IMPACT OF BIOMASS BURNING PLUME ON RADIATION BUDGET AND ATMOSPHERIC DYNAMICS OVER THE ARCTIC

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ABSTRACT

The aim of the research was to determine the impact of July 2015 biomass burning event on radiative budget, atmospheric stratification and turbulence over the Arctic using information about the vertical structure of the aerosol load from the ground–based data. MODTRAN simulations indicated very high surface radiative cooling (forcing of –150 Wm^{-2}) and a heating rate of up to 1.8 $Kday^{-1}$ at 3 km. Regarding LES results, a turbulent layer at around 3 km was clearly seen after 48 h of simulation.

1 INTRODUCTION

Lidar measurements conducted with a complex multi–wavelength Raman systems provide important information about the vertical structure of optical properties corresponding to the aerosol occurrence in the atmosphere. Lidars give high–quality wavelength–dependent profiles of particle extinction and backscattering coefficients. Such profiles may be used for an appreciable variety of further retrievals to deliver additional knowledge about the atmosphere. In this paper, we introduce one of the possibilities for reprocessing of the lidar and in–situ data to obtain information on radiation budget and atmospheric dynamics in the light of the Arctic measurements.

We focus on a strong event with a high aerosol load that was observed over Spitsbergen between 10–14 July 2015. It was characterized by a dense layer of biomass burning particles transported to the Arctic from wildfires that had spread over the Alaskan tundra at the beginning of July 2015 [1]. During that period, the observed aerosol optical properties exceeded the mean climatological summer values by a factor of at least 10. In particular, aerosol optical depth (AOD) as well as scattering and absorption coefficients at the Earth's surface increased to values of 1.2, 145 and 10 Mm^{-1} at 550 nm respectively. It was expected that such event would have a high impact on the optical properties over Spitsbergen, and thus it was chosen for further detailed study.

2 METHODOLOGY

In this section we describe the methodology applied for calculating radiation fluxes and atmospheric dynamics, using vertical profiles of single scattering albedo at ambient conditions that were obtained by the means of in–situ and lidar measurements.

2.1 Measurements

The measurements were carried out at two research stations in Ny–Ålesund on Spitsbergen. French–German (AWIPEV) station, located within the village, handled lidar measurements. Italian Gruvebadet laboratory, located approx. 1 km SW from Ny–Ålesund, maintained in–situ instruments [1].

The extinction (σ_{ext}) profiles were retrieved from signals measured by the Koldewey Aerosol Raman Lidar (KARL), equipped with a Nd:Yag laser which is emitting pulses at 355, 532, 1064 nm with 10 W each. The signals were received on a 70 cm mirror with a 1.75 mrad field of view. Geometrical compression affected the signal below 700 m a.g.l. [2]. Single wavelength M903 Nephelometer (Radiance Research) equipped with a xenon flash lamp and an opal diffuser measured scattering coefficient (σ_{scat}) at 530 nm within 10–170° integration range. Particle Soot Absorption Photometer (PSAP; Radiance Research) measured absorption coefficient (σ_{abs}) at 467, 530, 660 nm based on changes in the light attenuation indicated by the aerosol load on filter. Joint measurements of TSI Scanning Mobility Particle Sizer (SMPS 3034) and TSI Aerodynamic Particle Sizer Spectrometer (APS 3321) allowed for retrieval of aerosol size distribution in the range of 0.01–20 μm. Vertical profiles of basic thermodynamic quantities (air temperature, air pressure, relative humidity, wind speed and direction) were measured by the Vaisala radiosonde RS92.

2.2 Retrieval of aerosol single scattering properties at ambient conditions

The aerosol model for atmospheric radiative transfer calculations is built based on the following approach. Assuming constant with altitude single scattering albedo at dry conditions (ω^d), one can calculate its profile at ambient conditions (ω^a). Firstly, the value of ω^d is calculated from nephelometer and PSAP measurements at dry conditions. Secondly, by taking the lidar σ^a_{ext} profile and introducing both extinction enhancement factor (the ratio between extinction coefficient at ambient conditions to its value in dry conditions [3]) as well as Handel model (relating aerosol hygroscopicity and the relative humidity [4]), one can calculate the profile of extinction coefficient at dry conditions (σ^d_{ext}). From the σ^d_{ext} and ω^d profiles the absorption coefficient (σ^d_{abs}) profile can be retrieved. Taking into account, that σ_{abs} is weakly dependent on the relative humidity, one can assume no change of σ^d_{abs} during transition to ambient conditions (σ^a_{abs}). Finally, from σ^a_{abs} and σ^a_{ext} (lidar measurements) one can calculate the profile of ω^a at ambient conditions. Retrieval of the asymmetry parameter (g) is also possible, provided that at first, a hygroscopic growth factor related to the relative humidity is introduced [3]. Then, assuming a value of refractive index for a known particle size distribution, one can obtain g by means of Mie theory. The detailed description of the proposed approach is given in [5].

2.3 Model setups

MODTRAN v. 5.2.1 (The moderate–resolution atmospheric radiance and transmittance model) [6] was adopted to calculate profiles of the r_h. The MODTRAN solver uses discrete ordinate radiative transfer model (DISORT). In the simulations, 8–stream MODTRAN band model "M" with 17 absorption coefficients within each spectral bin and correlated–17k speed option were used. All calculations were performed assuming oceanic values of surface albedo with a Fresnel reflection included. The model calculated the clear–sky radiative fluxes and heating rates in the range of 0.3– 200 µm for two cases: the atmosphere without and with the aerosol load, referred to as "pristine" and "polluted" cases, respectively.

EULAG (The 3D nonhydrostatic anelastic Eulerian–semi–Lagrangian) model [7] was set up to perform implicit large–eddy simulation (ILES) of the two defined cases (pristine and polluted) assuming additionally clear–sky and non–condensing conditions. Initial profiles of wind speed and potential temperature θ were in both cases based on radio–soundings from Ny–Ålesund performed at 12:00 UTC on July 10 2015. The vertical velocity was initially set to 0, and a large–scale horizontal pressure gradient was applied in terms of the geostrophic wind $\mathbf{U_g}$=(10,10) ms^{-1} with the Coriolis parameter set to 1.4 x 10^{-4} s^{-1}. The r_h profiles from the MODTRAN were applied and kept constant in the simulations, which were run for 48 h.

3 RESULTS

In the following section a brief description of the obtained vertical profiles of optical and radiative properties, as well as turbulence are given. More detailed description and discussion is to be found in [5].

3.1 Impact of absorbing aerosol on radiative properties and atmospheric dynamics

Vertical profiles of aerosol and radiative properties (Fig. 1) show significant variability. Lidar extinction profile indicates a dense layer of biomass burning aerosol between 1–3.5 km, where extinction and absorption coefficients reach up to 300 and 20 Mm^{-1}, respectively. Since an appreciable variability of the relative humidity is observed (20–80 %; Fig. 1d), the particle hygroscopicity plays an important role. Thus, the noticeable rate of change of extinction coefficient at ambient conditions (black line) from 2 to 3.5 km results from the variability of the relative humidity. The corresponding extinction profile at dry conditions indicates a constant value within the layer. In comparison to the profile of potential temperature (Fig. 2b–black line), a retrieval seems to be reasonable. The vertical profile of single scattering albedo at dry conditions (Fig. 1c–blue line) is assumed constant and equal to the value obtained by in–situ measurements (0.92).

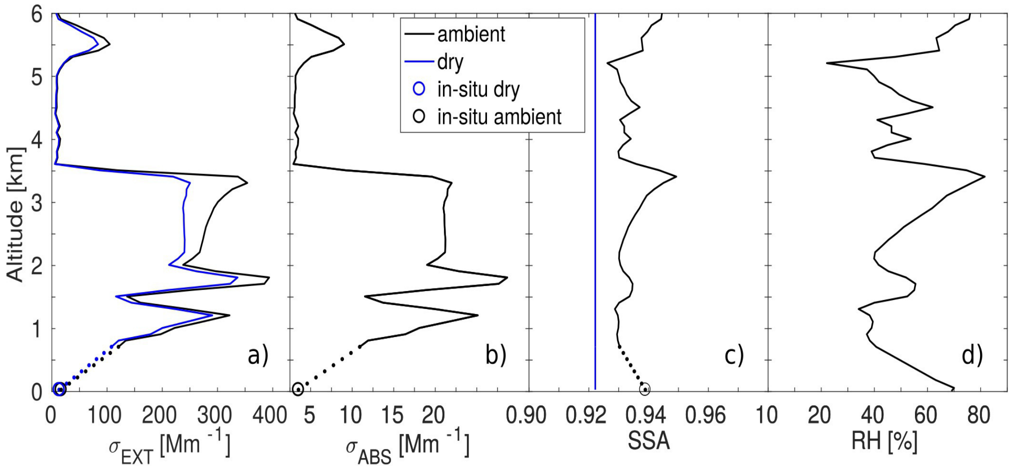

Figure 1 Vertical profiles of optical properties at 10 July 2015 12:00 UTC obtained from the measurement, and presented retrieval (sect. 2.2).

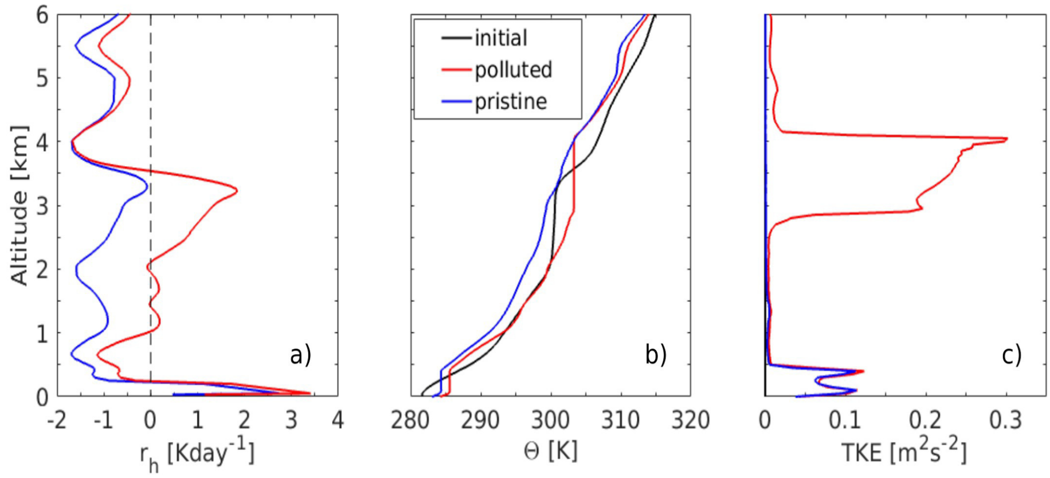

Figure 2 Vertical profiles of the heating rate (a), potential temperature (b) and turbulent kinetic energy (c). The black line represents initial conditions and the red/blue lines profiles from the polluted/pristine cases at t=48h. The heating rates are kept constant in time.

The values at ambient conditions (Fig. 1c–black line), however, range from 0.93 to 0.95. The vertical variability results from the Raoult's effect embedded in the Kohler relation used for the calculations. Thus, in comparison to dry conditions the aerosol has less absorbing properties, especially in the layers with high relative humidity (i.e. at 3.5 km). The heating rate profile calculated for the pristine case (Fig. 2a–blue line) indicates background conditions to cool the troposphere (up to –1.8 Kday^{-1}) within the first 6 km, except for the lowermost layer influenced by the surface properties. The polluted case, however shows a local heating rate (up to 1.8 Kday^{-1}) between 1 and 3.5 km caused by the biomass burning aerosol. The particular value of the heating rate is also related to the water vapor relative contamination.

As indicated by the initial profiles of potential temperature (Fig. 2b–black line), atmospheric conditions are stable at the beginning of the performed large–eddy simulations, except in the layer between 1.8 and 3.5 km where θ is nearly constant with height as a result of vertical mixing.

At time t=48 h in the polluted case, existence of a well–mixed layer is visible between 2.8 and 4 km, indicating that it is lifted with time (Fig. 2b–red line). In the pristine case, however, the initial well–mixed layer disappears over time and is not visible at t=48 h. The profile of turbulent kinetic energy from the polluted case (Fig. 2c) at t=48 h shows regions with relatively high values; up to 0.1 m^{2}s^{-2} below 0.5 km and between 0.2–0.3 m^{2}s^{-2} in the region of 2.8–4 km, with vertical velocities of as high as 1ms^{-1} (not shown for brevity). These regions correspond to layers with a constant potential temperature. On the other hand, the profile of turbulent kinetic energy calculated for the pristine case is almost entirely constant and near zero, with exception of the lowermost atmospheric layer, which is altered by the surface properties (Fig 2c–blue line). Very little vertical mixing takes place above the surface layer.

4 CONCLUSIONS

A brief presentation of the possibility of using lidar data for radiative transfer and atmospheric dynamics calculations has been given. We considered an event with high concentrations of biomass burning aerosol transported from North America to the Arctic that occurred between 10–14 July 2015 over Spitsbergen. On July 10, the radio–soundings indicated a layer with well–mixed air between 1.8–3.5 km with corresponding high values of relative humidity (60–80 %). The single scattering albedo of 0.95–0.96 and a positive heating rate of up to 3 Kday^{-1} were obtained. The EULAG simulations provided profiles of turbulent kinetic energy and potential temperature over a 48 h period, and clearly indicated the development of vertical mixing and rising of the well–mixed layer, however only in the polluted case. The layers of biomass burning aerosol seem to locally heat the surrounding air causing changes in the stability within the mid troposphere. Thus, impacting the atmospheric dynamics.

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