Folia Fac. Sci. Nat. Univ. Masarykianae Brunensis, Geographia 25 (2001): 35 - 48

ULTRAVIOLET RADIATION INTENSITY AT THE H. ARCTOWSKI BASE (SOUTH SHETLANDS, KING GEORGE ISLAND) DURING THE PERIOD FROM DECEMBER 1994 - DECEMBER 1996

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ABSTRACT

The article presents the first results of measurements of UVB radiation taken during the 1994/96 period at the Polish Henryk Arctowski Station, King George Island, South Shetland Islands (62°09’42”S, 58°28’10”W). Daily sums of UVB radiation are analysed as result of the following basic factors: ozone depletion, intensity of global radiation, and total extraterrestrial UV radiation. The influence of cloudiness on UVB radiation is also investigated. Variations of ozone concentration and daily sums of UVB radiation are compared with two Antarctic stations (Amundsen-Scott, Palmer) as well as with Ushuaia station (southern Argentina) for the season of the ozone depletion (September – December). From this analysis follows that a clear relation between ozone concentration and UVB radiation is further modified by cloudiness. Its effect is evident in increased variability of UVB maximum values at Arctowski Station in comparison with southern situated Palmer and Amundsen-Scott Stations.

AKEY WORDS: Antarctic ozone depletion - UVB radiation - influence of cloudiness

INTRODUCTION

Measurement of ultraviolet radiation intensity in the B_2 band (290 - 320 nm) was undertaken at the H. Arctowski Antarctic Station, owned by Poland, as part of the activities of the first expedition of the Czech antarctic program, approved and underwritten by grant No. 205/94/0156 of the Grants Agency of the Czech Republic. The expedition took place between 1994 and 1997, and bore the title Changes in Energy Balance and Ultraviolet Radiation and Their Effect on the Natural Ecosystems of the Antarctic.

Measurement was accomplished using UV Biometer Model 501 version 3, manufactured by SOLAR LIGHT Inc. of Philadelphia, which includes a built-in recorder. With regard to the construction of this device it is necessary to state that the UVB_2 measurements of the UV Biometer are output in MED (Minimum Erythema Dose) units. 1 MED.h^{-1} is equivalent to the UVB_2 radiation intensity necessary to bring about minimal irritation (i.e., reddening) in skin of average pigmentation after an hour of exposure. Conversion into physical units is accomplished by means of the relationship: 1 MED.h^{-1} = 5.83.10^{-2} W.m^{-2}, or 210 kJ.m^{-2}.h^{-1}. In view of the units of measurement and their relationship to effects on human skin, calibration of the sensor is done using what is known about the erythemal effects of individual wavelengths. These wavelengths are described by the so-called McKinlay-Diffey erythemal action spectrum, which quantifies the contribution made by the particular spectral intensities within the defined band to the appearance of erythema. (For more information, see SOLAR LIGHT Co. INC., 1991). From the above it follows that the results of the measurements presented in the article, whether our own or those of other stations, do not represent instantaneous or daily measurements of total UVB_2 intensities in the physical sense, but rather of their biological impact.

The UV Biometer was thoroughly evaluated at the Solar and Ozone Observatory of Czech Hydrometeorological Institute (ČHMÚ) in Hradec Kralove immediately before being transported to the Antarctic. The sensor was installed on the roof of the base's meteorological station, located on King George Island in Admiralty Bay (geographical coordinates $\varphi = 62^{\circ}09'41''56$, $\lambda = 301^{\circ}31'49''99$ E).

Measurements proceeded without a hitch from 1.12.1994 until 6.2.1995, when the sensor was damaged during a blizzard. It was subsequently repaired, re-calibrated and re-installed on 24.12.1995 and functioned without interruption until November 1998. Taking part in the effort were Polish workers from the Department of Antarctic Biology PAS Warsaw (J. Rudka in 1997 and I. Zwolska in 1998).

The results presented in this article are taken from the first series of measurements, that is, from the periods 1.12.1994 - 6.2.1995 and 24.12.1995 - 31.12.1996. In spite of the fact that the processed data files represent a period barely exceeding one year, they provide interesting, so-far unknown evidence about the UVB regime at H.Arctowski Station.

It is impossible to evaluate the UVB radiation regime in the area of the Antarctic without also analysing stratospheric ozone concentration (hereinafter χO_3). Therefore our own processing of UVB_2 radiation data is preceded by an analysis of time changes in χO_3. The appropriate data (daily values of χO_3) were taken from TOMS DATA, Version 7 (1996).

From the standpoint of destruction of the ozone layer over the Antarctic and its consequences in escalation of UV radiation intensity, the important period extends from roughly the second half of August until the end of November, when destructive processes at work in the ozone are at their most marked. This fact is attested to in a wealth of published material put out by, e.g., WMO (Antarctic Ozone Bulletin), or as part of the Antarctic program of the USA, e.g., NSF (United States National Science Foundation) UV Radiation Monitoring Network (1995 - 1997). It has also already been noted in scientific publications (e.g., Weiler, Penhale, 1994).

In the interests of briefly presenting the development of the ozone depletion in the area of the H.Arctowski Station, a fairly simple overview of ozone concentration (χO_3) was used, focusing on mean levels present during the 15.8. - 30.11. period in the years from 1978 to 1992 (Tab. 1).

The values in the table indicate an obvious if somewhat irregular decline in χO_3 over the fifteen year period. The average drop is in the range of a very significant 110 DU.

Very clear differences in the development of the ozone depletion are presented in Fig. 1, which depicts linear trends for the mid-July to mid-October period in the years 1978-81 and 1989-92. These offer evidence of a mean smoothed decline in χO_3 from 343 to 267 DU during the months in question in 1978-81, and from 278 to 216 DU during the same months in 1989-92. This corresponds to a reduction in mean χO_3 levels of 58 DU between the two sets of years.

PROCESSING RESULTS OF THE UVB INTENSITY MEASUREMENTS

Fig. 2 presents a graphic overview of the UVB_2 intensity regime on the scale of the daily sum (ΣI_{UV} [$J.m^{-2}.d^{-1}$]), complemented by daily sums for global solar radiation (ΣI_G [$MJ.m^{-}2.d^{-1}$]) and sunshine duration (Sd [h]). From this it follows that ΣI_{UV} values peak in November and December, in 9 cases exceeding the 5 $kJ.m^{-2}.d^{-1}$ level (the absolute maximum reaches 6.75 $kJ.m^{-2}.d^{-1}$). It is worth noting that the maxima do not appear in the period when the stratospheric ozone hole is at its largest (i.e., in September or October) but rather as it starts to dissipate (in November or December). From a temporal standpoint then, ΣI_{UV} extremes appear to be conditioned not only by the degree of destruction of the ozonosphere but to a significant extent also by the culmination of extraterrestrial UV radiation values which occurs in the yearly regime around the time of the winter solstice. In addition to the changes in total daily radiation logically to be expected from seasonal shifts in the Sun's declination and the geographic latitude of the location under measure, there is marked fluctuation present in the ΣI_{UV} regime which is also typical for ΣI_G and Sd. The sources of variability responsible for time-based changes in ΣI_G and Sd have already been discussed in Prošek, Janouch and Kruszewski (1998) and consist primarily in wide temporal variations in overcast along with accompanying changes in cloud genera. Both factors are especially contingent upon rapid fluctuations in the pressure field along the Antarctic periphery and associated changes in air advection (see e.g., Schwerdtfeger, 1984).

It is obvious at a glance that changes in ΣI_{UV} over time are closely interlinked to changes in ΣI_G, which is also attested to by the high value of the correlation coefficient ($r = 0.927$). This connection is logical when we consider that UV radiation is but one component of the larger solar radiation spectrum. The relation between ΣI_{UV} and Sd, with $r = 0.648$, is less clear-cut although still significant at the 0.05 probability level. With a coefficient of determination of $r^2 = 0.42$, however, changes in sunshine duration only account for 42% of total variance in the cases under observation.

These facts taken together provide adequate evidence for a regression relationship between ΣI_{UV} a ΣI_G (Fig. 3). In order to fill in the picture given by the foregoing relation and to take into account the absorption of UVB_2 radiation as it passes through the atmosphere, the dependence of ΣI_{UV} on the extraterrestrial intensity of the entire UV spectrum was similarly calculated (ΣIex_{UV}) (Fig. 4). Both regression relationships show markedly close dependence (note the coefficient of determination (r^2) in both figures). A clear majority of variance (around 90% for both pairs of variables) is well described using a power law relationship as also indicated in Fig. 4.

By means of a detailed evaluation of the correlation field surrounding each regression curve, it becomes possible to set aside groups of points which in each case demonstrate significant deviation from the least squares line (see Figs. 3 and 4). These have been demarcated using the digits 1 to 4. A finer analysis was undertaken for these groups to determine the cause of their relatively substantial deviation from the regression relationship:

Group 1 - consists of a group of December and January days (from the period after the closing of the ozone depletion) with relatively low mean cloudiness (1.0/10 - 7.0/10, with a mean of 4.5/10) and relatively long sunshine duration (59.4 - 88.1 %, with a mean of 68.4 %), resulting in a high daily global radiation sum which, however, co-occurs with low ΣI_{UV} values. These are clearly contingent upon relatively high χO_3 values, fluctuating in this group of days in the interval between 281 - 342 DU, with a mean of 309.7 DU.

Group 2 - represents a series of November and December days (from the period when the ozone depletion is subsiding), in which the cloudiness is relatively variable (4.5/10 - 10.0/10, with a mean of 8.3/10) as well as the sunshine duration (0.0 - 63.6 %, with a mean of 17.3 %). On all of these days the ratio of ΣI_{UV} to ΣI_G is relatively large. These days, then will be examined in greater detail in what follows.

Group 3 - consists once again of December and November days, this time typically with a big cloudiness (7.8/10 - 10.0/10, with a mean of 9.6/10) and therefore also with a relatively short sunshine duration (0.0 - 18.2 %, with a mean of 2.5 %). These days, in spite of high "potential intensity" of UV radiation (ΣIex_{UV}), exhibit only relatively modest ΣI_{UV} values. They are days, then, which, even though occurring practically at the peak of summer, have ΣI_{UV} values at winter norms as a consequence of substantial overcast.

Group 4 (marked by date) - represents days from September to December with fairly variable and on the whole increased cloudiness (4.5/10 - 9.0/10, with a mean of 7.4/10) accompanied by a relatively long sunshine duration (0.0 – 63.6 %, with a mean of 25.9 %). On these days, instances of high ΣIex_{UV} intensity are accompanied by relatively high ΣI_{UV} values. Furthermore, the points in Group 4 are identical with the six highest points of Group 2. By virtue of its extreme ΣI_{UV} values, the indicated group is the most interesting of all and has no equal in the globally declining portions of the yearly ΣI_{UV} variation curve. This is corroborated in Fig. 5. Here, the dependence of the yearly ΣI_{UV} regime upon ΣIex_{UV} is depicted from the standpoint of temporal succession in the independent and dependent variables. Succeeding points in the correlation field were significantly connected to preceding values, as can be seen from Fig. 4, in which a thick line joins points in rising areas and a thin line points in falling areas of the ΣI_{UV} yearly variation curve. In spite of fairly pronounced irregularity, it follows from Fig. 5 that, while there is a overall decline in ΣI_{UV} values, in the period between the winter solstice and summer solstice (indicated by the thin line) there is an overarching tendency to lower ΣI_{UV} values. In the period between the summer solstice and winter solstice, on the other hand, the tendency is toward more elevated values (thick line), obviously due to the ozone hole. Clearly evident once again are the six November and December days alluded to previously, which are characterised in greater details in Tab. 2.

In addition to the dependence relations depicted in Figs. 3 and 4, a graphical treatment was done of the potential tie between ΣI_{UV} and values of χO_3 (Fig. 6). This shows unequivocally an influence by χO_3 on the level of ΣI_{UV} is present only in the isolated cases already presented in Tab. 2 (the highest points in the correlation field). The scattergram indicates that one χO_3 value may be mapped onto a wide range of ΣI_{UV} values as a result of dependence on weather conditions, in particular cloud genera and cloudiness.

The six days presented in Tab. 2 received special attention in terms of their daily UVB_2 radiation and global solar radiation regimes (I_G) (Fig. 7). The intensity of UVB_2 radiation is indicated in $MED.h^{-1}$ in addition to $W.m^{-2}$. From the graph it is apparent that the UVB_2 regime is predetermined by the I_G regime, even if in places (e.g., around 7. h on 10.11., in the morning and evening hours of 15.11., between 6. - 8. h on the 23.11., in the morning hours on 27.11., after 16. h on 3.12. and between 9. - 13. h on 7.12.) somewhat pronounced differences may arise. Also worth noting are the relatively high stress levels for human skin which occur on these days (Tab. 3).

In order to compare the character of the regime and levels of χO_3 and ΣI_{UV} at the H.Arctowski Station in 1996 with other areas of the Antarctic, data from three additional stations was employed. These stations represent the central section of the Antarctic continent (Amundsen-Scott, USA), its periphery (Palmer Station, USA) and its extreme outer periphery, the so-called Antarctic Convergence (Ushuaia, Argentina). Source data for χO_3 and ΣI_{UV} was obtained for these stations from the NSF UV Radiation Monitoring Network (1995 - 1997). The daily values of χO_3 archived in these samples were acquired via measurements of satellite TIROS (by help of TOVS: TIROS-N Operational Vertical Sounder, NOAA), NIMBUS 7, METEOR, ADEOS and Earth Probe (by help of TOMS: Total Ozone Mapping Spectrometer NASA). The year 1996 falls into a period of time when the functioning of the satellites and their equipment changed (see Tab. 4). Due to missing data at individual satellites it was necessary to employ for mentioned stations all of these possible sources.

Basic information about the χO_3 and ΣI_{UV} regimes for the stations is presented in Fig. 8 for the period from September to December 1996. For the Ushuaia, H.Arctowski and Palmer Stations, it is possible to claim a certain similarity in χO_3 regimes (especially between the H.Arctowski and Palmer Stations). For both stations, overall growth in χO_3 is from roughly 200 to not quite 400 DU in the period extending to around the start of November, interrupted however by a pronounced decline in concentration to as low 200 DU. Of the 8 total declines, only 4 were evident at the Ushuaia station. Early development of the periphery of the ozone hole typically proceeds in a pulsational manner, the sole steady decline in χO_3 not occurring until the period from 5.11. to roughly 10.12. Even in this second phase, however, development of the ozone hole is tied to a short-term rise in χO_3. At the Ushuaia station, there are only hints of an unbroken decline in χO_3 between 5.11. and 10.12. The indicated variability in χO_3 in the case of these three stations is a clear consequence of their location at the edge of the area of O_3 destruction in the Antarctic.

In contrast with the foregoing stations, the development of χO_3 at the Amundsen-Scott station is straightforward: there is no significant short-term pulsation, and the process is longer-lasting. This obviously corresponds to a situation of stable destruction of O_3 in the central portions of the ozone hole. The decline here is already apparent at the beginning of August, with a minimum of 108 DU reached on 30.9. or 21.10. From the second half of October until the beginning of December, χO_3 declines more or less systematically until, with a sharp rise from 7 - 13.12., the yearly evolution of the ozone hole comes to an end.

It is accurate to say that, on the whole, ΣI_{UV} values grow in a mutually dependent nonlinear fashion from the beginning of the observation period (at Amundsen-Scott Station due to the polar night from 19.9.). (See growth trends marked in Fig. 8 and the accompanying equations). The actual picture of timechanges in ΣI_{UV}, though, is highly unstable. Individual maxima and minima in ΣI_{UV} correspond, in a number of cases, to extremes in χO_3. There is very clear growth in short-term ΣI_{UV} fluctuations at the Ushuaia, Arctowski and Palmer stations from around the 2nd 10-day period in November until the end of the observation period. This is a consequence of no more than short stretches of clear days interspersed with short stretches of cloudy days, during which the influence of the overall decline of χO_3 on the growth of ΣI_{UV} is either clearly evident or completely suppressed. Individual maxima in ΣI_{UV}, which appear at all station until the end of October and early November, are the combined result of three factors: growth in extraterrestrial UV radiation intensity, a fall in χO_3 and reduced cloudiness.

Maximum values of ΣI_{UV} at Amundsen-Scott Station appearing in the time frame from the beginning of November until the beginning of December are independent of the immediately preceding period of maximum ozone destruction. Aside from the influence of cloudiness (which is neither so variable nor so significant as it is along the Antarctic periphery) and the decline in χO_3, elevated ΣI_{UV} values at this location can be ascribed to extraterrestrial UV intensity, which reaches significantly elevated values only after the start of November. The instant χO_3 starts to increase, ΣI_{UV} markedly declines.

CONCLUSION

From the comparison of the χO_3 and ΣI_{UV} regimes at H. Arctowski and Palmer Stations it follows that the period in which the ozone hole appears at Palmer Station can be characterised as typical, at the very least for peripheral sections of the Antarctic in the Antarctic Peninsula and nearby archipelago. By contrast, increased variability in ΣI_{UV} values at H.Arctowski Station can be explained to a certain extent by the exposed position of this station with regard to sharp changes in the pressure field and fast-moving frontal systems in the Drake Straits. These have an understandable impact on the variability of cloud cover with all of its consequences.

The problems presented in this article concerning UVB_2 radiation intensity and ozone concentration have had but one goal - to acquaint the reader with the first facts about time changes in UVB_2 radiation at H.Arctowski Station emerging from the analysis of both variables after the first complete year of their measurement. When further data are acquired in succeeding years, the results presented here will immediately be put in context, clarified if necessary, and, of course, widened to include material from other Antarctic stations.

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Tab. 1 Mean ozone concentration (χO_3 [DU]) during the period 15 August –30 November in the years 1978 - 92 for the geographical co-ordinates of the H.Arctowski Station (according to TOMS DATA, Version 7, 1996).

Year	1978	1979	1980	1981	1982	1983	1984
χO_3	371.6	324.7	321.4	316.9	304.0	315.6	288.3

Year	1985	1986	1987	1988	1989	1990	1991	1992
χO_3	295.3	302.8	275.3	276.2	285.2	274.4	260.0	261.8

Tab. 2 Characterisation of days with maximum daily sums of UVB_2 radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]) in the period December 1994 - February 1995 and December 1995 - December 1996 at the H. Arctowski Station. (χO_3 [DU] – ozone concentration, ΣI_G [MJ.m^{-2}.d^{-1}] – daily sum of global radiation intensity, ΣIex_{UV} [Mj.m^{-2}.d^{-1}] – extraterrestrial intensity of UV radiation, Sd [h, resp.%] – sunshine duration or relative sunshine duration resp., $\overline{C}$ - mean daily cloudiness (in tenths) from observations 09 and 15 h MLT, Cg – dominant cloud genera).

Date	ΣI_{UV}	ΣI_G	ΣIex_{UV}
10.11.1996	5.36	20.56	2.68
15.11.1996	6.21	24.68	2.79
23.11.1996	6.75	28.09	2.94
27.11.1996	5.88	17.45	3.01
3.12.1996	5.86	20.77	3.09
7.12.1996	5.69	28.32	3.13

Date	χO_3	Sd [h]	Sd [%]	$\overline{C}$	Cg
10.11.1996	182	5.5	32.2	7.0	St, Ac, As
15.11.1996	195	11.1	63.6	4.5	Sc, Ac
23.11.1996	213	-	-	5.5	Sc, Ac
27.11.1996	198	1.3	6.9	8.5	St, Sc, As
3.12.1996	204	3.5	9.7	9.0	Sc, Ac
7.12.1996	259	9.7	50.4	8.0	Sc, Ac

Tab. 3 Duration [h] of selected intensities of UVB_2 radiation [MED.h^{-1}] and the highest level of MED.h^{-1} on selected days in November and December 1996.

Date	10.11.	15.11.	23.11.	27.11.	3.12.	7.12.
1MED.h^{-1}	9.9	9.8	9.8	9.9	8.4	9.0
2MED.h^{-1}	6.4	7.5	7.3	7.3	7.0	6.9
3MED.h^{-1}	2.2	4.6	5.5	4.9	3.5	4.5
4MED.h^{-1}	-	-	3.1	1.3	2.3	-
max. MED.h^{-1}	4.2	4.5	4.5	5.5	4.9	3.9

Tab. 4 American satellites and their equipment for measurement of O_3 concentration operated in the 1970s, 1980s and 1990s (source: Data Products by Spacecraft, http://toms.gsfc.nasa.gov/)

Satellite	Equipment	Period of measurement
TIROS-N	TOVS	to Nov. 1978
NIMBUS 7	TOMS	Nov. 1978 - May 1993
METEOR	TOMS	Aug. 1991 - Dec. 1994
ADEOS	TOMS	Sep. 1996 - Jun 1997
Earth Probe	TOMS	since Aug. 1996

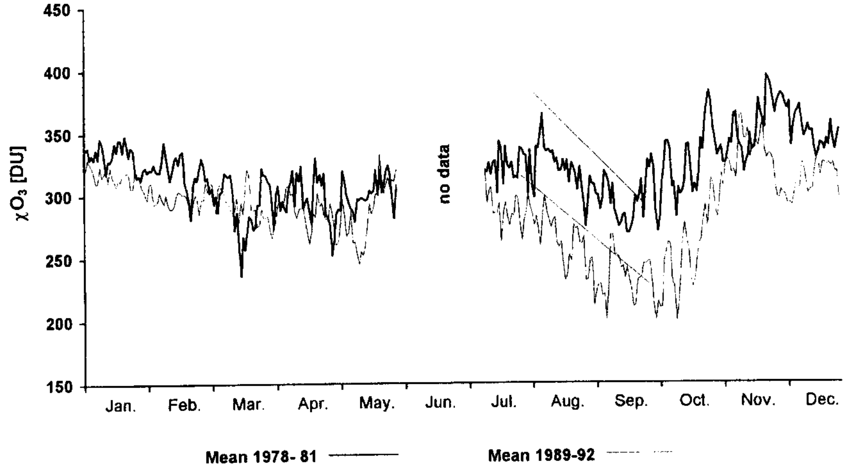

Fig. 1 Comparison of mean yearly regime of ozone concentration (χO_3 [DU]) and mean development of ozone depletion (July – October) at the H. Arctowski Station in the years of 1978 – 81 and 1989 – 92

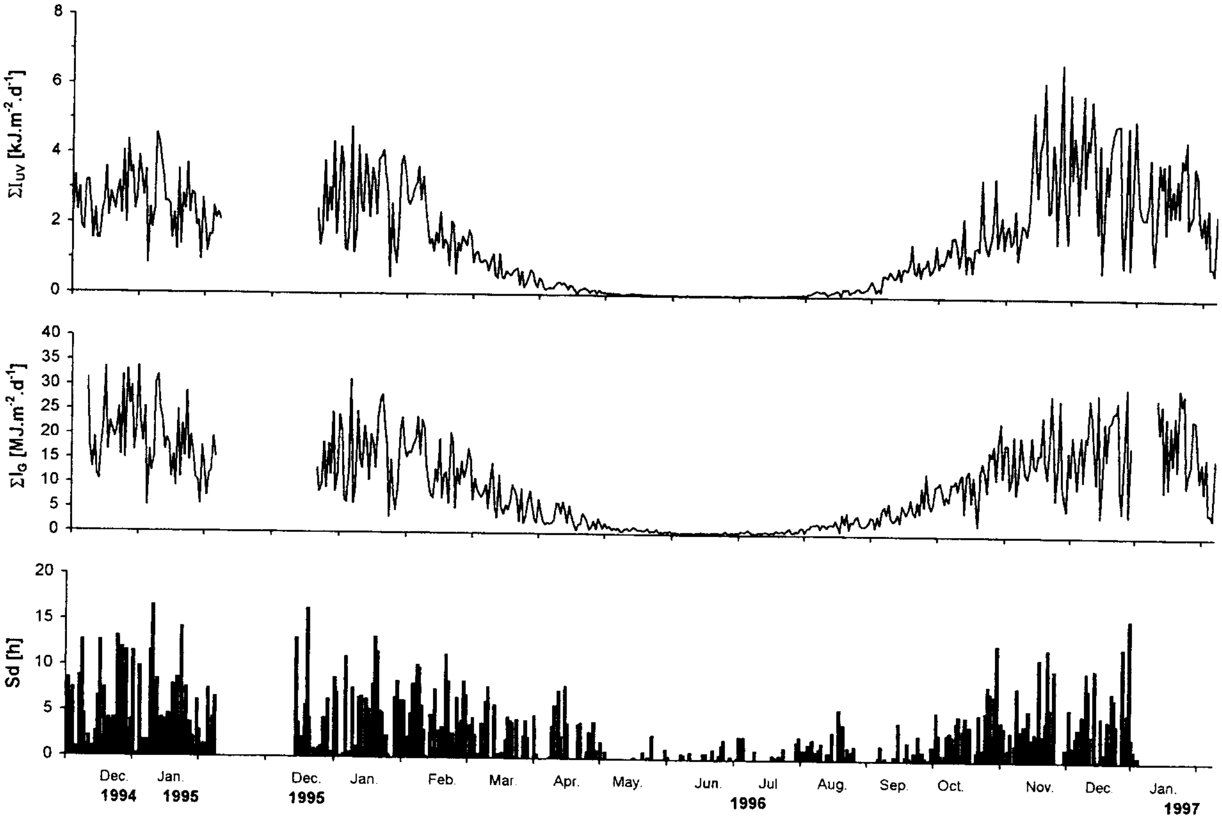

Fig. 2 Regime of daily summary intensities of UVB$_2$ radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]), daily summary intensities of global radiation (ΣI_G [MJ.m^{-2}.d^{-1}]) and sunshine duration (Sd [h]) at H. Arctowski Station in the periods 1 December 1994 – 12 February 1995 and 24 December 1995 – 31 December 1996

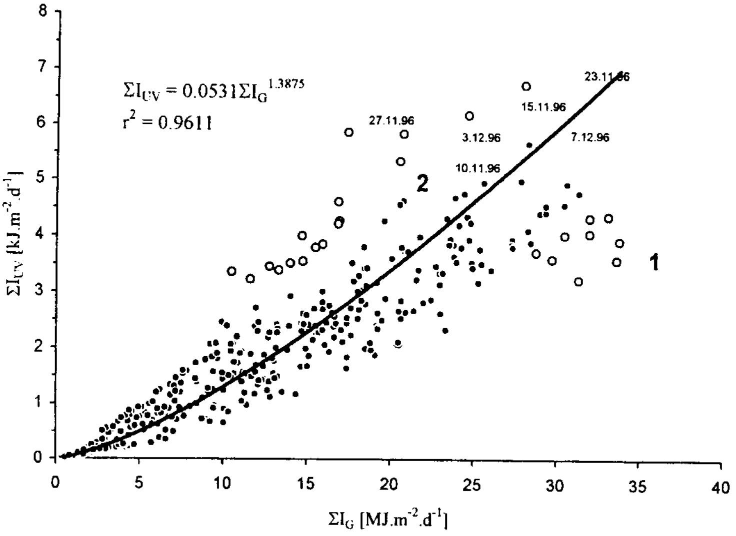

Fig. 3 Regression dependence of daily summary intensities of UVB$_2$ radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]) on daily summary intensities of global radiation (ΣI_G [MJ.m^{-2}.d^{-1}]) completed by regression equation and coefficient of determination (r^2). Periods: 1 December 1994 – 12 February 1995 and 24 December 1995 – 31 December 1996.

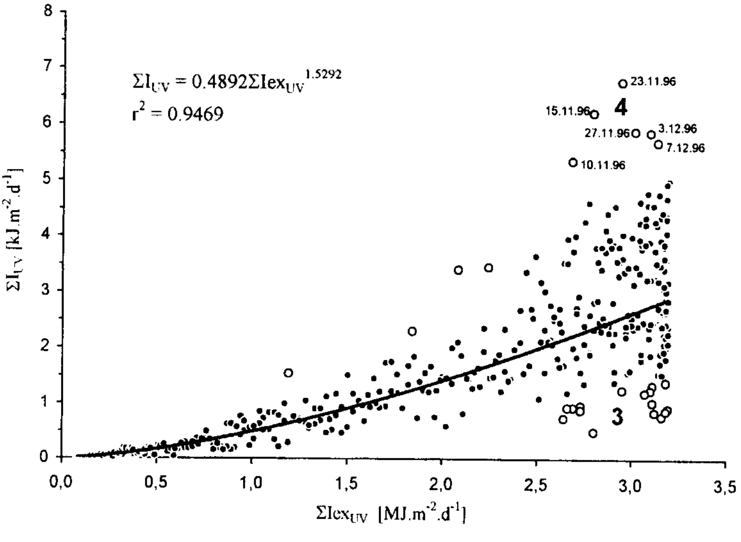

Fig. 4 Regression dependence of the daily summary intensities of UVB$_2$ radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]) on the daily summary intensities of extraterrestrial UV radiation (ΣI_{exUV} [MJ.m^{-2}.d^{-1}]) completed by regression equation and coefficient of determination (r^2). Periods: 1 December 1994 – 12 February 1995 and 24 December 1995 – 31 December 1996.

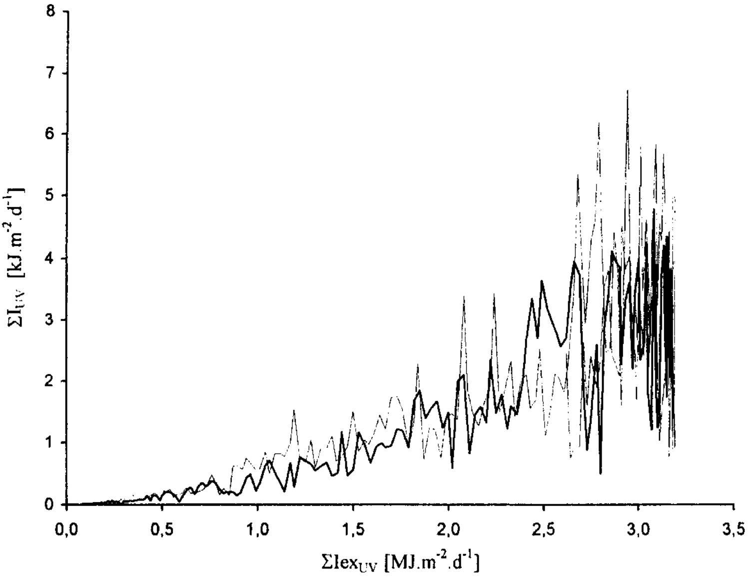

Fig. 5 Connection of the points of the correlation field in Fig. 4 according to time succession. Full line – period between winter and summer solstice, dashed line – period between summer and winter solstice.

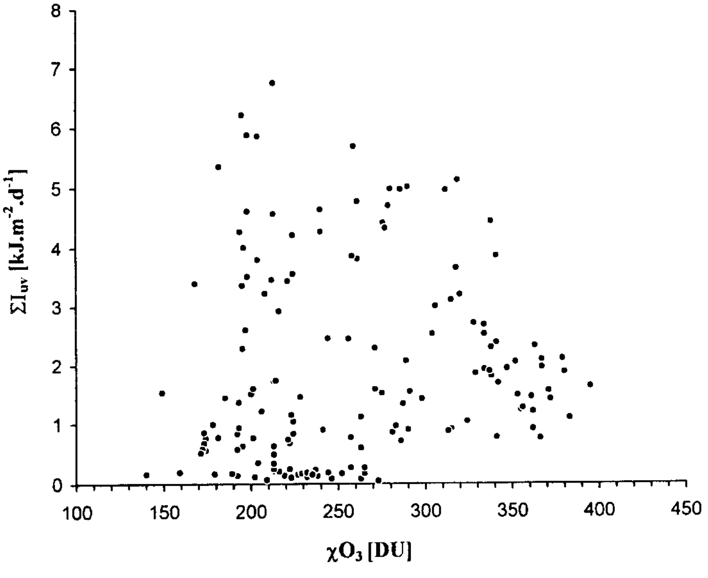

Fig. 6 Correlation field of the dependence of daily summary intensities of UVB$_2$ radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]) and the daily ozone concentration (O_3 [DU]). Periods: 1 December 1994 – 12 February 1995 and 24 December 1995 – 31 December 1996.

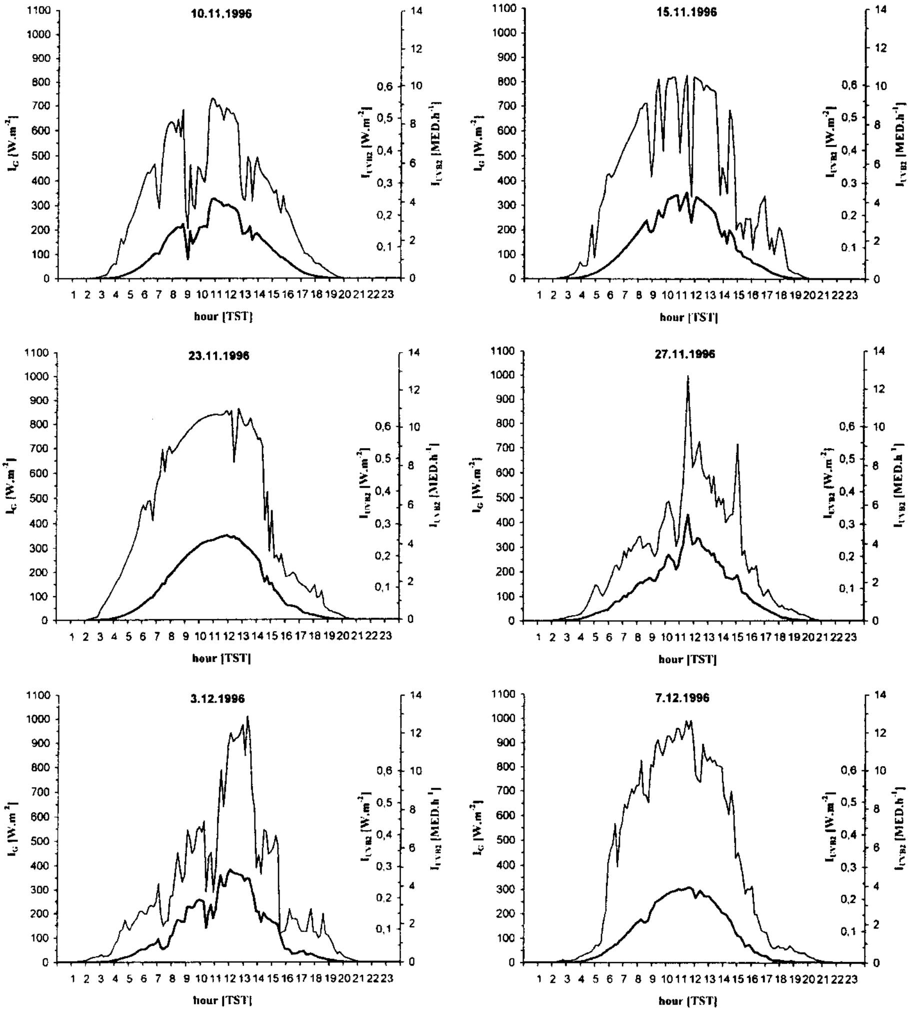

Fig. 7 Selected daily regimes of UVB_2 radiation intensity (I_{UV} [$W.m^{-2}$ or $MED.h^{-1}$ resp.]) and global radiation intensity (I_G [$W.m^{-2}$]) in November and December 1996

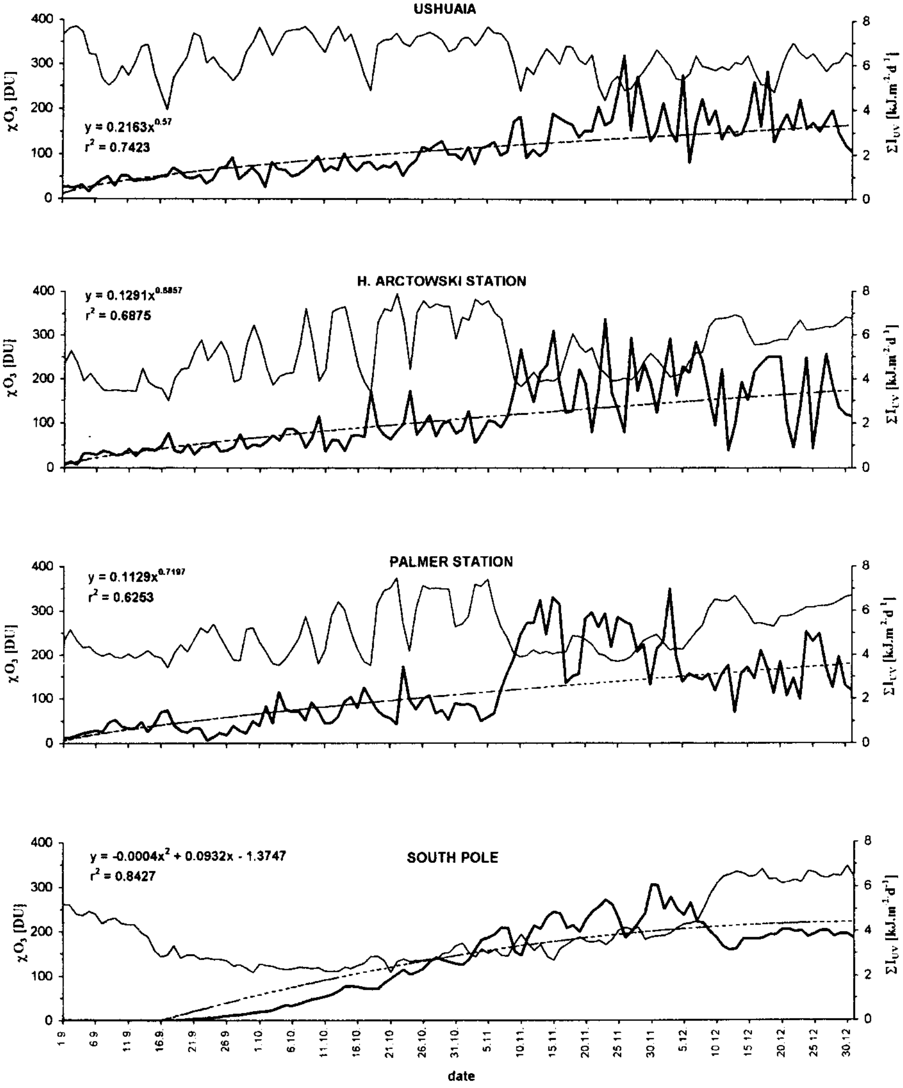

Fig. 8 Regime of daily summary intensities of UVB$_2$ radiation (ΣI_{UV} [kJ.m^{-2}.d^{-1}]) and of daily ozone concentration (χO_3 [DU]) at the Ushuaia, H.Arctowski, Palmer and South Pole stations in the period 1 September – 31 December 1996