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Effect of altitude on aerosol optical properties

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Abstract. The ELT project is currently under way in Europe and North America. Astronomical sites depend critically on sky transparency and on aerosol loadings. A quantitative survey of aerosol optical properties at candidate ELT sites is an essential part of the site selection process. There are basically two methods to characterize aerosol properties: ground based measurements and satellite measurements. In this paper we will establish a full climatology of two sites very close to each other, but at a difference of 2300m in altitude: Izaña and Santa Cruz located in the Canary Islands. Both have sun photometers from the AERONET network. We also use the aerosol index determined from TOMS satellite data to determine how aerosol optical properties vary with altitude. We establish a correlation between the TOMS index and the aerosol optical thickness in both sites. Aerosol optical properties show very good correlation between Izaña and Santa Cruz. As a result we establish a set of relationships helpful to characterize sites at elevated altitude from data of neighbouring sites at low altitude.

Keywords. Site testing, atmospheric effects, aerosols, sun photometer

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1. Introduction

It is important for astronomers to identify high-quality observatory sites. An exhaustive approach towards prospecting for good sites is to make measurements at all potential candidate sites. However this is very difficult and time consuming. The ideal is, if possible, to make measurements at accessible low-altitude places near the candidate sites and then to extrapolate the results to more elevated places. An important study is to see how geophysical data affecting astronomical observations vary with altitude. In this paper, we focus on aerosol optical properties at two sites located in the Canary Islands; Izaña at an altitude of 2367 m and Santa Cruz at an altitude of 52 m and separated from each other by some dozen kilometres.

2. Data and method

The instruments used for ground measurements are the CIMEL sun photometers from the AERONET Network. These radiometers make measurements of direct sun and diffuse sky radiance within the spectral range of 340–1020 nm (Holben, *et al.* (1998)). The direct

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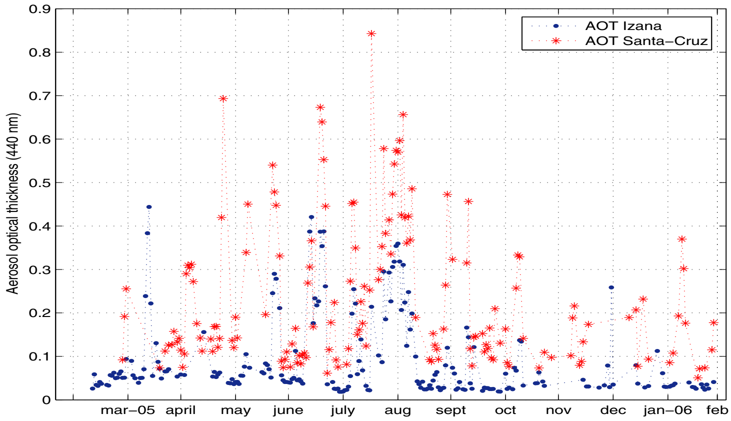

Figure 1. Daily values of the aerosol optical thickness (AOT) at Izaña and Santa Cruz.

sun measurements are acquired in eight spectral channels 340, 380, 440, 500, 670, 870, 940, 1020 nm. The 940 nm band is used to estimate total precipitable water vapour content (WVC). The bandwidths of the interference filters vary from 2–10 nm. The aerosol optical thickness (AOT) is computed from the Bouguer-Beer-Lambert law. The Angstrom parameter (ANG) is derived from a multispectral log-linear fit to the classical equation: AOT $\propto \lambda^{-ANG}$.

The sky radiance almucantar measurements are acquired at 440, 670, 870 and 1020 nm. A flexible algorithm for retrieval of aerosol physical properties developed by Dubovik & King, (2000) was used for retrieving aerosol size distribution over a range of sizes from 0.05–15 μm, together with spectrally dependent complex refractive index and SSA (Single Scattering Albedo) from spectral and sky radiance data. An automated and computerized cloud screening algorithm (Smirnov, *et al.* (2000)) was applied to direct sun measurements.

The use of satellite observations is the most efficient way to determine aerosol physical properties on large temporal and spatial scales. Among these instruments, the Total Ozone Mapping Spectrometer (TOMS) has the capability to sense aerosols (Hermann, *et al.* (1997)) and derive their optical properties (Torres, *et al.* (1998), (2002)) over both land and ocean, through the aerosol index (AI).

3. Results

The period of study extended from March 2005 until February 2006. We will characterize atmospheric optical conditions by the aerosol optical thickness at 440 nm (AOT), the water vapour content (WVC) and the Angstrom parameter (ANG) (870-440 nm). Daily AOT values in Fig. 1 depict very low values for Izaña compared to Santa Cruz, except during summer time, where dust events occur. The annual mean for Izaña is 0.08, which is 2.8 times less than the annual mean of Santa Cruz (0.23). From this Figure we can deduce that the aerosol layer is below Izaña's altitude most of the time, except in summer when dust events occur. During July and August the aerosol layer is higher than 2400 m as reported by (Hsu, *et al.* (1999)).

The annual mean of the Angstrom parameter is 1.2 for Izaña and 0.6 for Santa Cruz. Small-particle aerosols dominate Izaña's atmosphere. The Angstrom parameter at Izaña

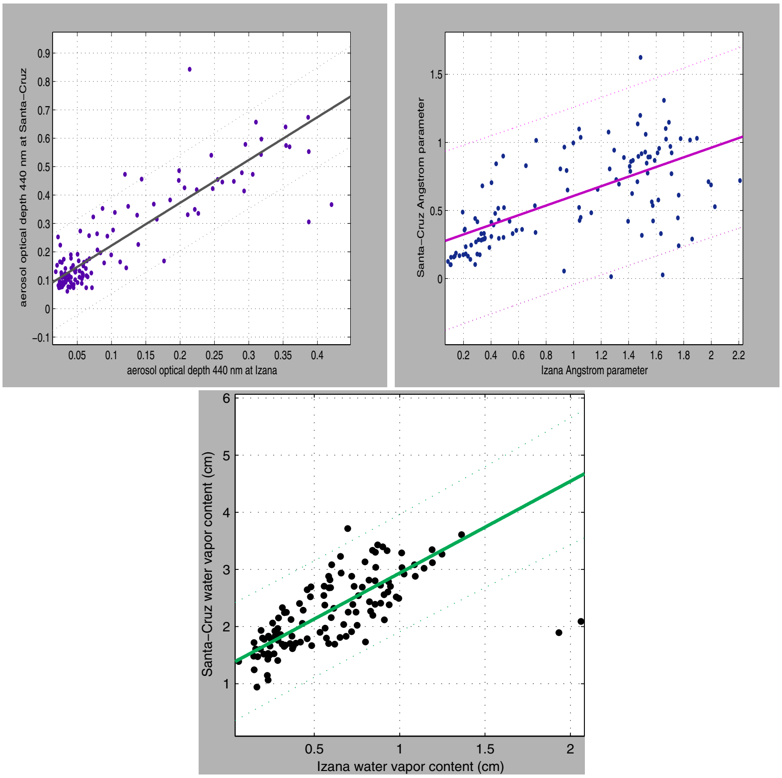

Figure 2. Scattergrams of AOT Santa Cruz versus AOT Izaña, ANG Santa Cruz versus ANG Izaña and WVC Santa Cruz versus WVC Izaña.

is around 1.5 most of the time except in summer during dust events. The annual mean water vapour content is 0.5 cm for Izaña and 2.2 cm for Santa Cruz.

The aerosol optical thickness (AOT) frequency distribution is very narrow at Izaña with a modal value at 0.05 and broader at Santa Cruz with a modal value around 0.1. About 70% of Izaña's AOT occur below 0.05, which denotes good observation conditions. About 70% of Santa Cruz's AOT occurs below 0.25.

The Angstrom parameter histogram is bimodal at both sites. The modes at Izaña are 0.3 and 1.6. The second one is dominant. At Santa Cruz the modes are 0.3 and 0.9.

The water vapor content histogram modes are 0.3 cm at Izaña and 2.5 cm at Santa Cruz. About 95% of the occurrence is below 1.2 cm for Izaña and higher than 1.2 cm for Santa Cruz.

Figure 2 shows scattergrams of the relation between Santa Cruz and Izaña concerning aerosol optical depth, Angstrom parameter and water vapour content. The resulting relationships show notable correlations (correlation coefficients of 0.92, 0.78 and 0.66, respectively).

$\text{AOT}_{SantaCruz} = 1{,}5(\pm 0.15)*\text{AOT}_{Izaña} + 0.07(\pm\ 0{,}02)$ R=0.92
$\text{ANG}_{SantaCruz} = 0.35(\pm\ 0.098)*\text{ANG}_{Izaña} + 0.25(\pm\ 0{,}11)$ R=0.66
$\text{WVC}_{SantaCruz} = 1{,}6(\pm\ 0.31)*\text{WVC}_{Izaña} + 1{,}33(\pm 0{,}2)$ R=0.78

No specific correlation was found for monthly mean values of the single scattering albedo (SSA). Monthly SSA values at 440 nm vary from 0.95 to 0.6 at Santa Cruz and from 0.9 to 0.7 at Izaña. The values at Santa Cruz are most of the time higher than

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the Izaña values, except in October, January and February, which means that Izaña's aerosols are more absorbent.

Concerning the relationships between the Izaña and Santa Cruz aerosol size distributions, we found very high correlations, varying from 0.97 for June and decreasing progressively to 0.6 for December.

Concerning the satellite measurements, the relationships between the TOMS aerosol index (AI) and the corresponding aerosol optical thicknesses (AOT) give satisfying correlations: the correlation coefficient of AI and AOT for Izaña is 0.68 and the one for Santa Cruz is 0.75. The relationships concerning AOT and AI are:

$AOT_{Izaña} = 0.12 {*} AI_{Izaña} + 0.05$ $R = 0.68$.

$AOT_{SantaCruz} = 0.22 {*} AI_{SantaCruz} + 0.16$ $R = 0.75$.

We can thus retrieve the aerosol optical thickness starting from the aerosol index signal.

4. Conclusion

In this work we have characterized the aerosol optical properties of Izaña and Santa Cruz during a year. For that purpose we used the AERONET data. We have established the climatology of both sites. We find linear relationships between Izaña and Santa Cruz aerosol optical properties; aerosol optical thickness, water vapour content and the Angstrom parameter give good correlations (92%, 78,5% and 66,4%, respectively). Size distribution correlates well (R varying from 98% to 60%) for June, July, August, September, October, November and December. January, February, March, April and May give no correlation. The single scattering albedos of both sites do not seem to correlate. One surprising thing is that the single scattering albedo decreases with increasing wavelength, even during dust events. We have established correlations between TOMS Aerosol Index (AI) and the aerosol optical thickness (AOT) (R at Izaña is 68,5% and at Santa Cruz 75,5%). Now the question is, can we use these relationships in other locations close to the Canary Islands, like the Atlas mountains of Morocco, for example?

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