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## Satellite and ground measurements of solar erythemal UV radiation and ozone in Argentina

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### Abstract

Solar erythemal UV radiation incident on Argentina from tropical to high latitude regions has been measured with ground-based instruments as well as with the TOMS instrument on board of the NASA Earth-Probe satellite. These data permit validation of the UV index, a measure of solar risk to UV exposure, forecasted daily by CONAE (Argentina National Commission on Space Activities) and the Argentine National Weather Service. Model calculations of this index are also presented. In addition, we analyzed the UV effects from the Antarctic ozone hole passing over the continental part of the country using TOMS data corrected by a factor derived from the intercomparison of TOMS satellite data with those determined with Southern Hemisphere ground-based spectroradiometers. In this way, we obtained a rather comprehensive description of the amount of erythemal UV radiation and consequently of the UV index for the entire country, as well as the ozone total column and profile (the latter one at Buenos Aires). The results presented in this work were determined through collaboration between the following institutions: GSFC/NASA in USA, Institute Pierre Simon Laplace in France, University of Innsbruck in Austria and CEILAP, IFIR, CONAE, SMN, Universities of Rosario and San Luis in Argentina. The need to use erythemal irradiance and ozone results in Argentina, one of the most exposed regions of the Southern Hemisphere to study the effects of ozone depletion and consequently UV detrimental effects, has been partially covered in the framework of this North–South collaboration.

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### 1. Introduction

Solar UVB irradiance (range 280–320 nm) increased significantly the last decades at mid and high latitudes, mainly due to the significant ozone depletion mostly caused by chlorine-bearing anthropogenic contaminants

observed in these regions of the Earth (Herman et al., 1996; Madronich et al., 1998; Herman and McKenzie, 1999; WMO, 1994a, 1999). In particular, the situation is even more complicated in the Southern Hemisphere (SH), due to the development of the Antarctic ozone hole, which appears in the period of July–August, arriving at its maximum in September–October and disappearing in November–December (WMO Antarctic Bulletins, [www.wmo.ch/index-en.html](http://www.wmo.ch/index-en.html)).

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The increase in the UVB irradiance is well correlated with the intensification of associated biological irradiances, such as erythema-weighted irradiance (skin reddening), which is used internationally as a reference for determining the UV index, a measure of the sunburn risk to solar exposure (WMO, 1994b; Roy and Gies, 1998). These biologically-weighted irradiances are obtained by integrating the UV spectral irradiance  $I(\lambda, t)$  (280–400 nm) multiplied by the corresponding action spectrum  $B(\lambda)$ , i.e.,

$$I(t) = \int I(\lambda, t) \cdot B(\lambda) d\lambda. \quad (1)$$

The action spectrum is usually chosen from published values (i.e., Jagger, 1985; Madronich, 1993; UNEP, 1998). In particular for erythema, the most common one is that proposed by McKinlay and Diffey (1987).

The UV index is defined as the product of 40 times the erythema irradiance (expressed in the International System of Units), in order that this index can be expressed with a number ranging mainly from 0 to 10 or more. However, values as high as 20 or even more has been registered (Cede et al., 2002b) during the SH summer solstice in the high altitude Andes Mountains intertropical desert of Puna of the Atacama region. This UV index is a measure of the solar risk for humans exposed to solar radiation (Roy and Gies, 1998). At the Institute of Physics and the Astronomical Observatory of Rosario, Argentina, in collaboration with the Institute of Medical Physics of the University of Innsbruck, Austria and the Argentina National Weather Service, a computational program based on model calculations and expected cloud coverage was developed for predicting this index for all Argentina, through the National Weather Service daily forecast system (Piacentini et al., 2000a).

Biometer instruments that measure erythema irradiance have UV-photon detector combined with a filter that simulates the erythema action spectrum. In addition to biometers, the erythema irradiance can be de-

rived if the UV solar spectrum is measured (at least in some wavelengths with narrowband sensors), and this irradiance is then determined applying Eq. (1).

## 2. UV measurements and model calculations

One interesting result obtained as part of this North–South scientific collaboration is the intercomparison of erythema irradiance measured from the ground-based Argentine Ultraviolet Network of the National Weather Service and the derived UV data ([toms.gsfc.nasa.gov](http://toms.gsfc.nasa.gov)) from the Total Ozone Mapping Spectrometer (TOMS) instrument on board of Earth Probe/NASA satellite. The Argentine network of Solar Light and YES instruments was provided by the WMO and the calibration procedure is described in detail in the work of Cede et al. (2002a). The first series of data correspond to the largest latitudinal dataset available in the SH spanning intertropical latitudes (La Quiaca at 22.11°S) to Antarctic ones (Marambio Argentina Antarctic Base at 64.23°S). In Table 1, we present results for selected places where data for this intercomparison were considered. The percentage relative differences ( $\Delta$ ) are rather small for most of the locations, with a maximum value of 12.6% in SH summer (near maximum) and 15.6% in winter (near minimum), which is a little higher as expected, due to the mean low irradiances in winter that increases the relative difference. The corresponding standard deviations are 8.9% and 8.7%, respectively. These results can be compared with other TOMS-ground intercomparisons such as those made by Kalliskota et al. (2000), which gives results for Ushuaia (with respect to another instrument), San Diego and Palmer Antarctic Station 20%, 40% and 25% rms differences, respectively. Compared to these results, the agreement shown in Table 1 is quite good, even for places rather contaminated such as Buenos Aires city.

Fig. 1 shows a 2D temporal representation of the results for the erythema irradiance measured at Buenos

Table 1

Ultraviolet exposure (daily integrated erythema irradiance) TOMS data for Argentina National Weather Service (NWS) stations compared with ground based biometers for January and July 1998

Argentina NWS Stations	Lat (°S)	Lon (°W)	Altitude (m a.s.l.)	UV exposure in January (kJ/m <sup>2</sup> )			UV exposure in July (kJ/m <sup>2</sup> )		
				TOMS	Ground	$\Delta_{Jan}(\%)$	TOMS	Ground	$\Delta_{Jul}(\%)$
1. La Quiaca	22.11	65.57	3459	9.5	8.3	12.6	3.6	3.05	15.3
2. Pilar (Córdoba)	31.66	63.88	338	6.5	5.9	9.2	1.2	1.2	0
3. Rosario	32.96	60.62	25	6.1	6.2	–1.6	0.97	0.85	12.4
4. Buenos Aires	34.61	58.41	25	6.2	5.9	4.8	0.85	0.86	–1.2
5. Comodoro Rivadavia	45.78	67.50	46	4.5	4.6	–2.2	0.4	0.41	–2.5
6. San Julián	49.32	67.75	62	4.1	4.4	–7.3	0.32	0.27	15.6
7. Ushuaia	54.8	68.27	14	3.2	3.6	–12.5	–	0.11	–
8. Marambio	64.23	56.78	300	2.3	2.5	–8.7	–	0	–

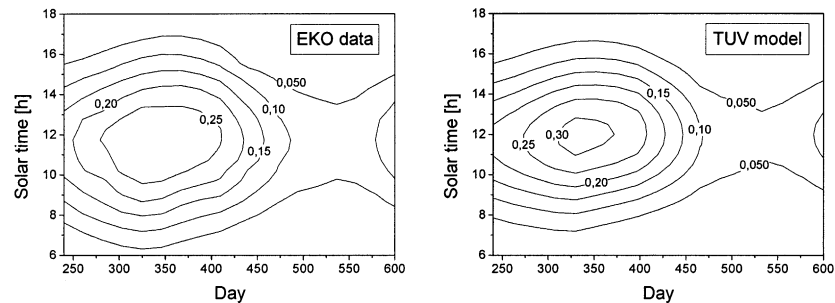


Fig. 1. 2D temporal representation of solar erythemal irradiance along the hours of clear sky days for the period August 2000–August 2001. Left: measured data with EKO Biometer at CEILAP, Buenos Aires, Argentina. Right: TUV model calculations.

Aires suburbs with an EKO biometer in the August 2000–August 2001 period for clear sky days, as function of the hours of the day and the days of the months. The EKO biometer is placed at CEILAP (Research Center in Laser and Laser Applications), the same location where a NASA AERONET (Aerosol RObotic NETwork) Cimel sunphotometer is placed and the lidar ozone profile measurements are done. The EKO instrument was installed during August 2000 under the auspices of the Argentina National Commission on Space Activities (CONAE), and was calibrated by EKO Instruments Trading Co, Tokyo, Japan (certificate of September 29, 1999).

Model calculations were done employing the TUV model developed by Madronich (1993) as described in the web page [www.acd.ucar.edu/TUV](http://www.acd.ucar.edu/TUV). The values of ozone total column are from the TOMS database ([www.jwocky.gsfc.nasa.gov](http://www.jwocky.gsfc.nasa.gov)), and the aerosol data are those given by AERONET for the same geographical location (see [aeronet.gsfc.nasa.gov](http://aeronet.gsfc.nasa.gov)). The rest of the parameters are as given by default in the Madronich code, except the albedo is chosen to be 0.06 for a combination of cement, grass and water reflectivities (Blumthaler and Ambach, 1988; Feister and Grewe, 1995), since Buenos Aires city is located in front of the very wide (more than 40 km) River Plate. This value is rather similar to that determined with TOMS satellite measurements for the place (Herman and Celarier, 1997). A rather good agreement is obtained between both series of data.

### 3. Erythemal irradiance at noon and UV index

Another comparison can be made by considering maximum erythemal irradiance near noon measured and modeled during the year. These maxima are displayed in Fig. 2. The mean percentage difference is  $(6.1 \pm 9.4)\%$ , confirming the good agreement between data and model calculations.

The UV index directly associated with these irradiances is also indicated in the right vertical scale of this figure. Also shown are the monthly mean UV index forecasted by CONAE for the same period, obtained

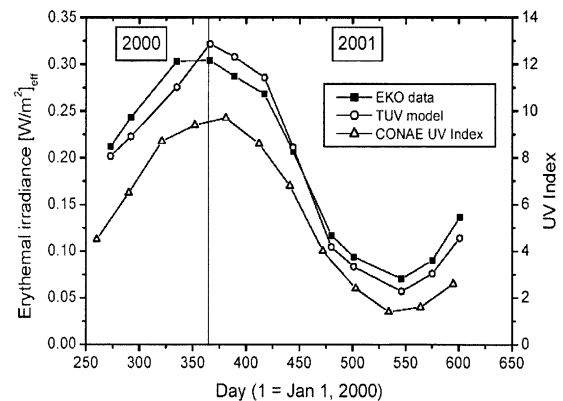


Fig. 2. Erythemal irradiance (left scale) incident at Buenos Aires, Argentina in the August 2000–August 2001 period: measurements done with the EKO biometer at CEILAP and TUV atmospheric radiative transfer model calculation for the same days. The corresponding UV index (erythemal irradiance multiplied by 40) is represented in the right scale, including also the CONAE UV index forecasted for this period.

from the historical records given in its web page ([www.conae.gov.ar](http://www.conae.gov.ar)). In this case, even if the general behavior is the same, a systematic underestimation of the UV index by the forecasted values is evident, which increases at autumn and winter seasons with respect to the other seasons.

The irradiance derived from Earth-Probe TOMS data taken over Buenos Aires was also compared to ground measurements obtained near Villa Ortúzar station of the National Weather Service with a Solar Light biometer of the UV Argentine Network. Using an average aerosol optical depth of 0.5 at 340 nm (Cede, 2001) for the satellite-derived data, the relative difference in the monthly doses at ground level from both series of data is only  $-4\%$ , with a  $\pm 5\%$  (2 sigma) uncertainty for all atmospheric conditions.

### 4. Ozone results

#### 4.1. Ozone profile measurements

The ozone vertical distribution is monitored by ground-based and satellite instruments around the

world. In this work, we present the ozone profile measured by a ground-based lidar system placed at CEILAP (CITEFA-CONICET) laboratory ( $34^{\circ}33'S$ ,  $58^{\circ}30'W$ ), in the Buenos Aires suburbs, Argentina. Also, we compare the ozone profiles measured by this system with data obtained by GOME (Global Ozone Monitoring Experiment)/ERB-2/ESA satellite instrument.

The lidar system developed at CEILAP utilizes the Differential Absorption Lidar (DIAL) technique in order to measure the ozone distribution. The altitude range for this system is between 20 and 35 km. The system includes two laser sources, one emitting a strong line absorbed by ozone and the other one, a line where ozone absorption is negligible. The backscattering radiation is collected by a telescope, the emitted wavelengths are detected by photomultipliers and finally the signals are acquired by a counter-board. More details of the system are given in the work of Pazmiño et al. (2003).

Fig. 3 shows the ozone profiles measured at Buenos Aires by the lidar in comparison with the GOME satellite data for two days of 2001, corresponding each one at the minimum and maximum ozone concentration period (April 10 and August 21), respectively. The satellite instrument uses a nadir-viewing UV spectrometer to measure the ozone distribution. In spite of the different vertical resolutions, there is a good agreement between the lidar and GOME ozone measurements in both days. The smooth ozone profiles obtained from GOME instrument after an inversion processing, cannot see high resolution structures present in the ozone profile showed by lidar measurements on both days.

At present the CEILAP's lidar system is undergoing several modifications and improvements, such as increasing the light collecting area and detecting the inelastic and elastic backscattered signals. The final system will be capable to detect the First Stokes nitrogen and water vapour Raman spectra pumped by two laser wavelengths at 308 and 355 nm. The Raman signals will

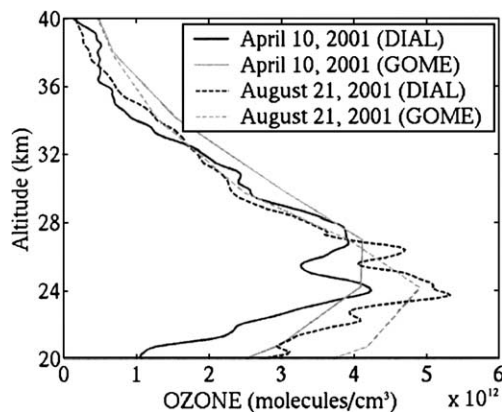


Fig. 3. Ozone profiles measured by the DIAL (Differential Absorption Lidar) technique at CEILAP, Buenos Aires, Argentina and with GOME/ERS-2/ESA satellite instrument.

permit us to avoid the problems linked to possible stratospheric aerosol interference. The range resolution of the system will be between the middle and high troposphere up to high stratosphere. This lidar system upgrade is a result of the joint effort between CEILAP and Institute Pierre Simon Laplace, France. Furthermore, this system will be placed on a mobile platform in order to measure the ozone vertical profile at different places in Argentina.

## 5. Total ozone during the Antarctic hole event

In previous papers (Piacentini et al., 2000b, 2002), it was demonstrated that there is a systematic shift between measurements of ozone total column over the SH done by TOMS on board of Earth-Probe/NASA satellite and ground data registered with Dobson and Brewer spectroradiometers from WMO and National Weather Services. The difference increases approximately linearly with a slope of 0.08% per degree latitude from around 2–3% over mid-latitudes, to 6–8% at SH polar latitudes. Considering this linear dependence, a program was developed to correct all the TOMS/Version 7 ozone data in the SH region from  $30^{\circ}S$  to the South Pole. Since the Antarctic ozone hole is the most significant event in the SH related to the stratospheric ozone layer depletion (i.e. WMO, 1999), we re-analyzed October 12, 2000 ozone hole, which extended to middle latitudes (around  $49^{\circ}S$ ) over Argentina. The original as well as the corrected results are displayed in Fig. 4. One way to compare the evolution in time and the extension of the ozone hole, is to represent the surface covered by the 220 DU value that has been defined as the ozone hole boundary. In order to determine the influence of the ozone column correction on the ozone hole area, we

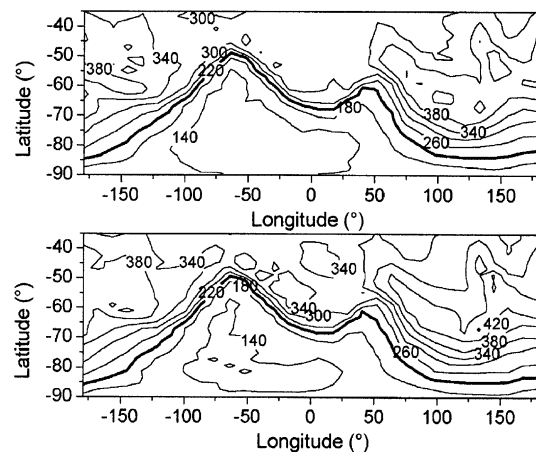


Fig. 4. Southern Hemisphere latitude-longitude representation of the ozone total column (in Dobson Units) measured by TOMS on board of Earth Probe/NASA satellite on October 12, 2000. Corrected (top) and uncorrected (bottom) data are presented (see text).

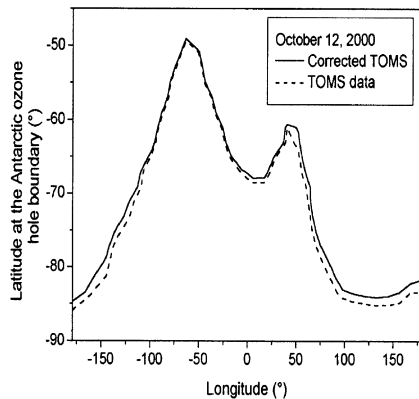


Fig. 5. Representation of the latitude at the Antarctic ozone hole boundary as function of the longitude for the day October 12, 2000, as registered by TOMS on board of Earth Probe/NASA satellite and corrected as described in the text.

present in Fig. 5 the corresponding boundary curve for both corrected and uncorrected cases. Integrating the pixel enclosed in these surfaces taking into account that the TOMS pixel is of  $1^\circ$  lat  $\times$   $1.25^\circ$  long and the Earth's curvature, we obtained a corrected area of 18.73 millions square kilometers compared to the original 17.87 million square kilometers, or a relative difference of +4.8%. So, in this way we determined that the ozone hole has actually a *larger area* than the area considered up to now.

## 6. Conclusions

Erythemal irradiance and the corresponding UV index have been obtained over Argentina, from the ground as well as from satellite data. Good agreement (within 15%) exists between both data series at almost all locations. A detailed study will be undertaken in order to improve the CONAE clear-sky UV index.

Ozone profiles were determined with the DIAL technique (LIDAR) from the Earth's surface and compared with the GOME/ERS-2/ESA satellite instrument, at Buenos Aires, Argentina. They compare well in general and particularly in the position and magnitude of the maximum.

Total ozone mapping spectrometer data were corrected with the coefficient determined from the inter-comparison made between these values and those measured from Earth at different locations of the Southern Hemisphere, that showed a systematic (increasing with latitude) difference. In particular, the Antarctic ozone hole analyzed in the present work (October 12, 2000) increases in 4.8% with respect to the original one, from 17.87 to 18.73 million square kilometers.

Future works are planned, following those developed up to now (Cede et al., 2002a,b; Piacentini et al.,

2002; Pazmiño et al., 2003; Ristori et al., 2003), in order to have a better understanding of the space-time evolution of solar UV irradiance and its biological related effects and of aerosol and ozone over one of the most affected regions of the world by the depletion of the stratospheric ozone layer.

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## References

- Blumthaler, M., Ambach, W. Solar UVB-albedo of various surfaces. *Photochem. Photobiol.* 48, 85–88, 1988.
- Cede, A. Erythemal UV in Argentina: measurements, climatological interpretation and comparison with satellite-derived data, Doctoral Thesis, University of Innsbruck, Austria, 2001 (Chapter 7).
- Cede, A., Luccini, E., Nuñez, L., Piacentini, R.D., Blumthaler, M. The Argentina ultraviolet network: calibration and uncertainties calibrations. *Appl. Opt.* 41, 6341–6350, 2002a.
- Cede, A., Luccini, E., Piacentini, R.D., Nuñez, L., Blumthaler, M. Monitoring of erythemal irradiance in the Argentina Ultraviolet Network. *J. Geophys. Res.*, 107, 2002b, [10.1029/2001JD001206](https://doi.org/10.1029/2001JD001206).
- Feister, U., Grewe, R. Spectral albedo measurements in the UV and visible region over different types of surfaces. *Photochem. Photobiol.* 62, 736–744, 1995.
- Herman, J.R., Bhartia, P.K., Ziemke, J., Ahmad, Z., Larko, D. UV-B increases (1979–1992) from decreases in total ozone. *Geophys. Res. Lett.* 23, 2117–2120, 1996.
- Herman, J.R., Celarier, E. Earth surface reflectivity climatology at 340 nm to 380 nm from TOMS data. *J. Geophys. Res.* 102, 28003–28011, 1997.
- Herman, J.R., McKenzie, R.L. Ultraviolet radiation at the Earth's surface, in: *Scientific Assessment of Ozone Depletion: 1998*. WMO Report 44, 1999 (Chapter 9).
- Jagger, J. *Solar-UV Actions on Living Cells*. Praeger, New York, 1985, p. 114.
- Kalliskota, S., Kaurola, J., Taalas, P., Herman, J.R., Celarier, E., Krotkov, N. Comparison of daily UV doses estimated from Nimbus7/TOMS measurements and ground-based spectroradiometric data. *J. Geophys. Res.* 105, 5059–5067, 2000.

- Madronich, S. UV radiation in the natural and perturbed atmosphere, in: Tevini, M. (Ed.), *UV-B Radiation and Ozone Depletion. Effects on Humans, Animals, Plants, Microorganisms and Materials*. Lewis Publisher, Boca Raton, USA, pp. 17–69, 1993.
- Madronich, S., McKenzie, R.L., Björn, L.O., Caldwell, M.M. Changes in biologically active ultraviolet radiation reaching the Earth's surface, in: *The UNEP Report, Environmental effects of ozone depletion: 1998 Assessment*. *J. Photochem. Photobiol. B: Biol.* 46, 5–19, 1998.
- McKinlay, A.F., Diffey, B.L. A reference action spectra for ultraviolet introduced erythema in human skin. *Commission Internationale de l'Eclairage (CIE) Journal*, 17–22, 1987.
- Pazmiño, A., Godin, S., Wolfram, E., Lavorato, M., Porteneuve, J., Quel, E., Mégie, G. Intercomparison of ozone profiles measurements by a differential absorption lidar system and satellites instruments at Buenos Aires, Argentina. *Opt. Eng.* 40, 55–65, 2003.
- Piacentini, R.D., Cede, A., Nuñez, L., Solar UV risk in Argentina. First tests of the ISUVn index, in: *Proceedings of the SPARC 2000 Second General Assembly*, Mar Del Plata, Argentina P/4.22, 2000a.
- Piacentini, R.D., Crino, E., Sirur Flores, J., Ginzburg, M. Intercomparison between ground based and TOMS/EP satellite southern hemisphere ozone data, in: *Proceedings of the SPARC 2000 Second General Assembly*, Mar Del Plata, Argentina P/2-3.2, 2000b.
- Piacentini, R.D., Crino, E., Sirur Flores, J., Ginzburg, M. Intercomparison between ground based and TOMS/EP satellite southern hemisphere ozone data new results. *Adv. Space Res.* 29, 1643–1648, 2002.
- Ristori, P., Otero, L., Fochesatto, J., Flamant, P.H., Wolfram, E., Quel, E., Piacentini, R.D., Holben, B. Aerosol optical properties measured in Argentina: wavelength dependence and variability based on sun photometer measurements. *Opt. Laser Eng.* 40, 91–104, 2003.
- Roy, C., Gies, P. Action spectra used in standards: impact on radiation protection, in: *Measurements of optical Radiation Hazards. International Commission on Non-ionizing Radiation Protection and International Commission on Illumination Reference Book*. Märkl-Druck, Munich, pp. 271–287, 1998.
- UNEP Report. Environmental effects of ozone depletion: 1998 Assessment (van der Leun, J.C., Bornman, J.F. editors). *Photochem. Photobiol. B: Biol.* 46, 1–108, 1998.
- WMO, Scientific Assessment of Ozone Depletion: 1994. WMO Report 37, Geneva, 1994a.
- WMO Report, WMO Meeting of Experts on UV-B Measurements, Data Quality and Standardization of UV Indices. Les Diablerets, Geneva, Switzerland. GAW Report 95, 1994b.
- WMO, Scientific Assessment of Ozone Depletion: 1998. WMO Report 44, Geneva, 1999.