AN IMPROVED CONAE SOLAR UV INDEX FOR ARGENTINA

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ABSTRACT

The National Commission on Space Activities of Argentina (CONAE) has been predicting a clear sky UV Index for solar risk prevention from November 1996 up to the present. It is based on a parametric atmospheric radiative transfer calculation for clear sky conditions, including mainly the ozone attenuation from NASA's TOMS data and the altitude (pressure) and coordinates of the selected site. Daily information for various locations of Argentina, as well as for other countries, are published via the web at www.conae.gov.ar. We present an improved version of the CONAE UV Index using the Tropospheric Ultraviolet & Visible Radiation Model (www.acd.ucar.edu/TUV), with the inclusion the effective aerosol data estimated for specific sites and a correction factor for cloudy sky.

INTRODUCTION

The UV index is widely used all over the world as an indication of the risk level for humans exposed to solar radiation, mainly UVB in the 290 nm – 400 nm range (WHO, 2002, UNEP, 2003). It is based on the *erythemal irradiance,* which is obtained multiplying the spectral solar UV irradiance (I) by the corresponding biological weighting function (B) (McKinlay and Diffey, 1987) and integrating in the UV wavelength range:

$$I_{eryth}(t) = \int I(\lambda, t) \quad B(\lambda) \quad d\lambda \qquad (1)$$

The UV index is derived from the erythemal irradiance in units of W/m^2 given by equation (1), multiplying it by a factor of 40 in order to bring it to the range 0 to 10+ (UNEP, 2003). The time normally corresponds to local noon. It has recently been shown that the range must be extended, even to values larger than 20 (UNEP, 2003; Cede et al, 2002a), in order to take into account the solar risk in regions like the intertropical high altitude Atacama desert in South America. It must be pointed out that in this region, the solar irradiance can be in special circumstances even larger that the *solar constant* (Piacentini et al, 2003).

Different countries employ this UV index, as summarized by Long (2003). Since solar irradiance is largely affected by ozone total column, knowledge of the spatial distribution of this atmospheric variable is of fundamental importance in order to cover a large fraction of the Earth, satellite data are thus essential to provide this information. Due to the large time series of ozone data (more than a quarter of century) and its excellent coverage, one of the most used sources of information in that provided by the TOMS (Total Ozone Mapping Spectrometer)/NASA instrument on board of different satellites (Nimbus 7, Meteor 3, ADEOS and Earth Probe). In Argentina, the National Commission on Space Activities (CONAE) is forecasting daily from 1996 a clear sky UV index, using TOMS EP data except for an interim period in which ADEOS data were used. The calculation is based in a simple radiative transfer model that includes this information as a main parameter and considers clear sky conditions. Just in some particular places, like La Quiaca, a constant mean aerosol total column has been used (www.conae.gov.ar). The CONAE index is provided for 40 cities of Argentina and 19 foreign places in Latin America.

We here propose an improved version of the CONAE UV index, through the use of the more elaborated TUV computational code (www.acd.ucar.edu/TUV/) and a average of daily values for the last years (2000 - 2003). For the aerosol total column, we considered the mean behavior as given by Cede (2001).

RESULTS

Since Argentina is a very elongated country, extending from low (tropical) to high latitudes, we present results of the UV Index for locations at three representative regions: North (La Quiaca), Centre (Rosario and Buenos Aires) and South (Argentina Antarctic Marambio Base).

We performed different tests to determine the best option in order to make predictions for several days ahead. We started with a simple linear extrapolation of the last three and five data points corresponding to given days for Rosario, Argentina, in the period 2000-2003. Comparing these data with actual values, the mean percentage difference is less than 4.3 %. We also considered a second order polynomial approximation for three data points, which does not improve the simple linear extrapolation results. Even if the uncertainty in the linear case in rather small, this method requires to follow the evolution of the ozone total column daily.

In order to avoid this need, to perform the calculations we selected a *mean daily ozone total column,* calculated using the measured values for each day in the last years (2000 to 2003). It is expected that we will be able to apply this method for the rest of the present decade (or at least for several years) since, as shown above, a significant reduction in the ozone depletion *trend* has been detected in the Southern Hemisphere, at low - middle latitudes. Otherwise, the mean variation in the ozone layer (form TOMS data) was lower than about 1% in the 1998-2003 period in this latitudinal band, thus producing a rather similar small variation in erythemal irradiance (and related UV index, see e.g. Madronich, 1993; McKinlay and Diffey, 1987). Of course, periodic examination of ozone data provided by ground stations and/or spacecraft will be necessary, in order to detect any (unlikely) sudden change in the mean values.

Starting with La Quiaca, we applied the TUV (Tropospheric Ultraviolet Visible) algorithm developed by Madronich (www.acd.ucar.edu/TUV), incorporating the corresponding values for the coordinates, height (pressure), single scattering albedo, surface albedo as given in Table 1. The mean ozone total column is determined from the TOMS/EP data base and the rest of atmospheric variables and parameters are given by default in the TUV algorithm. We use a YES biometer (erythemal solar irradiance meter) of the Argentinean UV Monitoring Network National Weather Service, in order to compare the data with model calculations. These calculations were made including all other solar (extraterrestrial solar irradiance) and atmospheric variables and parameters (ozone total column and profile, pressure, single scattering albedo, soil reflectivity, aerosol profile) and adjusting the aerosol total column in order to reduce to a minimal expression the data-model relative difference. The corresponding aerosol optical depth is usually called the *effective AOD* (Blumthaler, 2000).

Figure 1.a shows the UV Index at La Quiaca, Argentina. The reference values are those measured with a YES biometer during clear sky days during the July 1996 – December 1998 period. The *standard* CONAE UV Index is displayed as well as the *improved* one developed in the present work (see Table 2 for a comparison between both UV index).

Figure 1.b (top) gives the clear-sky *improved* UV Index for La Quiaca, Argentina, made with the TUV model and daily ozone data, compared with the same type of estimate considering *mean* daily ozone TOMS/EP data. At the bottom of the same figure, we show the clear-sky UV Index differences with respect to the YES biometer measurements, of the results obtained with the TUV program and with the *standard* CONAE UV Index displayed in Figure 1.a. It can be seen that the mean values are rather similar, but only in this particular location (see figures 2.b and 3.b for other locations), since in the determination of the conventional UV index the scale height of the aerosols was assumed non null (but smaller than that used for Rayleigh scattering) and also to the fact that in this region the aerosol total column does not vary significantly along the days of the year (Cede, 2001)**.** Even if the mean annual value of the percentage difference is lower for the *standard* Index than for the *improved* one (due to the very clear sky conditions almost all the year round that is rather well reproduced by a simple radiative transfer model), the standard deviation in the latter case is significantly lower (47% lower), which is a real improvement in the calculations.

Similar analyses are presented for the Central (most populated) region of the country (Rosario and Buenos Aires cities) were the improvement is evident in the mean value of the relative percentage difference as well as in the standard deviation (figures 2 and 3).

For the Argentina Antarctic Marambio Base and due to the presence of the Antarctic ozone hole (Brasseur et al, 1999) from about August to December of each year, the information of the solar risk is more difficult to determine in this period of the year. Therefore, and as indicated in Figure 4, an *enveloping Gauss function,* - determined adjusting the measured data, has been added to the mean clear-sky UV index estimate, in order to take into account the possible passage of the ozone hole over this geographical place, which produce the dispersed points under the Gauss curve. This curve thus gives an estimate of the possible maximum value of the UV index, that would be registered in the case of the presence of the ozone hole in clear sky conditions. It must also be pointed out that the standard and improved CONAE UV index comparisons in this geographical place has been analyzed in the first semester period, outside the ozone hole one.

Cloud correction factor

We also include a cloud coverage correction factor, in order to determine the attenuation originated by cloudiness (measured in octas) at sea level and at high altitudes. The corresponding *cloud mean transmittance* factor is given in Table 3, following the work of Cede et al (2002c). In the web, the UV index information will then be given as columns for clear sky and different clouds conditions. This factor must be used with care, since it was obtained for mean cloud conditions and in rather long periods of time (more than an hour) and without discrimination of the cloud type. Also, if the Sun is uncovered, even with clouds in the sky, no correction must be included.

CONCLUSIONS

We improved the CONAE UV index for Argentina. This index is of importance in order to give indications of solar risk to persons exposed to intense Sun (WHO, 2002; UNEP Report, 2003; McKinlay and Diffey, 1987).

The main conclusions of the present work are:

- The detailed TUV calculations of the clear-sky UV index for Argentina give in general better agreement with the measured data and a lower dispersion, when compared to the previous calculations. Details about calibration and uncertainty data analysis are given in Cede et al (2002b). The particular difference values for each location are given in Table 3.
- For high Southern Hemisphere location (like the Marambio Antarctic Base) and during the ozone hole event, a *gaussian function* was added to the normal estimate, in order to represent the maximum possible UV index to be attained in this geographical place.

ACKNOWLEDGEMENTS

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REFERENCES

Blumthaler, M. Postgraduate Course on "Solar UV radiation and biological effects". National University of Rosario, Argentina under the auspices of IAI (Interamerican Institute of Climate Change Research), November 2000.

Brasseur G P, J J Orlando and G S Tyndall. Atmospheric chemistry and global change, Oxford University Press, Oxford, Great Britain, 1999.

Cede A. "Erythemal UV in Argentina: Measurements, climatological interpretation and comparison with satellite-derived data". Doctoral thesis, University of Innsbruck, Austria. 2001.

Cede A, Luccini E, Nuñez L , Piacentini R D and Blumthaler M, "Monitoring of erythemal irradiance in the Argentina Ultraviolet Network". Journal Geophysical Research 107, D13, 2002a (DOI: 2002/2001JD001206).

Cede A, Luccini E, Piacentini R D, Nuñez L and Blumthaler M, "Calibration and uncertainty estimation of erythemal radiometers in the Argentina Ultraviolet Network". Applied Optics, 41, 6341, 2002b.

Cede A, Luccini E, Piacentini R D, Nuñez L and Blumthaler M. "Effects of clouds on erythemal and total irradiance as derived from data of the Argentine Network", Geophysical Research Letters 29,76-1 76-4, 2002c.

CONAE Web page (www.conae.gov.ar), enter in the *UV Index* link

Long, C. "UV Index Forecasting Practices around the World", SPARC Newsletter 21, June 2003

McKinlay, A.F. and B.L. Diffey. "A reference action spectrum for ultra-violet induced erythema in human skin. In Human Exposure to Ultraviolet Radiation: Risks and Regulations. W.F. Passchier and B.F.M. Bosnjakovich, eds. International Congress Series. pp. 83-87, 1987.

Piacentini R D, Cede A and Bárcena H. "Extreme solar global and UV irradiances due to cloud effect measured near the summer solstice at the high altitude desertic plateau Puna of Atacama". Journal of Atmospheric and Solar Terrestrial Physics. 65, 727-731, 2003.

Piacentini R D, Cede A, Luccini E and Stengel F. "Determination of the UV solar risk in Argentina with high-resolution maps calculated using TOMS ozone climatology". Advances in Space Research (in press) 2004.

TUV Web page (www.acd.ucar.edu/TUV/)

UNEP Report "Environmental effects of ozone depletion and its interaction with climate change", 2003.

WHO (World Health Organization) "Global solar UV index. A practical guide". WHO Publication, 2002.

Figure 1.a) UV Index at La Quiaca (22.11ϒS, 65.57ϒW, 3459 m asl), Argentina. The references values are measured with a YES biometer during clear sky days during the period 1996 – 1998. We also show the standard CONAE UV Index and the one developed in the present work, which is obtained employing the TUV model with mean ozone obtained from the TOMS/EP data base, a mean effective aerosol optical depth of 0.1 at 340 nm, single scattering albedo of 0.99 and soil reflectivity of 0.06. The rest of the parameters are as given by default in the TUV algorithm.

Figure 1.b) Top. UV Index forecast for La Quiaca, Argentina, obtained with the TUV model, considering mean ozone values and the rest of the parameters as described in Figure 1a, compared with respect to the same type of forecast but using daily ozone TOMS/EP data for the next day. Bottom. UV Index differences with respect to the YES biometer measurements, of the results obtained with the TUV program (see Figure 1a) and with the standard CONAE UV Index.

Figure 2.a) Same as Figure 1a, but for Rosario city (32.96 ϒS, 60.62 ϒW, 25 m asl), during the period 1999–2001, but with effective aerosol as in reference [1] and a single scattering albedo of 0.93.

Figure 2.b) Same as figure 1.b, but for Rosario city.

Figure 3.a) Same as Figure 1.a, but for Buenos Aires city (34.61ϒS, 58.41ϒW, 25 m asl), during the period 1997 – 1999, but with mean effective aerosol of 0.55 at 340 nm and single scattering albedo of 0.93.

Figure 3. b) Same as Figure 1.b, but for Buenos Aires city.

Figure 4.a) Same as figure 1.a, but for Argentina's Antarctic Marambio Base (64.23ϒS, 56.72ϒW, 300 m asl), during the period 1996 – 1998, but with effective aerosol as in reference [1] and single scattering albedo of 0.93. Note: A Gauss function has been added to the mean UV index forecast, in order to take into account the possible passage of the ozone hole over the geographical place. It is determined adjusting measured data.

Figure 4.b) Same as figure 1.b, but for the Antarctic Marambio Base. Note: The UV index has been analyzed in the first semester period when no ozone hole is present.

Table 1. Values of the complementary variable AOD (Aerosol Optical Depth at 340 nm) and parameters (single scattering albedo and soil reflectivity or albedo) used in the TUV algorithm, for each location in Argentina. Mean constant AOD values have been used for La Quiaca and Buenos Aires, due to their small monthly variations along the year (Cede, 2001).

Table 2. Comparison of the model/parameter differences between the CONAE standard and the improved UV Index.

Table 3. Cloud correction factor to be applied to the improved UV index.

Table 4. Differences between data and model calculations for different characteristic locations in Argentina for the mean and standard deviation values.

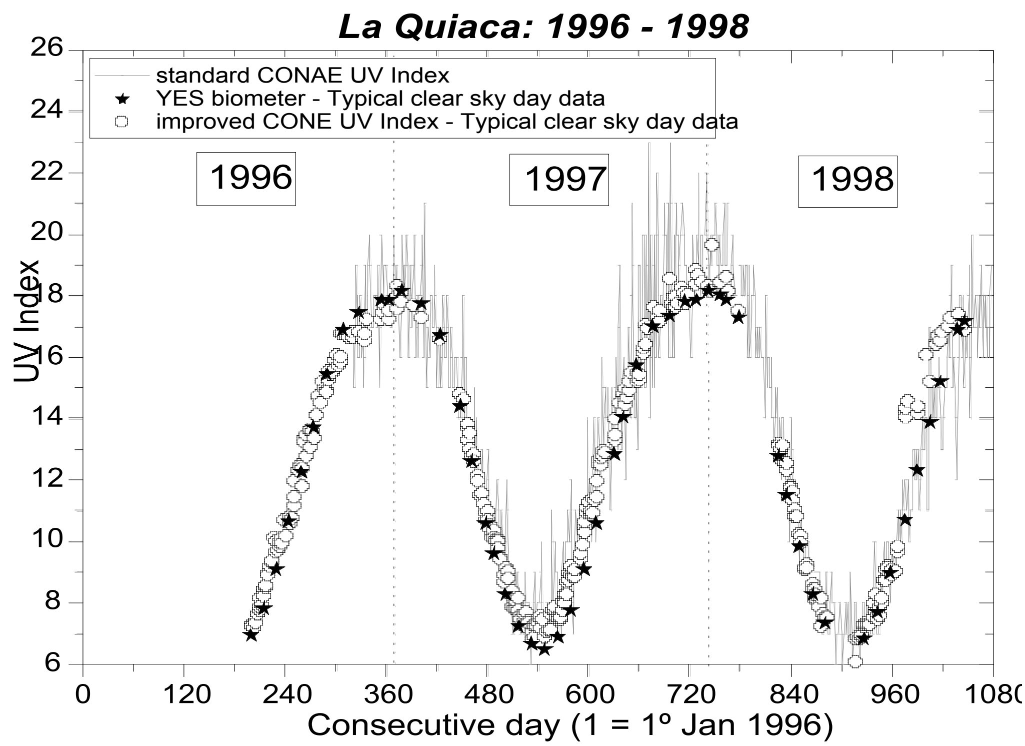

Figure 1.a) UV Index at La Quiaca (22.11ºS, 65.57ºW, 3459 m asl), Argentina. The references values are measured with a YES biometer during clear sky days during the period 1996 – 1998. CONAE UV Index and improved one developed in the present work, is obtained employing the TUV model with mean ozone from TOMS/EP NASA data base, mean effective aerosol of 0.1 at 340 nm, single scattering albedo of 0.99 and soil reflectivity of 0.06. The rest of the parameters are as given by default in the TUV algorithm.

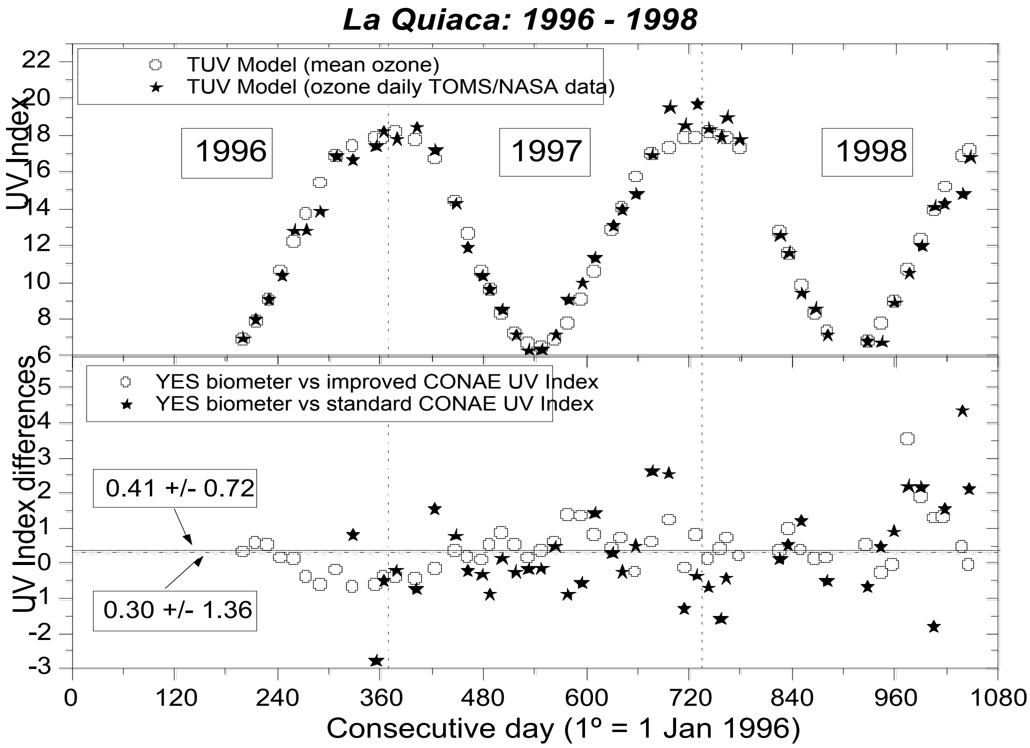

Figure 1.b) Top. UV Index forecast for La Quiaca, Argentina, made with TUV model which considers mean ozone values and the rest of the parameters as described in figure 1, compared with respect to the same type of forecast but considering daily ozone TOMS/EP NASA data for the next day. Bottom. UV Index differences with respect to YES

biometer measurements, of the results obtained with the TUV program (see figure 1) and with the standard CONAE UV Index.

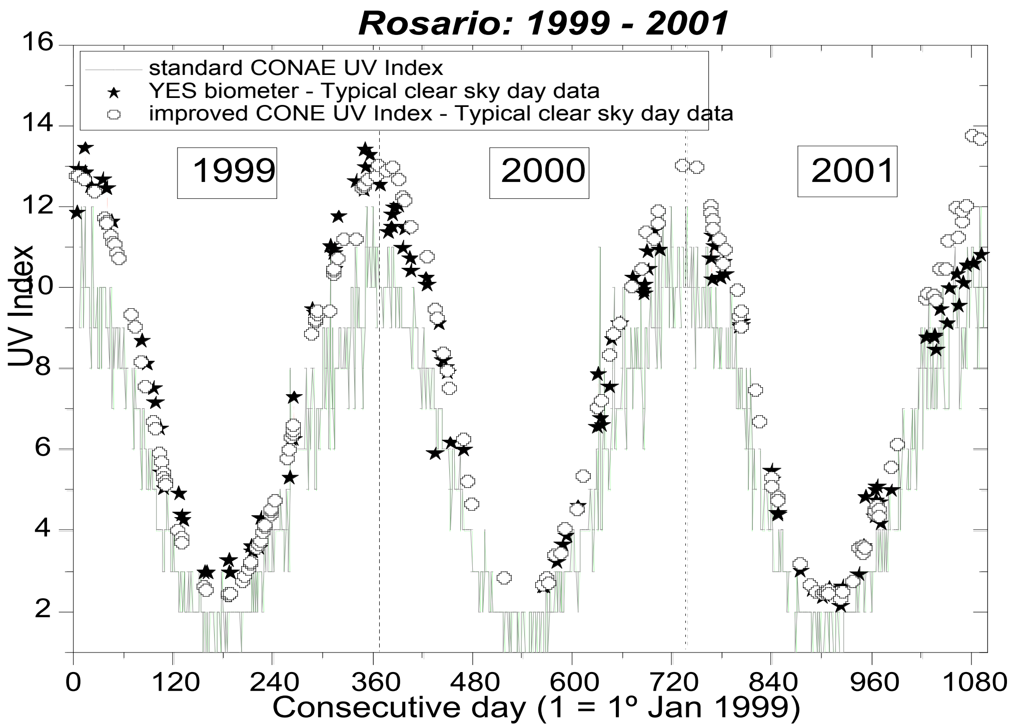

Figure 2.a) Same as figure 1, but for Rosario city (32.96 °S, 60.62 °W, 25 m asl), Argentina, during the period 1999–2001 but with effective aerosol as in reference [1] and single scattering albedo of 0.93.

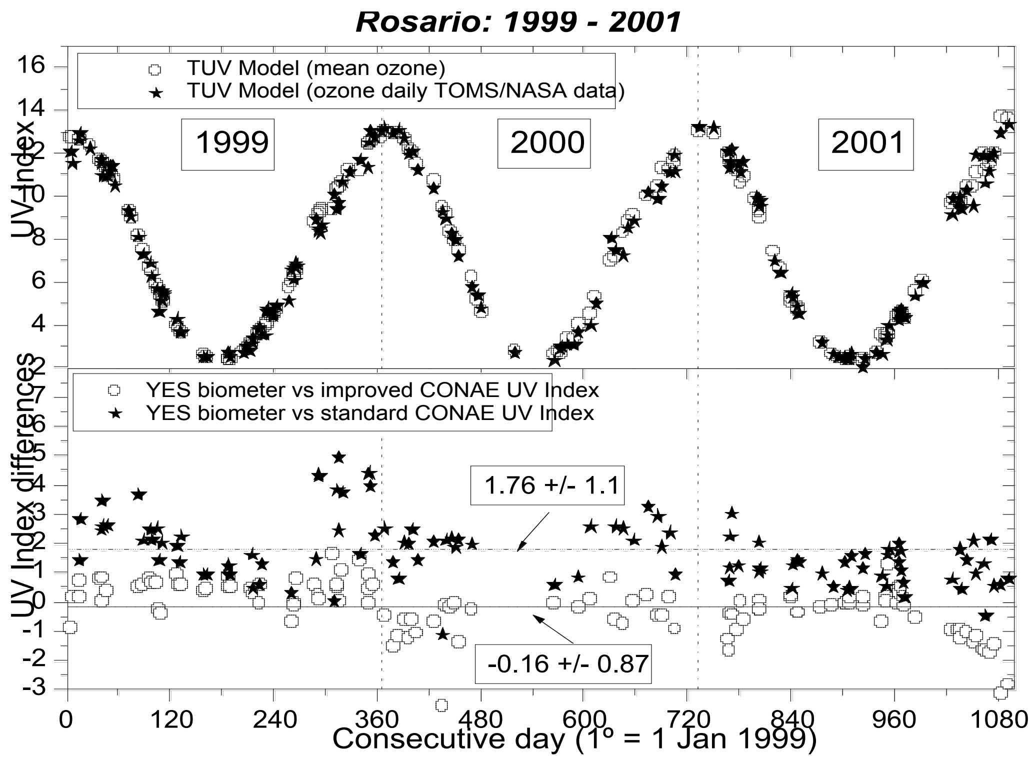

Figure 2.b) Same as figure 1.b, but for Rosario city, Argentina.

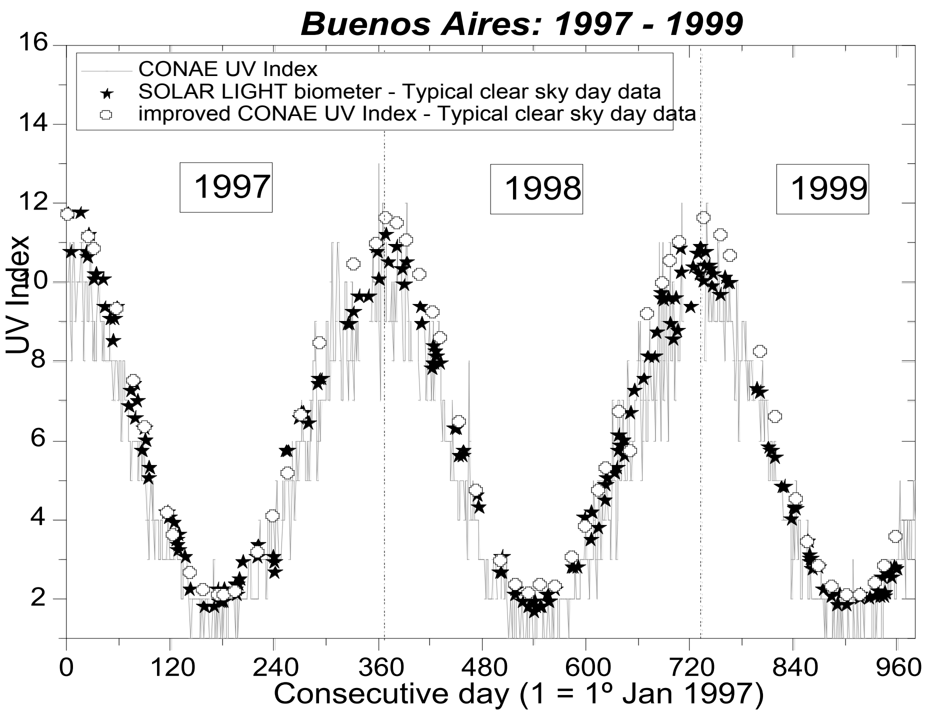

Figure 3.a) Same as figure 1.a, but for Buenos Aires city (34.61°S, 58.41°W, 25 m asl), Argentina, during the period 1997 – 1999 but with mean effective aerosol of 0.55 at 340 nm and single scattering albedo of 0.93.

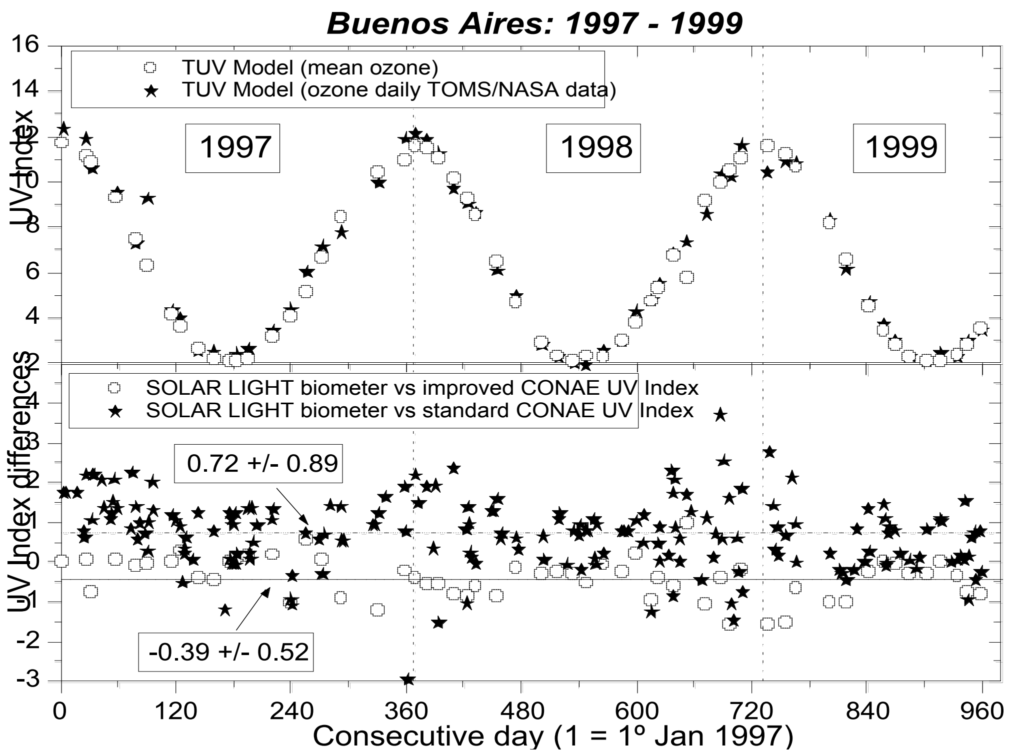

Figure 3. b) Same as figure 1.b, but for Buenos Aires city, Argentina.

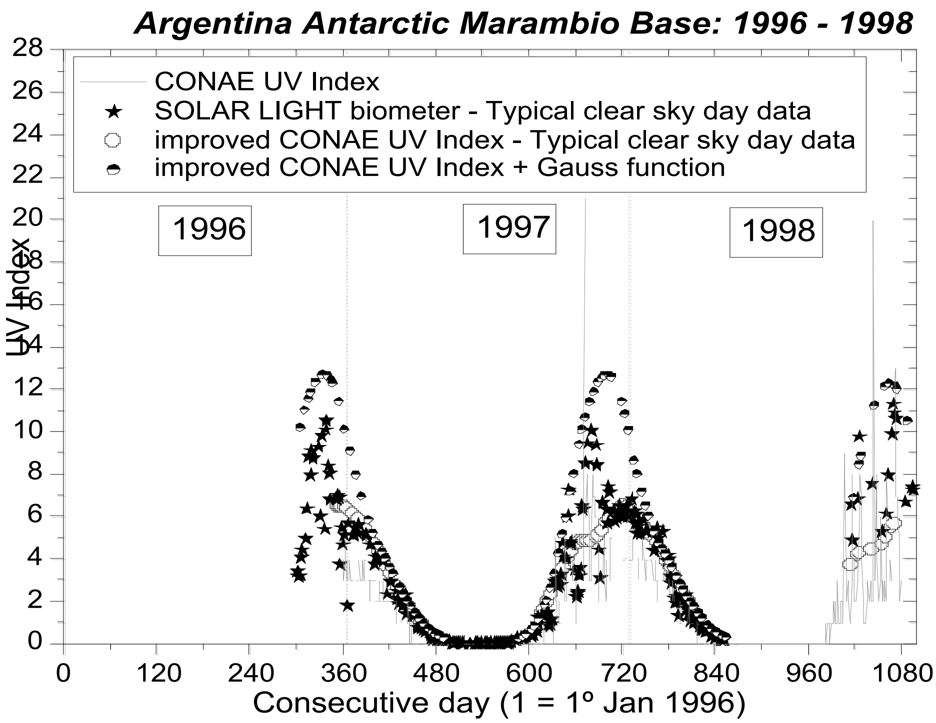

Figure 4.a) Same as figure 1.a, but for Argentina Antarctic Marambio Base (64.23ºS, 56.72ºW, 300 m asl), during the period 1996 – 1998 but with effective aerosol as in reference [1] and single scattering albedo of 0.93. Note: A Gauss function has been added to the mean UV index forecast in order to take into account the possible passage of the ozone hole over the geographical place. It is determined adjusting measured data.

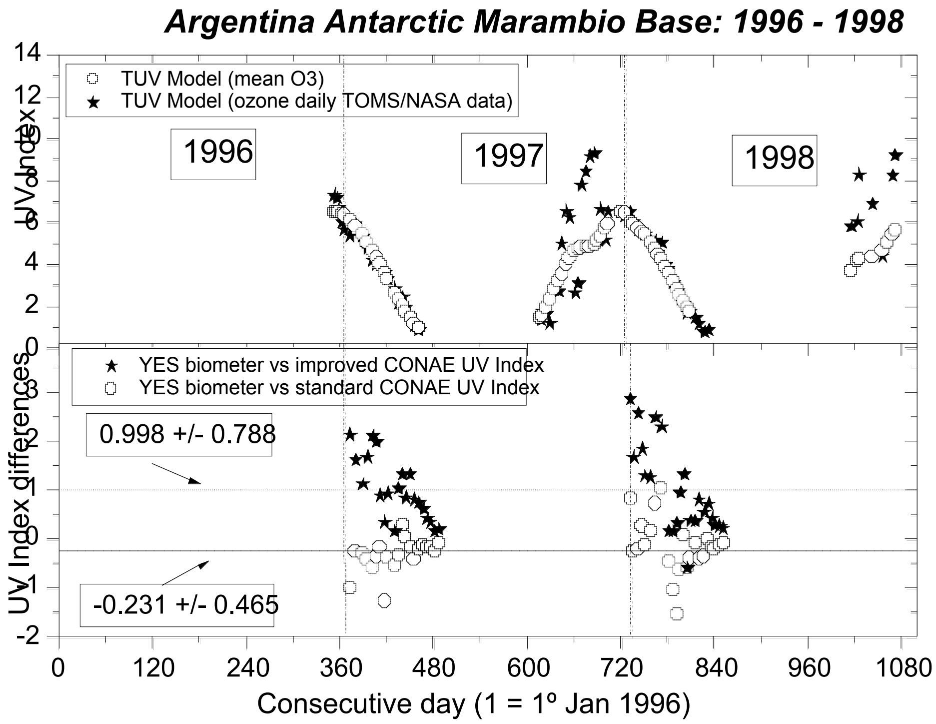

Figure 4.b) Same as figure 1.b, but for Argentina Antarctic Marambio Base. Note: The UV index has been analyzed in the first semester period outside the ozone hole one.

Places	*Period*	*Biometer*	*Mean effective AOD (at 340 nm)*	*Single scattering albedo*	*Soil Reflectivity*
La Quiaca (22.11°S, 65.57°W, 3459 m asl)	**July 1996 – Dec 1998**	**YES**	**0.1 (+)**	**0.99**	**0.06**
Rosario (32.96 °S, 60.62 °W, 25 m asl)	**Jan 1999 – Dec 2000**	**YES**	**Variable along the year (Cede, 2001)**	**0.93**	**0.06**
Buenos Aires (34.61 °S, 58.41 °W, 25 m asl)	**Jan 1997 – Aug 1999**	**SOLAR LIGHT**	**0.55 (*)**	**0.93**	**0.06**
Argentina Antarctic Marambio Base (64.23 °S, 56.72°W, 300 m asl)	**Oct 1996 – Dec 1998**	**SOLAR LIGHT**	**Variable along the year (Cede, 2001)**	**0.93**	**0.4**

Table 1. Values of the complementary variable (Aerosol Optical Depth at 340 nm) and parameters (single scattering albedo and soil reflectivity or albedo) to be used in the TUV algorithm, for each location in Argentina. (*) Note: Mean constant AOD values has been used for La Quiaca and Buenos Aires, due to their small monthly variations along the year (Cede, 2001)

Cloud coverage	*0/8*	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*
Erythemal irradiance, sea level	**1**	**0.99**	**0.98**	**0.97**	**0.96**	**0.91**	**0.82**	**0.67**	**0.41**
Erythemal irradiance, high altitude	**1**	**0.98**	**0.98**	**0.98**	**0.97**	**0.94**	**0.90**	**0.78**	**0.56**

Table 3. Cloud correction factor to be applied to the *improved* CONAE UV index.

<table>
<tr><th rowspan="3">Location</th><th colspan="4">|YES Data - Model| UV Index differences in</th></tr>
<tr><th colspan="2">Mean values</th><th colspan="2">Standard deviations</th></tr>
<tr><th>Standard model</th><th>Improved model</th><th>Standard model</th><th>Improved model</th></tr>
<tr><td>La Quiaca</td><td>0.30</td><td>0.41</td><td>1.36</td><td>0.72</td></tr>
<tr><td>Rosario</td><td>1.76</td><td>0.16</td><td>1.10</td><td>0.87</td></tr>
<tr><td>Buenos Aires</td><td>0.72</td><td>0.39</td><td>0.89</td><td>0.52</td></tr>
<tr><td>Argentina Antarctic Marambio Base</td><td>0.83</td><td>0.13</td><td>0.74</td><td>0.54</td></tr>
</table>

Table 4. Differences between data and model calculations for different characteristic locations in Argentina for the mean and standard deviation values.