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POLARIMETRIC METHOD OF ESTIMATION OF VERTICAL AEROSOL DISTRIBUTION IN APPLICATION TO OBSERVATIONS OF OZONE AND NO_2

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ABSTRACT

The degree of polarization of skylight at the zenith during twilight depends on the aerosol content in the atmosphere. The long-term observations at the high-mountain research station "Kislovodsk" (North Caucasus) have shown, that the variation of the degree of polarization after the eruption of the El Chichon volcano can serve as the effective parameter characterizing the vertical aerosol stratification in the atmosphere. The results of the measurements are confirmed by the numerical calculations. The algorithm of the retrieval of the vertical aerosol distribution on the base of the measurements of the degree of polarization is proposed. This method can be applied for the increasing of the precision of O_3, NO_2 and other gases content measurements.

1. INTRODUCTION

The connection of the degree of polarization of skylight at the zenith during the twilight with the aerosol in the atmosphere was first discovered by Shah (1969). The next experimental (Coulson, 1983; Elansky et al., 1987,1988) and theoretical (Volz,1981;Wu and Lu,1988) investigations gave the opportunity of the retrieving of the vertical aerosol distribution on the base of the polarization me-measurements. As these measurements are being carried out with the help of the simple instruments, they are available for each ozonometric station.Thus obtained information is useful for the heightening of the accuracy of the vertical O_3 and NO_2 profiles and is absolutely necessary in the cases when the observations of the trace gases are being carried out in the polluted atmosphere after the violent volcanic eruptions.

In the present paper the variations of the degree of polarization during the period after the eruption of the El Chichon volcano are described. The comparison of the observation data with the results of the model calculations explains some features of this process and give opportunity to choose the more effective scheme for the retrieval of the vertical aerosol distribution on the base of the polarization measurements.

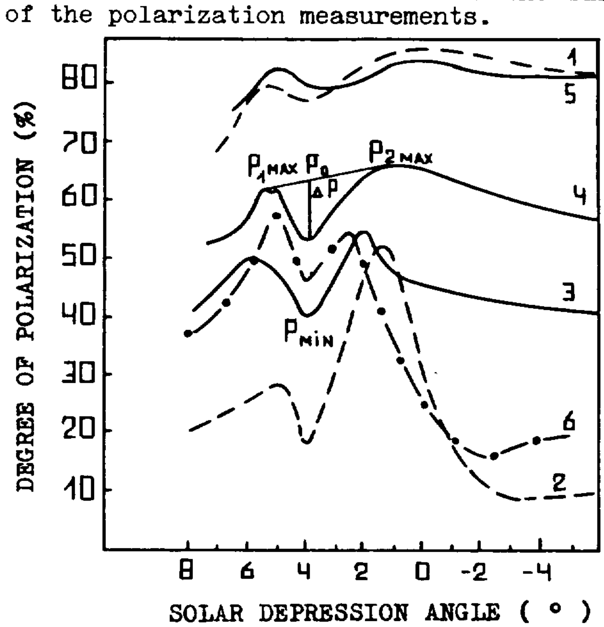

Fig. 1. Examples of the polarization curves for the twilight zenith measurements: 1,2- Mauna Loa (1977, 1982); 3,4,5,6 - Kislovodsk (1983, 1984,1988,1992).

2. OBSERVATIONS

Since 1983 at the "Kislovodsk" Observatory in the North Caucasus (43,7°N, 42,7°E,2070 m a.s.l.) each autumn the measurements of the degree of polarization of skylight at the zenith P(z) during the twilight (z - the solar depression angle) have being carried out. The field of view of the instrument is $1^\circ \times 1^\circ$, the working wavelength - 750 nm, precision - 0,5%, the values of $z < 8^\circ$.

In Fig. 1 the exemples of P(z) dependencies are given : obtained at the Mauna Loa Observatory in 1977 (the background conditions) and in 1982 (just after th eruption of the El Chichon volcano) (Coulson, 1983) and obtained by us in the period of the gradual cleaning out of the atmosphere from the volcanic aerosol (Elansky et al.,1987,1988) and in 1992(after the eruption of the Pinatubo volcano).

The theoretical works (Volz, 1981; Wu and Lu, 1988) have showed that when the earth's shadow passes through the stratospheric aerosol layer (SAL) the minimum is to be formed on the curves P(z), as the polarization of the light scattered by the aerosol is lower than the polarization of of the light scattered by the molecules.

Our measurements had shown that as far as the atmosphere became clearer the value of the degree of polarization increased and the depth of the minimum decreased (see Fig.2 and 3). The most clean (for the period since 1982) atmosphere was in 1988, when our curve P(z) practically coincided with the Coulson's curve obtained in 1977. In Fig.3 comparison is given of the year to year variations of the relative depth of the minimum $\Delta P/P_o$ (values averaged over September-October) and the maximum value of the backscatter profile R_{max}, got by averaging the data of the lidar stations Hampton (37.1° N, 76.3° W)- and Boulder (40.01° N, 105.15° W)- over the period July-November (taking into account the long-way transport of the aerosol in the stratosphere). (Ozone data, 1985-1989).

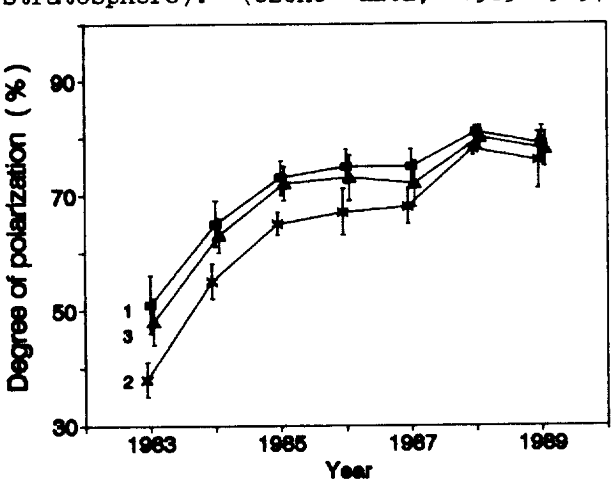

Fig. 2. Year to year variations of P_{1max} (1), P_{min} (2), P_{2max} (3) (see Fig.1.).

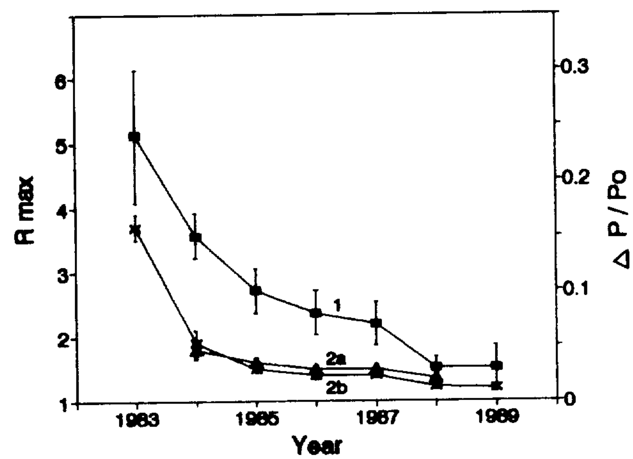

Fig. 3. Year to year variations of the relative depth of the minimum $\Delta P/P_o$ (1) and the maximum value of the lidar profile R_{max} for Hampton (2a) and Boulder (2b).

One can see that both parameters were decreasing with nearly the same velocity from year to year as moving away from the moment of the eruption of the El Chichon volcano. I.e. the both parameters can characterize the power of the aerosol layer in equal measure.

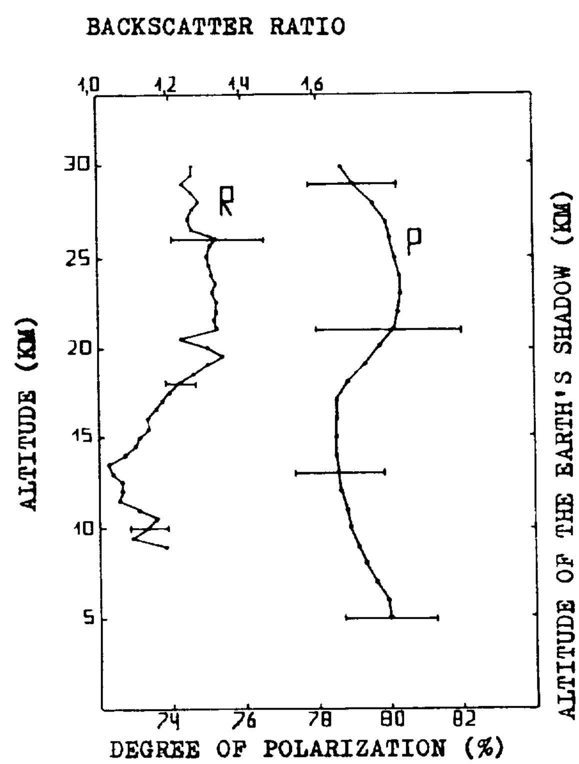

Fig. 4. Polarization $P(h_s)$ and lidar R(h) mean profiles obtained at the Kislovodsk Observatory in 1988.

The comparison of the polarization and lidar vertical profiles shows that the minimum of the degree of polarization is observed at the moment when the altitude of the earth's shadow (h_s) coincides with the altitude (h) on which the density of the aerosol layer is approximately half its maximum value. Thus the lower border of the aerosol layer can be estimated by the location of the minimum of the degree of polarization. The analysis shows also that both values practically didn't change during the transition from the disturb to the background conditions.

In autumn of 1988 the simultaneous measurements of the polarization and lidar profiles were carried out at the "Kislovodsk" Observatory. Nine coincident in time (with the difference not more than 1.5 h)profiles were obtained. In Fig.4 the mean profiles $P(h_s)$ and R(h) and their standard deviations are shown. To the very weak SAL corresponded the weak minimum of the degree of polarization.Its altitude location confirm the conclusions made before. But it was impossible to look for the more exact correlations between $P(h_s)$ and R(h) because of the small aerosol content in the atmosphere.

3. THE MODEL CALCULATIONS

The first step in the numerical investigation of aerosol and degree of polarization connection is the solution of the direct problem, i.e. the calculation of P(z) for the atmosphere with the different aerosol characteristics on the

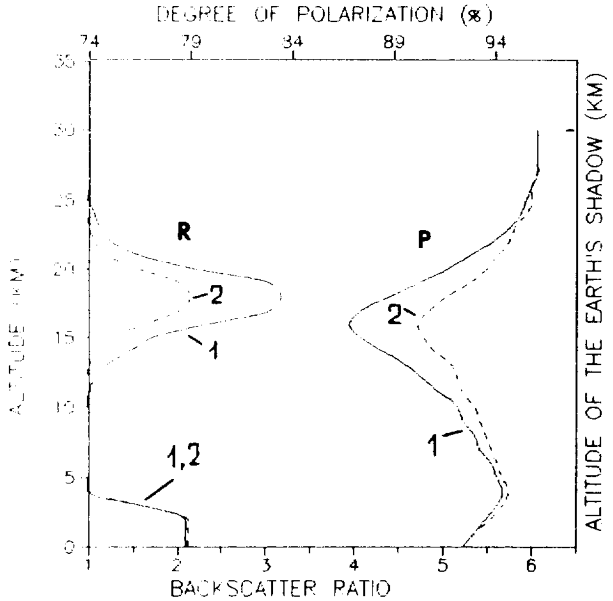

Fig. 5. Comparison of the set R(h)profiles and the calculated for them $P(h_s)$ profiles.

base of the model of the sunlight transport in the spherical atmosphere during the twilight. In Fig. 5 are given the 2 set R(h) profiles which differ only by the density of the aerosol layer and the calculated corresponding dependencies $P(h_s)$.The $P(h_s)$ profiles differ only by the depth of the minimum ΔP. Its altitude is the same for the both profiles and approximately coincides with the altitude on which the density of the aerosol layer is half its maximum value

Fig. 6 displays the dependencies $\Delta P(R_{max})$: the curve 1 was drawn after the results analogous to those given in Fig. 5, the curve 2 - after the data of the Fig. 3 (curves 1 and 2a). One can see that both the theoretical and the experimental dependencies are nonlinear and monotonously increasing.But there are the essential differences between them. These differences characterize the degree of the approaching of the model to the real characteristics of the atmosphere as well as the fact that the polarization and lidar measurement were carried out in the different regions of the Earth.

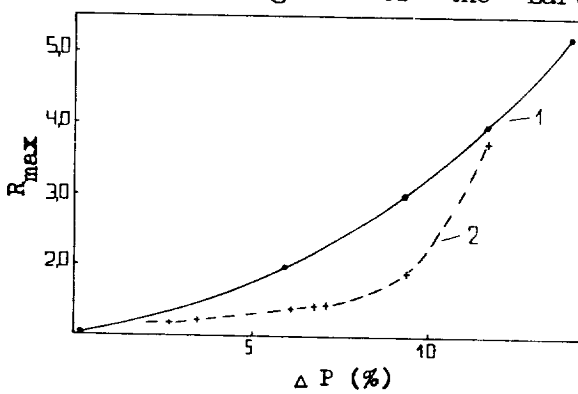

Fig 6. Minimum's depth ΔP vs maximum value of the lidar profile R_{max} after theoretical (1) and experimental (2) data.

The attempt to estimate influence of the aerosol size distribution on the calculated dependencies P(z) with and without taking into account the multiple scattering is shown in Fig. 7. One can see that the increasing of the modal radius of the scattering particles results in decreasing of the degree of polarization but in different measure for different solar depression angles. The locations of extrema are the same for all 4 curves. But the relative depth of the minimum $\Delta P/P_0$ is practically independent on the aerosol size distribution only when multiple scattering is taken into account. The model calculations have shown as well, that the increasing of the altitude of the mixing layer and its aerosol density results in the lowering of the minimum's location. There was also estimated the possibility of the resolution of the thin structure of the aerosol layers ($\Delta h \approx 3$-4 km) and the influence of the tropospheric aerosol layers on the polarization profiles.

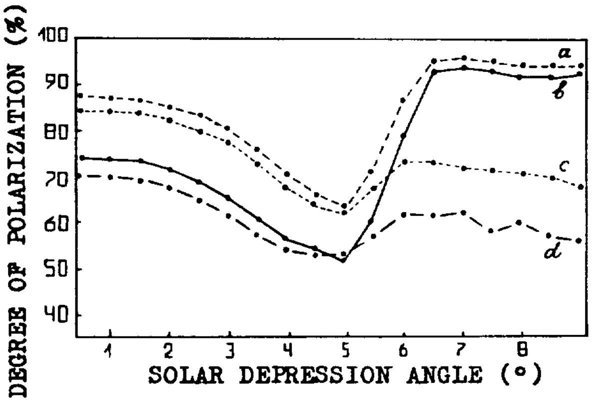

Fig. 7. Calculations of the degree of polarization for two models (R_{max}=4,5): with the modal radius of the aerosol particles 0,075 (a,c) and 0,15 (b,d) in cases when the single scattering approximation was applied (a,b) and when the multiple scattering was taken into account (c,d).

The retrieval of the vertical aerosol profile on the base of the degree of polarization measurements was made by the reduction method (Pytyev, 1983) which utilize the standard aerosol model (Wu and Lu, 1988) and the statistical information about the backscatter coefficient from the data of the lidar sounding. This method allows to construct the algorithm ensuring the retrieval with the minimum possible error. Only single scattering is taken into account. As an initial vertical profile the average profile of the backscatter coefficient for the given latitude was taken. Fig 8 demonstrates the solution of the direct and inverse problem for the closed scheme: 1) the computation of the degree of polarization for the set backscatter coefficient's profile, 2) the result serves as the initial data for the solution of the inverse problem. The different conditions of the observations were modelled in the form of the different noise levels being put over the degree of polarization. The discrepancies between the initial and final profiles didn't exceed 5% when noise level was 10%. The inverse problem was calculated for the case, when the measurements were carried out on the fixed wavelength. But the described earlier influence of the big variability of the aerosol's optical characteristics on the degree of polarization makes it preferable to go over to the multi-wave method. In this case the influence of the multiple scattering on the retrieval of the aerosol profiles can be taken into account more precisely.

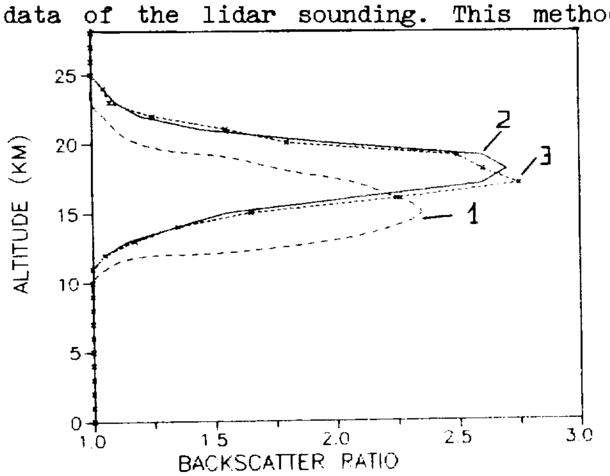

Fig. 8. Solution of the direct and inverse problem for the closed scheme: 1- average backscatter coefficient's profile, 2- set profile for the direct problem, 3- result of the retrieval.

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