REVISTA BOLIVIANA DE FÍSICA 20s, 16-18, 2011
ISSN 1562-3823. INDEXADA EN: SCIELO, LATINDEX, PERIÓDICA

Study on aerosol properties over Madrid (Spain) by multiple instrumentation during SPALI10 lidar campaign

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SUMMARY

Understanding the effect of aerosols upon radiative forcing requires information about vertical profiles. Lidar techniques represent a powerful tool for studies of the vertical structure of the aerosol field. During the SPAin Lidar Intercomparison 2010 (SPALI10) campaign, several multiwavelength Raman lidar systems measured simultaneously in order to assess their performances. Multiwavelength lidars can provide relevant vertically-resolved information on aerosol optical properties because the wavelength dependence of the backscatter and extinction coefficients allows for a more detailed discrimination of aerosol types. Several lidar stations belonging to SPALINET, the Spanish and Portuguese Lidar NETwork and also EARLINET, the European Aerosol Research Lidar NETwork, intercompared during a campaign that took place in Madrid from 18 October to 5 November 2010. The products provided by the lidar systems were compared with ancillary data. At ground level, aerosol size distribution was continuously monitored. Additionally, the column-integrated characterization of the atmospheric aerosol was performed by means of a sun photometer. The extensive dataset obtained during SPALI10 field campaign enables to compare ground-level in-situ measurements with remote sensing techniques to determine vertically-resolved optical and microphysical properties of aerosols. Several relevant features shown in the comparison of the results obtained by the different instruments are discussed in this work.

Key words: Aerosols, lidar, size distributions.

INTRODUCTION

The high variability of tropospheric aerosols both in space and time is one of the main reasons of the high uncertainty of radiative forcing estimates in climate change studies [Forster, 2007]. The aerosol vertical distribution is of crucial importance in radiative transfer calculations. In studying the vertical structure of the aerosol field and its temporal and spatial evolution, lidar techniques represent a powerful tool because of their capability to provide aerosol profiles with high resolution. Multiwavelength lidars can provide additional information on aerosol characterization because the wavelength dependence of the backscatter and extinction coefficients allows for a more detailed discrimination of aerosol types [Müller, 2001]. Several lidar stations belonging to SPALINET, the Spanish and Portuguese Lidar NETwork [Sicard, 2009] and also EARLINET, the European Aerosol Research Lidar NETwork [Bösenberg, 2003] intercompared during SPALI10 (SPAin Lidar Intercomparison 2010) field campaign that took place in Madrid (40.45ºN, 3.73ºW, 663 m asl) from 18 October to 5 November 2010. All network stations routinely perform internal quality checks and participated in intercomparisons both at the instrument and algorithm levels with standardized procedures [Matthias, 2004]. In this work, several relevant features shown in the comparison of vertically-resolved optical properties of aerosols with ground-level in situ data and column-integrated aerosol properties provided by sun-photometer remote sensing techniques, are discussed.

METHOD AND RESULTS

The aim of the campaign was to compare simultaneous lidar measurements from several network stations (Madrid, Granada, Barcelona and Évora) with a reference lidar system from Potenza (Italy) in order to assess their performances measuring the same atmosphere during the same time periods. Simultaneously, an extensive dataset from both ground-level in-situ measurements and remote sensing techniques was collected for characterizing aerosol optical and microphysical properties. All lidar systems were collocated close on a flat terrain, with laser pointing close to the zenith. Several sessions each with some hours of measurement time were scheduled for every day of the campaigns, both at day and night, in order to obtain sufficiently long periods with stable atmospheric conditions and with all lidar systems working properly. The results of the campaign can be considered satisfactory as the campaign allowed to check the performances of the systems and when they were not fully satisfactory, the reasons of the failure were understood and a way to solve them could be defined.

All the intercompared lidar systems use pulsed Nd:YAG laser emitting at 1064, 532 and 355 nm, configured in a monostatic biaxial alignment pointing vertically to the zenith, except for the Évora system, that is tilted 5º to improve cirrus studies. The receiving lines consist of Cassegrain or Newtonian telescopes and wavelength separation units with dichroic mirrors, interferential filters and polarization cubes. From the elastic lidar signal, aerosol backscatter coefficient profiles have been retrieved using the Klett algorithm [Klett, 1981]. The retrieval of backscatter coefficient profiles requires the use of a modeled value for the lidar ratio (i.e., the ratio between aerosol extinction and backscatter coefficient), a value of 50 sr was selected. The column integrated characterization of the atmospheric aerosol was performed by means of an automatic sun tracking photometer Cimel CE-318-4 [Holben, 1998], operated by the Granada team. This instrument makes direct sun irradiance measurements at 340, 380, 440, 670, 870, 940 and 1020 nm. These solar extinction measurements are then used to compute Aerosol Optical Depth (AOD) at each wavelength. The AOD is derived from the total optical depth obtained from direct sun-photometer measurements data. The sky radiance measurements, performed at the almucantar and principal planes at 440, 675, 870, and 1020 nm together with solar direct irradiance measurements at the same wavelengths, were used to retrieve the aerosol single-scattering albedo, phase function, aerosol optical thickness and the volume size distribution (dV(r)/dlnr (cm^3cm^{-2})) using the radiative transfer code SKYRAD.pack software [Nakajima, 1996]. At ground level, the temporal evolution of particle number concentration for particles with aerodynamic diameter smaller than 10, 2.5 and 1 μm (PM10, PM2.5 and PM1, respectively) were monitored at the experimental site. Dry ambient sub-micrometer size distributions were monitored at the site by using a Scanning Mobility Particle Sizer (TSI SMPS 3936), combining a long Differential Mobility Analyzer (DMA) and a Condensation Particle Counter (CPC model 3775) working in the scanning mode. On a larger particle size range, an Optical Particle Counter (GRIMM 1108) was used. Both instruments allow to obtain a single plot for number distributions between 0.015 to 10 μm by joining their data. Volume distributions (dV/dlog(Dp)) were calculated assuming that aerosol particles were spheres with a radius equal to the centre radius of each bin measured by the instruments.

The meteorological analysis showed a synoptic situation mainly governed by high-pressure systems over the Iberian Peninsula during the first two weeks of the campaign, promoting stagnation. After these days there was a 3-day rain episode ending on 31 October, followed by a period with the Azores high-pressure system dominating over the peninsula, yielding the entry of air masses from the Atlantic. Figure 1 shows aerosol backscatter profiles derived from the Madrid system range-corrected signals, at the three elastic wavelengths, for 21 October (Top panels) and 2 November (Bottom panels) daytime sessions. On 21 October, there was a thermal inversion at 1100 m asl, determined by the inflexion point of the virtual potential temperature profile. The backscatter profiles show two aloft layers, at 1600 and 2100 m asl, probably due to the stagnation conditions. Backscatter-related Ångström exponents obtained between the 532 and 355 nm and 1064 and 532 nm profiles for these layers are different than that of the mixing layer, indicating different aerosol characteristics. Assuming the aerosol source was local, the change in the characteristics might be caused by chemical transformation in the atmosphere of previous days' emitted aerosols. On the 2 Nov, all the aerosol content was comprised in the mixing layer, that reached 2000 m asl. Backscatter-related Ångström exponent obtained between 1064 and 532 nm was constant, with a value of 1.5, in this case due to the cleaning of the atmosphere from day-to-day.

Figure 2 shows the column-integrated volume size distributions provided by the sun-photometer and derived from ground-level measurements, using the lidar profiles to determine the scale height required to make them comparable [Fernández-Gálvez, 2011]. The two techniques measure different quantities; sun-photometer remote sensing is sensitive to the aerosol optical properties of the entire column, while in-situ instruments measure the aerosols at ground-level, which may not be representative of the distributed aerosol in the total boundary layer. The distributions obtained by in-situ instrumentation at surface level (in $\mu m^3\ cm^{-3}$) are converted into columnar distribution ($cm^3\ cm^{-2}$) for comparison with sun-photometer retrievals by means of a scale height provided by the lidar profile. The observed size distributions are typically bimodal, with the first modal radius between <0.015 and 0.4 μm, and the second between 0.5 and >10 μm. Between these modal values generally there is a minimum (inflection point), corresponding to a radius of about 0.4 μm. The agreement between the volume size distribution provided by the inversion code and that measured at ground-level was reasonable, taking into account the assumptions made for the comparison. The presence of a lofted layer with a different type of aerosol, although with very low backscattering values, might influence the comparison, raising concern about the validity of the scale height value employed in the conversion of the surface data

CONCLUSIONS

During the SPALI10 lidar intercomparison campaign at Madrid, the products provided by multiwavelength lidar systems were compared with ancillary instrumentation data. At ground level, aerosol size distribution was continuously monitored between 15 nm and 20 μm by merging two particle counters. Additionally, the column-integrated characterization of the atmospheric aerosol was performed by means of a sun-photometer. The vertically-resolved aerosol optical properties at three wavelengths provide information about the type of aerosol present in the different layers observed. A comparison of columnar versus ground-level measurements of aerosol size distribution was performed. In-situ measurements at ground-level were converted into column-integrated values using the retrieved scale height values provided by lidar profiles. Both techniques yield bimodal aerosol size distribution, with an inflection point around 0.4 μm, with better agreement in the size range between 0.2 and 2 μm, where the inversion algorithm for sun-photometer data is more reliable. Aerosol layer structure detected by the lidar system might explain the discrepancy observed in the absolute values and shape of each mode on the 21 October, when several layers with aerosols with different optical properties were detected aloft. A better agreement is found on the 2 November, when all the aerosol where comprised in the mixing layer, with constant optical properties. Further investigations are ongoing to obtain relevant vertically-resolved aerosol optical properties from multiwavelength Raman lidar systems.

ACKNOWLEDGMENTS

The work was supported by the European Union under project nº 025991 (RICA), by the MICINN under the projects CGL2010-17777, CGL2008-01330-E/CLI & CGL2010-09225-E and by the ESA-CEOS Intercalibration of Ground-Based Spectrometers and Lidars (CEOS-IC-PR01) project.

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