Optica Applicata, Vol. XXXVI, No. 4, 2006

Studies of aerosol physical properties in the coastal area

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In the marine boundary layer over coastal areas marine aerosol size distribution and concentration strongly depend on wind speed and location of the measuring point accross the surf zone. The measurements were taken from several stations on the Polish coast of the Baltic Sea by means of the lidar system FLS-12 and the laser particle counter CSASP-100-HV-SP. The results obtained provide valuable inputs for investigations of the physical processes, as well as an important data set for use in the development of aerosol type modeling and aerosol dynamics in the coastal areas.

Keywords: aerosol, physical properties, marine boundary layer, surf zone.

1. Introduction

The contribution of aerosol particles to moisture and energy exchange processes at the sea surface, to the global salt flux, their role in cloud droplet formation processes and their influence both upon the maritime atmospheric radiation balance and propagation at visible and infrared wavelengths or visibility assessment are of increasing concern [1, 2]. Visibility decreases due to a reduction of the contrast ratio by scattered light. A thorough understanding of such phenomena is essential to an accurate assessment of many processes important for the development of coupled ocean-atmosphere global circulation models, including the pollution problem. Due to its light attenuation and scattering properties, aerosols are important factors in satellite investigations of the ocean surface [3, 4].

The wind dependence of the aerosol type which is predominant in the marine boundary layer is especially clear in coastal areas where wind direction and duration play the decisive role as regards the type of particles which can be found in the marine boundary layer [5, 6].

2. Methods

The measurements were carried out in order to investigate the dynamics of marine aerosols in the coastal areas of the southern Baltic Sea (17–19°E and 54.4–55°N).

The FLS-12 is a tunable laser system designed for remote sensing of the air in the VIS range of spectrum. The backscattered energy from various distances is collected by a Cassegranian configured telescope, which has a primary mirror of 280 mm in diameter and it is registered by separate channels of multichannel (8 channels) photoreceiver. The measurements were carried out using three wavelengths: 440, 560 and 670 nm. The backscattered signal was registered every 50 ns, that is, every 7.5 m on the optical path. The useful part of the optical path ranged from 40 to 600 m. The lidar system FLS-12 was installed in a van and stationed on the top of the dunes at a fixed distance from the sea. The lidar measurements were compared with simultaneous measurements with a laser particle counter CSASP-100-HV-SP (made by PMS, USA). The laser counter was placed at different distances along the lidar sensing path. The lidar FLS-12 provides information about aerosol concentrations from size range $r \in (0.5, 5\ \mu\text{m})$, while the laser counter from the range of sizes $r \in (0.5, 32\ \mu\text{m})$. A detailed description of the FLS-12 lidar and the laser particle counter CSASP-100-HV-SP is given in [6].

The wind speed and direction as well as wet and dry-bulb temperatures were recorded, in addition to other supporting information. The air temperature varied from 278 to 293 K, while the wind speed varied from 0.5 to 12 m/s and the wind direction varied from NE to SW. Each measurement session lasted for at least 8 hours.

3. Methodology of the lidar measurement

The comparative method introduced by POTTER [7] was used to derive the aerosol size distribution and concentration by means of the lidar FLS-12. It was assumed that aerosols are comprised of optically homogeneous, non-absorbing, spheres $r \in (r_1, r_2)$ in size. Lidar based data served for the determination of aerosol size distribution and its concentration at particular altitudes for particles $r \in (0.5, 5\ \mu\text{m})$ in size. The following procedure was employed:

– total concentration

$$N_c(z_i, h_i) = \int_{0.5}^{r} n_r \mathrm{d}r = \frac{a(z_i, h_i)}{b^2(z_i, h_i)} \exp\left[-0.5 b(z_i, h_i)\right] \tag{1}$$

– particle concentration from the range of sizes r_i, $r_i + \mathrm{d}r$

$$N_r(z_i, h_i) = N_c(z_i, h_i) f(r) \tag{2}$$

where $f(r)$ is a normalized size distribution function,

$$f(r) = b \exp\left[-b(z_i, r_i) r\right] \tag{3}$$

Using the same guidelines as above and the aerosol size distribution and concentration, the extinction coefficient in the lidar equation can be defined as follows:

$$\alpha_{ij}(R_i, \lambda_j) = \int_{r_1}^{r_2} Q(r_i, \lambda_j) S(r) \mathrm{d}r \tag{4}$$

where: $S(r)$ – total, geometric cross section of aerosol particles per unit volume, $Q(r, \lambda_j)$ – dimensionless extinction coefficient, r – particle radius. Thus, the extinction coefficient may be replaced with the scattering coefficient and then functions $S(r)$ and $Q(r, \lambda_j)$ can be written as follows:

$$S(r) = ar^2 \exp(-br) \tag{5}$$

$$Q(r_i, \lambda_j) = 2 - \frac{4}{\chi} \sin\chi + \frac{4}{\chi^2}(1 - \cos\chi) \tag{6}$$

where: Mie parameter $\chi = 2x_j\,(m - 1)$, $(x_j = 2\pi r/\lambda_j)$, m is relative light refraction coefficient, a and b – distribution parameters.

Function $S(r)$ can be described by the Nakajima–Tanassara distribution which is widely applied to determine the number of particles in unit volume in the size range from r_i to $r_i + \mathrm{d}r$, therefore, $S(r) = n(r) = \mathrm{d}N/\mathrm{d}r$ [8]. The form of Eqs. (5) and (6) allows formula (4) to be solved analyticaly.

4. Results

Both instruments were callibrated during numerous experiments, which were carried out at different coastal stations of the southern Baltic coast between 1993–2000. The results of such calibrations are presented in Fig. 1.

The results presented in Fig. 1 show good correlation of data obtained with the use of both instruments ($r^2 = 0.917$). Detailed information regarding the calibration of measurements made with FLS-12 lidar and CSASP-100-HV-SP laser counter is given in [5].

Figure 2 presents the variations of total mass of marine aerosols with offshore distance for different wind speeds measured at altitudes of approx. 6–7 m a.s.l. (FLS-12) and 2 m a.s.l. (CSASP-100-HV-SP). In this figure, the "0" on the X-axis denotes shoreline, the negative numbers (see Fig. 2**a**) distance towards land and positive numbers (see Fig. 2**b**) – distance through the surf zone towards open sea. The results presented in Fig. 2 were collected during different experiments and at two stations of the southern Baltic coast. The data presented in the figure reveal that in both cases total marine aerosol concentration increases with wind speed. In the range

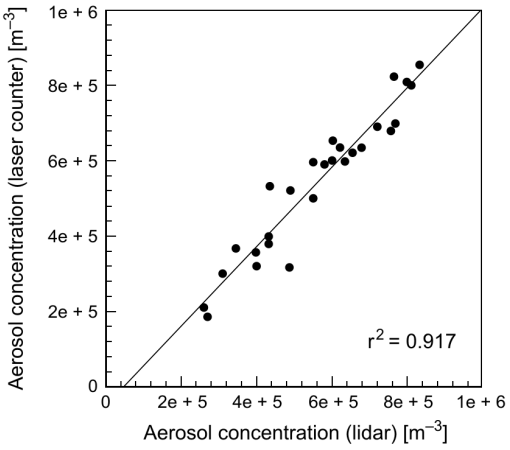

Fig. 1. Aerosol concentrations obtained from simultaneous measurements with FLS-12 lidar and CSASP-100-HV-SP laser counter.

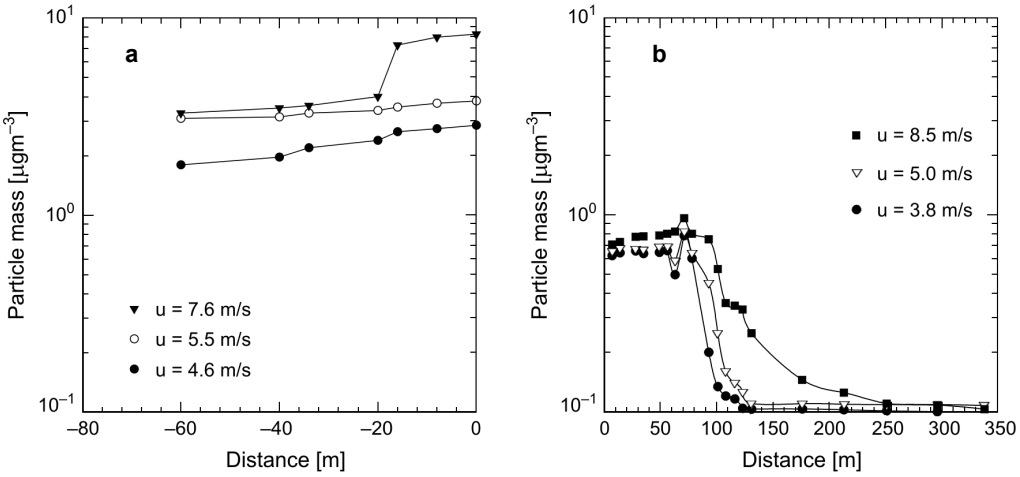

Fig. 2. Variations of total aerosol mass with distance and for different wind speeds measured with CSASP-100-HV-SP laser counter (**a**) and FLS-12 lidar (**b**).

of wind speeds from 3.8 m/s to approximately 8.5 m/s the aerosol concentrations in the marine boundary layer were increasing with distance towards the land. In the breaker zone (distances from 0 to approx. 120 m offshore, Fig. 2**b**) enhanced production of marine particles due to wave breaking is manifested by higher marine aerosol concentrations (factor of up to 6) than in the open sea area (from approx. 150 m offshore). At distances from –100 m to 0 m (beach, Fig. 2**a**) the aerosol concentrations obtained from measurements with the CSASP-100-HV-SP are higher by a factor of up to one order of magnitude. This shows the cumulative effect of wave

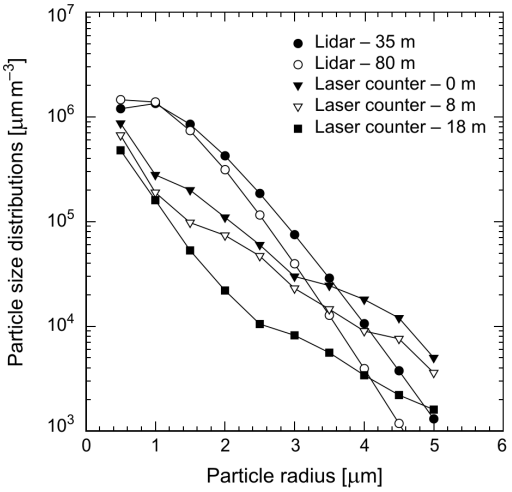

Fig. 3. Particle size distribution measured with FLS-12 lidar and CSASP-100-HV-SP laser counter at different offshore distances.

breaking, which results in enhenced concentration of aerosol particles on the beach. Additionally, the laser counter measurements were made at an altitude of approx. 2 m a.s.l. while the measurements made across the breaker zone (FLS-12 lidar) were made at altitudes of approx. 6–7 m a.s.l. By assuming that the average aerosol concentration in the marine boundary layer over the coastal area is a result of the balance of the two fluxes, emission and deposition, the differences of concentrations at high wind speeds shown in Fig. 2 can be explained. The differences in data collected with both instruments can also be explained with advection processes concerned with different air masses during the experiments. Changes of aerosol concentrations with altitude were caused mainly by deposition fluxes, whose values linearly depended on particle deposition velocity. The total concentration decreases with altitude and the difference between 10 m and 50 m is of an order of about 1.5 [5]. However, the concentrations presented in Fig. 2 show much faster decrease over the beach than over the outside of breaker zone area.

The variations of particle size distribution are presented in Fig. 3. Data were collected for onshore winds of speeds 9 m/s.

The results obtained by means of both instruments show the same tendency to decrease with an increase of particle size and increase of offshore distance. In the case of results obtained with lidar the slope is greater than that obtained with the laser counter. This may be related to the higher altitude of lidar measurement (7 m a.s.l. *vs*. 2 m a.s.l.) and thus faster deposition of larger particles. Also, lidar measurements were made in the center of the surf zone, where the production of marine aerosol particles due to wave breaking is the greatest, which results in higher concentrations of smaller particles. Similar observations were made by PETELSKI and CHOMKA [9] during his studies in the coastal area of Lithuania.

5. Conclusions

The results presented in this paper confirm that the lidar method is a very useful tool for investigating marine aerosol physical properties in the marine boundary layer over the coastal area and the open sea. However, it is necessary to calibrate such results and the simultaneous measurements with laser particle counters are very suitable for this purpose. The aerosol concentrations and size distribution at the sea surface allow determination of the aerosol component of extinction and optical thickness in the atmosphere. These parameters fully describe the influence of aerosols on radiation over the sea surface. Knowledge of these parameters and combining them with variations of wind speed and direction as well as other hydrometeorological factors allows corrections to be made in the model of radiation transmission in the real atmosphere. Also, the results obtained from such studies facilitate the derivation of marine aerosol emission fluxes in the measurement area.

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Received January 30, 2006
in revised form April 21, 2006