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Observations of the 1995 ozone hole over Punta Arenas, Chile

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Abstract. We examine the appearance of the ozone hole over a populated area with more than 100,000 inhabitants. The largest population concentrations on the South American continent nearest the ozone hole region are Punta Arenas, Chile (53.0° S, 70.9° W) and Ushuaia, Argentina (54.5° S, 68.0° W), located close to the strait of Magallanes, opposite the Antarctic Peninsula. A special field mission was held in Punta Arenas, in September-October 1995 to investigate the vertical distribution of ozone during the appearance of the Antarctic ozone hole. Previous work has shown that the city of Punta Arenas is located at the edge of the hole area and is affected every year during a few days in the October period. The ozone trend near these locations is -0.5% per year using the yearly averages and -1.2% per year using the October means. This trend is 2 to 5 times larger than the global average. Several ozonesondes of the electrochemical concentration cell type were launched from Punta Arenas to determine the vertical distribution of ozone during "normal" and "perturbed" conditions. The ozone hole passed over Punta Arenas on October 12, 13 and 14, 1995. In addition to the sondes, which were launched once a day, ozone column amounts and UVB radiation were measured with a ground-based ozone Brewer spectrophotometer. The strongest ozone depletion over Punta Arenas in 1995 occurred on October 13, when the ozone column decreased from a "normal" value of about 325 Dobson Units (DU) to 200 DU; the vertical distribution of ozone on October 13 compared with October 6 shows depleted ozone roughly 50% less during hole conditions in the stratosphere. The UVB intensities have increased accordingly. The spectral ratio for October 13 to October 4 is 13 times larger at 297 nm.

Introduction

One of the most significant environmental changes that occurs in the atmosphere is ozone depletion in the stratosphere. Stratospheric ozone depletion can be expressed by a negative ozone trend [*Stolarski et al.*, 1991], which is normally defined for any latitude between 65°N and 65°S. A numerical linear trend is obtained from ozone data by fitting techniques that allow the separation of terms such as seasonal variation, quasi-biennial oscillation, solar cycle, and noise signals. In the Antarctic region there is an additional strong seasonal effect known as the ozone "hole", which is a strong ozone reduction in the Antarctic spring. Since the natural ozone layer works as a screening element that reduces UVB (280 to 320 nm) radiation at the surface, larger UVB radiation intensities are expected at the ground, especially in Antarctica [*Frederick and Snell*, 1988; *McKenzie et al.*, 1991]. This UVB radiation is considered damaging to living systems [*Ley et al.*, 1989; *De Fabo et al.*, 1990; *Karentz et al.*, 1991; *Cullen et al.*, 1992]. With the global tendency for decreasing stratospheric ozone there is an expected tendency for increasing UVB intensites at ground level [*Madronich*, 1992; *Kerr and McElroy*, 1993; *Herman et al.*, 1996].

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The Antarctic ozone hole is a phenomenon of strong ozone depletion in the Antarctic stratosphere [*Stolarski et al.*, 1986; *Stolarski*, 1988; *Solomon*, 1988, 1990]. The enhanced ozone destruction is a consequence of heterogeneous chemical reactions that occur in the presence of a special type of aerosol, the polar stratospheric clouds, which act as if they enhance reaction rates that destroy ozone by reacting mainly with chlorine [*Toon and Turco*, 1991]. The cold temperatures in the Antarctic stratosphere favor the formation of the stratospheric clouds in local spring. For many years the Antarctic ozone hole has developed over the South Pole, and the geographic area that it covers has been increasing over recent years to close to 20 million square kilometers, covering mostly the polar and the Antarctic Peninsula region. Because the cold temperatures of the Antarctic stratosphere are a necessary condition, the Antarctic ozone hole area is not expected to expand much more [*Herman et al.*, 1995].

The Antarctic Peninsula is uninhabited, except for Antarctic research stations. The largest group of populations on the South American continent nearest the South Pole are Punta Arenas, Chile (53.0°S, 70.9°W) and Ushuaia, Argentina (54.5°S, 68.0°W), the first with about 100,000 inhabitants and the second with about 30,000. The ozone trend at Punta Arenas was determined by using total ozone mapping spectrometer (TOMS) data. For measurements between November 1978 and May 1990, *Stolarski et al.* [1991] report an average global trend of -0.26% per year for data obtained between 65°N and 65°S. The trend is strongly latitude dependent, being nearly zero close to the equator, and larger at higher latitudes (and larger in the south than in the north, because of dilution effects of the Antarctic ozone hole).

We used the ozone database of *Krueger et al.* [1992] in this study to calculate the ozone trends at Punta Arenas. It includes 14 years of TOMS data and is used in this work as an ozone climatology, for reference. The TOMS data show that at Punta Arenas the yearly ozone trend is -0.5%, using the yearly averages; using the monthly October averages, the trend reaches -1.2% per year (October is the month in which most of the ozone hole appearances occur at Punta Arenas). Thus the ozone trend near Punta Arenas is 2 to 5 times larger than the global average of *Stolarski et al.* [1991]. Being located nearest the ozone hole affected area, these populations are the first group exposed to the ozone hole effects. It is therefore important to understand the behavior of the Antarctic ozone hole as it manifests itself over these populated areas. In addition to local Antarctic effects it has been observed that the ozone hole phenomenon also has indirect effects at lower latitudes, by the export of ozone-poor air masses northward [*Atkinson et al.*, 1989; *Kane*, 1991; *Kirchhoff et al.*, 1996].

To observe stratospheric ozone and UVB radiation, a Brewer spectrophotometer was installed in Punta Arenas, at the local University of Magallanes campus, in June 1992. Since then the ozone hole has been observed at Punta Arenas every year, mostly in October. In October 1995 a special field campaign was organized jointly by the Instituto Nacional de Pesquisas Espaciais (INPE) Brazil and University of Magallanes (UMAG) Chile, aimed at measuring the vertical distribution of ozone during the appearance of the ozone hole. The objective of this paper is to describe the appearance of the Antarctic ozone hole over Punta Arenas, Chile, during October 1995.

Measurement Methods

Ozonesondes

The measurement technique to obtain the vertical distribution of ozone uses the electrochemical concentration cell (ECC) ozonesonde. This ozonesonde is a small, balloon-borne device developed at the National Oceanic and Atmospheric Administration (NOAA) [*Komhyr*, 1969; *Komhyr and Harris*, 1971]. ECC ozonesondes are carried aloft on balloons, in addition to standard meteorological radiosondes that measure temperature, relative humidity, and pressure from the ground to the burst altitude of the balloon, normally near 28-30 km. The ozone sensor of the ECC ozonesonde is an iodine/iodide redox concentration cell composed of two platinum electrodes immersed in neutral buffered iodide solutions of different concentrations in the anode and cathode chambers. An electric current is generated when air containing ozone is pumped into the cathode. Along with measurements of ambient air pressure, temperature, and instrument temperature, this current is converted into ozone partial pressure (in nanobars) the primary data product for the ECC ozonesonde, which is transmitted to a ground receiver by 403 MHz telemetry. For the digital sondes a vertical resolution of about 15 m can be achieved. The ECC launches of this data set use the same procedures as those used for the long-term observational program at Natal, Brazil, which has given excellent results [*Kirchhoff et al.*, 1981; 1983; 1991]. The sampling pump efficiencies for the ECC sondes are individually calibrated before flight, following a procedure described by *Torres and Bandy* [1978]; the ozonesondes are also calibrated in the laboratory against UV ozone photometers, whose calibrations are traceable to the photometric ozone standards of the National Institute of Standards and Technology. The accuracy and precision of the ECC ozonesonde have been described by *Torres and Bandy* [1978], *Barnes et al.*[1985], and *Hilsenrath et al.*[1986]. Ozonesondes have also been useful for tropospheric studies [*Logan and Kirchhoff*, 1986; *Kirchhoff et al.*, 1988; 1990] and for ozone concentration variations near the ground [*Oltmans*, 1981; *Oltmans and Komhyr*, 1986], and large ECC databases have been used for the study of ozone trends at different height levels [*London and Liu*, 1992; *Logan*, 1994].

Total Ozone

Total column ozone and UVB radiation were measured by using an automated Brewer spectrophotometer [*Brewer*, 1973; *Brewer and Kerr*, 1973]. This instrument, developed by the Atmospheric Environment Service, Canada, was specifically designed to measure accurately the ultraviolet radiation necessary for the calculation of ozone column amounts by using direct solar beam absorption. The Brewer instrument makes observations at five wavelengths, which are sampled by using a stepping motor chopper. The resolution is about 0.6 nm, and the wavelengths are placed at 306.3, 310.0, 313.4, 316.7, and 319.9 nm. The instrument includes automatic wavelength calibration using an internal mercury discharge lamp, as well as a relative spectral intensity source from a quartz - halogen lamp. A computer-controlled azimuth mount ensures automatic solar pointing.

UVB Radiation

Spectral UVB radiation is also measured by the Brewer spectrophotometer with an optional special device that allows observations between about 290 and 325 nm with a resolution of about 0.5 nm [*Kerr and McElroy*, 1993]. Each measurement spectrum is the result of a forward and backward wavelength scan of the instrument over the above range, an operation that takes between 5 and 10 min. Measurements of spectra have been made at least once per hour.

Results and Discussion

Figure 1 shows total ozone values in Dobson units (DU), measured with the Brewer spectrophotometer. The appearance of the ozone hole over Punta Arenas is very clear and represents a drop in ozone column from about 325 to 200 DU. The lowest ozone is seen on October 12,13, and 14. In comparison the largest ozone depletion at McMurdo, for example, in the observations of 1988, was 217 DU [*Deshler et al.*, 1990].

Figure 1 also shows the column ozone measured by the ozonesondes by integrating the partial pressures with height. The agreement is quite good. Exact agreement is not expected, since the balloon drifts away from Punta Arenas with the local winds, and by the time it measures ozone in the stratosphere, the balloon may be as far away horizontally as 100-150 km. A list of the ozonesoundings is shown in Table 1. On October 22-23, as shown in Figure 1, the ozone column increases to about 375 DU, observed by the sondes and by the spectrophotometer. This increase is due to an air patch of enhanced stratospheric ozone that passed over Punta Arenas. Such patches of enhanced ozone, which are similar to air patches with enhanced humidity (clouds), can be easily recognized in TOMS and Tiros operational vertical sounder maps of the southern polar region. The total ozone variation at the bottom of Figure 1 shows the ozone integral of the lower stratosphere (between 12 and 20 km). Because of the sharp

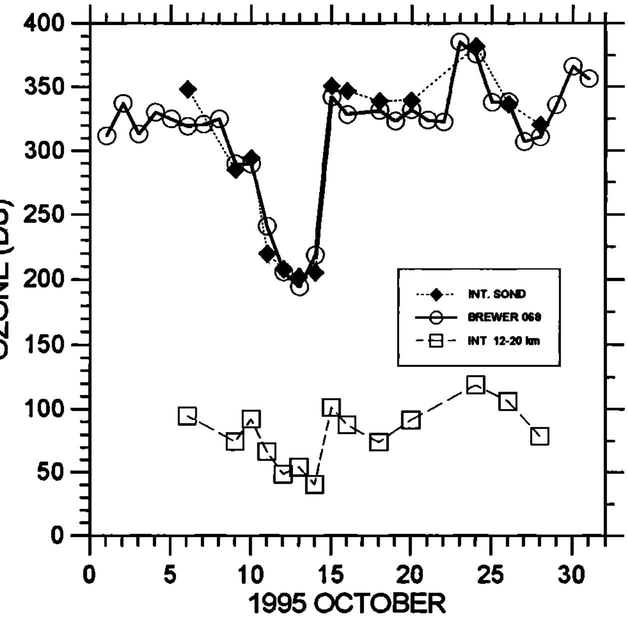

Figure 1. Column ozone measured by two different techniques: the Brewer spectrophotometer data are shown by circles, and the sonde integrals are shown by diamonds.

drop in ozone the total ozone variation is a very clear signature of the presence of the ozone hole over Punta Arenas.

During October 1995, 14 ozonesondes were successfully launched from Punta Arenas while continuous measurements were made with the Brewer spectrophotometer. Figure 2 compares the Brewer spectrophotometer total ozone amounts with the ozonesonde height integrals. The largest differences are in the range of less than 10%; the average difference is of the order of 1% with a standard deviation of 4%. The good comparison of the Brewer spectrophotometer with the sounding's total ozone column values is a sign that the independent measurement techniques were performed adequately.

During the appearance of the ozone hole over Punta Arenas in 1995 there was a simultaneous very clear change in stratospheric temperature, as observed with the vertical soundings. Since stratospheric ozone is responsible for stratospheric warming, it is expected that warming rates will be lower with less ozone. After several days of ozone depletion, lower stratospheric temperatures are expected. Investigations by *Tsay and Stamnes* [1992] estimate temperature decreases of 0.4 K/day for a 20% ozone reduction scenario with solar zenith angles around 55°.

The temperature profiles are shown in Figure 3. Two groups of three days each are graphed in Figure 3: the profiles for October 12,13, and 14 during the perturbed (ozone hole) period and the second group of October 16,18, and 20, representing local normal conditions, after the appearance of the ozone hole (see Figure 1). Large temperature differences can be seen in the height region between 10 km (the height of the tropopause) and 27-28 km. The ozone hole days have temperature minima near -70°C at about 18 km (Table 2 shows the two averages), whereas the normal days of the second group have minima around -55°C. Thus the days with the ozone hole have smaller temperatures in this height region, roughly 14°C lower. Table 2 shows that the temperature variability with height, as expressed by the standard deviation, in the interval between 10 and 20 km is not very much different for the two groups. On October 13, when the ozone column was the lowest, the temperature near 18 km was also lower than that on the other days: -76°C. The co-variation (decrease) of temperature and ozone column is roughly in agreement with the variability predicted by *Tung and Yang* [1988]: a decrease of about 7% in ozone column for each 2°C decrease in temperature is expected. Using this formulation, from our Figure 1 the ozone column decrease is of the order of 38% which should lead to a temperature decrease of about 10.8°C. Thus our observed temperature decrease is somewhat larger than what one would expect from the *Tung and Yang* [1988] formulation, possibly because our observations may also include other dynamic effects.

In 1991 and 1992, ozonesoundings in Antarctica were also made from across de Drake strait, on King George Island, one of the South Shetland islands near the top of the Antarctic Peninsula. The observation site was the Brazilian manned Comandante Ferraz Station (62.1°S, 58.4°W), from which a number of ozonesoundings were launched [*Kirchhoff and Marinho*, 1992]. The temperatures observed near the tropopause for this earlier sonde set are higher (average near -66°C), even though the observation site was somewhat closer to the pole.

The time evolution of the temperature cross section is shown in Plate 1. Starting October 5 and up to October 9 the temperature near its center of symmetry (around 18 km, slightly below the peak ozone, which is seen at 21 km) is between -53.8°C and -64.4°C (color ranges as shown in Plate 1). Starting October 9-10, the temperature sharply decreases by about 10°C, staying at this lowest limit up to October 14; over the period of the presence of the ozone hole the temperature is in the interval -75.0°C to -64.4°C, and after October 13-14 it again increases back to the -64.4°C to -53.8°C interval. The highest temperature interval (-53.8°C to -43.1°C) is associated with the highest ozone column seen on October 23-24, a small ozone bulge that passed over Punta Arenas. During these two days the peak of the ozone concentration, between 175 and 200 nbar, remains near 21 km.

The dynamics over Punta Arenas, that is, the air motion in the stratosphere, has a characteristic pattern. The winds in the stratosphere near 55°S blow in a clockwise direction when the observer is looking down at the south pole. Looking at total ozone charts, as, for example, those provided by TOMS one can see that a succession of low and high ozone "clouds" pass over Punta Arenas in a sequence of just a few days. This behavior explains in part the large day-to-day variability that can be seen in the Brewer spectrophotometer total ozone data. Backward trajectories [*Harris and Kahl*, 1990] show a polar outward motion from the south pole, mainly from west to east, but with a component to the north.

Table 1. List of Ozonesoundings at Punta Arenas, Chile, for October 1995

Number	Date	Hour, UT	Burst Height, hPa
1	Oct. 6, 95	1540	4
2	Oct. 9, 95	1528	4
3	Oct. 10, 95	1536	4
4	Oct. 11, 95	1740	20
5	Oct. 12, 95	1507	4
6	Oct. 13, 95	1520	4
7	Oct. 14, 95	1556	5
8	Oct. 15, 95	1431	8
9	Oct. 16, 95	1424	5
10	Oct. 18, 95	1422	4
11	Oct. 20, 95	1359	4
12	Oct. 24, 95	1621	4
13	Oct. 26, 95	1358	25
14	Oct. 28, 95	1354	4

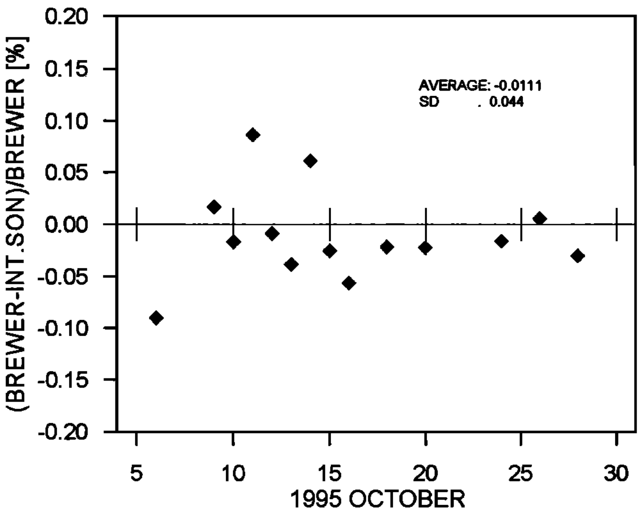

Figure 2. Comparison of the Brewer spectrophotometer column ozone and sonde height-integrated ozone concentration data for the 14 ECC ozonesoundings at Punta Arenas.

This is observed also for Punta Arenas in the sonde wind data, shown in Figure 4. A mass plot of the wind direction for the six days considered before is shown. For the winds there seems to be no major difference between days showing ozone hole effects and normal days, but October 12 is more eastward than the rest of the sample. The wind direction varies roughly from 200° to 260°. The largest variability seems to occur near the ground. Thus the wind direction seems to be in agreement with the general description of the stratospheric air motion mentioned above.

The wind speed variations are displayed in Figure 5. Near the ground the wind velocities were less than about 18 m s^{-1}, and the magnitudes increase with height. One sees the expected rather large variability in the wind speed. From the data available there seem to be no significant changes in the wind behavior for normal and perturbed conditions, except, perhaps, that the westerly component was stronger at the beginning of the hole event. Table 3 shows the average wind speed and wind direction in 2 km layers.

The ozone profiles for normal days are shown in Figure 6. Near the tropopause the ozone partial pressure is very low, only 20 nbar; from the tropopause to the ozone peak, near 21-22 km, the ozone partial pressure increases to a maximum of about 160 nbar, thereafter decreasing to about 35-40 nbar near 35 km.

In contrast to the ozone profiles for the normal days, Figure 7 shows the three perturbed profiles obtained October 12,13, and 14, 1995. The difference between these profiles and the ones in Figure 6 is striking. Near the ozone peak and slightly lower there is considerable vertical structure in the ozone partial pressures shown for the perturbed days. The ozone is significantly depleted with respect to the normal days. Roughly, the ozone "peak" is now around 90 nbar. Ozone depletions are seen at all heights above about 12 km. Similar vertical layers are called laminae in the work of *Mlch and Lastovicka* [1996], who describe ozone observations in central Europe quite different, for example, from observations

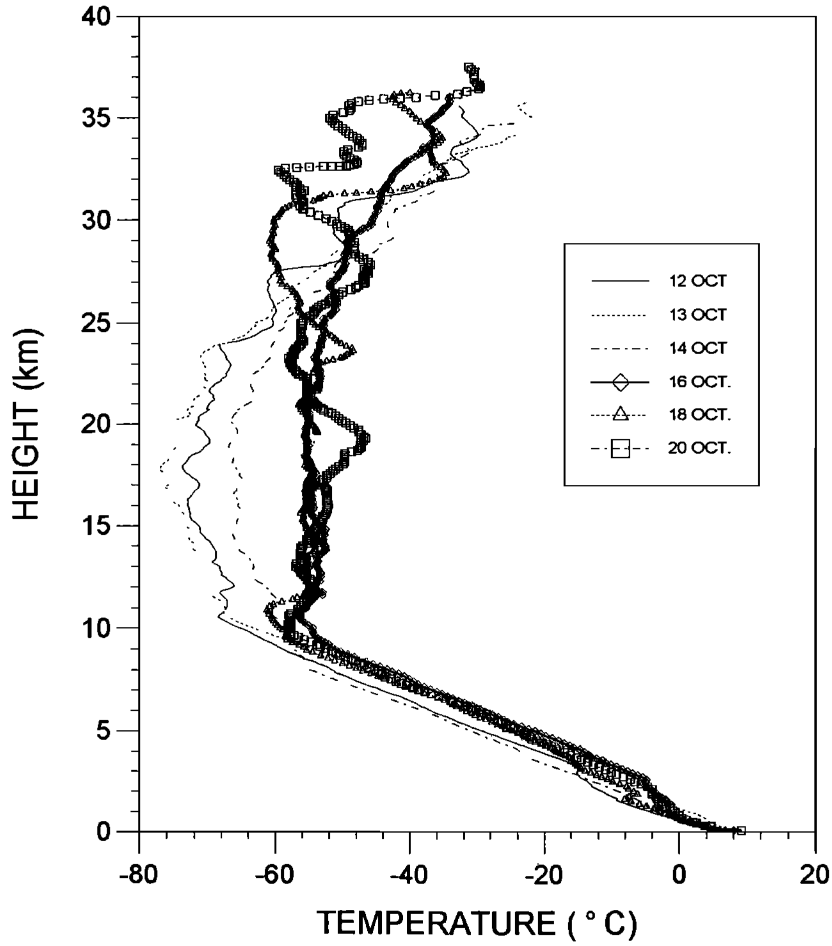

Figure 3. Vertical distribution of atmospheric temperatures during three normal (outside the ozone hole period) and three perturbed (ozone hole) days at Punta Arenas.

Table 2. Average Temperature During October 1995, Punta Arenas, Chile

Height, km	Outside Ozone Hole		Inside Ozone Hole	
	Temperature,°C	s.d.	Temperature, °C	s.d.
0-1	3.83	3.04	1.93	3.26
1-2	-2.21	3.43	-6.62	3.36
2-3	-7.68	3.55	-12.62	4.49
3-4	-13.39	3.82	-18.66	5.05
4-5	-20.04	3.96	-26.04	5.33
5-6	-27.32	4.43	-34.26	5.97
6-7	-34.20	5.16	-41.44	6.37
7-8	-42.05	5.08	-48.73	5.94
8-9	-49.09	3.82	-54.84	3.98
9-10	-54.90	2.94	-59.26	2.47
10-11	-58.30	3.17	-63.82	3.55
11-12	-57.55	3.87	-63.86	3.98
12-13	-56.43	3.06	-65.88	3.72
13-14	-56.38	3.41	-67.22	3.11
14-15	-55.87	4.30	-68.53	3.16
15-16	-55.45	4.52	-69.17	3.88
16-17	-55.19	5.27	-69.61	4.48
17-18	-55.12	5.73	-69.64	5.31
18-19	-54.41	6.75	-70.00	4.32
19-20	-54.70	5.83	-69.46	3.67
20-21	-54.03	5.96	-69.19	3.27
21-22	-54.80	6.13	-67.34	3.40
22-23	-53.77	6.39	-66.46	3.10
23-24	-53.34	6.89	-66.29	3.79
24-25	-53.39	6.71	-63.34	2.99
25-26	-52.33	6.85	-60.21	2.01
26-27	-50.30	7.73	-57.62	2.96
27-28	-50.61	7.08	-54.80	3.58
28-29	-49.31	7.40	-48.56	2.59
29-30	-48.60	7.62	-47.12	3.41
30-31	-48.77	6.91	-44.99	3.96
31-32	-45.60	6.33	-38.88	2.92

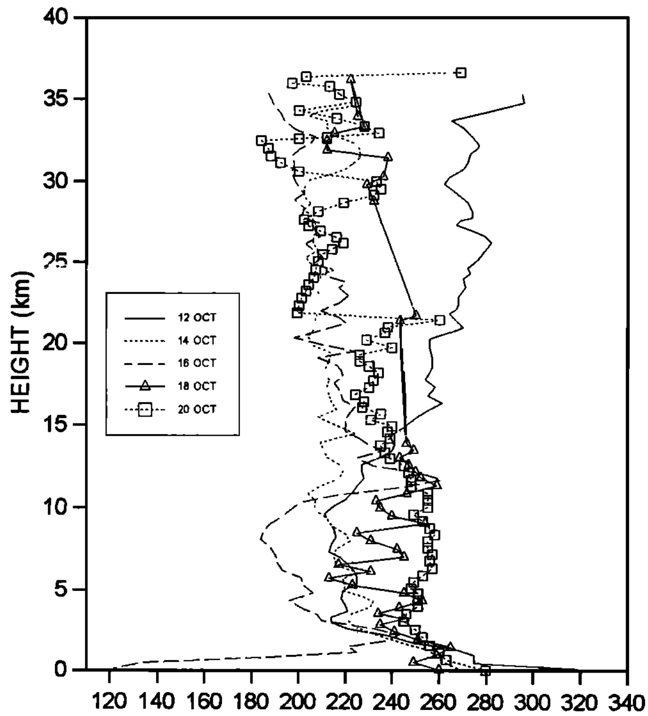

Figure 4. Mass plot of wind direction as a function of height for 5 days in October 1995 at Punta Arenas.

made at McMurdo, during 1986, when the ozone depletion was confined to the height range 12-20 km [*Deshler et al.*, 1990]. For the season of 1993 there was again a strong depletion in the height range 15-18 km, but this may have been in part the result of effects of aerosols released by the Mount Pinatubo volcanic eruption [*Grant et al.*,1994; *Johnson et al.*,1995]. The largest percentage depletions occur in the lower stratosphere, as will be shown in detail in Figure 9, but the largest amount of ozone is depleted from slightly below the peak height up to the top of the layer. In comparison, McMurdo observations of 1987 show that ozone removal in the height range of 15-18 km was nearly total, decreasing from about 150 nbar to zero. This strong ozone removal in the lower stratosphere has also been observed at the Brazilian Antarctic Station in the 1992 data set mentioned before. Very clearly, ozone was almost completely depleted in the height range 15-18 km, for example, on the profile obtained on September 25, 1992, and for October 20, 1992 (not shown). For the present data set, ozone decreases over this height range were not so severe over Punta Arenas in 1995. For clarity, average profiles for the normal and perturbed days were obtained and are shown in Figure 8; the horizontal error bars are the standard deviation of the 3-day averages. Numerical values are shown in Table 4.

The ozone partial pressure cross section is shown in Plate 2. The peak of the ozone layer is very clearly seen at 21 km, before and after the appearance of the ozone hole. During the ozone depletion period the partial pressure of ozone at 21 km drops by a

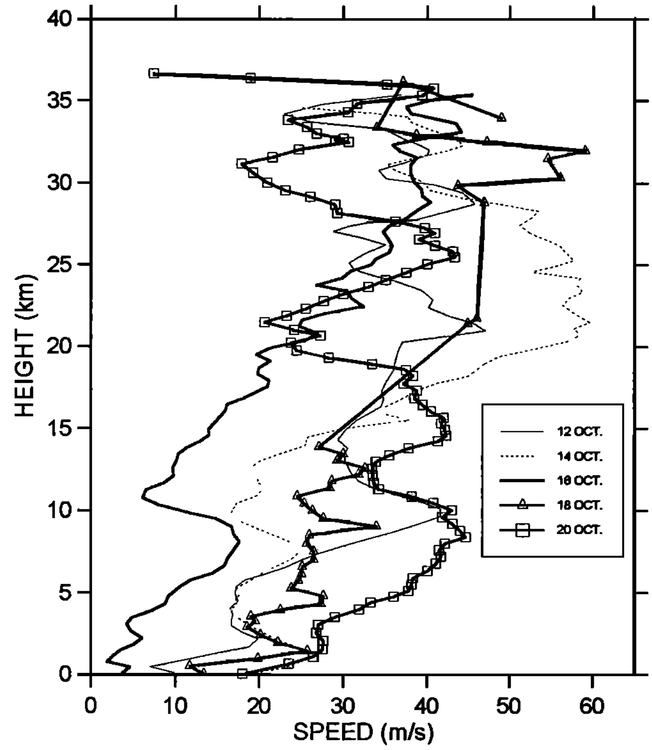

Figure 5. Mass plot of the wind velocity as a function of height for 5 days in October 1995 at Punta Arenas.

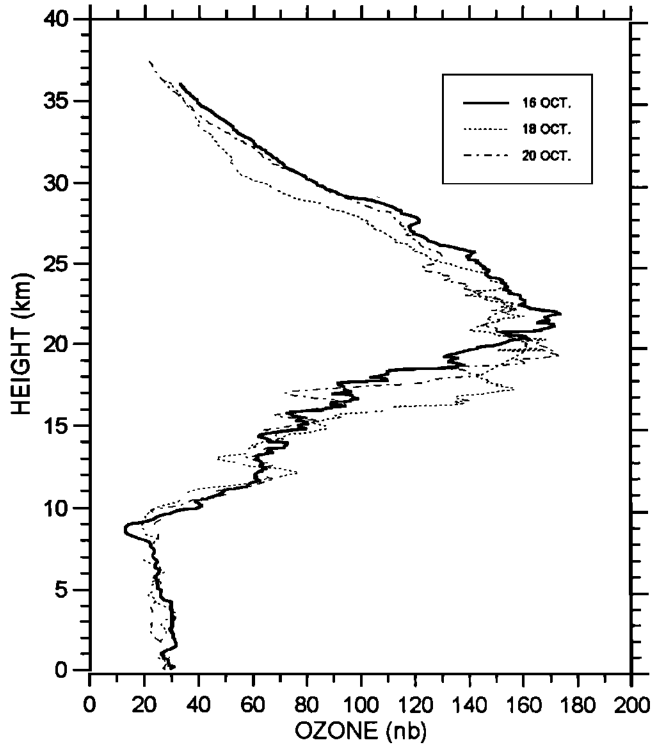

Figure 6. Vertical profile of ozone concentration, expressed as partial pressure, for 3 days in October 1995, outside the ozone hole period.

factor of 2, from the interval 150-175 to 75-100 nbar, during October 12-14.

The time evolution of the ozone partial pressures at different heights is very similar, as can be seen in Figure 9. The largest ozone depletion occurs in the height interval from 18 to 20 km, at the peak of the ozone layer. The depletion is smallest in the height region of 32-34 km. The ozone loss, that is, the depletion (of the average 3-day layer) relative to the normal (3-day average) layer is shown in Figure 10, using the same height intervals as those shown in Figure 9. Most of the different height intervals have a loss factor of about 40%, except for heights slightly below the peak, around 18 km, where the percent loss factor can reach up to 55%.

The consequence of the lower ozone concentrations in the stratosphere during perturbed days is a larger UVB intensity at ground level. Because of generally cloudy conditions in Antarctica, ground measurements of UVB radiation may be strongly affected by clouds. While this is not a serious problem for the measurement of ozone [*Brewer and Kerr*, 1973], it reduces direct UVB intensities considerably. The effect of clouds has been studied by *Tsay and Stamnes* [1992], and *Dahlback et al.* [1989] calculate the direct radiation intensities for clear skies.

Photobiologists express the impact of UVB radiation on different processes through action spectra, which are dimensionless numerical weighting factors which take into account the different efficiency of UVB at different wavelength. For obtaining a biologically effective value of a UVB radiation, the spectral irradiances (W/m^2/nm) are convolved with an action spectrum to produce the biological effective irradiance. Figure 11 shows the maximum UVB intensity (or UVB flux, integrated in wavelength, weighted by the International Commission on Illumination (CIE) action spectrum for erythema, [*CIE*, 1987] measured in W/m^2 for the days on which sondes were launched. These maximum values are observed near local noon. They may become small by attenuation from clouds, which is the case for the measurement of October 10, 1995. Clearly, the intensity for October 12, of more than 150 mW/m^2, reflects the ozone hole condition over Punta Arenas this day, being about 50% larger than the radiation intensity observed for the normal days.

More interesting to compare are the two UVB spectra, from 292 to 325 nm, one for a perturbed day (October 13, 1995, in this case) and one for a normal day (October 4, 1995), shown in Figure 12. The measurement units are W/m^2/nm (left vertical axis). Figure 12 also shows the ratio of the two UVB spectra to

Table 3. Wind Averages at Punta Arenas During October 1995

Height Interval, km	Speed, m/s		Direction, degree	
	Average	s.d.	Average	s.d.
0-2	10.03	8.26	233.21	75.80
2-4	11.46	6.85	257.5	61.68
4-6	15.38	7.93	259.75	57.80
6-8	22.29	7.22	271.51	61.70
8-10	24.98	9.35	271	65.74
10-12	22.30	10.40	281.73	53.88
12-14	25.03	10.96	273.17	45.49
14-16	29.78	13.75	273.13	44.86
16-18	33.23	15.31	266	42.89
18-20	40.22	17.61	261.62	42.94
20-22	46.19	16.97	262.67	42.00
22-24	46.94	18.19	259.33	41.75
24-26	47.98	15.47	255.91	43.44
26-28	49.73	15.00	256.84	43.42
28-30	51.08	14.72	253.21	41.53
30-32	48.29	13.54	247.85	39.25

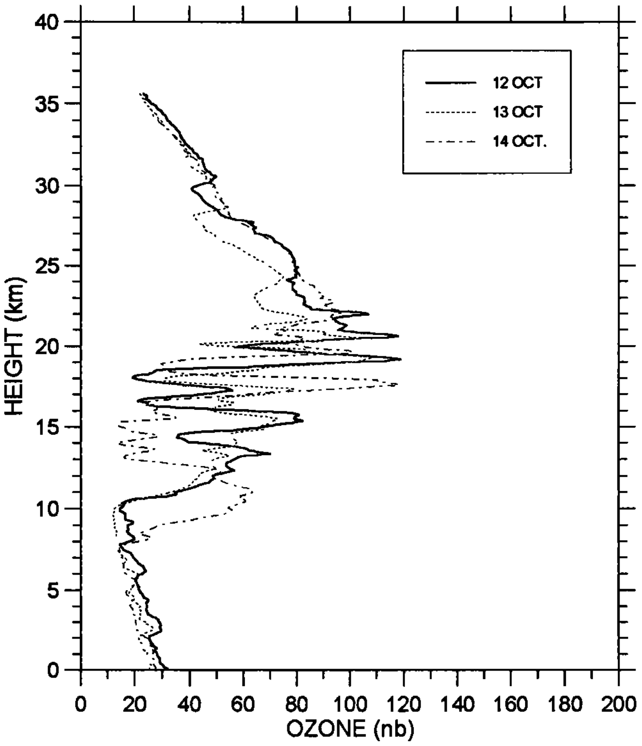

Figure 7. Vertical profile of ozone concentration, expressed as partial pressure, for 3 days in October 1995 during the ozone hole period.

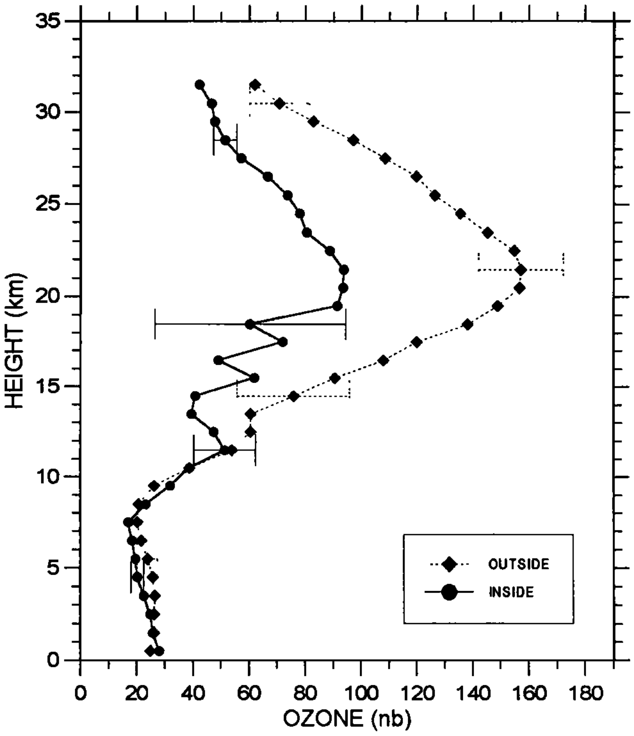

Figure 8. Average ozone profiles characterizing ozone hole conditions and normal conditions (when there is no ozone hole).

demonstrate by how much the radiation intensity increases with respect to the normal day. The ratio is displayed by squares; it has a clear maximum value (right vertical axis) of about 13, at 296-297 nm. Thus, at this wavelength, where by coincidence the human skin has its largest sensitivity, the UVB intensity on the perturbed day (October 13) was 13 times larger in comparison with the normal day (October 4). The decrease of the ratio at lower wavelengths, after the peak, may be a consequence of stray light. Although the data are subjected to a stray light correction, it may be necessary to improve the procedure at the shortest

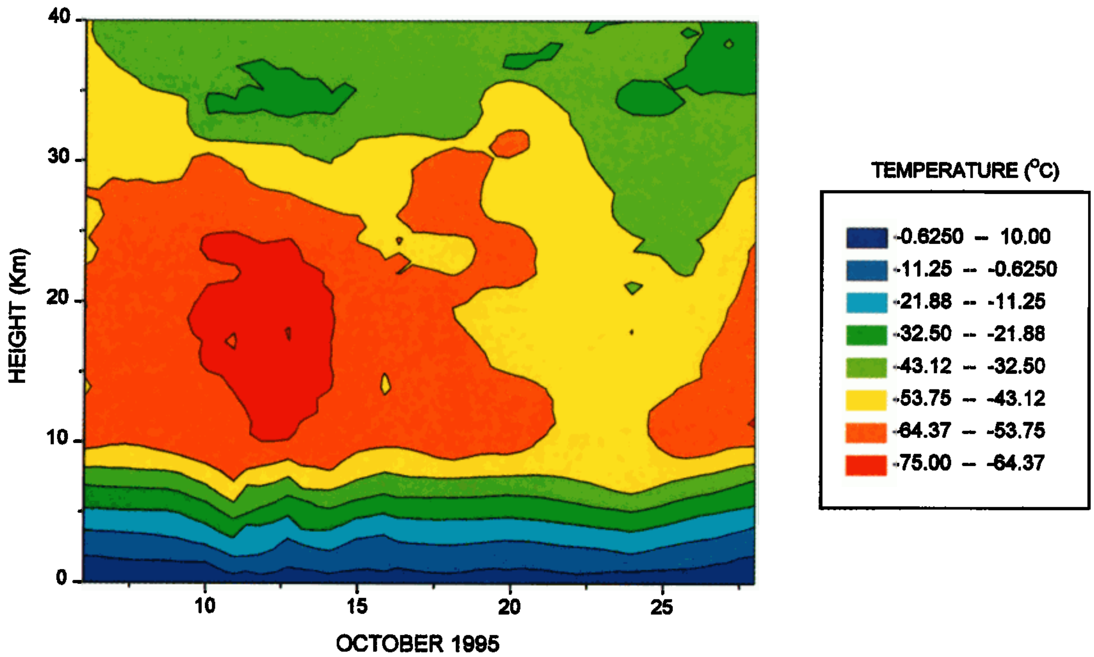

Plate 1. Height times time cross section showing the evolution of temperature during the ozone hole condition of October 1995 at Punta Arenas.

Table 4. Ozone Average Profiles for the October 1995 Soundings at Punta Arenas, Chile

	All Soundings		Soundings Outside Ozone Hole		Soundings inside Ozone Hole	
Height, m	Ozone, nbar	s.d.	Ozone, nbar	s.d.	Ozone, nbar	s.d.
500	25.56	3.67	24.68	3.80	27.77	2.12
1500	25.98	2.64	26.12	2.88	25.63	1.86
2500	25.78	3.34	26.17	3.46	24.78	2.83
3500	25.21	3.48	26.31	3.16	22.34	2.53
4500	23.98	4.02	25.59	3.45	20.1	2.26
5500	22.50	3.63	23.69	3.53	19.43	1.44
6500	20.49	4.23	21.35	4.38	18.32	2.88
7500	19.29	4.01	20.15	3.78	16.92	3.68
8500	21.34	7.74	20.61	6.79	23.13	9.56
9500	27.60	15.51	26.07	13.42	31.66	19.69
10500	38.76	17.65	38.76	16.48	38.76	20.87
11500	53.08	13.89	53.76	14.83	51.26	10.93
12500	57.03	12.48	60.38	11.51	47.37	9.98
13500	55.12	16.02	60.39	10.71	39.31	18.86
14500	67.55	24.95	75.73	20.11	40.64	20.09
15500	83.50	28.40	90.44	25.71	61.85	25.64
16500	93.93	37.60	107.89	29.05	49.08	24.62
17500	107.92	32.19	120.01	22.69	71.98	29.49
18500	115.96	43.42	138.32	20.78	60.34	33.97
19500	135.92	31.62	149.03	18.00	91.44	27.09
20500	139.08	33.23	156.83	14.74	93.39	21.91
21500	139.62	32.80	157.30	15.20	93.73	18.39
22500	137.60	33.88	155.08	17.68	88.67	14.75
23500	128.45	34.83	145.47	22.17	80.31	10.00
24500	117.34	34.91	135.51	26.90	77.95	3.47
25500	113.83	30.60	126.29	23.48	73.53	6.78
26500	107.25	28.41	119.61	19.03	66.34	9.35
27500	94.54	27.33	108.45	16.60	56.90	8.44
28500	87.15	23.55	96.84	15.95	51.23	4.11
29500	75.20	19.81	82.75	15.17	47.70	3.71
30500	64.08	14.14	70.62	10.67	46.46	1.88
31500	56.88	11.58	61.76	9.00	42.21	2.21

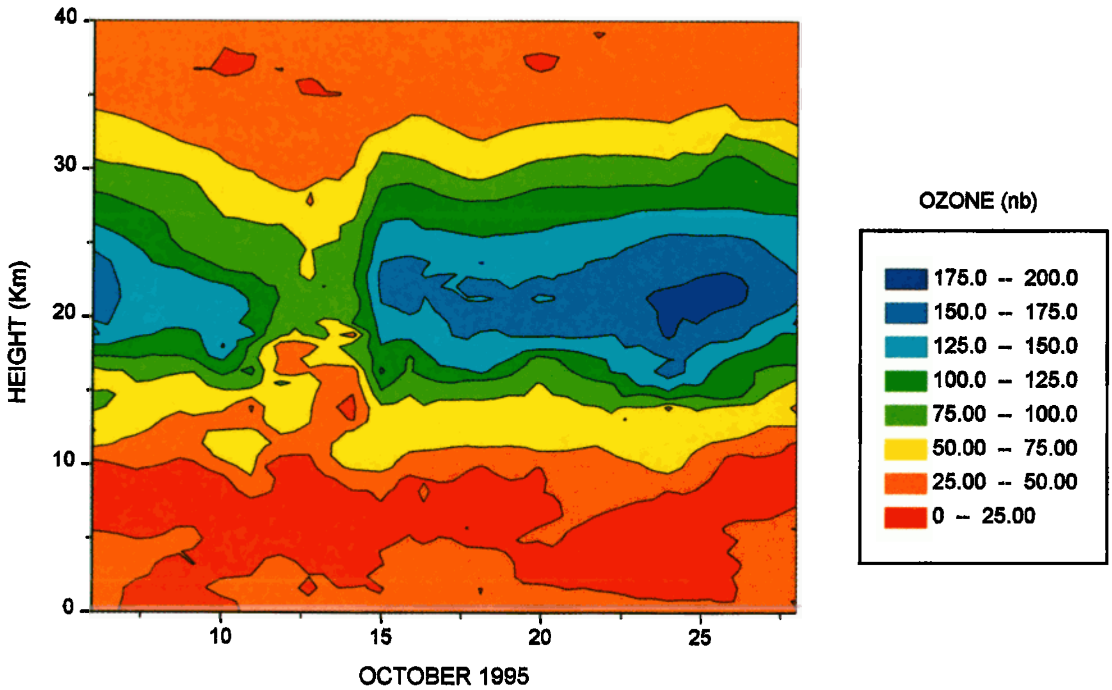

Plate 2. Height times time cross section of the ozone partial pressure showing its time evolution during the appearance of the ozone hole over Punta Arenas in October 1995.

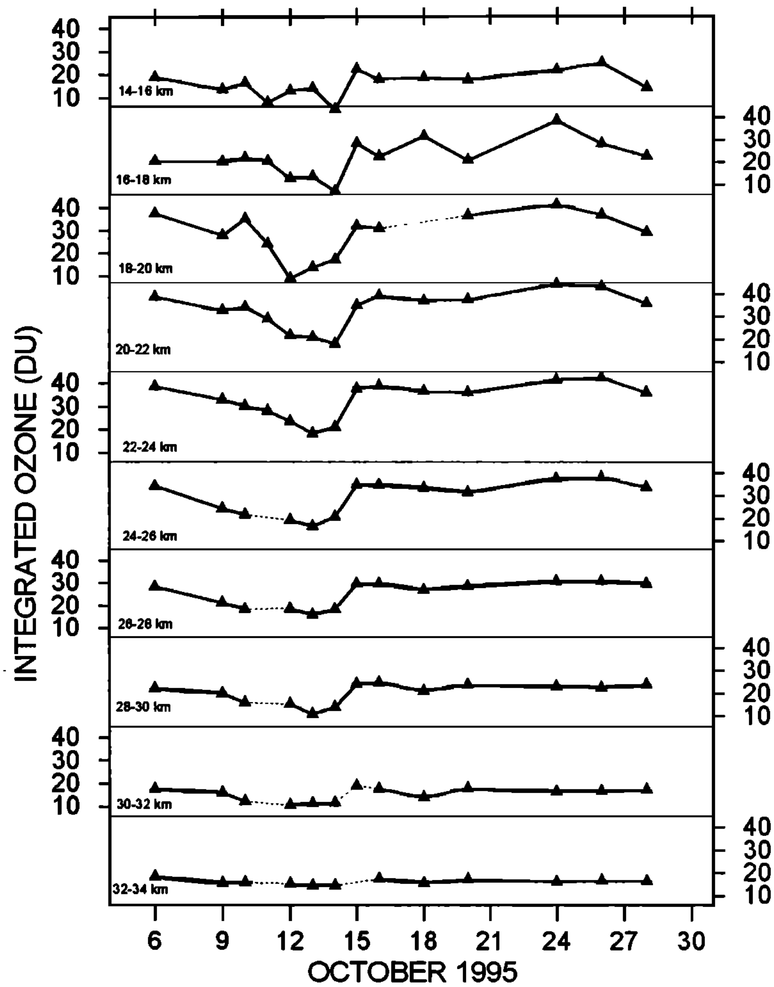

Figure 9. Average time evolution of ozone integrals in 2 km atmospheric layers, from just above the tropopause to the top of the ozone layer.

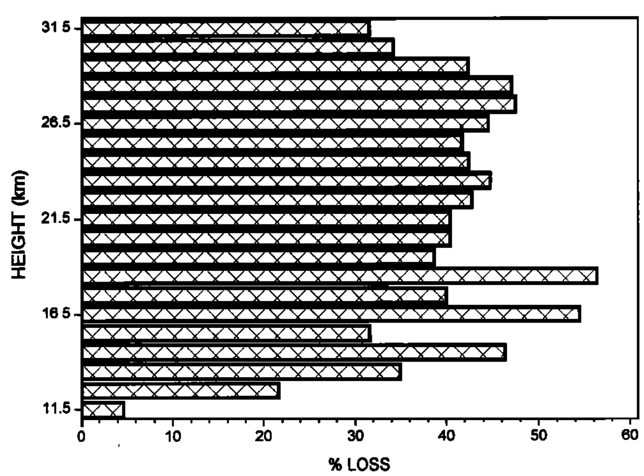

Figure 10. Ozone loss for the ozone hole condition, expressed in percentage of the normal layer.

wavelengths. To this end the stray light effect is presently under intense investigation by the manufacturer.

It is expected that large UVB enhancements have a changing effect on the environment, which in Antarctica means especially the ocean life systems. Is the phytoplankton primary production, which is the basis of the food chain, affected by changes in UVB? This question has been addressed by *Lubin et al.* [1992] pointing out that the highest productivity of the coastal waters of the southern ocean coincides with late spring and early summer: Phytoplankton blooms are initiated during the period of maximum ozone hole development in Antarctica.

Other UVB-induced biological effects on plants, animals, and populated communities such as Punta Arenas are expected as well. The task of observing the effect of enhanced UVB on these areas will require an enormous multidisciplinary effort. The medical community is already very interested in health problems associated with UVB enhancements. We hope that the results of this comprehensive documentation of the 1995 ozone hole appearance over Punta Arenas will further stimulate research in related scientific areas.

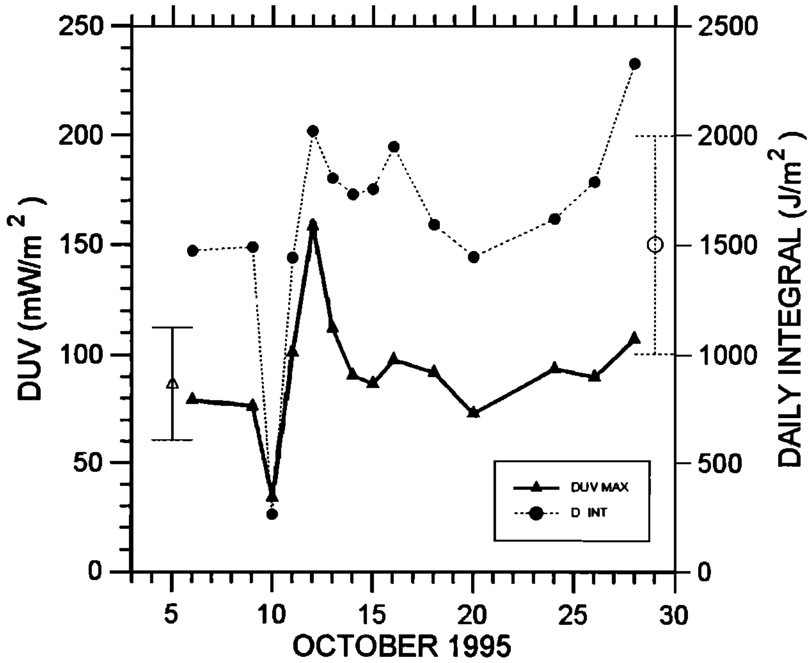

Figure 11. Maximum UVB radiation intensity measured with a Brewer spectrophotometer during the ozone hole appearance in October 1995 at Punta Arenas. The maximum observations near local noon are shown, as well as the daily radiation time integrals.

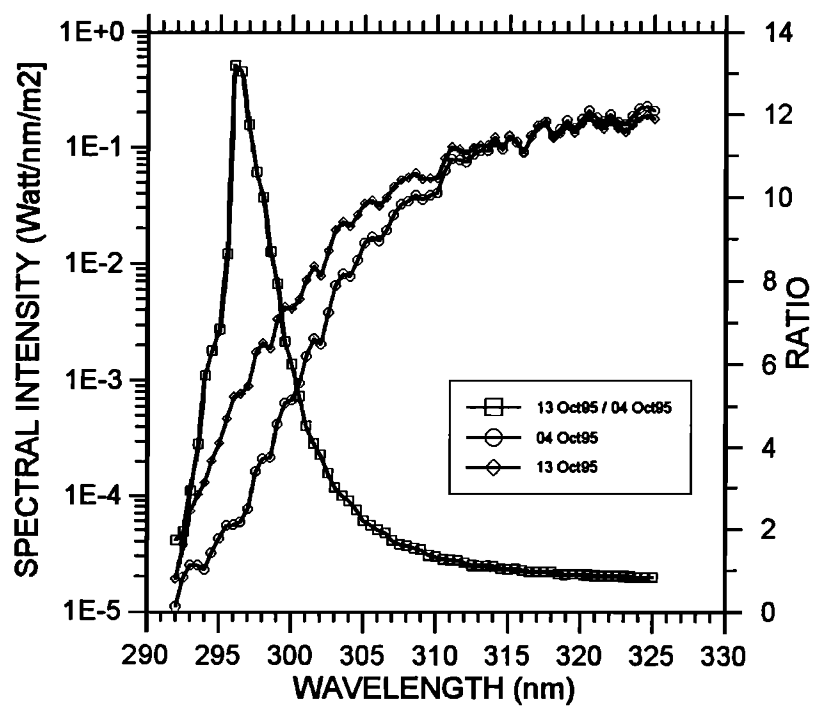

Figure 12. UVB spectra measured with a Brewer spectrophotometer for 2 days in October 1995 at Punta Arenas. The ratio of the two spectra is also shown to express the difference between the perturbed day and the normal day.

Summary

The Antarctic ozone hole has been observed over Punta Arenas, Chile, a populated region of 100,000 inhabitants across the Antarctic Peninsula. Measurements of the vertical column of ozone and UVB radiation from 290 to 325 nm were made with a Brewer spectrophotometer. The vertical distribution of ozone was measured by using ECC ozonesondes launched on balloons. The ozone hole appearance over Punta Arenas in 1995 is documented in detail, showing the following highlights:

1. In 1995 the ozone hole appeared over Punta Arenas during approximately 4-5 days in October, when the ozone column decreased to values of about 200 DU.

2. The vertical ozone concentrations measured by ECC ozonesondes were reduced to approximately 50%. Most of the ozone depletion occurs around the peak of the ozone layer, but percentwise the depletion is more severe in the lower stratosphere.

3. The stratospheric temperatures decreased by more than 10° during the appearance of the ozone hole.

4. The highest integrated UVB biologically effective intensity, near local noon, was observed on October 12, 1995, with 160 mW/m^2, which is twice as much radiation as the normal background, and of the order of average summer intensities.

5. Wen we look at the spectral intensities more carefully, the perturbed days have shown intensities more than 10 times as large as those on nonperturbed days. At 297 nm, for example, where the ratio maximizes, there was 13 times more intensity ($mW/m^2/nm$) on October 13 than on October 4.

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