration decreases with height much faster than the control layer. At 25 km, the ozone partial pressure is 70 nb, compared to 110 nb of the control layer.

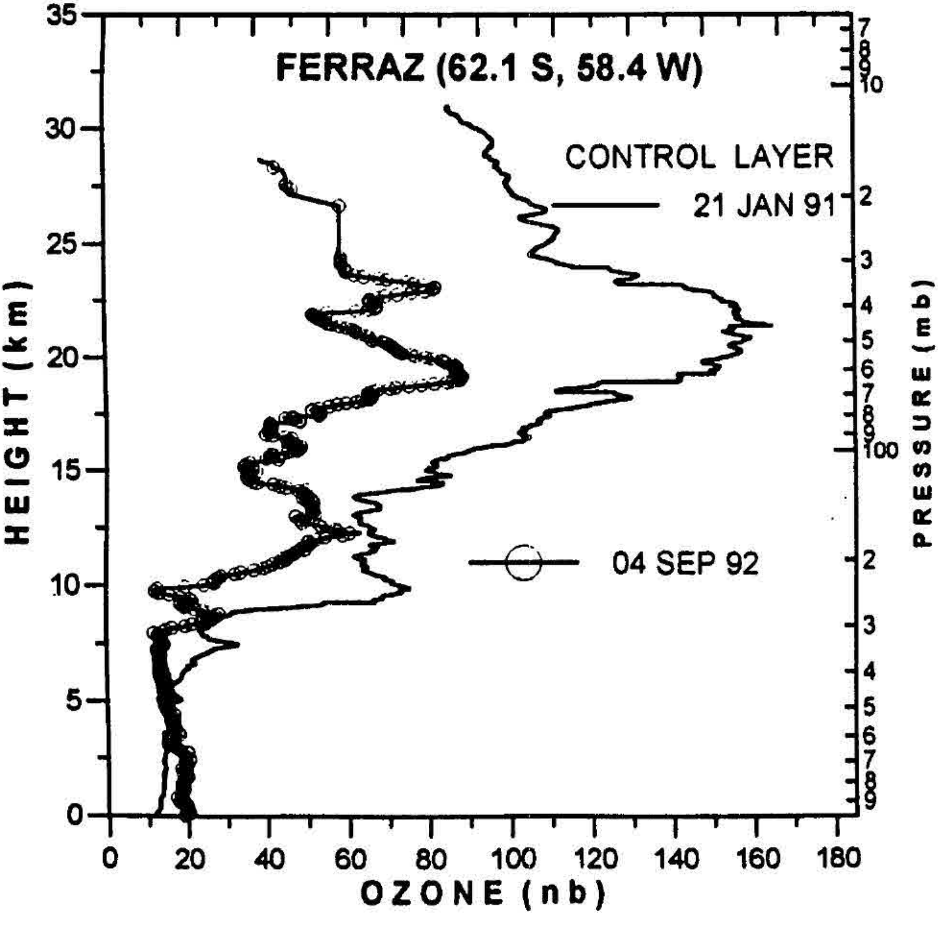

Figure 6 - The ozone hole observed on September 04, 1992, shown with the control layer, for comparison.

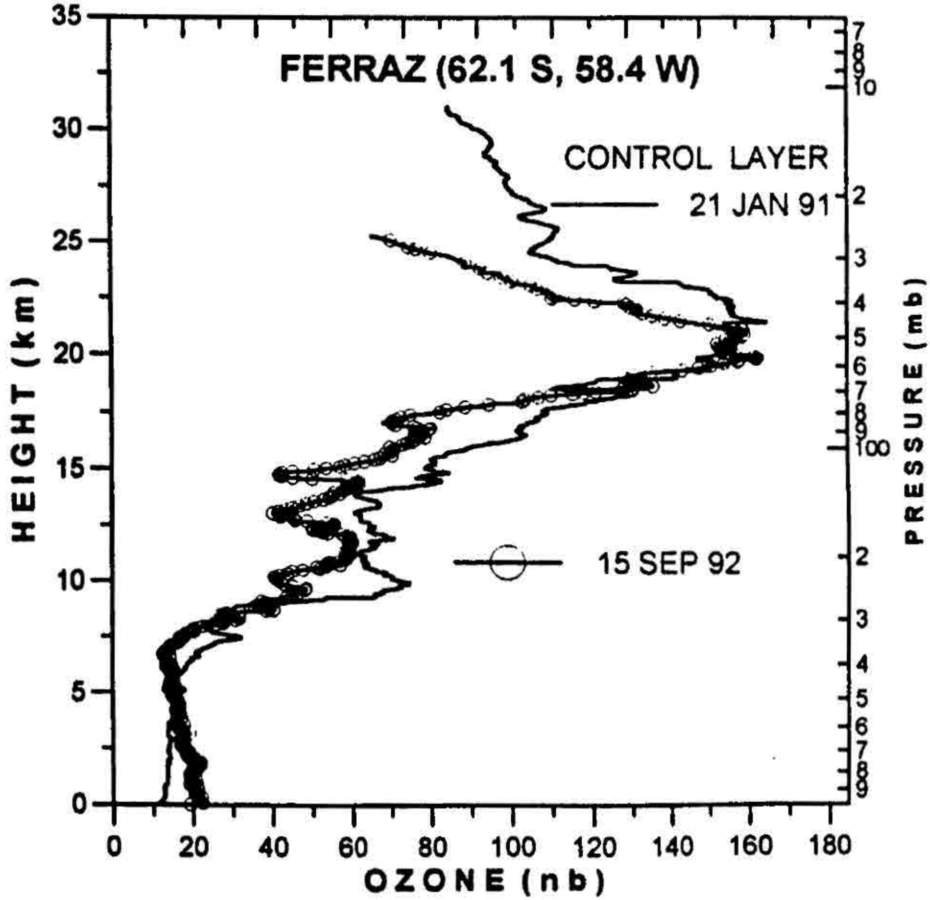

Figure 7 - The ozone layer for September 15, 1992, which is very similar to the control layer, but above the peak, the ozone decay with height is much faster.

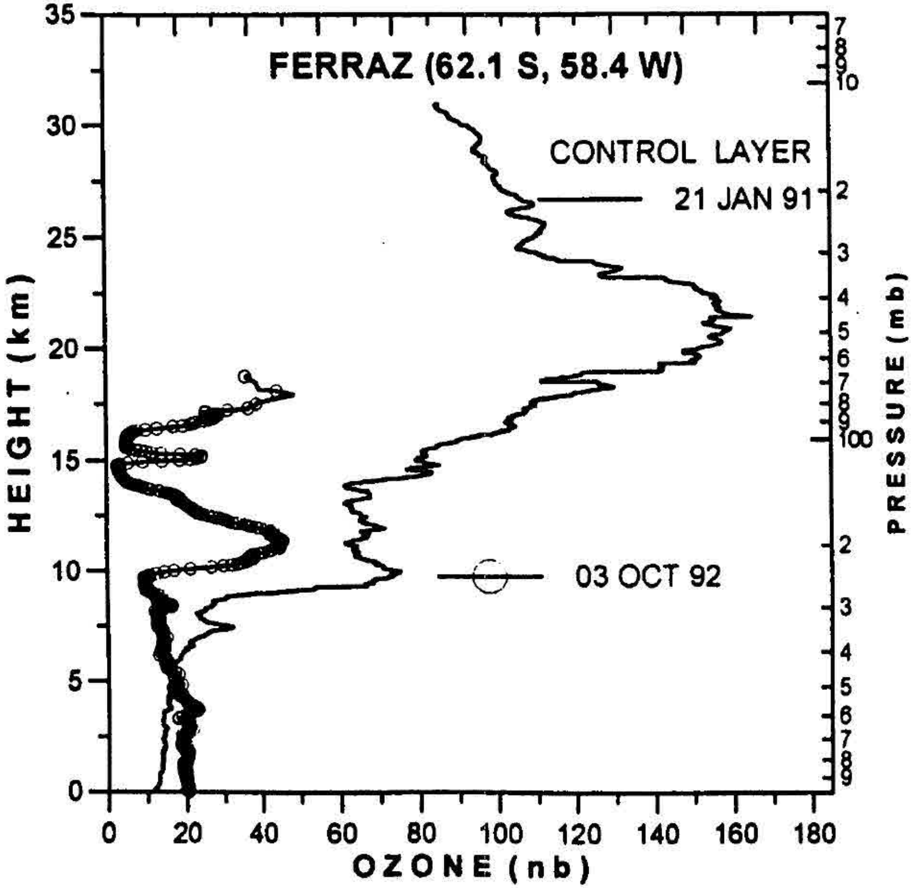

Figure 9 - The ozone hole observed on October 03, 1992, shown with the control layer, for comparison.

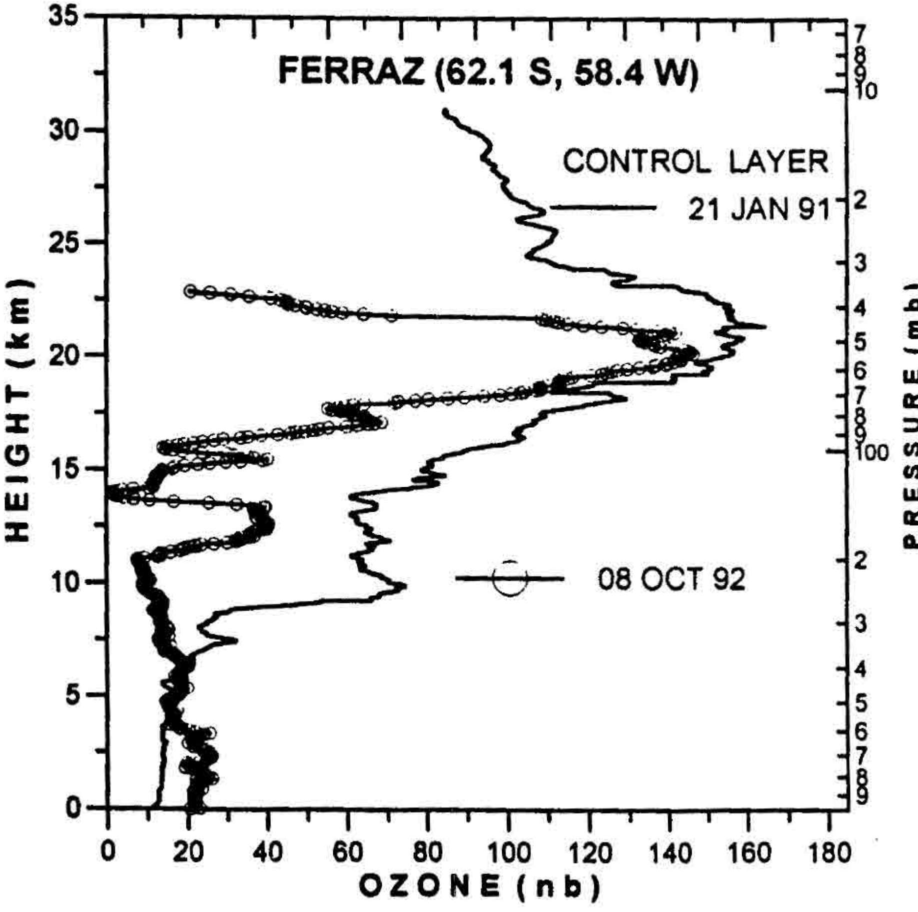

Figure 10 - The ozone hole observed on October 08, 1992, shown with the control layer, for comparison.

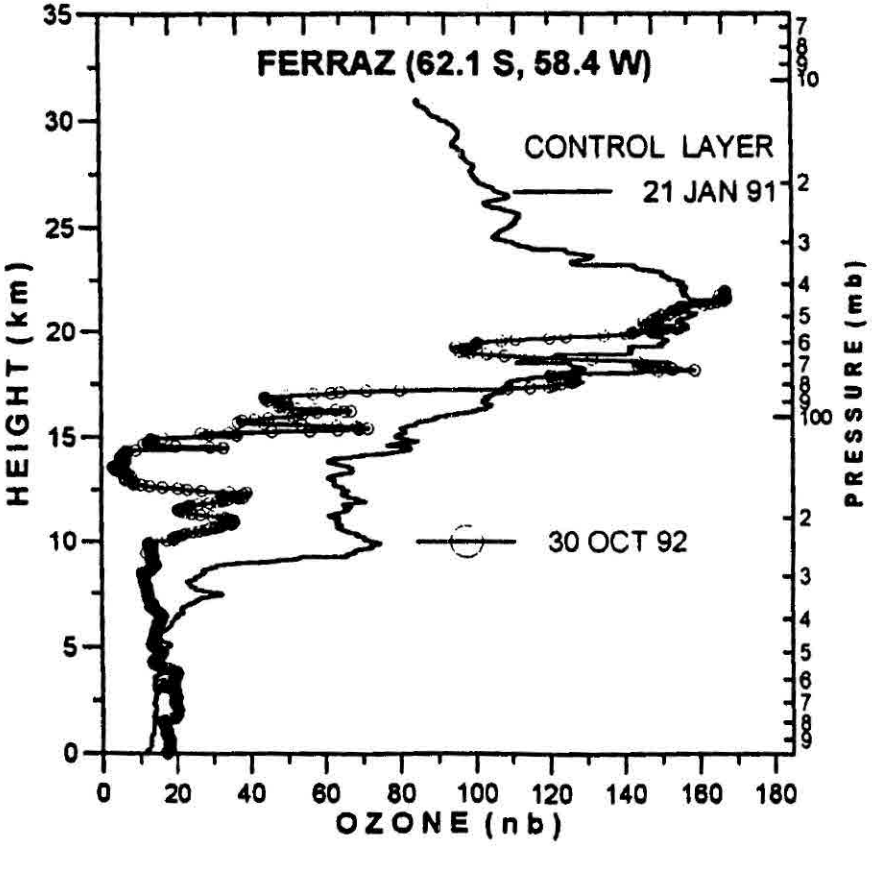

Figure 11 - The ozone hole observed on October 30, 1992, shown with the control layer, for comparison.

CONCLUSIONS

From the ozone observations at the Brazilian Antarctic station Ferraz, during 1992, including pre-hole and hole periods, it may be concluded that the Antarctic ozone destruction at this location is highly variable. Ozone depletions near the ozone layer peak were around 50%, but with occasional larger destruction. On several occasions severe ozone depletions were seen at lower stratospheric heights, where the ozone partial pressure measured by the sondes nearly vanished.

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