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Aerosol effects on the UV irradiance in Santiago de Chile

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ABSTRACT

Santiago de Chile (33°27′ S–70°41′ W) is a mid-latitude city of 6 million inhabitants with a complicated surrounding topography. Aerosol extinction in Santiago is determined by the semi-arid local climate, the urban pollution, a regional subsidence thermal inversion layer, and the boundary-layer wind airflow. In this paper we report on spectral measurements of the surface irradiance (at 290–600 nm wavelength range) carried out during 2013 in the heart of the city by using a double monochromator-based spectroradiometer system. These measurements were used to assess the effect of local aerosols, paying particular attention to the ultraviolet (UV) range. We found that the aerosol optical depth (AOD) exhibited variations likely related to changes in the subsidence thermal inversion and in the boundary-layer winds. Although the AOD at 350 nm typically ranged from 0.2 to 0.3, peak values of about 0.7 were measured. The AOD diminished with the wavelength and typically ranged from 0.1 to 0.2 at 550 nm. Our AOD data were found to be consistent with measurements of the particulate matter (PM) mass concentration.

1. Introduction

Increases in surface ultraviolet (UV) irradiance may lead to adverse effects on the biosphere including terrestrial and aquatic ecosystems as well as public health (Douglass et al., 2011). Therefore, an improved understanding of the UV climate has become of great interest. Previous studies have shown that satellite-derived UV estimates are biased at polluted sites (Tanskanen et al., 2006, 2007; Weihs et al., 2008; Ialongo et al., 2008; Kazadzis et al., 2009a, 2009b; Ialongo et al., 2009; Buchard et al., 2008; Douglass et al., 2011; Cabrera et al., 2012; Damiani et al., 2013), and also at sites affected by desert dust intrusions (Anton et al., 2012). In the particular case of Santiago de Chile, differences usually larger than 30% under cloudless conditions have been reported between ground-based measurements and estimates of the UV index (UVI) retrieved from the Total Ozone Mapping Spectrometer (TOMS) and from the Ozone Measurement Instrument (OMI) (see Cabrera et al., 2012; Damiani et al., 2013). The significant differences between ground-based measurements and satellite estimates found over heavily populated areas underline the importance of the tropospheric extinctions on local UV climatology and the need of ground-based measurements aimed at characterizing the optical properties of local aerosols.

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Aerosol loading in Santiago is affected by the surrounding topography, the semi-arid local climate, the urban pollution, the regional subsidence thermal inversion layer, and the boundary-layer winds (see Perez and Salini, 2008; Oyanadel et al., 2006; Gramsch et al., 2000, 2006, 2009). The dispersion of local aerosols is constrained by the complicated surrounding topography (see Fig. 1) and the regional subsidence thermal inversion layer, which increases the near-ground lower-tropospheric stability over Santiago and determines the near-surface aerosol climatology (see Muñoz and Alcafuz, 2012). Seasonal changes in the subsidence thermal inversion layer over Santiago lead to variations in the depth of the aerosol layer; indeed, in fall and winter the depth of the aerosol layer is appreciably smaller with respect to spring and summer (see Muñoz and Undurraga, 2010). This is consistent with urban pollution measurements that show not only an increment in average surface concentrations in winter, but also the occurrence of multi-day episodes of high particulate matter concentrations associated with the strengthening of the subsidence thermal inversion (see Rutllant and Garreaud, 1995).

Although the effect of aerosols on the UV climatology in Santiago is significant, no ground-based measurements of the aerosol optical properties in the UV range have been previously reported. Part of the problem arises from the fact that accurate measurements of the aerosol extinctions in the UV region require quality-controlled measurements of the UV spectra. However, because of the scarcity of spectroradiometer systems that comply with the required standards, the spectral UV monitoring stations in the southern hemisphere are currently underrepresented in the existing international networks (such as the Network for the Detection of Atmospheric Composition Change NDACC, see Wuttke et al., 2006).

In the past, it has been assumed that aerosol extinctions in the UV region can be estimated by extrapolation from their effects in the visible region. However, even in the visible range, no reliable data regarding the optical properties of the aerosols in Santiago have been reported. Ground-based measurements of the aerosol optical depth (AOD) were carried in Santiago more than a decade ago by using a sunphotometer of the AErosol RObotic NETwork (AERONET, see Holben et al., 1998). This instrument operated in Santiago only between August 2001 and October 2002 (Escribano et al., 2014).

Satellite-derived estimates of the AOD have also been questioned in the case of Santiago. Estimates of the AOD retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument have shown consistency when compared with AERONET measurements elsewhere (Levy et al., 2010; Bréon et al., 2011; Hyer et al., 2011; Mei et al., 2012). However in the case of Santiago, a poor correlation was reported after comparing AERONET measurements over the period of 2001–02 (at 550 nm) with estimates of the AOD retrieved from MODIS (Oyanadel et al., 2006). Also a poor correlation was found when MODIS-derived estimates of the AOD have been compared with particulate matter (PM) mass concentrations measured over the period of 2000–10 in Santiago (see Escribano et al., 2014). This latter result was unexpected since at other locations (where atmospheric turbidity is driven by aerosols), a good correlation between MODIS-derived data and PM concentration has been reported (see Schaap et al., 2009; Boyouk et al., 2010; Tsai et al., 2011; Estellés et al., 2012).

In this paper, we report on the first quality-controlled spectral measurements of the UV and visible irradiance in Santiago. These measurements were carried out during 2013 by using a double monochromator-based spectroradiometer meant to comply with the recommendations of the World Meteorological Organization (WMO) (Seckmeyer et al., 2001) and the NDACC specifications (Wuttke et al., 2006). The AOD was retrieved from our spectral measurements and used to weigh up the local tropospheric extinction. Ground-based measurements of the PM mass concentrations, as well as AOD estimates retrieved from different satellites were used for further comparisons.

2. Irradiance measurements

Ground-based spectral measurements of the solar irradiance were carried out at the campus of the Universidad de

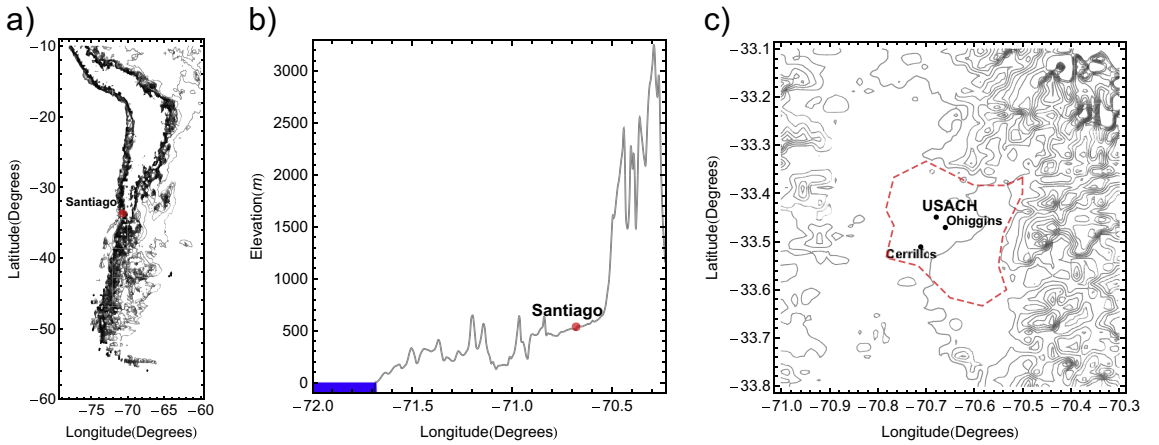

Fig. 1. a) Santiago is surrounded by a complicated topography. b) Elevation along latitude 33°27′ S; the USACH Campus is located in Santiago at 33°27′ S–70°41′ W; the shaded area indicates the sea. c) Dotted line indicates the metropolitan area of Santiago; the locations of the USACH Campus, the "Parque O'higgins" station as well as the Cerrillos district are indicated in the plot.