Atmósfera 21(1), 1-12 (2008)

Erythemal irradiance at the Magellan's region and Antarctic ozone hole 1999-2005

C. CASICCIA, F. ZAMORANO
Laboratorio de Ozono y Radiación Ultravioleta, Universidad de Magallanes, UMAG
Avda. Bulnes 01855, Casilla 113-D, Punta Arenas, Chile, and
Centro de Estudios del Cuaternario Fuego-Patagonia y Antártica
Avda. Bulnes 01890, Punta Arenas, Chile
Corresponding author: C. Casiccia; e-mail: claudio.casiccia@umag.cl

A. HERNÁNDEZ
Centro de Estudios del Cuaternario Fuego-Patagonia y Antártica
Avda. Bulnes 01890, Punta Arenas, Chile

Received August 17, 2006; accepted April 12, 2007

RESUMEN

La parte más austral del cono sur de Sudamérica, que algunas veces se encuentra bajo la influencia del agujero de ozono antártico (AOA), ocasionalmente recibe altos niveles de radiación ultravioleta B (UV-B: 280-320 nm). La Universidad de Magallanes en Punta Arenas, Chile (Lat. 53° S; Long. 70.9° W), ha realizado mediciones de radiación ultravioleta eritémica desde 1999, las cuales se iniciaron con la instalación de cuatro instrumentos en diferentes localidades de la región de Magallanes, la región más austral de Chile y próxima al continente Antártico. En este estudio se muestran los datos obtenidos con instrumentos Solar Light en diferentes puntos de la región de Magallanes desde 1999 hasta 2005, como también datos de la columna total de ozono medida en Punta Arenas con el instrumento Brewer (Serie 180) además de datos del Total Ozone Mapping Spectrometer (TOMS). Estos datos muestran un número significativo de días en 2004 con baja concentración de ozono, señalando que la recuperación de la columna de ozono en estas latitudes es todavía incierta. Se han analizado datos de mediciones de radiación eritémica obtenidos de las estaciones de la red de medidores instalada en la región de Magallanes, con especial atención al periodo primavera verano, en el que la actividad del AOA es más intensa. En algunas ocasiones se observaron disminuciones entre 20 y 53% en la columna total de ozono. Durante estos periodos también se observaron aumentos de la radiación UV-B. Al comparar éstos, con los valores de radiación para aquellos días considerados normales, los niveles de radiación UV-B son mayores aproximadamente entre 50 y 200% en las diferentes estaciones.

ABSTRACT

The most austral zone of the Southern Cone of South America, which is sometimes under the influence of the Antarctic Ozone Hole (AOH), occasionally receives enhanced levels of ultraviolet B radiation (UV-B: 280-320 nm). Ultraviolet erythemal irradiance measurements began in 1999 by the University of Magallanes in Punta Arenas (Lat. 53.0° S; Lon. 70.9° W), Chile, with the installation of four instruments in different locations in the Magallanes region, which is the southernmost region in Chile and the nearest to the Antarctic Continent.

Data from Solar Light instruments, the Brewer spectrophotometer (Serial 180) and the Total Ozone Mapping Spectrometer (TOMS) from 1999 to 2005 for the Magellan's Region is presented in this paper. These data show a significant number of days in 2004 with low ozone concentrations, specifying that recovery of the ozone column at these latitudes is still uncertain. Data of erythemal measurements from the stations that are part of the Magallanes network were analyzed, with extra attention given to the spring-summer period when the activity of the AOH is more intense. On several occasions important decreases down to 20-53% in the total ozone column were observed. Along with these decreases, increased levels of UV-B radiation were observed. When compared to normal daily concentration values of the total ozone, the days with increased UV-B levels reached values between ~50 and ~200% above normal at the different stations.

Keywords: Ozone, ozone hole, UV-B radiation, Antarctic ozone hole.

1. Introduction

Antarctic stratospheric ozone loss has been regularly measured since the mid 1970s. During springtime this dramatic reduction in the Antarctic stratosphere has been named the Antarctic Ozone Hole (AOH) (Chubachi, 1984; Farman *et al*., 1985; Stolarski *et al*., 1986). The AOH has grown in intensity (minimum average measurements) and in the amount of area covered (WMO, 2003). Record ozone hole sizes close to 29 and 28 million km^2 during 2000 and 2003 were observed, respectively; the size during 2004 was almost 20 million km^2 and in 2005 was 25 million km^2. These values show a high inter-annual variability of the AOH size during the period 2000-2005. In terms of intensity of the AOH, considering the minimum measured at the Antarctic region in September-December period, it has been maintained under 100 Dobson units (1 Du = 0.001 atm cm) values (http://toms.gsfc.nasa.gov). This pronounced seasonal ozone loss results from heterogeneous chemical reactions (Stolarski *et al*., 1986; Solomon and García, 1986) and dynamical processes (Prather *et al*., 1990), which enhance ozone loss by reactions with chlorine and bromine (WMO, 2003).

Due to the dynamic conditions of the behavior of the Antarctic polar vortex, the AOH is not restricted to the Antarctic region. It also periodically affects lower latitudes during each spring, and the depletion of the total ozone produces abrupt increases of the ultraviolet radiation B (UV-B) (Casiccia *et al*., 1996, 2003; Kirchhoff *et al*., 1997a). This increase of the UV-B radiation is considered harmful to living beings of those lower latitudes (Diffey, 1991).

Regions near the South Pole, such as Chilean and Argentinean Patagonia and Tierra del Fuego island are locations that are affected by the AOH phenomenon (e.g. Pazmiño *et al*., 2005; Casiccia *et al*., 1996, 2003; Kirchhoff *et al*., 1997b, 1997c; Cede *et al*., 2002). Due to the geographic proximity of the AOH and its characteristic distortion, rotation and displacement, the population in this area may be the first human group to show health problems resulting from environmental effects of severe ozone depletion (Abarca and Casiccia, 2002; Abarca *et al*., 2002).

In order to study the influence of the AOH over the austral zone of the South Cone of South America, the Laboratory of Ozone and Ultraviolet Radiation of the University of Magallanes has installed a network of four radiometers that have been distributed throughout the Magallanes region: these stations are located in the following places: Puerto Natales (Lat. 51.9S; Lon. 70.9W), Punta Arenas (Lat. 53S; Lon. 70.9W), Puerto Porvenir (Lat. 53S; Lon. 70W) and Puerto Williams (Lat.

54S; Lon. 68W). Here we present the UV-B measurements and a detailed analysis of the erythemal irradiance (UV-Index) at each station during the period 1999-2005. Erythemal irradiance is defined as the wavelength-integrated spectral ultraviolet irradiance weighted with the CIE (Comission Internacionale de 1´ Éclairage-International Comission on Illumination) action spectrum for erythema normalized to 1 at 298 nm (McKinlay and Diffey, 1987). Here we used the UV-Index defined as 1 UV - Index = 25 m W/m^2 (for details visit: http://www.epa.gov/sunwise/uvilaunch.html). The present paper also shows the relationship between the ozone and the UV-Index measured at Magallanes region especially during the Antarctic ozone hole events.

2. Instruments and location

Each radiometer station is equipped with biometers Model 501 UV of the Solar Light Co. (SL501) and they are distributed in the Magallanes region. The interval of measurements is 15 minutes for each instrument (Fig. 1 and Table I). The Puerto Porvenir station data were not included in the analysis because the UV-Index variations are similar to those of the Punta Arenas station (station 2). These UV-B instruments use an action spectrum for erythema (McKinlay and Diffey, 1987). Once a year during winter time all instruments are located together with Brewer in Punta Arenas to determine the stability of the UV-Index measurements and very small corrections are applied to the biometers. Figure 2 shows results of inter-comparison campaigns during January-March 2002; the values considered for UV-Index in both instruments were those around the minimum solar angle and during selected clear sky days. The SL501 measurements correlate well with Brewer, with all correlation coefficients around 0.98. The total ozone column in Punta Arenas was measured with a Brewer MK-IV spectrophotometer, serial 068 (1999-2000) and a Brewer MK-III double monochromator serial 180 (2002-2005 with gap during 2004). The Brewer instrument includes automatic wavelength calibration using an internal mercury discharge lamp as well as a relative spectral intensity source from a quartz-halogen lamp (Brewer, 1973; Brewer and Kerr, 1973). For Puerto Natales and Puerto Williams stations the total ozone column used was TOMS data because in these locations we do not have surface measurements.

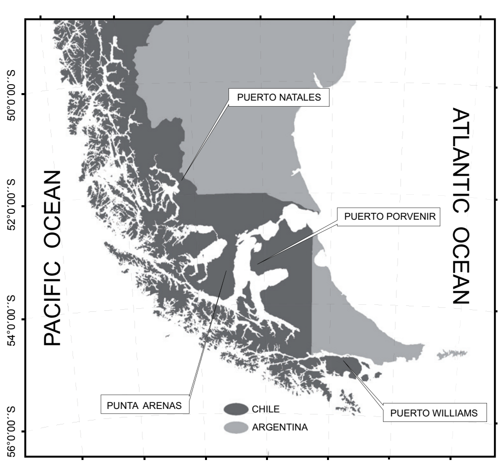

Fig. 1 . Geographical distribution of the Solar Light instruments of the Magallanes network.

3. Measurements

In Figure 3 the total ozone column for 2003 and 2005 for Punta Arenas is shown. Each point represents the mean for each day of the total ozone column obtained from the Brewer spectrophotometer, the 220 DU dashed line is shown for reference to the AOH condition. Conventionally, it is considered that there is an ozone hole when the ozone abundance is ≤ 220 DU in a specific geographic place. The hatched area indicates the high activity period of the AOH over Punta Arenas (and Magallanes region) from late August until end of October, and occasionally some activity of the AOH is observed over the Chilean-Argentine Patagonian region during November and December. Using TOMS overpass data for Punta Arenas, monthly means were constructed from 1978 to 1987, a period which may be considered as not influenced by the AOH. For reference, the vertical bars in this figure show the mean values and their respective deviations; these values are called AVE-CLI-TOMS in this work (Table 1 in Casiccia *et al*., 2003). On October 6, 2003, the ozone column measured was 159.7 DU, which is the lowest value in the last four years, and considering the monthly mean of AVE-CLI-TOMS it corresponds to 52% of ozone depletion. At the end of November 2003 (Julian days 330 to 333) there was another depletion event which technically was not an AOH event because the lowest ozone concentration measured was 227.7 DU, however, it was a 33% decrease compared to the AVE-CLI-TOMS for this month. Two years later, on October 8, 2005 the total ozone column measured was 161 DU, 52% lower than the AVE-CLI-TOMS. The behavior of the total ozone during September-October period was similar to that of 2003. In Figure 3b we find low values of ozone during February-April period in comparison with the AVE-CLI-TOMS. Several studies (e.g., Fioletov and Shepherd, 2003, 2005; Ajtić *et al.,* 2004) have demonstrated that these low values in the total ozone column can be explained by transport of ozone-depleted from Antarctic latitudes. The occurrence of low ozone concentrations events in the Magallanes region depends on the AOH behavior in terms of dynamical conditions of the polar vortex. The number of days in which the AOH has been over the Magallanes region varies from year to year. Figure 4 shows the number of events of low ozone in Punta Arenas. Because the Brewer 068 was returned to Brazil in 2001 and due to technical problems with the spectrophotometer Brewer 180 during 2004, we used TOMS data for these two years. Typically, results of comparisons of total ozone between ground stations and TOMS show a good agreement, with some exceptions especially in high latitudes. Labow *et al*. (2004) pointed out that the agreement of data of total ozone from TOMS and ground stations are very good, but should not be used for trends studies. The criterion for defining an event of low ozone is that the ozone column (daily average) must be lower than the reference AVE-CLI-TOMS minus twice the standard deviation of the mean (mean monthly-2σ). The number of days per year is shown in Figure 4a. During the period 1994-1999 a significant number of low ozone days were observed each year. Between 2001 and 2003 there were fewer significant days with low ozone events. However, during 2004 the number of days began to increase again recording 86 days and during 2005, 47 days were measured with low ozone events. Figure 4b shows the significant number of days per month, clearly showing the high variability during spring time. After 1995 the higher frequency occurred in February of 1998 with 27 days. Table II shows the number of days with events of low ozone in September-January period for each year (1992-2005). It is also important to take into consideration the number of days during the summer time, especially during January, because of the influence of the solar angle on the ultraviolet radiation during this period as well.

Table I. Stations and details of the Magallanes network of biometers.

Station	SL number	Latitude south	Longitude west	Height m	Start of database	Measurement interval, min
Puerto Natales	3739	51	70.9	18	Sept. 1998	15
Punta Arenas	3738	53	70.9	12	Sept. 1998	15
Puerto Porvenir	3740	53	70	26	Oct. 1998	15
Puerto Williams	3737	54	68	20	Oct. 1998	15

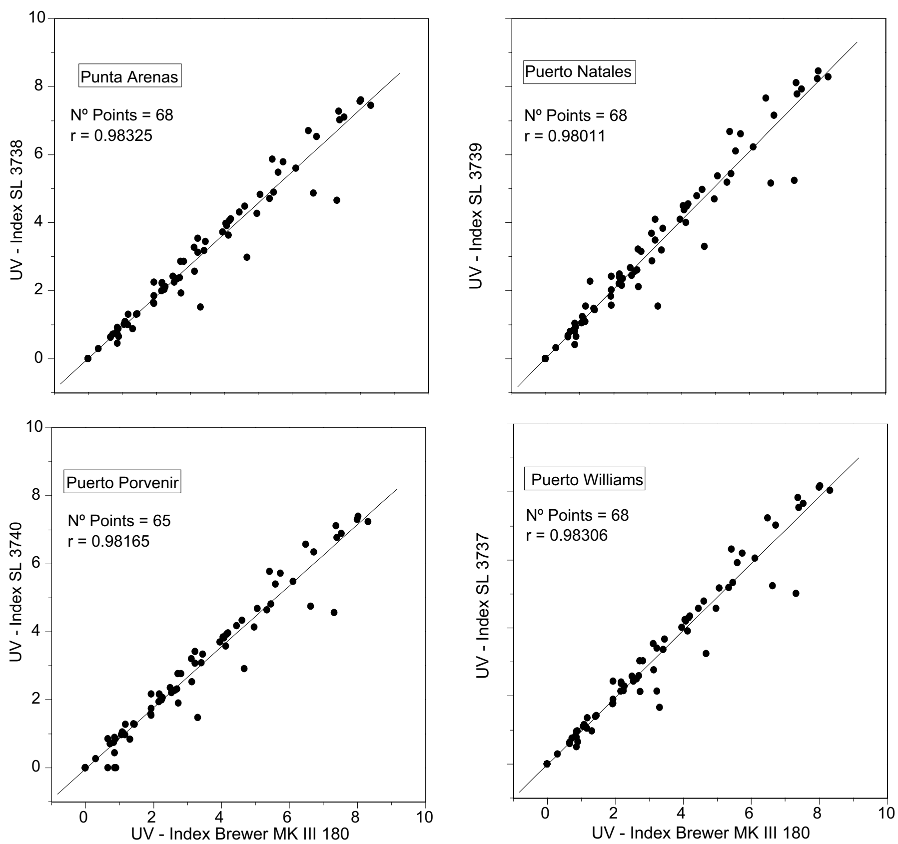

Fig. 2. Comparisons of UV-Index measurements with a Solar Light 501 (SL501) biometer and Brewer No. 180 during the intercomparison campaign, January-March 2002.

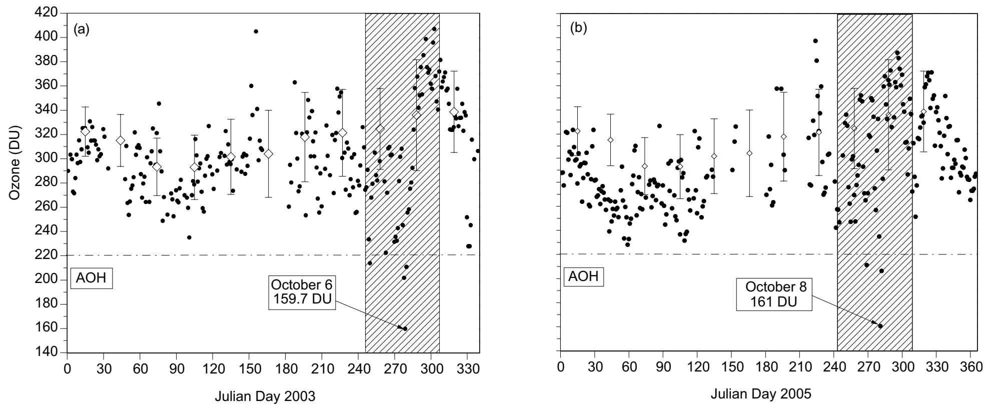

Fig. 3. Total ozone observed at Punta Arenas measured by Brewer instrument during 2003 a) and 2005 b). The vertical bar represents the AVE-CLIM-TOMS reference average plus and minus one standard derivation, shown for comparison.

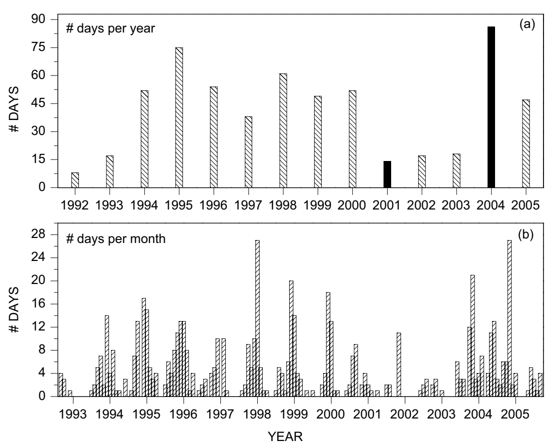

Fig. 4. Number of days under the climatological average minus two standard deviations. Data of 2001 and 2004 from TOMS instruments.

Table II. Number of days of low ozone events 1992-2005 for Punta Arenas station.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Sept.	4	2	1	6	3	1	5	-	7	2	1	6	13	5
Oct.	3	5	7	4	-	2	4	-	9	2	2	3	3	3
Nov.	-	7	13	8	4	9	1	2	-	-	3	3	2	1
Dec.	1	2	-	11	5	5	6	4	-	-	-	-	6	4
Jan.	-	-	14	17	13	10	10	20	18	2	-	2	12	6

Figure 5 presents the UV-Index for the minimum solar angle measured each day for the stations. Communication problems caused some gaps initially, which in turn caused the loss of some data. Figure 5 shows the typical annual variation of the UV-Index radiation with the minimum in winter and a gradual increase in the spring-summer period. During the austral spring time peak values were comparable to those in summer due to the influence of the AOH. The influence of the AOH and the sudden changes that occurred will be analyzed with events of extremely low ozone column during some days.

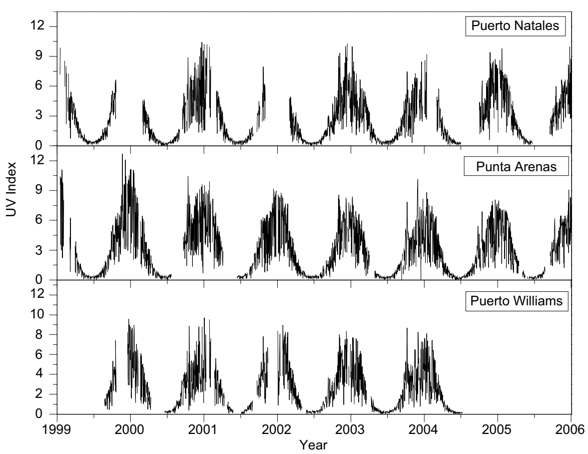

Fig. 5. UV-Index at the minimum solar angle, to 1999-2005 period for all stations of the Magallanes network obtained by the Solar Light Instruments.

Figure 6 shows the UV-Index and total ozone from September to October for the period 2000 to 2005 for each station; in the construction of this figure, months of the AOH activity, which vary from year to year, have been considered. The first plot of each of them shows the total ozone column for Punta Arenas measured with the Brewer instrument, and it also shows the events of the AOH over the stations of the network. For the year 2001 and 2004 data obtained from the TOMS instrument were used. On October 12, 2000 the ozone column in Punta Arenas was measured to be 162 DU, which represents 46% taking as a reference October 10 with 324 DU. On October 21, 2001 the ozone column was 219 DU in Punta Arenas showing UV-Index peaks in the stations of Puerto Natales and Puerto Williams. Punta Arenas was cloudy during this day and did not show a significant increase in the UV-Index. The year 2002 was the year that the AOH broke up early and did not have significant days with low ozone levels. October 6, 2003 was a day of low ozone in which the ozone column was 159.6 DU, which represents an ozone reduction of 52.5%. In reference to the AVE-CLI-TOMS this percentage is similar considering the ozone column of October 13, 2003 when it was 323 DU, which signifies 51% decrease. It occurred in three days. On October 12, 2004 (Table III), 195 DU was measured in Punta Arenas (TOMS data), –44% of depletion in comparison with October 19 with 350 DU. In 2005, specifically on October 8, there was a new and significant event that was similar to that in 2003. On that day the ozone column measured was 160 UD (Table III), what represented a decrease of 52% compared to October 10. In Puerto Natales station, on October 8 when the total ozone column was 165 DU, a decrease in the erythemal radiation was observed due to the cloudy sky conditions. During 2005 the station in Puerto Williams was not operative.

Figure 7 shows a comparison between two days, one with normal ozone and the other under the AOH during the events of 2003. On October 6, 2003 the measurements of the ultraviolet radiation at the different stations indicated the increase of the UV-Index as follows: Puerto Natales 7.3, Punta Arenas 7.7 and Puerto Williams 8.6. This sequence shows the different conditions of the ozone column over the region. The Puerto Williams station is closer to the Antarctic continent. From TOMS observations to this point the ozone column on October 6, 2003 was 135 DU (Table III), which is lower than in Punta Arenas, where it was 159 DU. In Puerto Williams the UV-Index increased 196.6% on October 13, 2003. Table III summarizes the percentage of depletion of ozone considering for each event a day with normal ozone column (for example October 10, 2000) in comparison with the day of low ozone (October 12, 2000); this table shows the increase of the UV-Index in all stations when the solar angle was at minimum angle during these days.

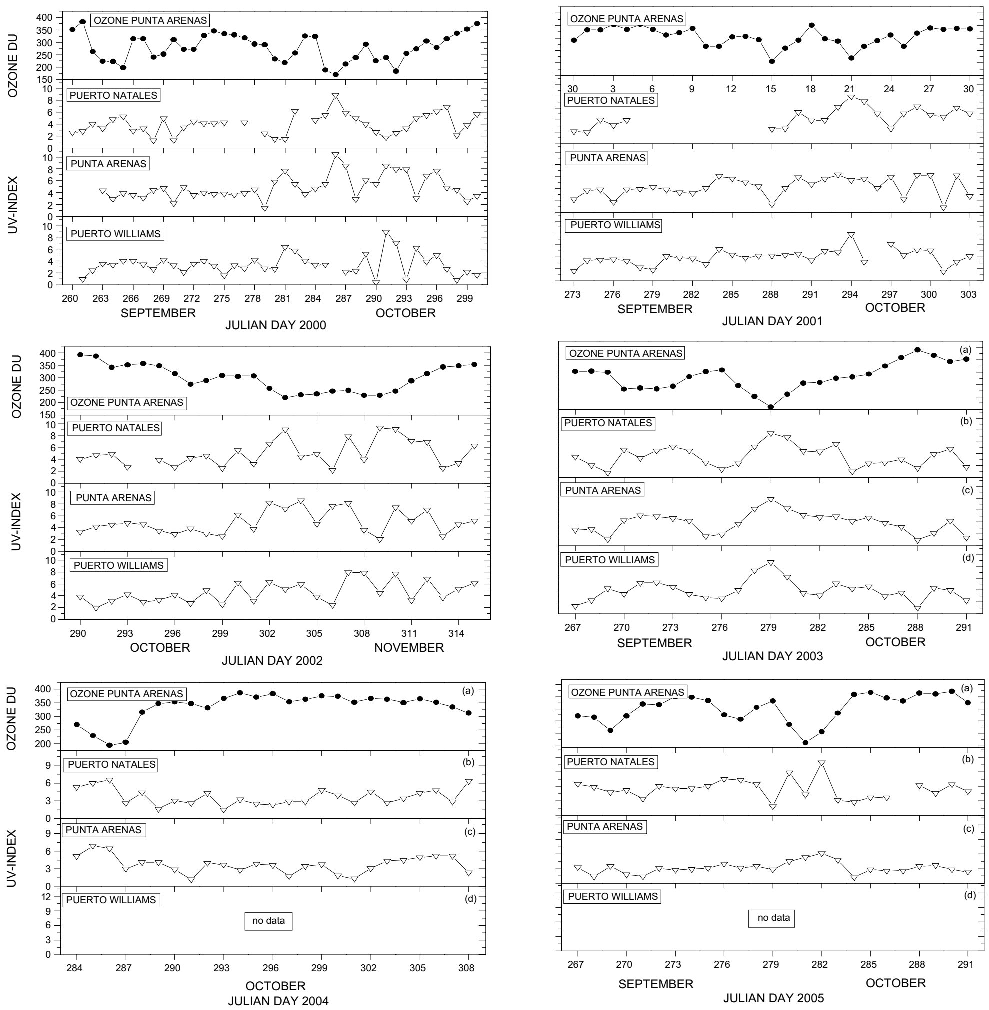

Fig. 6. UV-Index at the minimum solar angle during periods of the activity of the AOH over the Magallanes region. Ozone column measured at Punta Arenas is included.

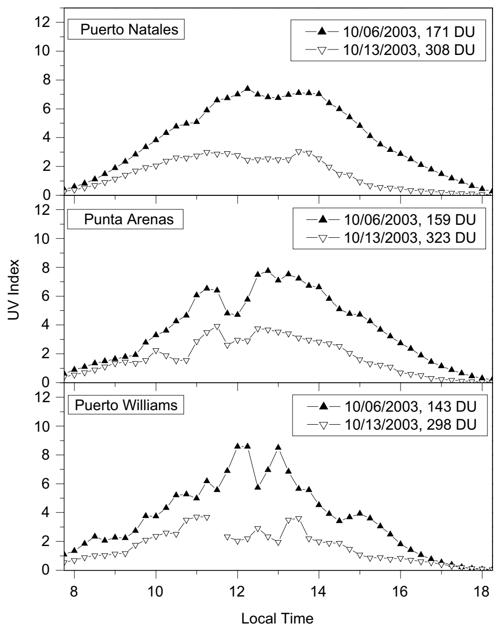

Fig. 7. Daily variation and comparison of the UV-Index of two close days, one of them with low ozone and the other with normal ozone during an event on October 6, 2003, at the stations Puerto Natales, Punta Arenas and Puerto Williams.

Table III. Ozone and UV-Index and percentage of increment at different stations (Table I) during the events of AOH over Magallanes.

Station	Ozone	UV Index	Ozone	UV Index	O_3 %	UV Index increment %
October 2000	12		10			
Puerto Natales*	180	8.9	332	4.6	–45.8	+93.5
Punta Arenas	170	10.4	324	4.6	–47.5	+126.1
Puerto Williams*	142	2.1	299	3.4	–52.5	–38.2
2001	21		19			
Puerto Natales*	257	8	313	4.0	–17.9	+100.0
Punta Arenas	219	5.3	297	5.6	–26.3	–5.4
Puerto Williams*	208	7.8	274	5.0	–24.1	+56.0
2003	6		13			
Puerto Natales*	171	7.5	308	2.5	–44.5	+200.0
Punta Arenas	159	7.8	323	3.8	–50.8	+105.3
Puerto Williams*	144	8.7	308	3.0	–53.2	+190.0
2004	12		19			
Puerto Natales*	218	6.6	366	1.5	–40.4	+340.0
Punta Arenas*	195	6.9	350	3.5	–44.2	+86.5
2005	8		6			
Puerto Natales*	165	1.9	334	4.8	–50.6	–60.4
Punta Arenas	160	5.7	333	3.2	–51.9	+78.1

*Ozone values retrieved from TOMS http://toms.gsfc.nasa.gov

Figure 8a shows the time evolution for ozone over Punta Arenas and 8b the cross section of the UV-Index between 08:00 and 18:00 h (local time) in the period September 1, 2004-October 31, 2004, (Julian day from 245 to 305). The measurements of the UV-Index correspond to the UV-Biometer 3738, and the total ozone data to Brewer 180, both at Punta Arenas station. This figure shows two significant events of ozone depletion on September 21 (JD 265) and October 12 (JD 286) with 179 DU and 195 DU respectively. The measurements of the alteration of the normal UV-Index behavior indicated peaks in the UV-Index of 5.4 on September 21 and 6.9 on October 12. These values are similar to those observed during the summer period, but they show increases on a few days and we need to consider that during this time the organisms of this region had just received values relatively low.

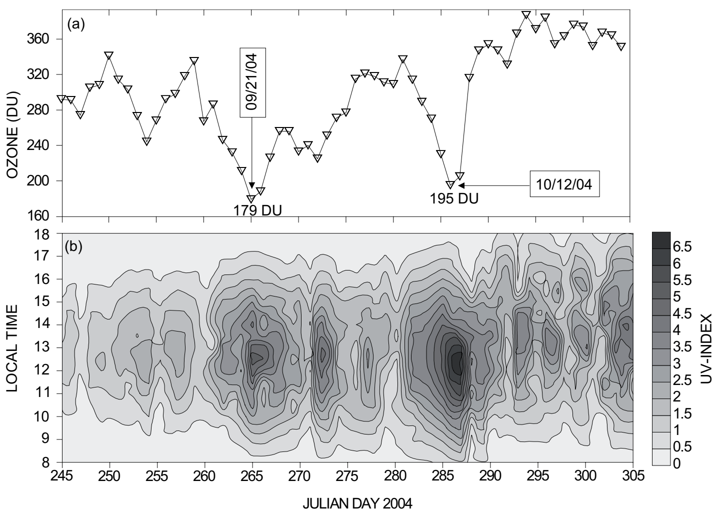

Fig. 8. a) Ozone column measured from Brewer 180 at Punta Arenas, September-October 2004. b) Daily evolution of the UV-Index.

4. Conclusions

UV Index measurements were taken over the Magallanes region with Solar Light biometers for latitudes from 51 to 54 South. The data indicate that this region is regularly subject to the influence of the AOH during the spring time. From Brewer ozone and TOMS data measurements during 2004-2005 period, a significant number of days that were under the climatological average were detected, this was the largest number observed so far considering the period of AOH activity during the last decade. During the period from August to October 1999-2005 pronounced increases in UV-B radiation were measured during days of low ozone. An example is October 12, which had an UV-Index of 9 and October 15, which had an UV-Index of 5. These numbers represent an increase of 100% in the integrated weighted values for erythema. These sudden changes in the incident radiation are very important for the particular study of UV radiation effects in the ecosystems at middle latitudes.

Acknowledgments

This work was supported in part by the Project "Centro de Estudios del Cuaternario Fuego-Patagonia y Antártica-CEQUA", it is financed by the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT-Chile) and the Government of the Magallanes Region. The spectrophotometer Brewer 068 was installed in Punta Arenas in 1992 thanks to an agreement between the Instituto Nacional de Pesquisas Espaciais (INPE-Brazil) and the Magallanes University (Chile). We are grateful for the provision of the TOMS data (via NASA/GSFC Code 613.3). In memory of Jim Scamlon.

References

Abarca J. F. and C. Casiccia, 2002. Skin cancer and ultraviolet-B radiation under the Antarctic ozone hole: southern Chile, 1987-2000. *Photodermatol. Photo.* **18**, 294-302.

Abarca J. F., C. Casiccia and F. Zamorano, 2002. Increase in sunburns and photosensitivity disorders at the edge of the Antarctic ozone hole, Southern Chile, 1986-2000. *J. Amer. Acad. Dermatol.* **46**,193-199.

Ajtić J., B. J. Connor, B. N. Lawrence, G. E. Bodeker, K. W. Hoppel, J. E. Rosenfield and D. N. Heuff, 2004. Dilution of the Antarctic ozone hole into southern midlatitudes, 1998-2000. *J. Geophys. Res*. **109**, D17107, doi:10.129/2003JD004500.

Brewer A. W., 1973. A replacement for the Dobson spectrophotometer? *Pure Appl. Geophys*. **106-108**, 919-927.

Brewer A. W. and J. B. Kerr, 1973. Total ozone measurements in cloudy weather. *Pure Appl. Geophys*. **106-108**, 928-937.

Casiccia C., V. W. J. H. Kirchhoff, V. Valderrama, F. Zamorano and Y. Sahai, 1996. Ozone hole observations over Punta Arenas, Chile. In: Proceedings of the XVIII Quadrennial Ozone Symposium L´Aquila, 12-21 September 1994-Italia, Atmospheric Ozone. Vol. 1, (R. D. Bojkov and G. Visconti, Eds.) 17-21.

Casiccia C., V. W. J. H. Kirchhoff and A. C. Torres, 2003. Simultaneous measurements of ozone and ultraviolet radiation: spring 2000, Punta Arenas, Chile. *J. Atmos. Env*. **37**, 383-389.

Cede A., E. Luccini, L. Núñez, R. Piacentini and M. Blumthaler, 2002. Monitoring of erythemal irradiance in the Argentine ultraviolet network. *J. Geophys. Res*. **107**, 4165, doi:10.1029/2001JD001206.

Chubachi S., 1984. Preliminary result of ozone observations at Syowa Station from February 1982 to January 1983. *Mem. Natl. Inst. Polar Res. Jap. Spec*. **34**, 13-19.

Diffey B. L., 1991. Solar ultraviolet radiation effects on biological systems. *Phys. Med. Biol.* **36**, 299-328.

Farman J. C., B. G. Gardiner and J. D. Shanklin, 1985. Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction. *Nature* **315**, 207-210.

Fioletov V. E. and T. G. Shepherd, 2003. Seasonal persistence of mid latitude total ozone anomalies. *Geophys. Res. Lett*., **30**, 1417, doi:10.129/2002GL016739.

Fioletov V. E. and T. G. Shepherd, 2005. Summertime total ozone variations over middle and polar latitudes. *Geophys. Res. Lett*. **32**, doi:10.129/2004GL022080.

Kirchhoff V. W. J. H., F. Zamorano and C. Casiccia, 1997a. UV-B Enhancements at Punta Arenas, Chile. *J. Photochem. Photobiol*. **38**, 174-177.

Kirchhoff V. W. J. H., C. Casiccia and F. Zamorano, 1997b. The ozone hole over Punta Arenas, Chile. *J. Geophys. Res*. **102**, 8945-8953.

Kirchhoff V. W. J. H., C. Casiccia, Y. Sahai, F. Zamorano and V. Valderrama, 1997c. Observations of the 1995 ozone hole over Punta Arenas, Chile. *J. Geophys. Res*. **102**, 16109-16120.

Labow G. J., D. P. Haffner, R. D. McPeters and P. Bhartia, 2004. A Comparison of TOMS & SBUV Version 8 Total Column Ozone Data With Data From Groundstations, *Eos* Trans. AGU, 85(47), Fall Meet. Suppl., Abstract A33D-0092.

McKinlay A. F. and B. L. Diffey, 1987. A reference action spectra for ultraviolet introduced erythema in human skin. In: *Human exposure to ultraviolet radiation: Risk and regulations*. (W. R. Passchier and B. M. F. Bosnajakovich, Eds.), Elsevier, New York 83-87.

Prather M., M. M. García, R. Louzo and D. Rinal, 1990. Global impact of the antarctic ozone Hole? Dynamical dilution with a three-dimensional chemical transport model. *J. Geophys. Res*. **95**, 3449-3471.

Pazmiño A. F., M. Godin-Beekmann, S. Ginzburg, S. Bekki, A. Hauchecorne, R. D. Piacentini and E. J. Quel, 2005. Impact of Antarctic polar vortex occurrences on total ozone and UVB radiation at southern Argentinean and Antarctic stations during 1997-2003 period. *J. Geophys. Res*. **110**, doi:10.129/2004JD005018.

Solomon S. and R. García, 1986. On the depletion of Antarctic ozone, *Nature* **321**, 755-758.

Stolarski R. S., A. J. Krueger, M. R. Schoeberl, R. D. Mc Peters, P. A. Newman and J. C. Alpert, 1986. Nimbus 7 satellite measurements of the springtime Antarctic ozone decrease. *Nature* **322**, 808-811.

WMO, 2003. Scientific assessment of ozone depletion, 2002. World Meteorological Organization, Report No. 47. Geneva.