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Attenuation by Clouds of UV Radiation for Low Stratospheric Ozone Conditions

Facundo Orte[1, a)], Elian Wolfram[1], Jacobo Salvador[1], Raúl D'Elia[1], Jonathan Quiroga[1], Eduardo Quel[1], Akira Mizuno[2].

[1]*Centro de Investigaciones en Láseres y Aplicaciones, CEILAP-UNIDEF (MINDEF-CONICET), UMI-IFAECI-CNRS-3351, Villa Martelli, Argentina.*
[2]*Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan.*

[a)]Corresponding author: pfacundo.orte@gmail.com

Abstract. Stratospheric poor ozone air masses related to the polar ozone hole overpass subpolar regions in the Southern Hemisphere during spring and summer seasons, resulting in increases of surface Ultraviolet Index (UVI). The impact of these abnormal increases in the ultraviolet radiation could be overestimated if clouds are not taking into account. The aim of this work is to determine the percentage of cases in which cloudiness attenuates the high UV radiation that would reach the surface in low total ozone column situations and in clear sky hypothetical condition for Río Gallegos, Argentina. For this purpose, we analysed UVI data obtained from a multiband filter radiometer GUV-541 (Biospherical Inc.) installed in the Observatorio Atmosférico de la Patagonia Austral (OAPA-UNIDEF (MINDEF – CONICET)) (51 º 33' S, 69 º 19' W), Río Gallegos, since 2005. The database used covers the period 2005-2012 for spring seasons. Measured UVI values are compared with UVI calculated using a parametric UV model proposed by Madronich (2007), which is an approximation for the UVI for clear sky, unpolluted atmosphere and low surface albedo condition, using the total ozone column amount, obtained from the OMI database for our case, and the solar zenith angle. It is observed that ~76% of the total low ozone amount cases, which would result in high and very high UVI categories for a hypothetical (modeled) clear sky condition, are attenuated by clouds, while 91% of hypothetical extremely high UVI category are also attenuated.

INTRODUCTION

The stratospheric ozone layer acts as a filter of UV solar radiation coming from the sun to the Earth surface. During the austral winter and spring season, the ozone layer suffers a deep depletion over the Antarctic region, which is well known as "ozone hole". The Observatorio Atmosférico de la Patagonia Austral is placed in subpolar regions and is affected for stratospheric poor ozone air masses related to the ozone hole during spring, since 80's decade [1, 2]. The depletion of ozone impacts directly in the UV solar radiation at surface, resulting in significant increases in the UVI for cloud free situations. If we consider the cloudiness, the impact of the UV radiation is attenuated drastically. Therefore, the impact of the increase of UVI related to the ozone depletion can be overestimated if clouds are not taking into account.

The aim of this paper is quantify the number of cases (or time) that the UVI is attenuated by clouds in cases for which the ozone amount is low, respect the normal situation during spring, when increases of UVI are expected for clear sky. The motivation of this study lies in that the season which is affected for poor ozone air masses over Río Gallegos (spring) coincide with the time when cloud optical depth (COD) became more important, to reach the maximum value during summer [3].

The quantification mentioned is achieved combining modeled UVI from a parametric model proposed by Madronich (2007) [4] with measurements of UVI that are obtained from a Multiband Filter Radiometer GUV-541 (Biospherical inc.) [5, 6] in cases of low Total Ozone Column (TOC) for Río Gallegos region.

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The coefficients used in the parametric model are obtained by mean of a non-linear fitting for Río Gallegos, using reliable UVI data obtained from the GUV instrument for clear sky condition, considering unpolluted atmosphere and low surface albedo.

METHODOLOGY

The method applied consist in obtain the best set of coefficients to calculate the UVI using the parametric model (Eq. (1)) proposed by Madronich (2007). Then the impact of clouds was analysed by comparing modeled (UVI_{mod}) and measured UVI (UVI_{GUV}), for cases with low ozone amount over Río Gallegos. The UVI_{GUV} is obtained from the Multiband Filter Radiometer GUV-541 with a time resolution of one minute [5, 6].

To obtain the best set of coefficients, a non-linear fitting is used applying the "shape" of the Eq. (1) [4] using the UVI_{GUV} for calibrated and reliable data:

$$UVI_{GUV} \sim a\mu^{b}\left(\frac{TOC}{300}\right)^{c} \tag{1}$$

Here, μ is the cosine of the solar zenith angle (SZA) and TOC is the Total Ozone Column, which is taken from the OMI date base, on board of AURA satellite [https://aura.gsfc.nasa.gov/omi.html]. Because the GUV-541 instrument was installed in June 2005 in the OAPA, we can consider that the company calibration was remained during June 2005 to December 2006 and we can take it as reliable data. For this reason, that period is used to determine the coefficients a, b and c.

The model can be considered valid under cloud free, unpolluted and low surface albedo conditions. To select "cloud free" data from the GUV-541 database for applying the non-linear fitting, the Cloud Optical Depth (CDO) derived from the GUV-541 is used [3, 5]. We consider "cloud free" periods when the COD is less than 0.1 for a time longer than 20 minutes and when the start time and end time of this period is further than 10 minutes from the data with CDO≥0.1. In addition, only data with SZA less than 60° are taken into account due to the fact that the error of the parametric model increase with the solar zenith angle up to ~10% for SZA=60° [4].

With the set of coefficients it is possible to calculate the UVI_{mod} for clear sky condition. Finally, we determined the cloud attenuation in the UVI by comparing with the UVI_{GUV} in any condition (clear and cloudy sky). The method to evaluate this attenuation is achieved by mean of the quantification of cases (taking one case as one minute, due to the time resolution of the GUV-541) that the cloud attenuates the UVI for its three highest categories: namely, "High", "Very High" and "Extreme" [7], which occur during episodes of low Total Ozone Column over Río Gallegos.

RESULTS

Parametric Model for Río Gallegos

The coefficients obtained by mean of the non-linear fitting described are: a=13.13; b=2.69; c=-1.23; Hence, the following equation is used for calculate the UVI in Río Gallegos:

$$UVI_{GUV} \sim 13.13\mu^{2.69}\left(\frac{TOC}{300}\right)^{-1.23} \tag{2}$$

Figure 1 presents a scatter plot for free cloud condition (COD<0.1) since June 2005 to December 2012. The linear fitting of the scatter plot shows very good agreement between the model and the measurement, which present a slope near to unity (1.1) and a bias of 0.19. The correlation coefficient R=0.99 reflect a strong correlation between both measurement and model for clear sky situations. The difference of the slope to the unity, which reflects an overestimation of the modeled UVI respect the measurement, can be related to the nominally free cloud conditions (COD<0.1) which include very thin clouds and also to the increase in the degradation of the instrumental calibration during the period evaluated.

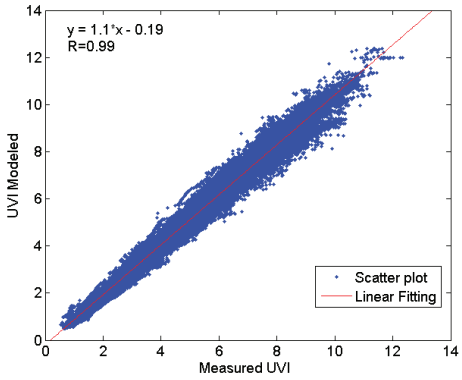

FIGURE 1. Scatter plot and linear fitting between UVI_{mod} and UVI_{GUV}.

GUV measurements data taken after 2012 are not used in this study because the instrument calibration for that period has not yet been verified.

Attenuation of UV radiation by clouds in low total ozone column cases

In this study we determine the attenuation of clouds in cases of "abnormal" condition of UVI in Río Gallegos region, considering "abnormal" as situation where the UVI take higher values due to the low content of ozone in the atmosphere, which can be related to the effect of the ozone hole passing over during spring season (September, October, November and December). To determine what is a condition of "low content of ozone" was calculated a climatology of the Total Ozone Column for Río Gallegos region using Multisensor Reanalisys Data [8] since 1979 to 2008 (Fig. 2). The value of TOC = 270 DU (blue line) was chosen as a threshold taking into account the standard deviation of the TOC.

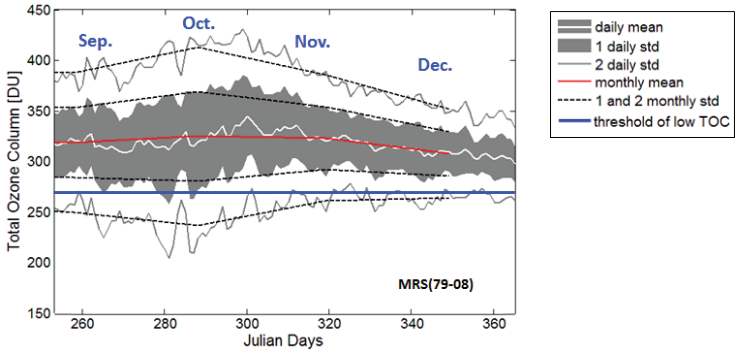

FIGURE 2. Total Ozone Column Climatology (1979 – 2008) [8]

Based on OMI data base of TOC, there were 56 days with ozone below that threshold between 2005 and 2012. Then, the UVI was modeled for those days with the aim to quantify the time that the UVI reach hypothetical categories (because the model supposed clear sky condition) of High, Very High and Extremely High UVI categories. The number of cases (or time in minutes, because the temporal resolution of the GUV-541) of each category for the calculated UVI is represented for the red bars in Fig. 3. On the other hand, the UVI measured was used to quantify the number of cases that the measurement (blue bars) reach the same categories at the same moment for which the UVI was modeled. As the UVI_{GUV} contain both cloudy and cloud free condition, and the model is only able to calculate the UVI for clear sky condition, the number of cases attenuated can be directly attributed to clouds if we neglected other factors, such as pollution.

Figure 3 shows that 76% (77%) of expected cases of High UVI (Very High UVI) category for clear sky condition with low ozone amount (red bars) are attenuated by clouds. For the Extremely High UVI category, we can observe an attenuation of 91% of total cases.

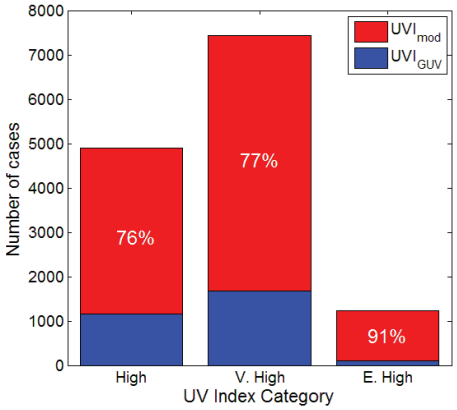

FIGURE 3. Number of cases (minutes) that reach each category for UVI_{mod} (red) and UVI_{GUV}(blue)

DISCUSSION – CONCLUSION

Using calibrated ground based measurement of UVI derived from a Multiband Filter Radiometer GUV-541 we have calculated a new set of coefficients of a parametric model to estimate the UVI in clear sky condition for Río Gallegos. In addition, we have estimated the percentage of number of cases attenuated by cloudiness that the UVI was expected to reach for the higher UVI categories for clear sky condition (modeled). The attenuation found was 76%, 77% and 91% for High, Very High and Extremely High UVI categories, respectively.

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