Statistics of light scattering phase functions in the Antarctic region

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The statistics of light scattering phase function variations in the atmospheric surface layer of the Antarctic continent and in adjoining sea water areas was analyzed for the range of scattering angles from 20° to 160°. The mean values and square root deviations of the angular scattering coefficients for conditions of the Antarctic stations and at the coast of Antarctica are found. It is shown that the probability distribution of aerosol component of light scattering factors is close to lognormal. A high level of correlation between light scattering factors for various scattering angles is pointed out. It is established that 99% of variance of the scattering phase function is described by two first eigenvectors of the covariance matrix.

The initial sample was represented by 461 light-scattering phase functions, 365 of which obtained in the coastal zone of the Antarctic continent.[1] The remaining 96 light-scattering phase functions were measured from onboard the research vessels of the Hydrometeorological service in the World Ocean waters to the south of 55°S during three cruises: the *Priliv* research vessel in the Pacific ocean in January–February of 1981; the *Professor Vize* research vessel in the Atlantic ocean, December 1982; and the *Academik Fedorov* research-expedition vessel in the Atlantic and Indian oceans, April–June of 1982. The measurement instrumentation of the Antarctic station "Mirnyi" was described in Refs. 1 and 2. During onboard measurements, the nephelometer was installed on a tripod on the deck wing of the guide bridge or on the upper deck at a height of 10–20 m above the sea level at the windward side in order to avoid the effect of aerosols generated at the vessel (smoke, ventilation emissions, etc.). The place of the device setting was not illuminated by any irrelevant light sources.

Most measurements at the station "Mirnyi" were carried out at high transparency of the atmosphere.[1] The values of meteorological visibility range (MVR) for 336 of 365 scattering phase functions exceeded 70 km, and the relative humidity of air did not exceed 80% (the minimum was 35%). Therefore, the measurement results at the station "Mirnyi" were processed separately, when studying the statistics of the light-scattering coefficient variations under conditions of extremely high atmospheric transparency. Meteorological conditions of measurements in the adjacent water area essentially differed from the conditions at the station "Mirnyi". In winter, at formation of the fast ice, the effect of the sink wind in the region of the station "Mirnyi" extends only to some tens of kilometers from the continental ice boundary. Meteorological conditions outside the sea ice band correspond to the sea subantarctic climate. More than 80% of the shipborne measurements were carried out at a relative humidity of air from 70 to 100% (the minimum was 55%) and at the MVR lower than 70 km. Five of 96 scattering phase functions, obtained under fog conditions, were excluded from the statistical analysis of results.

Our investigations show[3,4] that the probability distribution of the aerosol component of the light-scattering phase function in different regions of the Earth are close to lognormal. The same holds for the sample of the Antarctic measurements.

The integral probability distribution for logarithms of aerosol, molecular, and total scattering coefficients are plotted in Fig. 1.

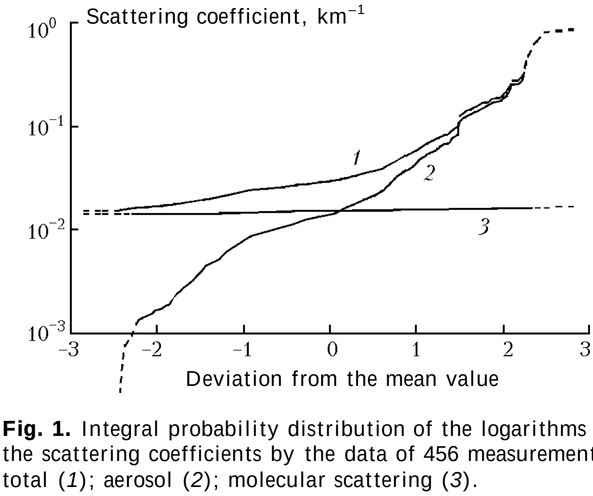

Fig. 1. Integral probability distribution of the logarithms of the scattering coefficients by the data of 456 measurements: total (*1*); aerosol (*2*); molecular scattering (*3*).

The scale along the probability axis (abscissa axis) is chosen so that the sample of the normal distribution could be presented by the curve close to the straight line. The ticks on the abscissa axis correspond to 0, ±1, ±2, and ±3 rms deviations from the mathematical expectation for the normal distribution law.

It is seen from Fig. 1 that the probability distribution for the aerosol scattering component can be treated as close to logarithmically normal in the range of the scattering coefficients exceeding a threshold level of 0.001 km^{-1}. The same holds for the angular light-scattering coefficients (phase functions).

The probability distribution for the scattering molecular component is close to normal at the linear scale, but its variance is two orders of magnitude lower than the variance of the aerosol scattering.

The probability distribution for the total scattering phase function differs from the logarithmically normal, but, at the same time, it is closer to normal at the logarithmic scale rather than at linear one. Besides, the light-scattering coefficients and their variances at different scattering angles differ by the order of magnitude. Therefore, the analysis of statistical parameters of the total light-scattering phase function variations was carried out for logarithms of the angular light-scattering coefficients.

The estimates of mean logarithms of the directed scattering coefficients and their rms deviations for measurements at the station "Mirnyi" and shipborne measurements in the South ocean waters are presented in Fig.2. The estimates of variations were obtained by methods of information-statistical analysis[5] accounting for the corrections for the level of measurement errors. The corrections were introduced only to measurement errors, the aerosol component instability during measurements of the scattering phase function (which should be taken into account, for example, in reconstruction of the size spectrum of aerosol particles) was not taken into account.

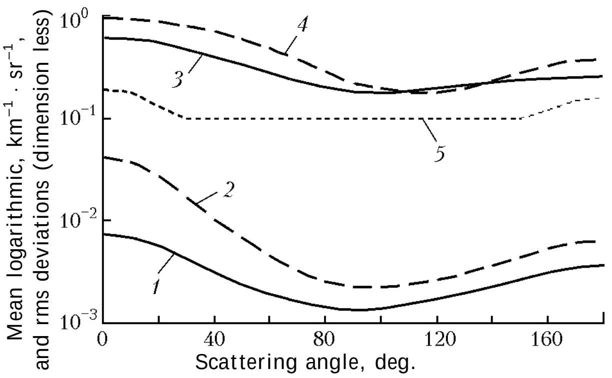

Fig. 2. Mean logarithmic scattering phase functions and rms deviations of the angular scattering coefficients: the mean logarithmic scattering phase function for measurements at continental stations (*1*); the mean logarithmic scattering phase function from the data of 91 shipborne measurements at the latitudes higher than 55°S (*2*); the estimate of the rms deviations of the angular scattering coefficients for measurements at continental stations (*3*); the estimate of the rms deviations of the angular scattering coefficients for shipborne measurements (*4*); the estimate of the rms level of measurement errors[5] (*5*).

The calculated mean light-scattering phase functions can be considered as a sufficiently statistically provided characteristic of the scattered light angular distribution in the near-ground atmospheric layer above the Antarctic and subantarctic water area. The presented estimate of angular scattering coefficient variations corresponds to a quite stable state of the atmosphere with no precipitation and fogs.

Autocorrelations of angular scattering coefficient logarithms calculated for the entire sample of 456 measurements are shown in Fig. 3. A high level of correlation should be noted, on the whole, more than 0.75, that is explained by correlation between the entire scattering phase function and the total scattering coefficient. Let us remind that the scattering coefficient values were obtained experimentally only in the angular range from 20 to 160° (Ref. 1). At angles of 0, 10, 170 and 180°, they were obtained through extrapolation of the scattering coefficient logarithms by the cosines of the scattering angles.[6] The small-angle scattering is weakly distinguished at a high atmospheric transparency, and the extrapolation error is small at the chosen algorithm.[6]

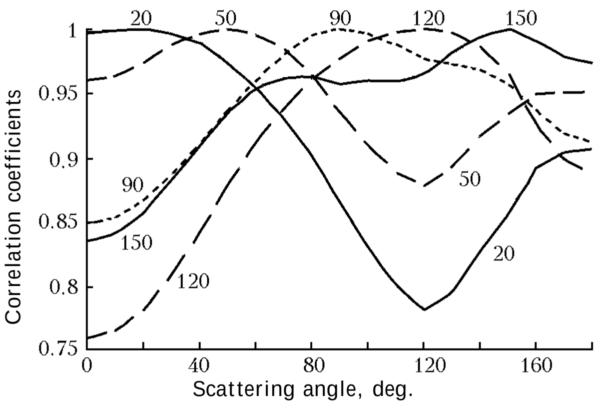

Fig. 3. Autocorrelation of angular scattering coefficient logarithms. Numbers near the curves correspond to the scattering angle, for which the angular behavior of correlation is shown by the given curve.

Correlations between the angular scattering coefficient logarithms and the integral scattering coefficient logarithms, as well as absolute and relative humidity of air for the entire sample (456 measurements) are shown in Fig. 4.

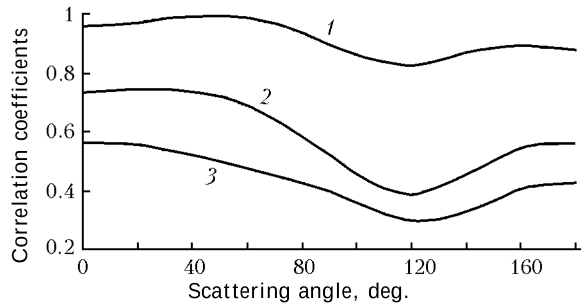

Fig. 4. Correlation between the angular coefficients of the directed scattering and the integral scattering coefficient (*1*), absolute (*2*) and relative (*3*) humidity.

The angular scattering coefficient logarithms are noticeable related to absolute and relative air humidity, and the mean level of correlation with absolute humidity is about 0.6.

Because of high intercorrelation between the angular scattering coefficient values, the entire scattering phase function at the logarithmic scale can be well approximated using the expansion in terms of the limited number of eigenvectors of the covariance matrix.

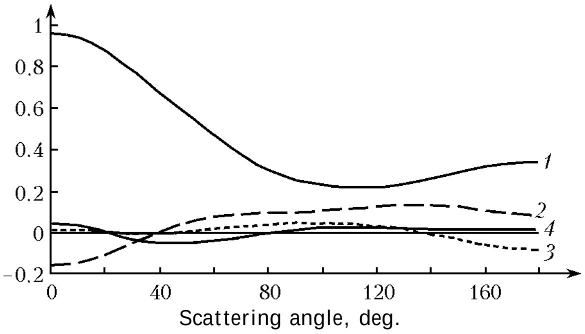

Fig. 5. Plots of four first eigenvectors of the covariance matrix. Numbers of the curves correspond to the current number of the vector.

Four first eigenvectors of the covariance matrix of the logarithmic scattering phase functions are graphically displayed in Fig. 5 at the scale proportional to the square root of the corresponding eigenvalues. The four first eigenvalues make 5.184; 0.2126; 0.02743, and 0.01449. The contribution of the two first eigenvalues into the spur of the covariance matrix is more than 99%. This means that the variations of the scattering phase functions at the logarithmic scale can be described with the error less than 1% by only two parameters, i.e., the coefficients of expansion in terms of two eigenvectors.

Conclusions

Estimates of statistics of the scattering phase function variations in the near-ground atmosphere of the Antarctic are obtained.

It is shown that the probability distribution for logarithms of the aerosol scattering coefficients is close to logarithmically normal.

Mean scattering phase functions are calculated for observation conditions at the coastal station "Mirnyi" and in the sea waters adjacent to the Antarctic. The obtained results have been compared.

The calculation results for angular correlations of the scattering phase functions show a high (more than 0.75) correlation between logarithms of the light-scattering coefficients at different scattering angles, as well as even higher correlation with the integral scattering coefficient.

The values of the scattering coefficient are well correlated with absolute and relative humidity of air, and the correlation with absolute humidity is higher.

Main components of the covariance matrix of the logarithmic scattering phase functions have been calculated, and it is found that the principal variations of the scattering phase functions can be described by expansion in terms of only two first eigenvectors with the error less than 1%.

The features and characteristics of the spatial light scattering distribution obtained for the Antarctic correspond to the conditions of the extremely high atmospheric transparency.

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