Effect on Irradiance of the eruption of the Cordon Caulle (Chile) at different altitudes in the Nahuel Huapi National Park (Patagonia, Argentina)

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ABSTRACT

Volcanic eruptions inject ash and non-ash particles into the atmosphere, modifying regional Aerosols Optical Depth (AOD) and aerosols size distribution, which affect irradiance at the earth's surface. In this paper, we analyze the effect of the eruption of Puyehue-Cordon Caulle (Chile) on irradiance in the area of the Nahuel Huapi National Park (NHNP) (~100 km southeast of Puyehue-Cordon Caulle), at different altitudes. In this paper we only included the results for direct and AOD obtained during field campaigns at two consecutive years, before and after the eruption. Three days presented clear skies during most of the day in 2011. Two of those days, showed AOD similar to the values in 2010. On the third days, at the lowest altitude site (804m.s.l.), AOD were near 200% larger than in 2010. The largest decreases observed, at noon, in the direct irradiance was ~30% at 380 nm and 25% at 500nm, increasing with Solar Zenith Angle (SZA). The effect was less pronounced at the site at highest altitude (1930 m.s.l.), where the AODs increase was near 90% and the direct noon irradiance decrease 10% at 380 nm and 7% at 500nm.

UV Radiation, Visible Radiation, Altitude Effect, Volcanic Eruptions, AOD

1. INTRODUCTION

Total solar radiation reaching the Earth's surface is influenced by scattering and absorption processes in the atmosphere and the ground, while direct radiation is affected by absorption. Several factors determine ground-level radiation. Some of these factors are geometric as sun-earth distance and solar zenith angle (determined by geographic position, time and season). The variation of the irradiance with these factors is well established and can be predicted. Other factors, as atmospheric gases and aerosols, clouds, altitude and surface albedo, are complex and more difficult to determine.

Several studies have shown the effect of the concentration and composition of aerosols on long- and short-term changes in irradiances[1-4]. Large differences have been observed in UV irradiances between urban and rural locations, or between rather polluted sites in the Northern Hemisphere and cleaner sites in the Southern Hemisphere[5].

Volcanic eruptions inject ash and non-ash particles (sulfate) into the atmosphere, affecting regional Aerosols Optical Depth (AOD)[6]. In the case of major eruptions, these particles can last for long periods even at sites far away from the emission source[10,11]. Ash particles contribute to the coarse mode fraction, while sulfate particles are comparatively smaller and thus belong to the fine particle mode[6]. It has been observed that the increase of SO_2 over areas affected by

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high volcanic activity or over regions close to coal burning industries, may result in approximately 2% attenuation of erythemal irradiance and, at some UV wavelengths, the reduction can exceed 20%[12].

A layer of sulfuric acid aerosol is present in the lower stratosphere, at all latitudes. During "background" conditions (volcanically quiescent periods), the dominant source of this aerosol layer is thought to be the photolysis of carbonyl sulfide and sulfur entering the stratosphere in the form of sulfur dioxide (SO_2)[13]. The other major source of sulfur to the stratosphere is the activity of volcanoes. Major volcanic eruptions can inject large amounts of this element directly into the stratosphere, increasing the stratospheric aerosol layer for several years. This effect was observed after the eruptions of El Chichón in 1982 and Mt. Pinatubo in 1991.

On June 4th, 2011, the Puyheue-Cordon Caulle volcanic complex (40°35′25″S 72°07′02″W, Chile) (Figure 1) erupted after a period of low activity. The Cordón Caulle is one of the most active in Southern Andes. During the eruption of 2011, ash, sand and pumice were ejected and the ash emission was blown east of the area affecting different downwind regions of the Southern Hemisphere around the world for several months[14].

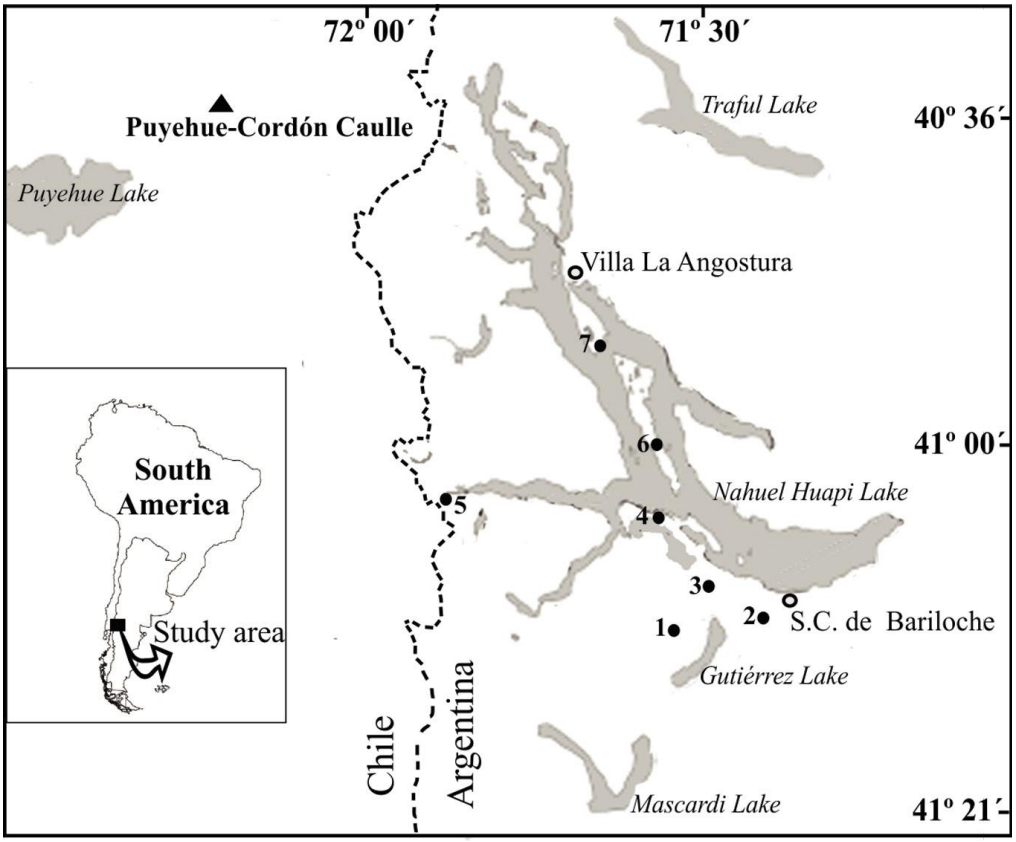

Figure 1. Study area: 1) Mt Catedral, 2) Mt Otto, 3) Laboratory 1 of Photobioloy, 4) 2 Port Pañuelo and San Eduardo Chapel, 5) Port Blest, 6) Victoria Island – Port 3 Anchorena and 7) Quetrihue Penninsula - Arrayanes Forest.

In this paper, we analyzed the effect of the most recent eruption of the Cordón Caulle on aerosols and direct irradiance at sites located at different altitudes inside Nahuel Huapi National Park (NHNP) (Figure 1).

2. DATA AND METHODOLOGY

Several field campaigns were performed during 2010 and 2011 to study the altitude effect on direct and total irradiances in the Andes. Two of the campaigns were carried out on September 17th to 23rd, 2010 and September 14th to 18th, 2011, at different points inside Nahuel Huapi National Park (NHNP), close to the city of San Carlos de Bariloche, located approximately at 100 km southeast from the Cordón Caulle (Figure 1).

During the field campaigns, simultaneous measurements of direct and total irradiance and aerosol optical depth (AOD) were taken at the Laboratory of Photobiology (LPh) (41.13S, 71.42W, 804m.s.l.), and a mobile station alternating between Mt Otto (41.15S, 71.38W, 1386m.s.l.) and Mt Catedral (41.17S, 71.48W, 1930m.s.l.) (Figure 1). Since the field campaigns were performed in September 2010 and 2011, before and after the volcano eruption, data was used to determine changes in irradiance at different altitudes. In this paper, the results for direct irradiance and AOD under clear sky conditions was considered.

The town of San Carlos de Bariloche (80,000 inhabitants, ~20,000 ha) is included in the Park (Figure 1). The city is surrounded by a mixed Nothofagus forest. The snow covers the surface during part of the winter and the weather is highly variable due to the strong westerly winds. The Laboratory of Photobiology is located at the west of San Carlos de Bariloche, on a derivation of the road to Catedral Village. The place is surrounded by a planted field of non-native pine tree species that is spotted with native trees and shrubs. The site lacks neighbors, except for a small research laboratory. Mt Otto is situated at ~4 km southwest from the city, it is a touristic point with a lift that reaches the top at 1386 m.s.l where the measurements were performed. Mt Catedral is a ski resort, and the measurements were done at a station set up at Lynch Mountain Refuge, located at 1930 m.s.l. During September of 2010 and 2011, the snow covered the surface at all the sites; however the snowpack was greater at higher altitudes.

Aerosols optical depth (AOD) and direct radiation were obtained by means of two handheld Microtops II sun-photometers. One of the instruments was operated at the Laboratory of Photobiology and the other at the mobile station. These instruments measure direct solar irradiance with an angle of view of 2.5° at 340, 380, 500, 936 and 1020 nm (bandwidth 2nm for 340 nm, 4nm for 380 nm and 10 nm for all other bands), deriving the AOD for each of those bands. These instruments were factory calibrated in August 2009 and December 2012, and in August 2011 at Tilcara (23.58S, 65.40W, 2492m.s.l.).

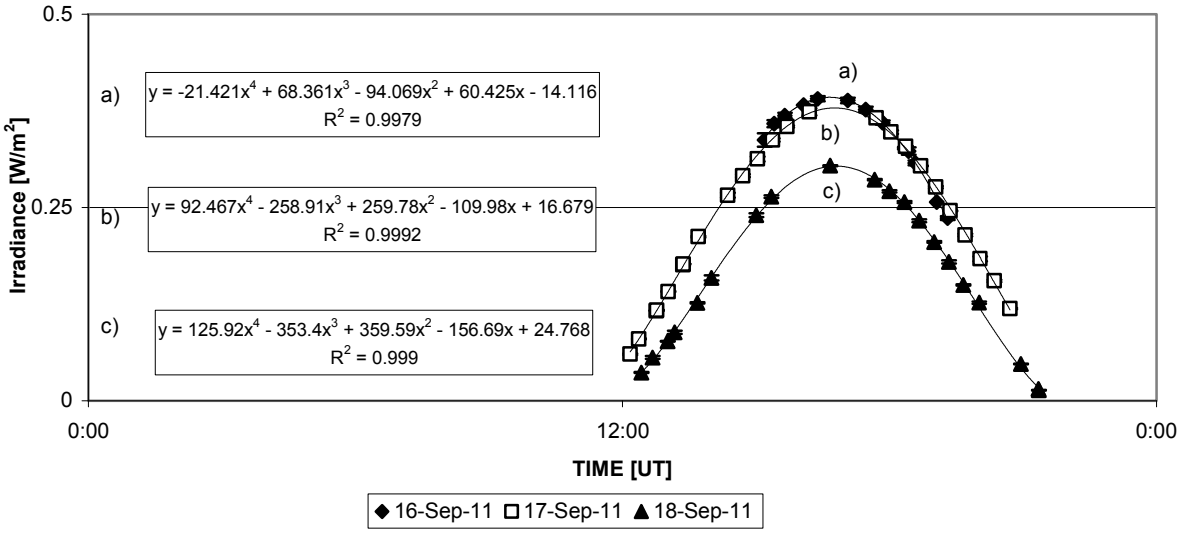

Figure 2: Direct irradiance corrected by earth-sun distance at 380 nm, measured at the Laboratory of Photobiology during campaign 2011. Equations on the left fit irradiances.

AOD and direct irradiance were measured every 20 minutes, if a clean direct sun observation was possible. Otherwise, the measurements were performed as often as possible. Direct irradiance each minute was calculated by fitting the measured values with a 4th degree polynomial. Then, direct irradiance each 1 degree Solar Zenith Angle was obtained, in order to compare irradiances at different sites and years. Figure 2 shows the mean values and one standard deviation for direct irradiance measured at the Laboratory of Photobiology, at 380 nm, during the campaign 2011. In the same figure, the fitting equations for the three days are provided.

In this paper we provide the results corresponding to UV (380 nm) and visible (500 nm) radiation. Correction for earth-sun distance was applied to irradiance values to allow the comparison among values at different days. The relative variation of direct irradiance between 2011 and 2010 was calculated in percent and analyzed as a function of SZA.

During field sampling, direct irradiance and AOD measurements were limited by the lift schedule (9:30 to 16:00 for Mt Catedral and 10:00 to 18:00 for Mt Otto).

Both field campaigns were performed in the month of September, one year apart. Since total irradiance was being measured in the LPh since 1998, we compared total irradiance for the period September 14th to 18th and September 20th to 23rd, for clear days, from the historical time series, in order to determine if there was any significant variation in earth-sun distance corrected irradiance, in the one week difference between years. We observed that mean value for one period was between one standard deviation for the other period, corresponding the largest values to the period of campaign 2011. Taking this into account, we consider that data collected at both campaigns can be compared to determine the effect of the volcano Cordon Caulle eruption.

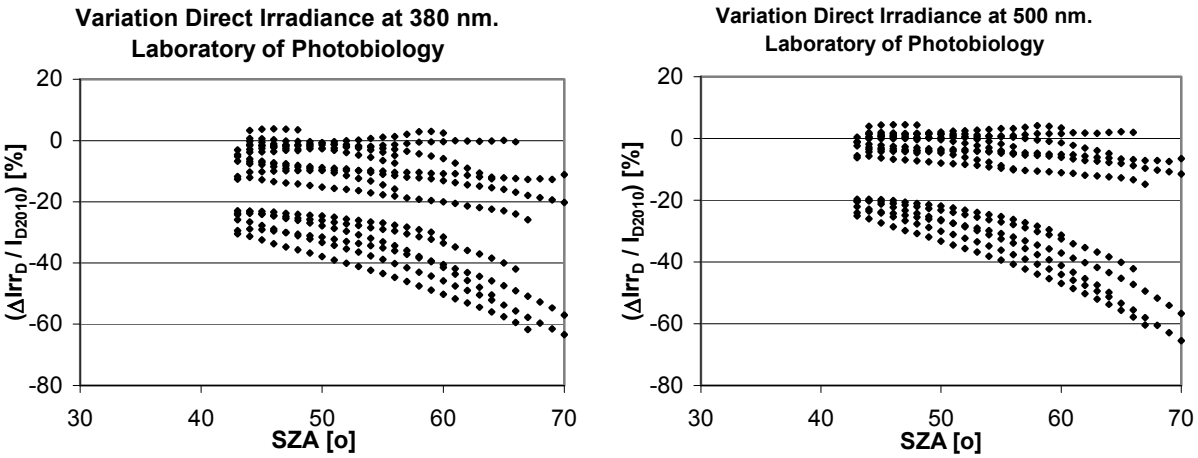

Figure 3: Variation direct irradiance in 2011, relative to 2010 at the laboratory of Photobiology, a) 380 nm and b)500 nm

3. RESULTS AND DISCUSSION

Decrease of direct irradiance at LPh at 380 and 500 nm is shown in Figure 3. Two well defined groups of values were observed. At 380 nm, one group showed from a slight increase to near 12% decrease, and the other group between 24 to 29% decrease, at noon, increasing at both groups with SZA to about 26 and 62%, maximum above 60 degrees SZA. Similar results were observed at 500 nm, but the decreases were smaller. At this wavelength, the two groups showed from slight increase to 6% decrease, at noon, and slight increase to 14% decrease, closed to 60 degrees SZA, and 20 to

24% decrease, at noon, and 62% decrease, for SZA larger than 60 degrees. The presence of these two groups is a consequence of changes in AOD. Figure 4 shows AOD measured at LPh during 2010 and 2011 campaigns. Values during September 16th and 17th, 2011 do not differ considerably from those measured during 2010, only AOD on September 18th are near 200% the values observed in 2010, and they are responsible for the larger decreases observed at the second group.

Direct irradiance variation for Mt Otto and AOD are shown in Figure 5. Irradiance decrease and AOD values are similar to those at LPh, at the corresponding days. See that, the decrease in irradiance looked lower because on September 18th there were no measurements at Mt Otto.

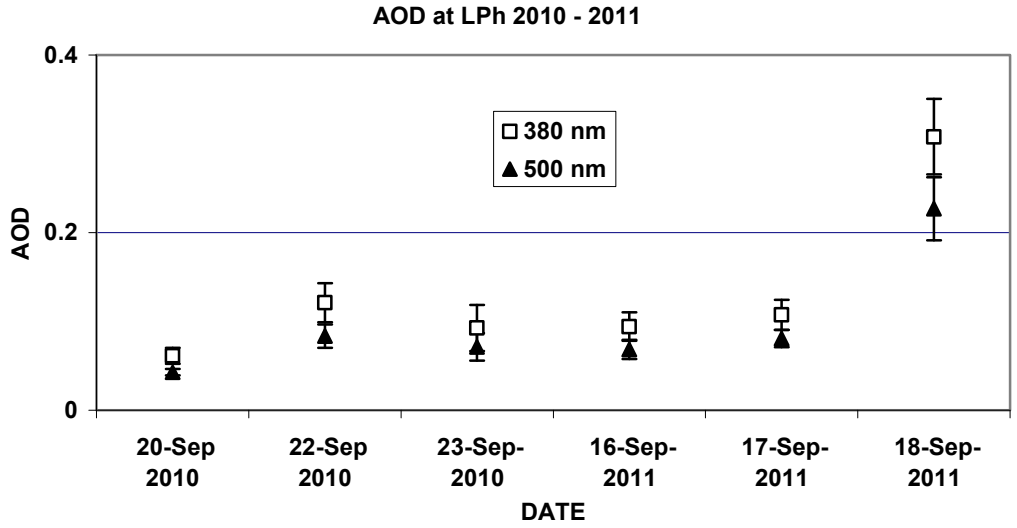

Figure 4: Daily Average AOD measured at Laboratory of Photobiology during 2010 and 2011 campaigns

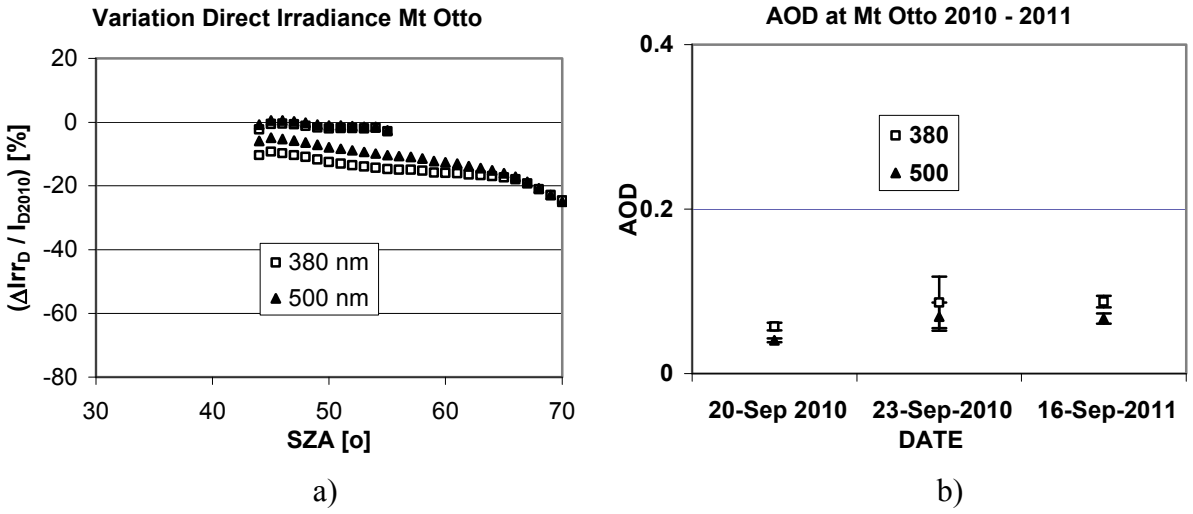

Figure 5: Variation direct irradiance in 2011, relative to 2010 (a) and daily Average AOD at Mt Otto (b)

Variation of direct irradiance and AOD at Mt Catedral resulted to be lower than at LPh, for the corresponding days. On September 18th, 2011, AODs increased near 90%, relative to 2010, less than half the increase at LPh, as a result, the irradiance decrease was only 10% (at 380 nm) and 7% (at 500 nm), at noon, increasing with SZA (Figure 6).

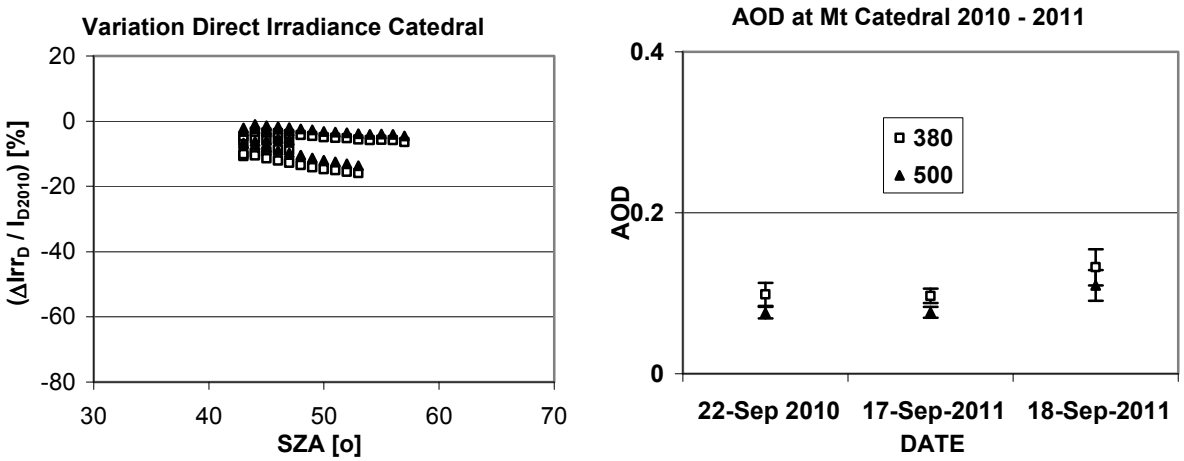

Figure 6: Variation direct irradiance in 2011, relative to 2010 (a) and daily Average AOD at Mt Otto (b)

4. CONCLUSIONS

Values of AOD were expected to change at the region of NHNP as consequence of the Puyheue-Cordon Caulle volcanic eruption. While AOD for 2010 and two of the clear sky days in 2011 were similar, on September 18th, 2011 the AODs measured at the LPh (804 m.s.l.) were 200% the values on 2010.On Mt Catedral (1930 m.s.l.) the difference was just near 90% .

This increase in AOD produced a decrease in the direct irradiance, relative to 2010. For LPh (804m.s.l.), the decrease at 380 nm was between 24 to 29% at noon (43 degrees SZA). The difference between irradiance on 2010 and 2011 increased with SZA being 62% near 60 degrees SZA. For 500nm, the values were smaller.

At Mt Otto (1386m.s.l) the AOD and direct irradiance variation was about the same as LPh, for the corresponding days.

Since the AODs increase at Mt Catedral (1930m.s.l.) was only 90%, the decrease in the direct irradiance was smaller than at LPh, being around 10% at noon at 380 nm and slightly lower for 500 nm..

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