Interpretation of weak backscattering signals in a weakly clouded atmosphere

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Abstract. It is used here the lidar equation describing signals from a weakly turbid atmosphere to solve the problem of the determination of the atmospheric aerosol parameters. It is worthwhile to note that the backscattering and extinction coefficients are constant along the beam path in this case. First approximation of the exponent process can be used to describe the atmospheric extinction. The weak lidar signals were analyzed here. It is useful for calculations of the extinction coefficient the preliminary known value of this parameter. The systematic errors were analyzed for different points along the beam path. The signal power was measured at sufficiently large distance. The systematic errors of the extinction coefficient can exceed the systematic errors of the backscattering signal power. It was shown that corresponding value achieve 20. There was investigated the influence of the systematic errors of the measured signal including background light on the obtained results. It was shown that the obtained results cannot be accurate enough if we use preliminary obtained data found before the measurement. It is found that the relative error of the measured signal <1%. It is very important the relative error of the corresponding extinction coefficient can be > 100%. There were investigated the results of measurements and the results of computations. First of all it is associated with the scattered irradiance. The cases were considered with absence and presence of water in the aerosol particles coating. It was shown that the developed models adequately describe the process of scattering by a particle. So it is possible significantly reduce the aerosol sizing error. This model can be applied in determining the pollution of the Arctic air basin.

1 Introduction

The Arctic climate has been changing in recent years. Most of the climate change is caused by global warming. But climate change is also affected by human impact. Over the past few years, attention has been drawn to the link between Arctic warming and atmospheric pollution with black carbon (soot), tropospheric ozone and methane. As temperatures rise, there are risks such as rising sea levels and methane escaping from frozen soils in permafrost areas, with consequences that may extend far beyond the Arctic. With regard to environmental damage, such a rapid increase in temperature threatens biological diversity and infrastructure in the Arctic and subarctic territories. To prevent warming in the Arctic, it is necessary to reduce emissions of greenhouse gases and black carbon. It is necessary to monitor changes in their concentration in the atmosphere, as well as the size of polluting particles. It is particularly important to conduct research on air pollution in the Arctic. Lidar systems can be used to determine the concentration of pollutants. The sufficiently high transparency of the Arctic air basin makes it difficult to interpret weak backscattering signals, which creates a problem for determining pollutants. This paper is devoted to solving this problem.

It is known that the high accuracy of aerosol investigations is associated with the environmental problems [1, 2]. The accuracy of lidar investigations depends on the lidar methods [3, 4]. The problem of the lidar investigations accuracy has been considered [5, 6].

These investigations are associated with significant statistical errors. The errors can be small enough on the sections of the beam path with constant atmospheric parameters. The multiposition lidar techniques differ from known techniques [7 – 9] by the presence of the criterion of applicability of these techniques.

It is considered lidar techniques for investigating the atmospheric parameters using short pulses. The solution of this problem is associated with the significant statistical errors. It can be considered the sections of the beam path with rather constant investigated parameters. There is considered solutions of the problem developed for weak lidar signal and the results of the analysis of the effectiveness of the processing. The errors of the extinction coefficient are considered for minimizing processing. The preliminary known parameters were useful for more accurate first order approximation to solve the problem. The model errors were calculated for monoposition lidar schemes. The investigation of the systematic errors was carried out for different points of the beam path. The backscattering signal power was measured at sufficiently large distances. There was investigated the systematic errors including the systematic errors of the background light. There was

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analyzed their influence on the results of the problem solution. It was found that results cannot be accurate enough if for the determination of the power of the background light are used data obtained before measurements.

There were investigated the results of measurements and the results of computations. First of all it is associated with the scattered irradiance. The cases were theoretically considered with absence and presence of water in the aerosol particles coating model of a spherical particle to explain the fact that the results of photoelectric measurements essentially depend on these properties [10]. It was shown that the developed models of a spherical particle with the radially variable refractive index adequately describe the process of scattering by a particle. So it is possible significantly reduce the aerosol sizing error. This model can be applied in determining the pollution of the Arctic air basin.

2 The weak lidar signals analysis

It is used here the lidar equation describing signals from a weakly turbid atmosphere The solution of the equation (1) was used to determine the extinction coefficient σ and the power of the background light P_*. It is worthwhile to note that the backscattering and extinction coefficients are constant along the beam path in this case.

So we can write the lidar equation [7]:

$$P_i = P_* + BR_i^{-2}\exp(-2\sigma R_i), \tag{1}$$

where P_i is the lidar signal, R_i is the section of the beam path, *B* is the lidar constant.

The error of lidar measurements δ^2 can be reduced using distance $R > R_1 = 2.5\ \text{km}$ [7]:

$$\delta^2 = \sum_1^n \{P_* + BR_i^{-2}\exp(-2\tilde{\sigma} R_i)(1 - 2\Delta\sigma R_i) - P\}^2 \tag{2}$$

where *n* is step number.

First approximation of the exponent process can be used to describe the atmospheric extinction

$$\exp(-2\Delta\sigma R) = 1 - 2\Delta\sigma R \tag{3}$$

Here we introduce the notation

$$\Delta\sigma = \sigma - \tilde{\sigma} \tag{4}$$

The weak lidar signals were analyzed here. It is useful for calculations of the extinction coefficient the preliminary known value of this parameter $\tilde{\sigma} = 0.03$ km^{-1} [7].

The systematic error of lidar signal is

$$\delta_i = P_* + BR_i^{-2}\exp(-2\sigma R_i) - P_i. \tag{5}$$

The systematic errors were analyzed for different points along the beam path R_i. The signal power was measured at sufficiently large distance.

3 Results of lidar measurements

3.1 The systematic errors of lidar measurements

There was investigated the influence of the systematic errors δ_i / P_i of measured signal including background light on the obtained results. The systematic relative error is shown in Figure 1. The results are found for the step $R_{i+1} - R_i$ = 0.225 km for experiment [5]. One can see that 0 < δ_i / P_i < 6%, the systematic error is negligible for R_i > 2.5 km. The error $(\sigma - \sigma_0)/\sigma_0$ is shown in Figures 2, 3.

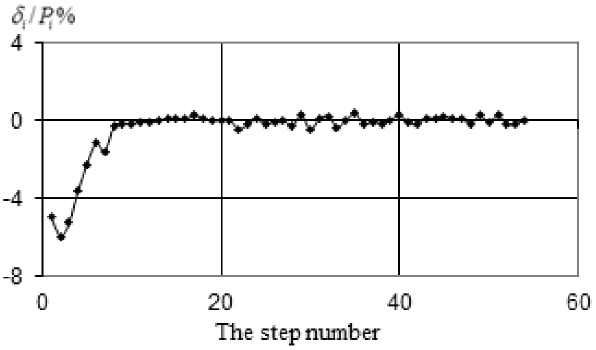

Fig. 1. The systematic relative error of measured signal (R > 0.48 km).

Here σ_0 is determined without the systematic error for R_i > 2.5 km (see Figure 2).

The consideration of the results in Figures 1, 3 shows that the $\dfrac{(\sigma - \sigma_0)/\sigma_0}{\delta_i / P_i}$ values can be rather different. We can see that corresponding value achieve 20.

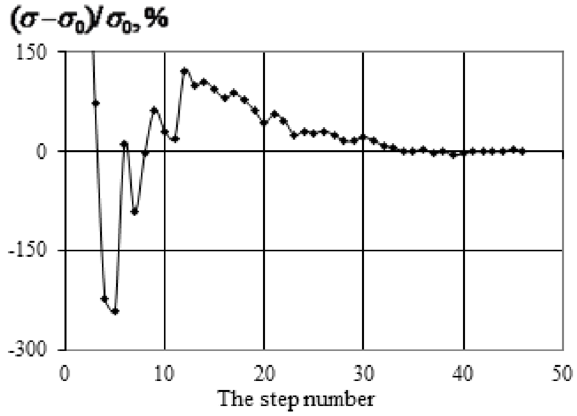

Fig. 2. The error $(\sigma-\sigma_0)/\sigma_0$ ($R > 2.5$ km).

3.2 The background light measurements

It was known that the obtained results cannot be accurate enough if we use preliminary obtained data found before the measurement. The power of the background light is to be determined very accurately [7] after sending the impulse. The result of this value determination P_{*0} cannot be accurate if it is found using data obtained before lidar measurement.

The error $(P_*-P_{*0})/P_{*0}$ is shown in Figure 4.

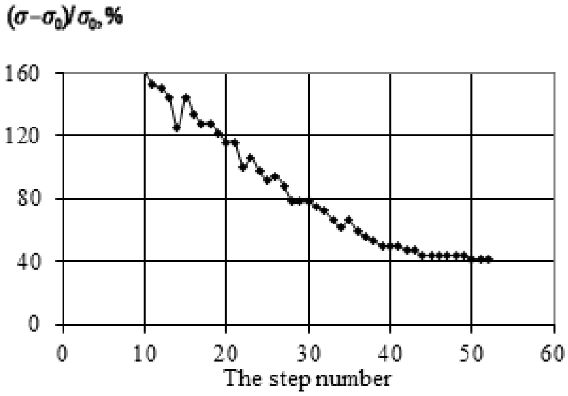

Fig. 3. The error $(\sigma-\sigma_0)/\sigma_0$ ($R > 1.8$ km).

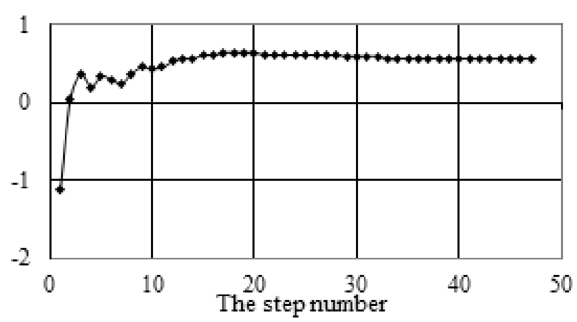

Fig. 4. The error $(P_*-P_{*0})/P_{*0}$ ($R > 2.5$ km).

It is found that $(P_*-P_{*0})/P_{*0}$ can be <1% but the error of the extinction coefficient is large enough.

The error $(\sigma-\sigma_0)/\sigma_0$ is shown in Figure 5 for procedure [7]:

$$\delta_0^2=\sum_1^n\left\{P_{*0}+BR_i^{-2}\exp\left(-2\sigma R_i\right)*\right.$$
$$\left.*\left(1-2\Delta\sigma R_i\right)-P_i\right\}^2 \qquad (6)$$

It is very important that the error of the extinction coefficient $(\sigma-\sigma_0)/\sigma_0$ can be > 100% because of the fact: $P-P_* \ll P_*$.

3.3 Optical sizing of weak aerosol particles

We use here the particle model [7]. The effectiveness of the used model is known.

We use the particles size distributions found by filter device (FD) and optical counter AZ-5 (OC) [7]. Figure 6 shows the value D(FD)/D(OC).

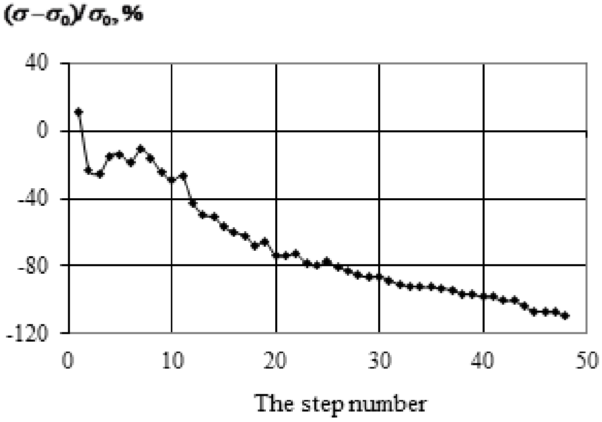

Fig. 5. The error $(\sigma-\sigma_0)/\sigma_0$ ($R > 2.5$ km).

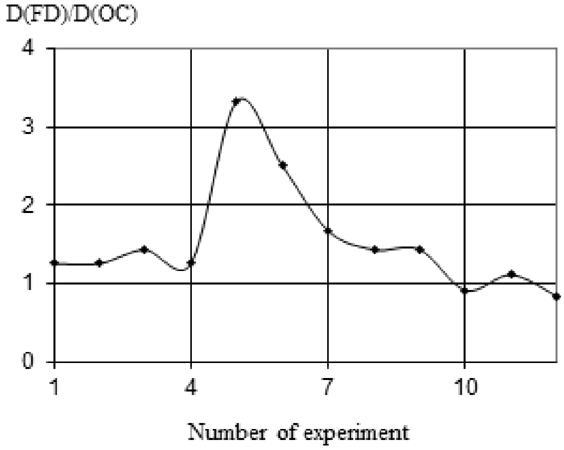

Fig. 6. The value D(FD)/D(OC).

One can see presents and absence of satisfactory agreement between the results for different experiments. Serious discrepancy takes place for the experiments №

5, № 6, especially for the experiment № 5. It is understandable that we can obtain serious errors in the results of optical particle sizing essentially depending on the properties of particles. We can consider the ratio $D(\mathrm{OC})/D(\mathrm{FD})$ for equal numbers of particles $N(\mathrm{OC}) = N(\mathrm{FD})$ per unit volume (*N* corresponds to size exceeded *D*). It gives possibility to find the particle sizing error. We can determine experimentally for the thickness of coating $R_1 - R_0$ the parameter $k = (R_1 - R_0)/0.01$. The results of experimental determining the value $g = D(\mathrm{OC})^2/D(\mathrm{FD})^2$ are presented in Figure 7 (the markers and the solid curve describe the results for the extinction coefficients $\sigma =$ 0.1 km^{-1} and $\sigma =$ 0.06 km^{-1}).

The results of the experiment including statistical errors (angle 90°) and the results of computations for the scattering angles 90° (solid curve) and 10° (dotted curve) are shown in Figure 8. Here are shown the results of computations of the relative scattered irradiance IR(1)/IR(1.33) with absence and presence of water in the coating of soot particles for different size parameters of the particles. These values are shown for value *k* = 12. The experimental results of the parameter *k* determination are presented in Figure 9. The experimental solid curve describes the average results.

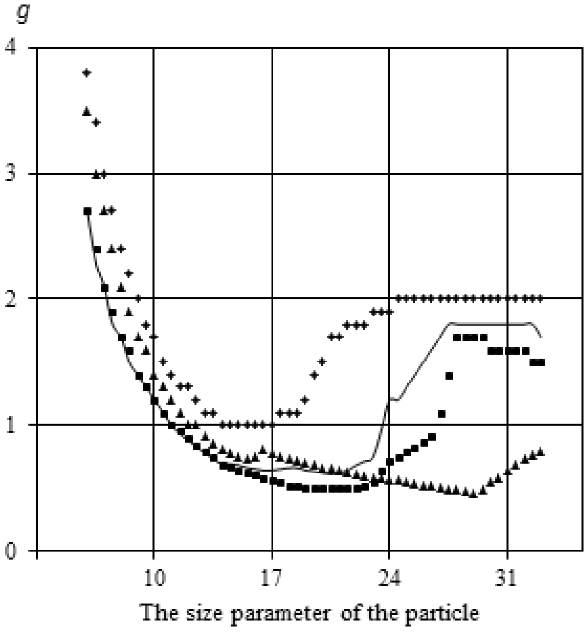

Fig. 7. The value $g = D(\mathrm{OC})^2/D(\mathrm{FD})^2$.

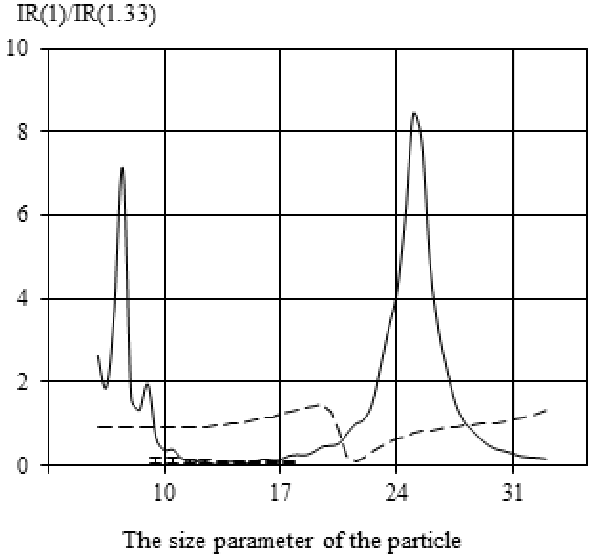

Fig. 8. Scattered irradiance IR(1)/IR(1.33) (*k* = 12).

Thus, there were investigated the results of measurements and the results of computations. First of all it is associated with the scattered irradiance. The cases were considered with absence and presence of water in the aerosol particles coating. It was shown that the developed models adequately describe the process of scattering by a particle. It was shown also that the influence of the particle properties on the scattered irradiance depends on the scattering angle. It is significantly less for the small scattering angle. So it is possible significantly reduce the aerosol sizing error. This model can be applied in determining the pollution of the Arctic air basin.

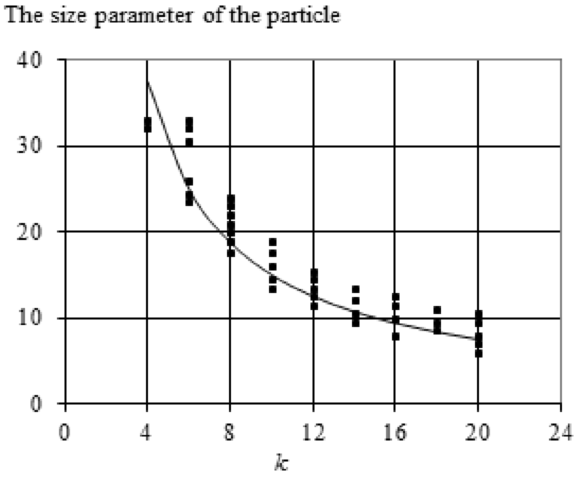

Fig. 9. Size parameter of the particle.

4 Conclusion

It was used here the lidar equation describing signals from a weakly turbid atmosphere to solve the problem of the determination of the atmospheric aerosol parameters. It is worthwhile to note that the backscattering and extinction coefficients are constant along the beam path in this case. First approximation of the exponent process can be used to describe the atmospheric extinction. The weak lidar signals were analyzed here. It is useful for calculations of the extinction coefficient the preliminary known value of this parameter. The systematic errors were analyzed for different points along the beam path. The signal power was measured at sufficiently large distance. The systematic errors of the extinction coefficient can exceed the systematic errors of the backscattering signal power. It was shown that corresponding value achieve 20. There was investigated the influence of the systematic errors of the measured signal including background light on the obtained results. It was shown that the obtained results cannot be accurate enough if we use preliminary obtained data found before the measurement. It is found that the relative error of the measured signal <1%. It is very important the relative error of the corresponding extinction coefficient can be > 100%.

There were investigated the results of measurements and the results of computations. First of all it is associated with the scattered irradiance. The cases were considered with absence and presence of water in the aerosol particles coating. It was shown that the developed models adequately describe the process of scattering by a particle. So it is possible significantly reduce the aerosol sizing error. This model can be applied in determining the pollution of the Arctic air basin.

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