

# Short-Term Variability of Extinction by Broadband Stellar Photometry

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## Abstract

Aerosol optical depth variation over short-term time intervals is determined from broadband observations of stars with a whole sky imager. The main difficulty in such measurements consists of accurately separating the star flux value from the non-stellar diffuse skylight. Using correction method to overcome this difficulty, the monochromatic extinction at the ground due to aerosols is extracted from heterochromatic measurements. A form of closure is achieved by comparison with simultaneous or temporally close measurements with other instruments, and the total error of the method, as a combination of random error of measurements and systematic error of calibration and model, is assessed as being between 2.6 and 3% root mean square.

## Method of Measurement

Aerosol optical depth from whole sky imager (WSI) star photometry is determined from the following successive steps. First, the star irradiance photometry (broadband, [400;900] nm) is performed by aperture or profile fitting methods. A priori knowledge of spectral and luminosity classification for observed stars, and of the absolute photometry for a standard star is next used. To infer the star irradiance in the case of the observations at high zenith angle, we use a correction for sky spectral brightness due to diffuse sources: airglow emission, zodiacal light and (non resolved stars) integrated starlight, and also a correction for atmospheric scattering of diffuse sources. To exclude the contribution of atmospheric absorption, the removal of atmospheric gaseous absorption is accomplished using LOWTRAN model, by taking into consideration daily values for total columnar ozone, 3-horur values for total columnar precipitable water vapor and the climatologic concentration values for other ten molecular species.

The difficulties inherent for observations with WSI are the high sky background, the low resolution (poor separation between stars) and coarse pixelization of star profiles (undersampling). Approximately 120 stars, not all present simultaneously on the sky, were measured on 300 clear nights from 1998 to 2003.

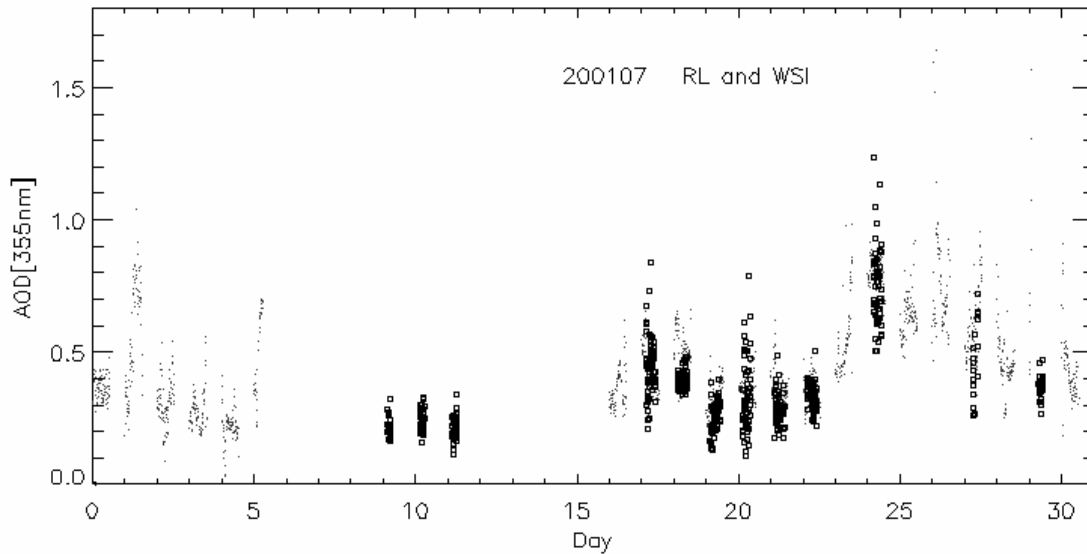
## Heterochromaticity

The residual optical thickness, which is broadband, is compared for star of various colors that are observed simultaneously. The method of solving for the residual transmission is by assuming the aerosol spectral contribution following an Angstrom law, and constraining the optical depth among different (stars) colors and directions. The wavelength-dependent aerosol optical depth (AOD) is modeled following the well-known empirical law,  $(AOD = \beta \lambda^{-\alpha})$ , where “alpha” is the Angstrom exponent and “beta” is the turbidity parameter. The AOD obtained at the center of the observing bandwidth, between 500 and 600 nm, is the most reliable monochromatic parameter, constructed from a heterochromatic measurement. Using an iterative method, with an a priori knowledge of atmospheric gases opacity, and a first guess for aerosol parameters, all the possible pairs of different colored star irradiances measured at the same moment are reduced to find the best transmission correction factor and best effective wavelength, in the atmospheric filter, for their color.

## Temporal and Spatial Variability of Aerosol Optical Depth

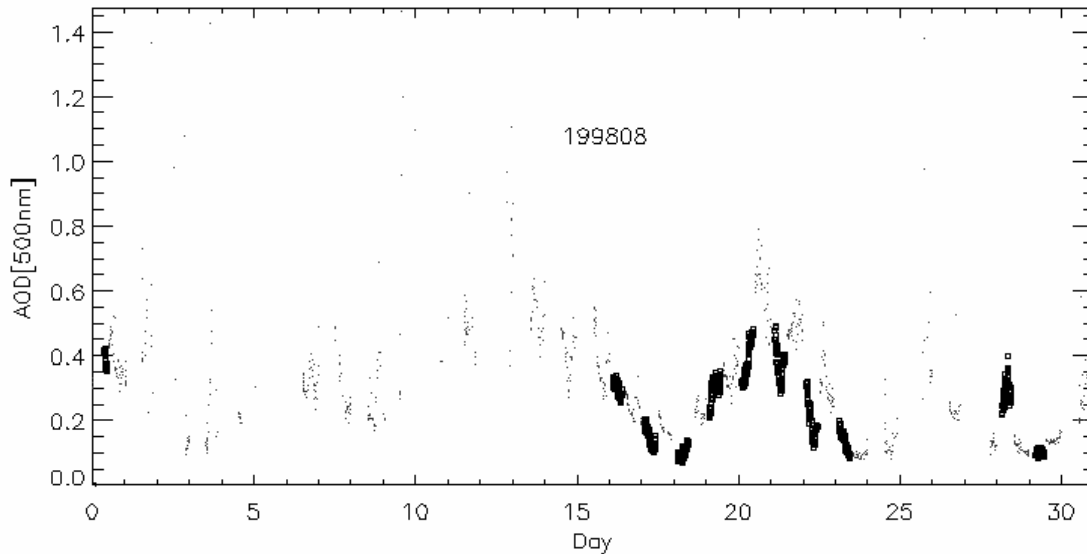
Rather than trying to obtain the optical thickness value towards each star direction, the method used in this study assumes that all irradiances from stars visible at the same time can be used to obtain the AOD, that is, the optical thickness in the vertical direction. This AOD should be comparable with the same amount determined with more precise methods, as the nighttime LIDAR. The comparison holds during the majority of nights measured because the aerosol spatial coherence distance, of a little under 200 km (Anderson et al. 2003), is also the maximum WSI observable distance, measured on an aerosol layer at 5 km height above the ground, between directions of stars situated as low as 3° elevation above the horizon, on the opposite ends of a big meridian circle.

For the entire interval 1998-2003, measurements made with three different instruments have been found to agree (WSI, Raman Lidar and Cimel photometer). As example, the good agreement can be seen in Figure 1, where the aerosol optical depth along vertical line-of-sight (LOS) at the wavelength of 355 nm from Raman Lidar measurements (point symbol) and AOD from star photometry with Whole Sky Imager (bold square symbol) inferred from multiple LOS are represented for July 2001.



**Figure 1.** Aerosol optical depth along vertical line-of-sight at the wavelength of 355 nm from Raman Lidar (point symbol) and from star irradiance photometry with Whole Sky Imager (bold square symbol) inferred from multiple lines-of-sight, for nights in July 2001

Also, in Figure 2 the comparison is made between successive measurements of the AOD during daytime at the wavelength of 500 nm by Cimel sun photometer (point symbol) and AOD during nighttime from star photometry with Whole Sky Imager (bold square symbol), for August 1998.



**Figure 2.** Aerosol optical depth during daytime at the wavelength of 500 nm from Cimel sun photometer (point symbol) and during nighttime from star photometry with Whole Sky Imager (bold square symbol), for August 1998.

## Conclusion

A statistically computed spatial coherence distance of 200 km for aerosol airmass was proposed (Anderson et al. 2003). When a 5 km-height aerosol layer is observed by the WSI, the range on the layer measures at most 180 km from horizon to horizon, i.e. all lines of sight for aerosol layer are within the coherence limit. Thus, vertical and oblique lines of sight are mostly conducive to same aerosol optical depth values.

The WSI instrument is proved thus useful not only for cloud cover observations, but also for aerosol optical depth observations.

## Reference

Anderson, Th., RJ Charlson, D Winker, JA Ogren, K Holmen. 2003 "Mesoscale variations of tropospheric aerosols." *Journal of Atmospheric Science* 60, 119-136.