Effects of ozone layer variation in Ultraviolet solar radiation level received at ground in Arica north of Chile

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Abstract. There is an important relationship between overexposure to the sun and various types of skin diseases and sight. Experimental measurements of solar ultraviolet index (UVI) measurements in Arica (ARI) in the period between 2006 to 2015, indicate that during the summer 83.1% was extreme (over 11), when occurs the annual minimum of ozone layer in this latitude. The effects to UVI by the ozone layer variation was study with satellital measurements of thickness of the ozone layer in Arica.

1. Introduction

The electromagnetic radiation emitted by the Sun comprises a broad spectrum. A small part of the ultraviolet solar radiation reaches the ground level after passing through the atmosphere and its different components, including the stratospheric ozone layer. The ultraviolet solar radiation B (UVB) 280 - 315 nm is strongly absorbed by the ozone layer, while the ultraviolet solar radiation A (UVA) 315-400 nm is not absorbed by the ozone layer and its levels are high from dawn until dusk at ground level, whereas (UVC) 100-280 nm is completely absorbed by the ozone layer in the stratosphere not reaching ground level [1].

The effects of ultraviolet solar radiation on the skin depend on factors such as the thickness of the skin penetrated by a specific wavelength and the person’s skin type [2].

In the case of the stratospheric ozone layer, the measurement with satellite instruments has reached great precision, allowing a permanent sampling all over the Planet. Although UV solar irradiances and erythema doses have been derived that affect the surface of the Earth from data obtained with satellite, based equipment such as NASA’s TOMS instruments [3-4], because the measurements of UVB depend strongly on local conditions, that influence the state of the atmosphere. The amount of UVB received at ground level depends on multiple local factors such as: cloudiness, suspended particles (aerosols), soil reflectivity (albedo), altitude of the place above sea level, stratospheric ozone. This factors makes its study more complex and introduces greater sources of indetermination in this type of measurements being necessary to contrast with calibrated biometers located in the place.
2. Materials and methods

Arica is a city located in the subtropical zone of northern Chile (25 meters above sea level, latitude: 18° 49'S; longitude: 70° 19'W) which presents a stable micro-climate. The weather conditions throughout the year, such as the lack of rainfall (less than 5 mm per decade), predictable wind regime, high percentage of clear sky days and high soil reflectivity, mainly due to desertification and composition mainly because of very reflective sand. The city is located at sea level; therefore, the population carries out a great number of outdoor activities.

3. Instrumentation

There are essentially two types of physical instruments for measuring solar UV irradiance: spectral, covering a region of the spectrum with very fine wavelength spacing (or measuring at fixed wavelengths with very good spectral resolution) and bandwidth Wide, which measure in a wide range of wavelengths with relative response close to unity in all of them, or approaching the response function of some biological system (usually called biometrics). The widespread use of a standardized metric for reporting UV radiation risk-namely erythemally weighted UV (UVery, in W/m²) or the UV index (UVI = 40 • UVery), has also facilitated meaningful comparisons. The most recent of these assessments predicts that although the ozone layer will gradually recover over the next few decades, the outlook for future UV is less certain [5].

The instrument is located in the highest part of the UV solar radiation laboratory with clear view. The measurements were carried out with a YES-UVB broadband biometer [6], calibrated periodically through a cooperation agreement between Tarapacá University (UTA) with the Chilean Meteorological Direction (DMC), by means of which this instrument forms part of the solar ultraviolet measurement network of our country. Calibrations are carried out in accordance with the recommendations of the World Meteorological Organization (WMO). The biometer has been in operation since September 2006.

Stratospheric ozone data are based on satellite measurements by the ozone measuring instrument (OMI / Aura satellite) and TOMS (Spectrometer for total ozone mapping), data are available at http://jwockey.gsfc.nasa.gov. OMI provides almost global coverage in one day with a spatial resolution of 13 x 24 km. TOMS is the oldest instrument for collecting and analyzing the stratospheric ozone layer and the properties of atmospheric solar UV radiation, this was replaced by OMI after operating between 1996 and 2005 [7]. Measurements of UVB solar irradiance were performed in Arica between September 20th, 2006 and December 31st, 2015, every five minutes.
4. UVI and ozone Arica measurements

**Figure 1.** Arica 2006 – 2015. Monthly averages of maximum daily UVI values Arica 2006 - 2015.

Figure 1 shows the monthly averages of daily maximum UVI in Arica between 2006 - 2015. The seasonal variation of UVI is observed, especially with high levels of UVI during the summer months. The data of the monthly averages of UVI measured at the solar midday reached in the summer of 2008 the maximum value of the analyzed period, corresponding to UVI = 14.4 and the minimum value of the average monthly UVI corresponds to July of the year 2011 UVI = 4.7. The minimum values are presented in the winter months of June and July. For most of the year the maximum values measured at solar midday UVI in Arica are over 6.

**Figure 2.** Average monthly values of the thickness of the ozone layer in Arica, 2006-2016.

Figure 2 shows the stratospheric ozone contents in Arica provided by the satellite instrument OMI / NASA between the years 2006 - 2016. The monthly averages of stratospheric ozone measured in the city of Arica range from a minimum value of 235.2 Dobson units (DU) in February 2006 and a maximum value of 277.7 (DU) in September 2011. The maximum thickness of the ozone layer is produced in Arica during the months of September and October.
and the minimum values are observed during the months of January, February and April. These results show that in this subtropical region the thickness of the ozone layer is lower during the summer when, due to the lower zenith angle, more UVB solar radiation is received and, therefore, more protection is needed, which represents a greater risk to health due the lower thickness of the ozone layer causes an increase in UVB radiation reaching ground level [8-9].

![Figure 3. Average monthly values of the thickness of the ozone layer in Arica, 1978-2015](image)

The monthly average of the satellite measurements of ozone are observed in figure 3, the average monthly ozone reaches the highest values during the months of September 274.5 DU and October 269.9 DU, and the minimum values in the months of February 253.4 DU and April 252.3 DU.

![Figure 4. Monthly average values of UVI 2006-2015, and thickness of the ozone layer 1978-2015](image)

Figure 4 shows the monthly averages of the thickness of the stratospheric ozone layer and the
ultraviolet solar index in Arica. The UVI measurements indicate that the highest monthly averages of the year are in the months January 12.4, February 12, November 11.5 and December 12.4 all values of UVI above 11 and the minimum values of the year are found on May 6.9, June 6 and July 6.2.

Nevertheless, the minimum values of the thickness of the ozone layer in Arica are found in January 255.3, February 253.4 March 253.8 April 252.3 and May 253.7 DU and the maximum values in August 269, September 274.5 and October 269.9 DU.

![Figure 5. Annual average values of ozone, with their respective standard deviation, Arica 1978-2016](image5.png)

Figure 5 shows the annual averages of the thickness of the ozone layer in Arica provided by different TOMS / NASA and OMI / NASA satellite instruments between 1978 and 2016.

![Figure 6. Daily satellite measurements of stratospheric ozone in (DU), Arica (1978 – 2016)](image6.png)
Table 1. Average maximum and minimum monthly values of O₃ 2006-2013 and percentages of variation of O₃. The percentages of variation of UVI were calculated with the TUV program.

Table 01 shows the annual maximum and minimum values of the thickness of the ozone layer. The maximum values are measured by satellite during the months of September and October in this latitude and the minimum values are measured during the months of January - February in Arica between the years 2006-2013, and the corresponding annual percentage variation of the thickness of the layer of ozone. Using the TUV program [10]. The corresponding variation in the ultraviolet solar index (UVI) was calculated for the summer months, the time of the year in which the maximum values of UVI are measured, given the annual variation of the thickness of the ozone layer. The percentages of annual variations in the thickness of the ozone layer ranged from 7.1 - 12.8% and the variations of UVI calculated with the TUV program were between 8.9 - 16.1% in the same period. These results are especially relevant at this latitude because for every 1% decrease in the thickness of the ozone layer the UVI increases by 1.26%, which has consequences in the increase of new cases of non-melanoma cancer.

| Year | O₃min (DU) | O₃max (DU) | % ΔO₃ | % ΔUVI | ΔUVI/ΔO₃ |
|------|------------|------------|--------|--------|----------|
| 2006 | 235.2      | 265.2      | 12.8   | 16.1   | 1.26     |
| 2007 | 244.7      | 276.0      | 12.8   | 16.1   | 1.26     |
| 2008 | 243.7      | 266.9      | 9.5    | 12.0   | 1.26     |
| 2009 | 245.5      | 273.3      | 11.3   | 14.0   | 1.24     |
| 2010 | 240.4      | 261.5      | 8.8    | 10.9   | 1.24     |
| 2011 | 246.5      | 277.7      | 12.7   | 15.9   | 1.25     |
| 2012 | 243.8      | 268.4      | 10.0   | 12.6   | 1.26     |
| 2013 | 244.0      | 261.3      | 7.1    | 8.9    | 1.25     |

Table 2. Minimum monthly values of O₃ 2006-2013 and variation of UVI for two values of different albedos corresponding to sand 0.165 and lawn 0.02 and the percentage of variation of corresponding UVI, calculated with TUV program.

| Year | O₃ (DU) | UVI Albedo = 0.165 | UVI Albedo = 0.02 | ΔUVI | %ΔUVI |
|------|---------|-------------------|-------------------|------|-------|
| 2006 | 235.2   | 13.3              | 12.4              | 0.93 | 7.5   |
| 2007 | 244.7   | 9.1               | 8.5               | 0.63 | 7.4   |
| 2008 | 243.7   | 6.9               | 6.5               | 0.47 | 7.3   |
| 2009 | 245.5   | 12.6              | 11.7              | 0.88 | 7.5   |
| 2010 | 240.4   | 12.9              | 12.0              | 0.91 | 7.6   |
| 2011 | 246.5   | 9.0               | 8.4               | 0.62 | 7.4   |
| 2012 | 243.8   | 13.0              | 12.1              | 0.91 | 7.5   |
| 2013 | 244.0   | 9.1               | 8.4               | 0.63 | 7.4   |
Table 2 shows the monthly minimum values of O₃ 2006-2013 and the variation of UVI for two different albedos values corresponding to the one existing in Arica (corresponding albedo sand = 0.165) and an albedo corresponding to cities in the southern zone (lawn albedo = 0.02). The percentage of variation of corresponding UVI was calculated using the TUV program.

The minimum values of ozone are measured by satellite during the summer months in this latitude between the years 2006-2013. The corresponding annual percentage variation of the UVI calculated for two different albedos (sand and lawn) allows to quantify the percentage of increase of the UVI in Arica due to its lack of vegetation compared to cities of the south zone where the surface of the soil is predominantly covered by Vegetation, calculations were performed using the TUV program. The of UVI increase due to the albedo difference were between 7.3 - 7.6% in the same period.

These results have special relevance in this latitude because people living in this area only by effect of the lack of vegetation, which implies surfaces with a greater albedo the UVI increases by more than 7%, have consequences due to overexposure to UVB solar radiation in the increase of new cases of non-melanoma cancer.

5. Results

The analysis of the results revealed that 16.6% of the maximum daily UVI measured at solar noon during the summer season in Arica are high and very high (8 < UVI < 10) and 83.1% to extreme (> 11 UVI) according to the scale used by the World Health Organization (WHO). The maximum solar ultraviolet irradiance in this latitude is received during the summer months January percentages - February, during these months the thickness of the ozone layer has annual minimum values. The maximum values of the thickness of the ozone layer occur during September - October.

The percentage difference between values to the maximum and minimum average annual thickness of the ozone layer in Arica 2006 - 2013 varies 7.1 -12.8%. UVI was calculated using TUV model, reveals that the corresponding differences in the solar ultraviolet index UVI for these variations in the thickness of the ozone layer during the same period, are 8.9 - 16.1%.

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