High resolution measurement of aerosol equivalent scale heigth over wide range

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Aerosol vertical optical depth (AOD) and horizontal extinction coefficient (AEC) have been measured with multiwavelength photometers at University of Granada, during the period 14th-18th July 2006. The AOD τ_{aer} has been measured by using an *Avantes USB2000* high grating spectrometer (*440–900 nm*, *1.5 nm* resolution); at the same moment a *FieldSpec* has been used to measure Horizontal Aerosol Extinction Coefficient (AEC) σ_{aer} in the range *400-700 nm*, with a resolution of *1 nm*. Both AOD and AEC were used to obtain an equivalent Aerosol scale height at different wavelength in the range *440-700 nm*, according to Mie scattering theory.

Introduction

Atmospheric aerosol dominates the optical properties of the atmosphere in the visible; gases have a small influence, except for few wavelength ranges. A correct parametrization of the optical properties of the atmosphere is important for visibility, sky radiation and climatic changes study (Charlson et alt., 1992Satheesh et alt., 2005). Atmospheric aerosol exhibits a high variability both in space and in time, in fact data on their optical properties are urgently needed. Aerosol density varies with heigth, and usually the parameter called Equivalent Scale Heigth (ESH) is introduced to describe this variation. The main objective of our analysis was to give an estimate of ESH starting from measurements of both vertical and horizontal extinction. The procedure is based on two ground-based optical methods to measure simultaneously the vertical and the horizontal spectral aerosol extinction coefficients. The measurements permit the estimation of an equivalent Aerosol scale heigth showing a different dependence respect to wavelength over the spectral range *440-700 nm* in different days.

1. Experiment

1.1 Horizontal extinction

The attenuation of light in the horizontal direction was determined by the method of distant contrasts. The measurement procedure is based on the fact that any object seen through the atmosphere appears fainter when the distance between it and the observer increases. Radiation coming from the object is attenuated by the scattering of aerosol and molecules; at the same moment the light coming from the Sun and the Sky is scattered by aerosol and molecules in between the object and the observer, making the object more and more similar to the horizon. The physycal quantity used to describe this similarity is the contrast C (Esposito et alt., 1996; Koschmieder, 1925), defined as the relative difference between the radiance of the object L_o, and the horizon radiance L_b:

$$C=(L_o-L_b)/L_b$$

As found by Koschmieder, the contrast $C(x)$ of an object near the horizon, in absence of clouds, is an exponential function with the distance between it and the observer:

$$C(x)=C(0)exp(-\sigma_e x) \qquad (1)$$

where σ_e is the extinction coefficient of the atmosphere and $C(0)$ is the contrast of the object placed near the observer. This procedure needs the measurement of $C(0)$, the contrast of the object near at the observer.

In the past the radiance of a small part of a distant object has been measured by a telephotometer, like described in Horvath (1981), Peseva et alt. (2001) and Jeongsoon et alt. (2007); in this instrument the light collected by a telescope passes through interference filters to a photomultiplier, measuring tipically at 6-7 wavelength. For this research an instrument based on a grating spectrometer has been used. It is based on a FieldSpec HandHeld, produced by Analytical Spectral Devices, a grating spectrometer equipped with a Silicon photodiode linear array detector. The light is collected by a telescope with 1° aperture, with a manual pointing system. In order to avoid the necessity to measure the radiance of the object at distance zero, the estimate of extinction coefficient σ_e is based on the measurements of the contrast of two distant objects, situated at distance respectively at distance x_1 and x_2.

$$C_1=C(x_1)=(L_{o1}-L_b)/L_b=C(0)exp(-\sigma_e x_1)$$
$$C_2=C(x_2)=(L_{o2}-L_b)/L_b=C(0)exp(-\sigma_e x_2)$$

The ratio between C_1 and C_2 furnishes an estimation of extinction coefficient σ_e without the necessity of measuring $C(0)$:

$$C_1/C_2=(L_{o1}-L_b)/(L_{o2}-L_b)=exp(-\sigma_e(x_1-x_2))$$

Giving for the extinction coefficient the following estimate:

$$\sigma_e=\frac{1}{x_2-x_1}\ln\left(\frac{L_{o1}-L_b}{L_{o2}-L_b}\right)$$

The object used in this study was a group of trees located on two hill crests, at distances $x_1=7\ km$ and $x_2=13\ km$, toward south. The above described method is valid only under several conditions: the aerosol should be distributed homogeneously in space and the illumination of the atmosphere should be homogeneous, that is in condition of cloudless sky. If the first condition is not fullfilled the procedure gives a vaule of the extinction coefficient averaged over the distance between the two objects (Esposito et alt., 1996).

The procedure can be applied in the spectral range 400-700 nm; outside this range the emissivity and reflectivity of the objects can vary, giving bias errors (Horvath, 1996). For all data the Rayleigh scattering coefficient of the air has been subtracted, in order to obtain the Aerosol spectral Extinction Coefficient (AEC) $\sigma_{aer\lambda}$.

1.2 Vertical aerosol optical depth

Vertical aerosol optical depth values were derived from solar irradiance spectra measured at ground level. The instruments used was an Avantes AVS-USB 2000 equipped with a one-dimensional linear CCD array, provided with a focusing system, whose field of view is 1°, avoiding solar diffuse light contamination. Spectral irradiance was collected every 15 minutes, from the sunrise to the sunset. The Langley calibration procedure was applied in order to obtain the Aerosol Optical Depth estimation in spectral ranges not affected by gaseous absorptions, between *440* and *900 nm*. (Esposito et alt., 2004) In this analysis, the ozone contribution to the optical depth, due to the Chappuis band *450–700 nm*, was taken into account by using the columnar daily data of the ozone content (available on the *TOMS* site *toms.gsfc.nasa.gov/eptoms/ep.html*). For all data the Rayleigh scattering coefficient of the air has been subtracted, in order to obtain the aerosol optical depth.

1.3 Measurement site

Measurement were taken during a field campaign held at University of Granada, in July 2006. Both AOD and AEC were measured simultaneously each 15 minutes. Horizontal extinction coefficients were measured by pointing two groups of trees toward South, over a hill near Sierra Nevada.

2. Measurement Analysis

2.1 Aerosol equivalent scale heigth

According to the scattering Mie theory (e.g., van de Hulst, 1957), under the hypothesis of spherical particles, the spectral aerosol optical depth τ_λ can be written as a function of the particle size distribution:

$$\tau_\lambda = \int_0^\infty dh \int_0^\infty \pi r^2 Q_{ext}(\lambda, r, \hat{m}) N(r, h) dr$$

Here *N(r,h)* is the aerosol size distribution (expressed in particles per unit volume per particle radius) at height *h*, *r* is the radius of the particles, assumed sphericals, *m* is the complex refractive index, and Q_{ext} is the extinction coefficient factor computed from Mie theory (van de Hulst, 1957). Under the same hypothesis, the aerosol exinction coefficient can be written as:

$$\sigma_{aer\lambda} = \frac{1}{\Delta x} \int_{x_1}^{x_2} dx \int_0^{\infty} \pi r^2 N(h_G, r) Q_{ext}(\lambda, r, \hat{m}) dr$$

Here $\Delta x = x_2 - x_1$ is the distance bewtween the objects used for measurement, and h_G is the heigth above sea level of mesurement location.

Assuming, as usual (Esposito et alt., 1996, Horvath, 1996, Pesasa et alt, 2001) that *N(h,r)* factorizes in two parts, with heigth dependence expressed by an exponential law, the aerosol size distribution can be expressed as:

$$N(h,r) = N(h)n(r) = N_0 n(r) \exp(-h/H_p) \qquad (2)$$

where N_0 is the particle concentration at sea level, and H_p is the aerosol scale heigth. With this assumption, the AOD τ_λ and the AEC $\sigma_{aer\lambda}$ can be written as:

$$\tau_\lambda = H_p N_0 \int_0^{\infty} \pi r^2 Q_{ext}(\lambda, r, \hat{m}) n(r) dr$$

$$\sigma_{aer\lambda} = N_0 e^{h_G/H_p} \int_0^{\infty} \pi r^2 n(r) Q_{ext}(\lambda, r, \hat{m}) dr$$

The ratio is a function of Aerosol scale heigth H_p:

$$\frac{\tau_\lambda}{\sigma_{aer\lambda}} = \frac{H_p N_0 \int_0^{\infty} \pi r^2 Q_{ext}(\lambda, r, \hat{m}) n(r) dr}{N_0 e^{-h_G/H_p} \int_0^{\infty} \pi r^2 Q_{ext}(\lambda, r, \hat{m}) n(r) dr} = \frac{H_p}{e^{-h_G/H_p}}$$

This equation can be inverted to give an estimate for H_p. It should be stressed that if the hypothesis of an exponential dependence of aerosol size distribution respect to heigth is not valid, H_p gives only an equivalent scale heigth, i.e. the scale heigth that an equivalent aerosol population following an exponential decay should have to give the same AOD and the same AEC observed. If the aerosol size distribution can not be factorized, as in (2), the equivalent scale heigth could be a function of the wavelength λ.

3. Results

The procedure has been applied to the range *440-700 nm*, obtaining H_p as a function of wavelength. Figure 1 shows the variation of the scale heigth computed for the day 14^{th}, July. It can be seen that there is no dependence from the wavelength, showing the validity of the hypothesis *(2)*.

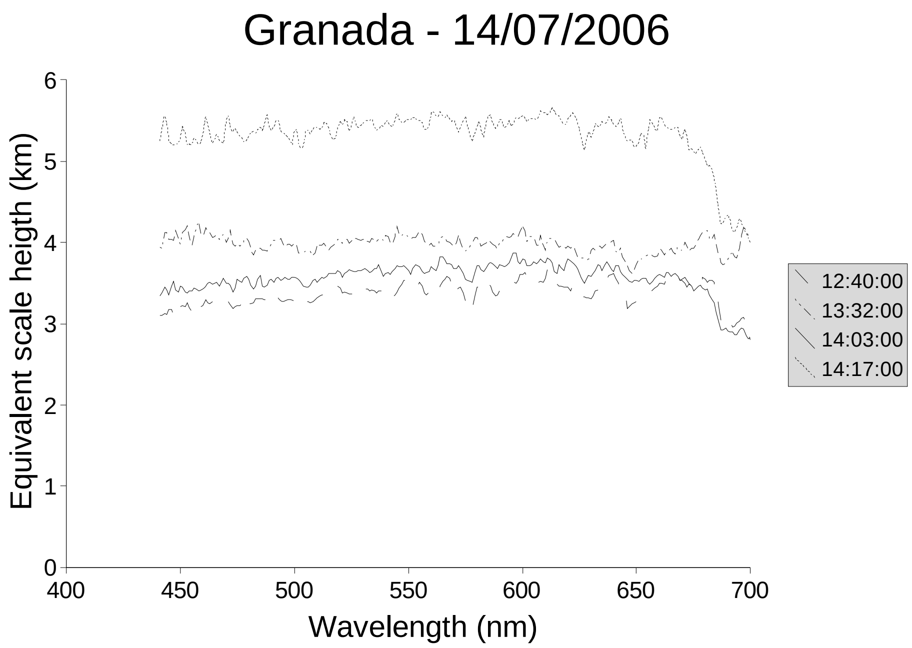

Figure 1: Aerosol equivalent scale heigth for the day 14th, July, 2006. Measurements taken in Granada (Spain).

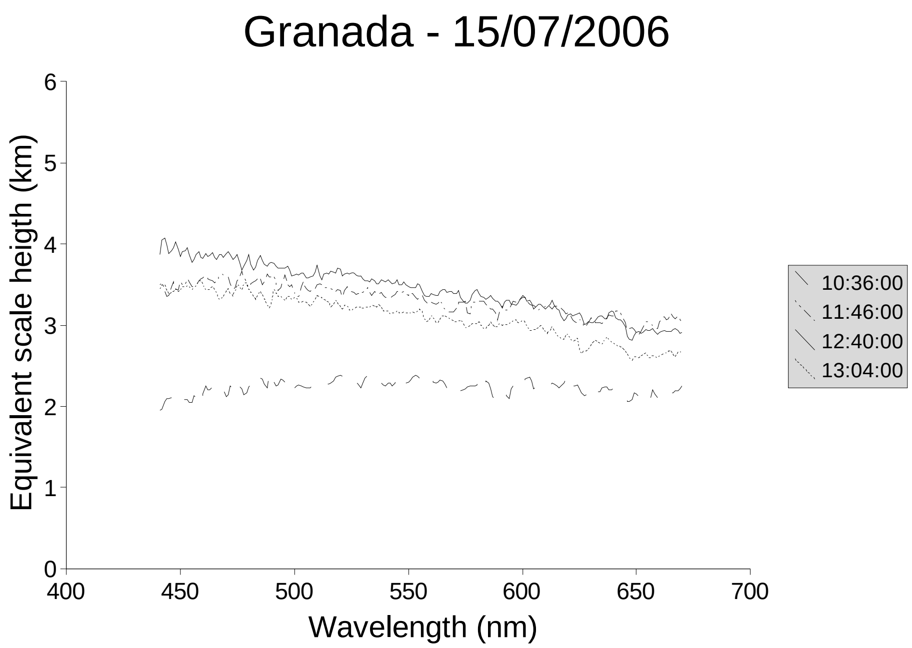

Figure 2: Aerosol equivalent scale heigth for the day 15th, July, 2006. Measurements taken in Granada (Spain).

Figure 2 shows the result of the procedure applied to measurements taken on 15th, July. In this case there is a variation of aerosol equivalent scale heigth respect to the wavelength, showing a change of aerosol size distribution over the column. The variation of $H_p(\lambda)$ at different hours shows that atmospheric aerosol distribution is changing over the column, reaching an uniformity at 13:04. This behaviour was probably due to a mixing of atmosphere, that implies a mixing of atmospheric aerosols from different atmospheric layers.

4. Conclusions

The optical properties of atmospheric aerosol τ_λ (optical depth) and $\sigma_{aer\lambda}$ (extinction coefficient) have been measured simultaneously in Granada (Spain, during the period 14-18 July 2006. horizontal extinction was measured by means of a FieldSpec spectrometer, applying a contrast method over two similar objects, and vertical aerosol optical depth with an Avantes spectrometer, applying Langley technique. Both instruments had an overlapping spectral region *440-700 nm*. Starting from AOD and AEC measurements, equivalent scale heigth has been estimated over the wavelength range 440-770 nm, giving information on vertical distribution and omogeneity of atmospheric aerosol population.

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