Earth-Science Reviews 140 (2015) 108–157

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Aerosol remote sensing in polar regions

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ARTICLE INFO

Article history:
Received 15 April 2014
Accepted 1 November 2014
Available online 10 November 2014

Keywords:
Sun-photometer measurements
Aerosol optical thickness
Polar aerosol optical characteristics
Lidar backscattering coefficient profiles
Satellite aerosol remote sensing
Multimodal aerosol extinction models

ABSTRACT

Multi-year sets of ground-based sun-photometer measurements conducted at 12 Arctic sites and 9 Antarctic sites were examined to determine daily mean values of aerosol optical thickness $\tau(\lambda)$ at visible and near-infrared wavelengths, from which best-fit values of Ångström's exponent α were calculated. Analysing these data, the monthly mean values of $\tau(0.50\ \mu m)$ and α and the relative frequency histograms of the daily mean values of both parameters were determined for winter–spring and summer–autumn in the Arctic and for austral summer in Antarctica. The Arctic and Antarctic covariance plots of the seasonal median values of α versus $\tau(0.50\ \mu m)$ showed: (i) a considerable increase in $\tau(0.50\ \mu m)$ for the Arctic aerosol from summer to winter–spring, without marked changes in α; and (ii) a marked increase in $\tau(0.50\ \mu m)$ passing from the Antarctic Plateau to coastal sites, whereas α decreased considerably due to the larger fraction of sea-salt aerosol. Good agreement was found when comparing ground-based sun-photometer measurements of $\tau(\lambda)$ and α at Arctic and Antarctic coastal sites with Microtops measurements conducted during numerous AERONET/MAN cruises from 2006 to 2013 in three Arctic

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http://dx.doi.org/10.1016/j.earscirev.2014.11.001
0012-8252/

Ocean sectors and in coastal and off-shore regions of the Southern Atlantic, Pacific, and Indian Oceans, and the Antarctic Peninsula.

Lidar measurements were also examined to characterise vertical profiles of the aerosol backscattering coefficient measured throughout the year at Ny-Ålesund. Satellite-based MODIS, MISR, and AATSR retrievals of $\tau(\lambda)$ over large parts of the oceanic polar regions during spring and summer were in close agreement with ship-borne and coastal ground-based sun-photometer measurements. An overview of the chemical composition of mode particles is also presented, based on in-situ measurements at Arctic and Antarctic sites. Fourteen log-normal aerosol number size-distributions were defined to represent the average features of nuclei, accumulation and coarse mode particles for Arctic haze, summer background aerosol, Asian dust and boreal forest fire smoke, and for various background austral summer aerosol types at coastal and high-altitude Antarctic sites. The main columnar aerosol optical characteristics were determined for all 14 particle modes, based on in-situ measurements of the scattering and absorption coefficients. Diurnally averaged direct aerosol-induced radiative forcing and efficiency were calculated for a set of multimodal aerosol extinction models, using various Bidirectional Reflectance Distribution Function models over vegetation-covered, oceanic and snow-covered surfaces. These gave a reliable measure of the pronounced effects of aerosols on the radiation balance of the surface–atmosphere system over polar regions.

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1. Introduction

Aerosols are one of the greatest sources of uncertainty in climate modelling, as their microphysical, chemical and optical characteristics as well as their concentration vary in time and in space, inducing significant direct radiative forcing effects on the surface–atmosphere system. In addition, they can alter cloud optical features and indirectly impact climate. The aim of this paper is to present an overview of the optical characteristics of atmospheric aerosol observed in polar regions during the past two decades, including recent measurements conducted with ground-based and ship-borne sun-photometers, or retrieved from remote sensing data recorded with visible and infrared sensors mounted onboard various satellite platforms. Optical instruments (e.g., lidars, sun-photometers) measure the characteristics of the atmospheric light field (internal, reflected, or transmitted). Specific procedures therefore need to be applied to convert optical signals to aerosol characteristics, such as particle size and shape distributions, or chemical composition. Similar procedures are also needed to derive the vertical concentration distribution from columnar measurements. They are based on the solution of the inverse problem of radiative transfer theory accounting for multiple light scattering, molecular and aerosol scattering and absorption, and surface reflectance effects.

The presence of a visibility-reducing haze in the Arctic was already noted by early explorers in the 19th century (see Garrett and Verzella, 2008, for a historical overview). The explorers also documented that haze particles were deposited on snow in remote parts of the Arctic (e.g., Nordenskiöld, 1883) and haze layers were also observed later by pilots in the 1950s (Mitchell, 1957). The source of the haze was debated for almost a century but poorly understood until the 1970s when it was suggested that this “Arctic Haze” originated from emissions in northern mid-latitudes and was transported into the Arctic over thousands of kilometres (Rahn et al., 1977; Barrie et al., 1981). The seasonality of the haze, which peaks in winter and early spring, was explained by the fact that removal processes are inefficient in the Arctic during that time of the year (Shaw, 1995).

Polar aerosols originate from both natural and anthropogenic sources (Shaw, 1988, 1995). In the Arctic regions, natural aerosols have been found to contain an oceanic sea-salt mass fraction that frequently