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Evaluation of sun photometer capabilities for retrievals of aerosol optical depth at high latitudes: The POLAR-AOD intercomparison campaigns

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ABSTRACT

Accuracy requirements for aerosol optical depth (AOD) in polar regions are much more stringent than those usually encountered in established sun photometer networks, while comparability of data from different archive centres is a further important issue. Therefore, two intercomparison campaigns were held during spring 2006 at Ny-Ålesund (Svalbard) and autumn 2008 at Izaña (Tenerife) within the framework of the IPY POLAR-AOD project, with the participation of various research institutions routinely employing different instrument models at Arctic and Antarctic stations. As reported here, a common algorithm was used for data analysis with the aim of minimizing a large part of the discrepancies affecting the previous studies. During the Ny-Ålesund campaign, spectral values of AOD derived from measurements taken with different instruments were found to agree, presenting at both 500 nm and 870 nm wavelengths average values of root mean square difference (RMSD) and standard deviation of the difference (SDD) equal to 0.003. Correspondingly, the mean bias difference (MBD) varied mainly between −0.003 and +0.003 at 500 nm, and between −0.004 and +0.003 at 870 nm. During the Izaña campaign, which was also intended as an intercalibration opportunity, RMSD and SDD values were estimated to be equal to 0.002 for both channels on average, with MBD ranging between −0.004 and +0.004 at 500 nm and between −0.002 and +0.003 at 870 nm. RMSD and SDD values for Ångström exponent α were estimated equal to 0.06 during the Ny-Ålesund campaign and 0.39 at Izaña. The results confirmed that sun photometry is a valid technique for aerosol monitoring in the pristine atmospheric turbidity conditions usually observed at high latitudes.

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1. Introduction

The surface-atmosphere system conditions observed in polar regions (high surface albedo and low Sun elevation angles) greatly strengthen aerosol-induced effects on the radiation budget, contributing to modify the overall albedo of the Earth-atmosphere system (Shaw et al., 1993). Despite the important role of aerosols, the knowledge of their physical and radiative properties, horizontal and vertical mass concentration distributions, and temporal variability remains inadequate (Forster et al., 2007). Surface-based (in-situ, photometric, lidar) measurements allow the achievement of detailed and accurate results, and constitute a unique way of obtaining reliable information on aerosol radiative properties over highly reflective snow- and ice-covered surfaces, even if observing stations in polar regions are still few and far between.

Sun photometry is a useful tool for obtaining information on the optical and physical properties of aerosols along the atmospheric vertical path (Dubovik and King, 2000). In the past decade, sun photometric networks have been developed all over the world, including AERONET (Holben et al., 1998), GAW-PFR (Wehrli, 2000), SKYNET (Kim et al., 2004), and SURFRAD (Augustine et al., 2000). These networks have an almost global coverage, but only a few stations provide measurements with continuity at high latitudes (Stone, 2002; Herber et al., 2002; Rozwadowska and Sobolewski, 2010). Because of the low aerosol concentration usually observed and low solar elevation angles, the acquisition of accurate aerosol optical depth (AOD) measurements by means of sun photometers is in general difficult at high-latitude sites. The contributions of molecular scattering and absorption to the total optical depth (TOD) need to be evaluated as accurately as possible, because their values are often comparable or greater than AOD (Ortiz de Galisteo et al., 2008). The correct evaluation of the solar zenith angle (SZA) is of great importance in calculating the relative constituent-dependent optical air mass (m). In fact, atmospheric light refraction increases with SZA, while the different vertical profiles of the various atmospheric components variably influence calculations of m (Reagan et al., 1986). Instrument calibration is another major issue. It is usually performed by applying the Bouguer–Lambert–Beer law in Eq. (1) to data-sets collected over a sufficiently wide range of m, at least from 2 to 5. The higher the latitude of the site, the narrower is the range of diurnal variation of m during a given period. For this reason, it is not easy to calibrate such instruments with accuracy at polar sites.

The POLAR-AOD programme was proposed to the ICSU/WMO Joint Committee for the International Polar Year (IPY), with the aim of developing studies on the direct effects of polar aerosols on climate, and establishing a bipolar network of spectral radiometers to characterize their optical properties (see *http://classic.ipy.org/development/eoi/details.php?id=299*, and Tomasi et al., 2007). Two field campaigns were planned and carried out as a basic part of the POLAR-AOD project, the first at Ny-Ålesund (Spitsbergen, Svalbard archipelago, Norway) in early spring 2006 and the second at Izaña (Tenerife, Canary Islands, Spain) in October 2008.

Dealing with these issues, several comparison studies have been developed in recent years. Kim et al. (2008) intercompared measurements of AOD performed at various sites worldwide over long periods from about 1 to 3 years, finding that Sun-pointing instruments provide AOD (500 nm) values that agree within ±0.01 in terms of mean bias difference (MBD), for estimates of root-mean-square difference (RMSD) and standard deviation of difference (SDD) varying between less than 0.01 and 0.04 (see caption of Table 2 for definitions of the cited statistical parameters). The subsequent comparison of these results with those obtained from previous intensive studies provided the following statistic evaluations: (i) absolute values of MBD < 0.005 and SDD within the 0.001 - 0.005 range, for all the wavelengths considered (500, 670, 780, 870 and 1020 nm), from the 3-month measurements performed at Alice Springs and Tinga Tingana (Australia) using a pair of CIMEL and SP01A sun photometers in the first campaign, and a pair of CIMEL models in the second (Mitchell and Forgan, 2003); (ii) MBD values within ±0.006 at 380, 450, 870, and 1020 nm, and within ±0.010 at 525 nm, with RMSD ranging between 0.006 and 0.012, and SDD values between 0.006 and 0.011, from measurements taken at the ARM-SGP facility (Oklahoma, USA) using an Ames Airborne Tracking sun photometer (AATS-6) and a CIMEL sun photometer during a 15-day campaign (Schmid et al., 1999); (iii) absolute values of MBD < 0.007 at different wavelengths, and RMSD values < 0.01 from an intercomparison of three sun photometers (CIMEL, PFR and SP01A models) at the Bratt's Lake Observatory (Canada) (McArthur et al., 2003).

Such results suggest that intercomparison activities are very useful for limiting the discrepancies of the AOD evaluations obtained at the various wavelengths using different sun photometers. The description of the results obtained in the Ny-Ålesund and Izaña campaigns is the primary objective of the present work. Section 2 describes the field activities and provides details of the adopted methodologies. The overall precision of AOD is estimated from the field measurements (Sections 3.1 and 3.2), and the spectral dependence of AOD is evaluated in terms of the Ångström exponent α (Section 3.3). A detailed description of the calibration results obtained at Izaña is given in Section 3.2.1, while the comparison of the results with those available in the literature is made in Section 4. Finally, recommendations for obtaining accurate and comparable AOD measurements are made in Section 5.

2. Technical characteristics of the instruments employed in the POLAR-AOD campaigns

The main characteristics of the instruments employed during the two campaigns are listed in Table 1. Different radiometer models were used by the participating institutions: (i) CIMEL CE318 sun/sky-radiometer, the standard instrument of the AERONET network (Holben et al., 1998) and its sub-networks AEROCAN, PHOTONS and RIMA; (ii) PREDE POM02 sun/sky-radiometer, adopted by the SKYNET network (Kim et al., 2004); (iii) Precision Filter Radiometer (PFR), designed by the Swiss Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (PMOD/WRC) and used in the World Meteorological Organization Global Atmospheric Watch (WMO/GAW) network (Wehrli, 2000); (iv) Carter–Scott SP01A and SP02 models, used by the Australian Bureau of Meteorology in its national network (Mitchell and Forgan, 2003) and by the National Oceanic & Atmospheric Administration/Global Monitoring Division (NOAA/GMD); (v) SP1A sun photometer, manufactured by Dr. Schulz & Partner GmbH and operated by the Alfred Wegener Institute for Polar and Marine Research (AWI) at their Antarctic and Arctic stations (Herber et al., 2002); (vi) ASP-15WL, designed at the Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR), and deployed at the Italian Terra Nova Bay station (Antarctica) during summer campaigns (Tomasi et al., 2007). Alongside the above fully automated instruments, some hand-held MICROTOPS II sun photometers of Solar Light Company Inc. were operated during the two campaigns, this instrument being particularly suitable for itinerant campaigns or harsh environmental conditions, since it does not require the use of solar trackers and data acquisition systems (Smirnov et al., 2011). Their results were evaluated separately from that of the sun-tracking instruments, and were not utilized in the final evaluations of uncertainty parameters, because, as will be shown, precision achievable with