OBSERVATIONS OF POLARIZED ZENITH-SKY RADIANCES DURING TWILIGHT WITH APPLICATION TO AEROSOL PROFILE EVALUATION

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ABSTRACT

Vertical profile of aerosol characteristics could be deduced using measurements of zenith-sky polarized radiance at twilight. It is proposed an algorithm for retrieval of aerosol profile using measurements of degree of polarization at 800 nm for solar zenith angles from 90^O to 96^O. Retrieval errors are analyzed. Preliminary results of measurements of degree of polarization at a few observational sites are discussed.

1. INTRODUCTION

Aerosol of the middle atmosphere plays an important role in the radiation budget of the Earth. After powerful volcanic eruptions and in polar regions where PCS are formed aerosol's influence on photochemical balance of ozone becomes the most pronounced. These are reasons of the necessity of monitoring of vertical aerosol distribution in the middle atmosphere.

A relation between the degree of polarization at the zenith during twilight under cloudless condition and the aerosol content variations in the troposphere and stratosphere was found experimentally in the work of *Shah* [1969]. A possibility of retrieval of vertical aerosol profile (VAP) on the basis of such observations was studied by *Wu and Lu* [1988], *Elansky et al.* [1993]. In later papers were investigated retrieval using space polarized observations [*Herman et al. 1997*, *Mishenko and Travis 1997*]. In this paper preliminary results of new observations of degree of polarization are presented, an algorithm for retrieval of aerosol profile using degree of polarization is proposed, and a preliminary analysis of retrieval errors is carried out.

2. INSTRUMENT

The instrument for polarization measurements is made up of a photometer with a mirror long-focus (1000 mm) objective (1 in Fig.1) and a rotating polaroid mounted after the objective (2). The instrument monitors radiation from a small solid angle (less than 1^o in the direction of the local zenith). For a sensor of radiative flux, a photomultiplier (4) (PM) is used. During the twilight period for solar zenith angles from 90^0 to 96^0, the radiative flux changes over 4-5 orders of magnitude; therefore, the measurements are performed in the mode of variable responsivity of PM. To very the responsivity of PM, photocathode voltage is varied. The dark current of PM is determined from measurements with a shutter closed (3). The intensities of two radiative components polarized perpendicularly to each other are determined on the basis of each 3-5 revolutions of the polaroid. A glass light filter and spectral sensitivity of PM control a sensitivity band of the instrument; the band is centered at 830 nm and its half-width is 70 nm. . The example of a signal recorded is given in Fig. 2.

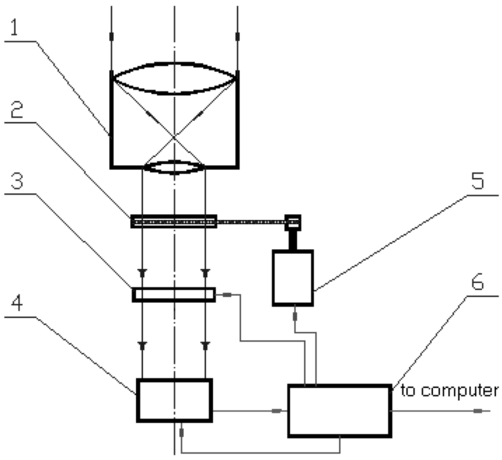

Fig.1. Scheme of the instrument.

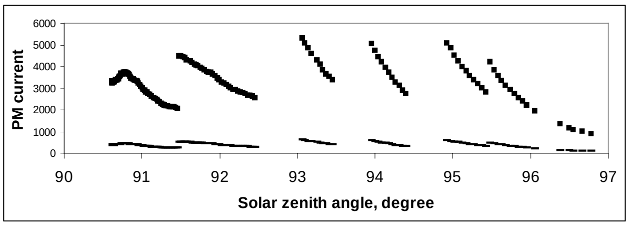

Fig. 2. Two PM currents caused by two polarized zenith intensities. Measurement of January 5, 2000 at Lovozero.

3. MEASUREMENTS OF POLARIZATION

To work through the procedure of measurements of the vertical aerosol distribution, test measurements of the degree of polarization of the twilight sky were carried out in the winter of 1999-2000 at the Zvenigorod (55.42^o N, 36.47^o E, 200 m.a.s.l., Moscow region) and Lovozero

(68^o N, 35^o E , Murmansk region) stations. In the spring of 2000, regular measurements were restarted at the high-mountain Kislovodsk station (43.73^o N, 42.66^o E, 2070 m a.s.l., North Caucasus). Polarization measurements are performed during twilight when the solar zenith angle changes from 90^o to 96^o.

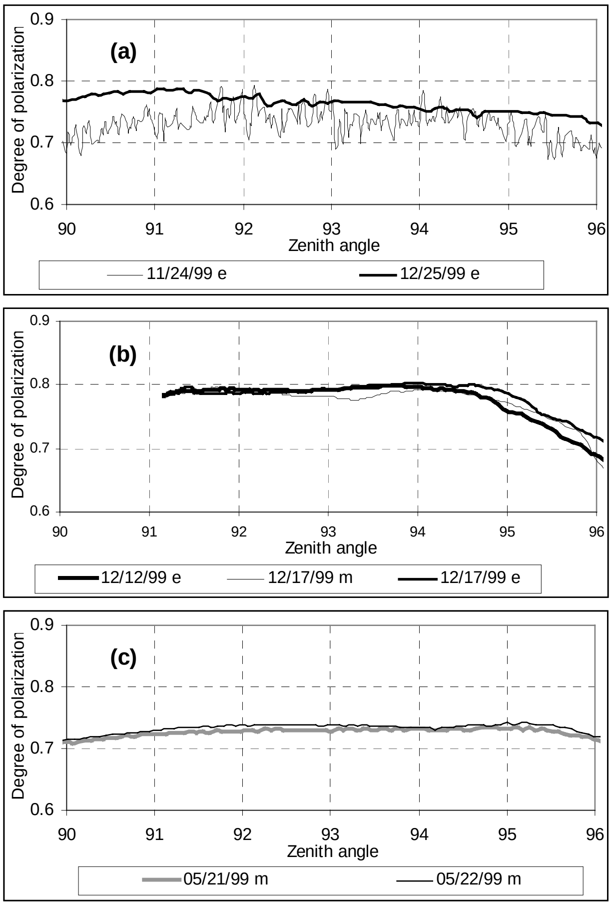

Fig. 3. The degree of polarization measured at Zvenigorod (a), Lovozero (b) and Kislovodsk (c).

The examples of polarization curves obtained are presented in Fig. 3. The degree of polarization observed at each of the three stations is close to 80%. In the polarization curve, the minimum corresponding to intersection of the Junge aerosol layer by the earth's shadow [*Elansky et al. 1993*] is not pronounced. This fact is indicative of small atmospheric aerosol content and thus of the complete elimination of products of last-decade volcanic eruptions from the atmosphere. Likewise, no effect of the near-tropopause aerosol is revealed, although this effect is usually significant. On the whole, the data obtained at all the stations confirm the fact that atmospheric aerosol in the Northern Hemisphere is at present in the background state.

4. MODEL OF POLARIZATION MEASUREMENTS OF AEROSOL

The PM currents $i_z^{\perp}$ and $i_z^{\parallel}$ corresponding to the above-mentioned intensities are related to the profile of aerosol characteristics $\boldsymbol{n} = n(h)$ through equalities

$$\begin{cases} i_z^{\perp} = k_0 k_z K_z^{\perp}(\boldsymbol{n}) + \tau_z + \nu_z^{\perp} \\ i_z^{\parallel} = k_0 k_z K_z^{\parallel}(\boldsymbol{n}) + \tau_z + \nu_z^{\parallel} \end{cases}, \qquad (1)$$

where k_0 is the coefficient of absolute calibration of the instrument, k_z is the coefficient of responsivity of PM (variations of this coefficient are described by a piecewise steady function of the solar zenith angle *z*), τ_z is the dark current of PM, ν_z is the random noise of measurements. Integral operators $K_z^{\perp}(\boldsymbol{n})$ and $K_z^{\parallel}(\boldsymbol{n})$ simulate the process of formation of radiative fluxes coming from the zenith in the atmosphere with the aerosol profile $\boldsymbol{n} = n(h)$. Measurements at one wavelength can not provide simultaneous determination of the concentration and microphysical characteristics of aerosol. Therefore, microphysical characteristics of aerosol were taken from other sources. Optical characteristics of aerosol were computed by the Mie theory. Profiles of aerosol concentration $\boldsymbol{n} = n(h)$ were being retrieved. For convenience of comparison of retrieved data with data of lidar sounding, the profiles of aerosol concentration were recomputed into aerosol backscattering ratios.

For simulation of radiative transfer in the atmosphere, the Monte-Carlo method and the method of direct integration with two orders of scattering taken into account were used [*Postylyakov et al. 2000b*].

For the available version of the instrument, responsivity coefficients k_z and the coefficient k_0 are unknown; these facts are taken into account in the retrieval algorithm. The dark current τ_z was measured at intervals of 30-50 revolutions of the polaroid. Dispersion of noise ν_z was considered constant. Its value was estimated from field measurements and, hereafter, is denoted as σ. The numerical value of σ was reevaluated in comparison with previous paper *Postylyakov et al.* [2000a] using new field measurements.

5. RETRIEVAL ALGORITHM

The algorithm of VAP retrieval was developed on the basis of theory of Measurement Computer Systems

(MCS) [*Pyt'ev and Chulichkov 1991*]. It was developed for a linearized variant of measurement scheme (1) in the framework of model including a random vector of measured signal with two specified moments of its distribution. In numerical simulation, for the mean profile of $\boldsymbol{n} = n(h)$, the background aerosol distribution. The covariance matrix of the vector $n(h)$ was preset as the diagonal one with the dispersion $(n(h))^2$. The distribution of aerosol microphysical characteristics was taken in accordance with the model [*WMO 1986*]: continental aerosol below 10 km, and stratospheric aerosol above 10 km.

6. ERROR ANALYSIS AND NUMERICAL EXPERIMENTS

Figures 4 and 5 show the rms errors of aerosol concentration retrieval on the basis of MCS theory. The errors were calculated for a measurement at 60 solar zenith angles from z=90.1^o to z=96^o with step 0.1^o. Percentage were calculated for background aerosol profile.

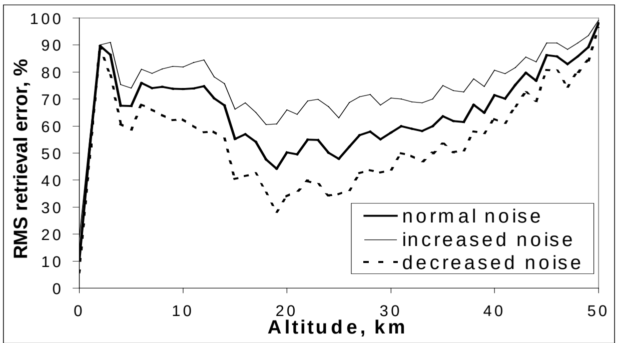

Fig.4. Percentage rms retrieval errors of aerosol concentration for different dispersions of measurement noise.

Figure 4 presents retrieval errors for resolution of 1 km for measurements distorted by a noise with different dispersions: σ (normal noise), $1/4\sigma$ (decreased noise), and 4σ (increased noise). A fourfold change in the noise dispersion leads to an error change of 10-15%. For all heights, at a height resolution of 1 km and a noise dispersion σ, the retrieval error exceeds 50% of the background aerosol concentration. As shown below, the retrieval accuracy can be heightened by degrading the resolution. Notice that, in periods subsequent to powerful volcanic eruptions, the aerosol concentration is enhanced. In such periods, the percentage error may become less than 10%. At heights below 5 km, the relative error decreases due to high aerosol concentrations in the atmospheric surface layer. In case of unknown coefficients k_z and k_0 retrieval errors increase at 1-3% in comparison with measurement carried out by an instrument with exactly known k_z and k_0.

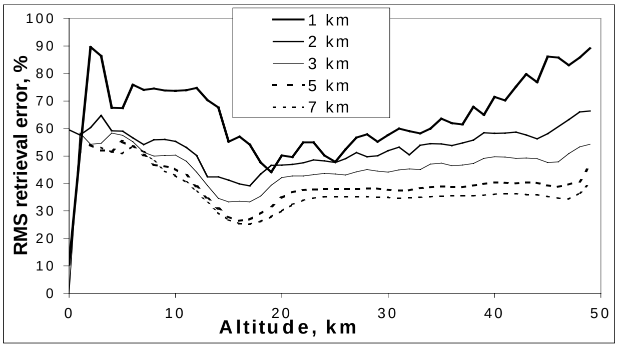

Fig.5. Percentage rms retrieval errors of aerosol concentration for different vertical resolution.

The dependence of the retrieval error on the vertical resolution is given in Fig. 5. As the vertical resolution degrades to 5 km, the retrieval error decreases below 40% for all heights above 11 km. At a further degradation of the vertical resolution, the retrieval error decreases only slightly. Figures 6 illustrate the numerical experiment on aerosol profile retrieval. The model aerosol layer is characterized by a thickness of 2 km and by a range of aerosol concentration variation equal to the background concentration. At a resolution of 1 km, it is difficult to reveal such a model layer against the noise background; at a resolution of 2 km, the layer manifests itself rather well; and, at a resolution of 3 km, the layer is clearly pronounced but its form is noticeably distorted.

7. CONCLUSION

At the Kislovodsk station, regular measurements of the degree of polarization of the zenith skylight were restarted. The degree of polarization observed at present in high and middle latitudes is characteristic for background concentrations of stratospheric aerosol.

A mathematical model of polarization measurements for aerosol profile retrieval is designed for usage in retrieval problem. The model takes into account multiple scattering of solar radiation in the atmosphere, variations in the responsivity coefficients of the instrument in accordance with the intensity of incoming radiation, and the absence of absolute calibration of the instrument.

An algorithm of aerosol profile retrieval from polarization measurements on the basis of the MCST is proposed. On the basis of field observations, a model of errors of radiation measurements is developed. Error analysis shows that the retrieval has enough accuracy to detect a 2-km aerosol layer, which exceeds background

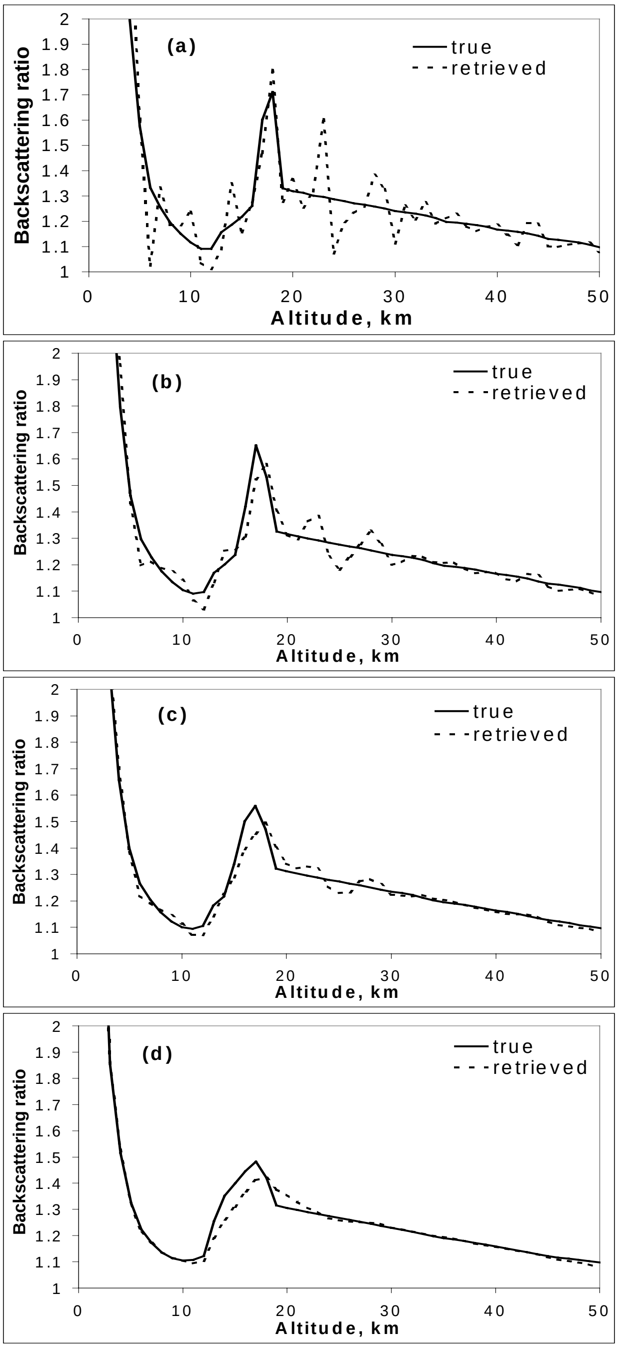

Fig.6. Numerical experiment on retrieval of aerosol backscatterring ration with resolution 1km (a), 2 km (b), 3 km (c) and 5 km (d).

concentration by more than 50 % at 12-25 km or by 60% at 5-45 km, or detect a 5-km aerosol layer, which exceeds background concentration by more than 25 % at 18-20 km or by 40% at 11-45 km. Notice that, in periods of the enhanced aerosol concentration (after powerful volcanic eruptions) this retrieval error may become less than 10%.

ACKNOWLEDGEMENT

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