The Determination of the Aerosol Spatial Structure in the Lower Part of the Marine Atmospheric Boundary Layer from Horizontal Lidar Data

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LONG-TERM GOALS

The long-term goal is to be able to predict the conditions for the transmittance of electromagnetic signals in the lower part of the marine atmospheric boundary layer (LP MABL). The problem calls for reliable methods of determining the relationships between the environmental factors (such as wind, waves, air humidity, etc.) and aerosol optical properties in LP MABL.

OBJECTIVES

The present work is concentrated on the problem of studying the microphysical properties of the maritime aerosol from lidar data. The SEAS database is analyzed in connection with the problem.

APPROACH

The interpretation of the backscattered lidar signal is based on various assumptions regarding the properties of the scattering medium [1-4]. The method of mean ordinates [5], which has been developed at the earlier stage of the work for treating precisely this kind of optical information, was applied for inverting the lidar-derived aerosol extinction into the aerosol particle size distribution (APSD). The principal difference between this method and other inverting methods for the same purpose is that in the method of mean ordinates, the most probable solution is defined as the aerosol model which is the closest to the mean over all acceptable solutions. This prevents possible great inversion errors inherent in other methods.

The experimental data used in this work (direct observations over APSD and lidar-derived profiles of the aerosol extinction) were obtained during SEAS by the groups of Dr. Clarke and Dr. Sharma.

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14. ABSTRACT
The long-term goal is to be able to predict the conditions for the transmittance of electromagnetic signals in the lower part of the marine atmospheric boundary layer (LP MABL). The problem calls for reliable methods of determining the relationships between the environmental factors (such as wind, waves, air humidity, etc.) and aerosol optical properties in LP MABL.

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WORK COMPLETED

Of the two lidar channels employed at SEAS (0.532 and 1.064 μm), only the first one turned out to be suitable for our purposes, because of a low accuracy and high noise at 1.064 μm [6]. The inversion results were compared with the direct observations over APSD during SEAS. The results for 23h06m of April 25, 2000 are shown on Fig. 1.

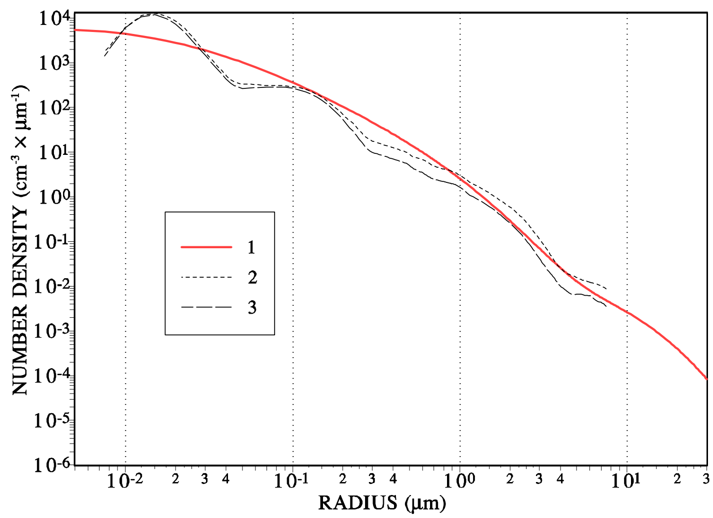

Fig. 1. The comparison of the APSD by inversion with the direct APSD observations (23h06m of April 25, 2000). 1, APSD by inversion; 2, measured APSD at 5 m; 3, measured APSD at 15 m. [The curve by inversion is confined between the experimental APSDs on the optically active particle size interval (0.5-5 μm), which proves the efficiency of the method].

It is seen that within the so-called optically active particle size interval (0.5-5 μm), the APSD by inversion is practically confined between the distributions measured at 5 and 15 m above the ground. At other intervals, which contribute less than 5% into the extinction [7], the APSD by inversion deviates, but still follows the experimental APSDs.

The direct SEAS data on APSD made it possible to refine the set of initial models for solving the inverse problem. In general such a set is based on the data available in literature, but preliminary knowledge of the actual aerosol allowed us to narrow the search for the solution. Fig. 2 shows the area of all measured APSD. The initial APSD set consisted of three-component lognormal models. The parameter sets for the small-particle and medium-particle fractions were constructed with the use of the curves 1,2, and 3,4, while the large-particle component was based on the observations over large aerosol particles in LP MABL [8].

This parameter set was used for inverting the lidar-derived aerosol extinction σ. Ten profiles of σ obtained by the SEAS lidar group were utilized for this purpose. It is seen from Fig.3a that σ oscillates significantly in time. We smoothed the aerosol extinction by the running mean, using different distances: 25, 50, 100, and 200m. The results are shown on Fig.3b. It is seen that long smoothing intervals cause significant distortions around individual peaks. For this reason, the consequent inversion was performed with the curve obtained by the running mean over 25 m. For the experimental error was taken the standard deviation of the smoothed curve from the experimental one. The points chosen for the inversion are shown in Fig. 3b as full circles.

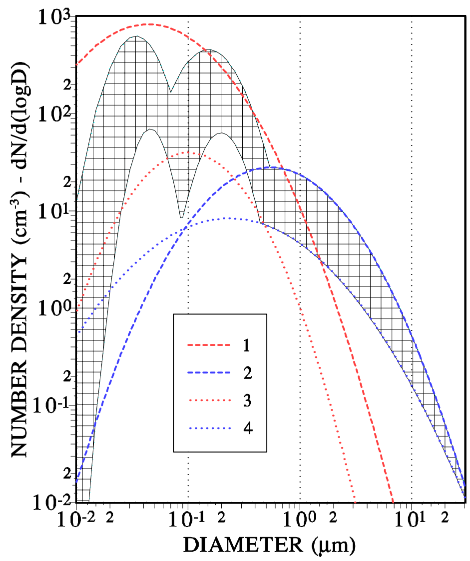

Fig. 2. The determination of the initial set of models.
The crosshatched section represents the area of all APSD measured during SEAS at 5 and 10m.
1,3, the upper- and lower-boundary model of the small-sized aerosol fraction;
2,4, the upper- and lower-boundary model of the medium-sized aerosol fraction.
[The distributions are constructed following the envelopes of the crosshatched ensemble].

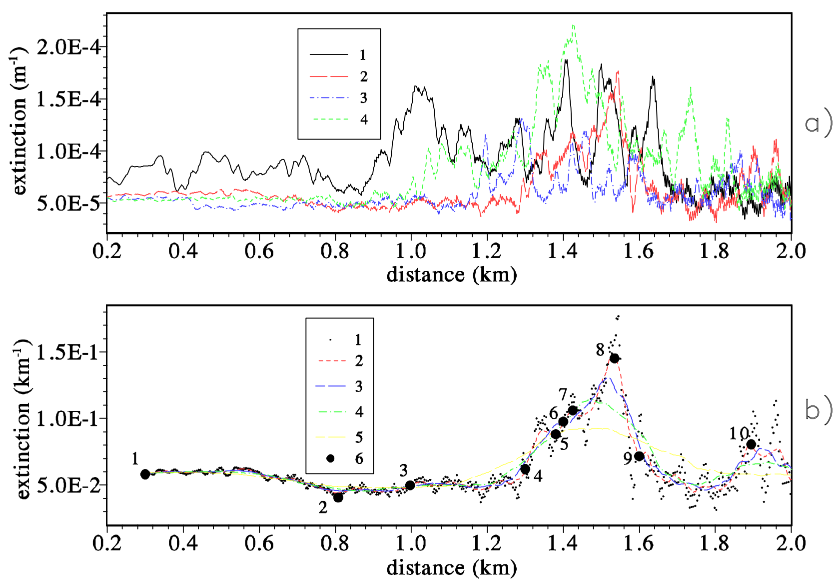

Fig. 3. a) Horizontal profiles of the lidar-derived aerosol extinction σ at 0.532 μm for April 25, 2000. 1, 23h06m; 2, 23h10m; 3, 23h13m; 4, 23h17m. b) Juxtaposition of the lidar-derived aerosol extinction σ (for 23h10m) and its profiles smoothed over different distances. 1, experimental σ; 2,3,4,and 5, profiles smoothed over 25, 50, 100, and 200 m respectively; 6, points chosen for the inversion.

The results of the inversion are shown on Fig. 4. The general run of APSD is not shown, because it practically coincides with that on Fig.1. Red circles on Fig. 4a represent the total number density N (cm^{-3}) obtained at each point by inversion. The inversion results were checked by using the ratio between σ at different points. The black circles on Fig. 4a represent the number density calculated at each point with the σ ratio; blue circles show the mean N at each point. Error bars represent standard deviations.

It is seen from Fig. 4a that N by inversion differs from the other estimate by no more than the standard deviation. The only exception is point 8 at the maximum σ, where the difference does not exceed two standard deviations. It may be concluded from Fig. 4a that horizontal variations of the aerosol extinction were primarily brought about by variations of the aerosol number density in LP MABL. Variations of the APSD shape played a secondary role.

Fig. 4b shows deviations of the normalized APSD (ASPD reduced to one particle) in relation to the APSD at the first point on the profile. It is seen that the reduced APSDs differ from point 1 by no more than 30%, except for the largest and smallest particles. This result is well within the APSD error, be it obtained by inversion or by direct observations.

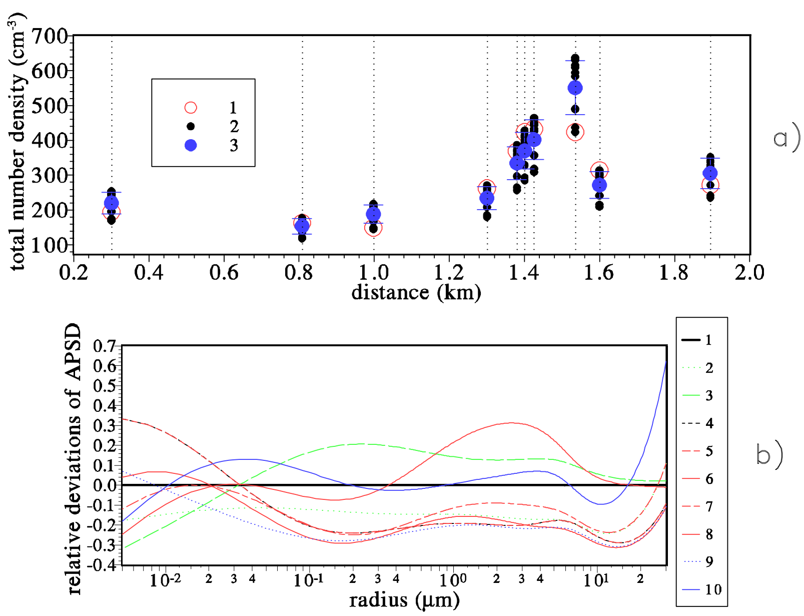

Fig. 4. a) The aerosol number density N in LP MABL along the lidar beam on April 25, 2000, 23h10m
1, N obtained by inversion independently at each point; 2, N estimated from the ratio of aerosol extinctions at different points; 3, N averaged over the estimates by the second method
[The difference between N by independent inversion and N by ratios of σ does not exceed the standard deviation]
b) Relative APSD deviations; 1 – 10, numbering of the points chosen for the inversion
[The normalized APSD at every point differs from that at point 1 by no more than 30%, with the exception of the smallest and largest particles]

It should be noted that the curve for point 8 shows a bulge at the optically active size interval (0.5-5 μm), which corresponds with a greater deviation of N. It is likely that the shape of APSD at this point differs most from the average over the whole profile. This assumption is corroborated by the fact that point 8 is situated at the site of a spray.

RESULTS

1. The method of mean ordinates for determining the aerosol microphysical characteristics in LP MABL from the backscattered lidar signal was checked against direct observations over APSD during SEAS. The tests confirmed the efficiency of the method, even when dealing with lidar data for only one wavelength.

2. The horizontal profile of the aerosol number density was retrieved from the lidar-derived aerosol extinction. It was proven that a profile of aerosol number density could be retrieved with a reasonable accuracy from lidar data even at only one channel.

3. It can be concluded from the analysis of the lidar-derived profiles of the aerosol number density N that the number density is the principal factor in variations of the aerosol extinction; the shape of APSD plays a secondary part.

IMPACT/APPLICATIONS

The analysis of the SEAS lidar data revealed the possibility to retrieve assuredly the aerosol number density along the lidar beam path by using lidar observations at only one channel. Bearing in mind that the aerosol number density is the principal factor affecting the aerosol extinction, the result can be of considerable use in studying the propagation of electromagnetic signals through LP MABL.

TRANSITIONS

Our approach to the problem of retrieving aerosol microphysical characteristics in LP MABL is used by Dr. J. Lenoble, University of Grenoble, France; Dr. O.V. Kopelevich, Institute of Oceanology of the Russian Academy of Sciences; Dr. A. Consortini, University of Florence, Italy.

RELATED PROJECTS

Our method for retrieving APSD from optical observations is being used in our NASA-funded project “The Refinement of the Atmospheric Correction Algorithm for Determining the Marine Chlorophyll Concentration from Space”.

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