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The vertical distribution of aerosol over Europe—synthesis of one year of EARLINET aerosol lidar measurements and aerosol transport modeling with LMDzT-INCA

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Abstract

Aerosol extinction vertical profiles measured with Raman lidar in the framework of EARLINET in 2000 are compared to profiles modeled by a general circulation model, LMDzT-INCA, at seven stations in Europe. Comparisons based on individual profiles show moderate correlation between model and data. Averaging aerosol extinction values on larger temporal or spatial scales improves the comparison. Furthermore, we show that the model succeeds to reproduce the mean annual aerosol distribution over Europe. Comparisons of the aerosol vertical distribution in two distinct regions of Europe are presented. For the northern stations, the observed yearly average aerosol extinction coefficient vertical profile and the modeled one show an average bias of 22%. For the southern stations the mean bias is slightly higher (29%). Both model and lidar show different extinction profiles in different parts of Europe, with higher values in upper heights in the South. According to modeled profiles of each aerosol component, this is caused by the presence of dust at altitudes between 2 and 6 km. In addition vertical mixing in the South seems to be more effective for the other aerosol components.

Keywords: Aerosol extinction; Vertical profiles; Aerosol composition; Saharan dust; GCM

1. Introduction

Aerosol radiative forcing is one of the largest uncertainties in predicting climate change (Charlson

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et al., 1992; Houghton et al., 1995) due to the still insufficient understanding of the aerosol distribution and the physical, chemical and optical aerosol properties on a global scale. A major unknown of the spatial aerosol distribution is the vertical distribution. Transport in the planetary boundary layer (hereafter referred to as PBL) and the free troposphere can be decoupled, resulting in different chemical composition, and thus aerosol optical properties in different layers. While the PBL aerosol often is of local origin, aerosol in elevated layers usually is transported over long range.

Today some 3D transport models with a multi component aerosol module exist which can simulate the vertical distribution of aerosol particles over Europe. These are general circulation models (GCMs) setup to simulate time periods of several years. On the other hand, lidar measurements give detailed information on occurrence, extent and development of aerosol structures. In the framework of the European Aerosol Research Lidar Network (EARLINET) and the German Lidar Network (Bösenberg et al., 2001, 2003), lidar observations were conducted at up to 22 stations distributed over Europe between 1998 and 2002. In this paper, we present first results of a comparison between aerosol extinction vertical profiles over Europe modeled by a global aerosol transport model, LMDzT-INCA, and the ones measured by seven Raman lidars in the framework of EARLINET in 2000. Comparisons of model results with individual lidar profiles have been reported in the literature (Guelle et al., 2000). However, here we synthesize for the first time information from 182 profiles of the vertical aerosol distribution. Interpretation in term of several aspects becomes this way possible, e.g. concerning the validity of a modeled aerosol vertical profile over Europe and the problems associated with comparing individual lidar profiles to large scale models, or the use of the modeled aerosol composition to understand the observed total aerosol extinction profile, and the representativity of the sometimes sparse lidar data. Our study is also meant to propose a new diagnostic for global and regional aerosol models by using averaged lidar profiles from lidar networks.

The complete comparison for all observed profiles can be found at the following web site: http://nansen.ipsl.jussieu.fr/AEROCOM/DATA/lidar.html.

2. Model description

The LMDzT-INCA couples the Laboratoire de Météorologie Dynamique general circulation model (Hourdin and Armengaud, 1999) and the Interaction with Chemistry and Aerosols (INCA) module developed at the LSCE. The resolution is 3.75° in longitude, 2.5° in latitude with 19 vertical layers up to 3 hPa. The meteorological fields are nudged with 6-hourly ECMWF reanalysis wind fields. Gas phase chemistry and transport characteristics have been recently described by Hauglustaine et al. (2004). Five different types of aerosol (sulfate, mineral dust, black and organic carbon, and sea salt) are internally mixed within 5 lognormal modes: soluble and insoluble accumulation modes, soluble and insoluble coarse modes, and soluble supercoarse mode. Aerosol size evolution is captured for processes such as sedimentation (Schulz et al., 1998), wet deposition (Guelle et al., 1998a,b) and humidity growth (Gerber, 1985). Sulfate production follows closely work from Boucher et al. (2002), but uses the on-line computed photo-oxidant fields from the gas phase chemistry module (Hauglustaine et al., 2004). Black carbon and particulate organic matter emissions are corrected for inter-annual variability of biomass burning (Generoso et al., 2003) based on the emission database from Liousse et al. (1996). Dust has been extensively studied in our group and is emitted as a function of windspeed (Schulz et al., 1998; Balkanski et al., 2003; Bauer et al., 2004; Timmreck and Schulz, 2004). Sea salt emissions are redistributed in three modes to better represent the wide range of observed particles (Guelle et al., 2001; Schulz et al., 2003). Mie calculations are done for each aerosol component in each mode. Although aerosol masses from different components are internally mixed within a mode, resulting in one mode diameter per aerosol mode, optical calculations then use the refractive index from individual aerosol components to derive component-wise extinction. Hourly values of aerosol extinction at 355 nm per model layer are interpolated from the adjacent four grid boxes to the lidar station locations. For most of the comparisons shown hereafter model data were picked at the exact time when lidar profiles were retrieved. Extinction is preferred as the primary validation parameter of the model because of two reasons:

(i) aerosol extinction can be measured with good accuracy using Raman lidars without relying on further assumptions about the aerosol type;
(ii) aerosol extinction is much less sensitive to variations of the model results in relative humidity, chemical composition or size distribution of the aerosols than aerosol backscatter is.

3. Lidar data

All lidar profiles were taken in the framework of the EARLINET project and the German Lidar Network. We consider here data from the stations Aberystwyth, Hamburg, Kühlungsborn, Lecce, Leipzig, Naples and Potenza (Bösenberg et al., 2003). Aerosol extinction