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Detection of Leonids meteoric dust in the upper atmosphere by polarization measurements of the twilight sky

Oleg S. Ugolnikov*, Igor A. Maslov

Space Research Institute, Profsoyuznaya st., 84/32, 117997 Moscow, Russia

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Abstract

A new method for the meteoric dust detection in the upper atmosphere based on the polarimetric observations of the twilight sky is proposed. Polarization measurements are effective for detection of the meteoric dust scattering on the background consisting basically of troposphere multiple scattering. The method is based on the observed and explained polarization properties of the sky background during different stages of twilight. It is used to detect the mesosphere dust after the Leonids maximum in 2002, estimate its altitude range and to investigate its evolution—slow decrease of the altitude. The polarization method takes into account the multiple scattering and sufficient contribution of moonlight scattering background and turns out to be more sensitive than existing analogs used in the present time.

Keywords: Twilight sky polarization; Leonids meteoric dust

1. Introduction

Wide possibilities of atmosphere sounding by twilight background photometry are known for a long time. If we measure the sky background intensity during the day, we will obtain the integral characteristics of the air column above the observer, that are contributed basically by lower dense layers of the atmosphere (Fesenkov, 1955). Upper layers do not influence on the daytime background. But as the twilight comes, the Earth's shadow is growing up covering higher atmosphere layers, and the effective altitude of single scattering rises with the Sun depression under horizon. Having measured the twilight sky intensity, we obtain the information about definite layer of the atmosphere. Continuing the measurements during the whole twilight period, we build the vertical atmosphere scan. This is the basic principle of twilight sounding method, being developed from the pioneering work (Fesenkov, 1923).

The physics and chemistry of upper atmosphere layers strongly depend on the contribution of solid and liquid particles that can vary in a wide range. Optical properties of stratosphere and mesosphere depend on the dust and aerosol density in these layers and can sufficiently change after the maxima of major meteor showers, which was observed by Link and Robley (1971) and Link (1975) as increase of twilight sky background intensity during different stages of twilight. The point of the sky and solar zenith angle (hereafter SZA) when it occurs correspond to definite altitude of Earth's shadow and effective altitude of scattering. This becomes the base of the method of detection of meteoric and volcanic dust in the atmosphere. The method was used to detect the dust from a number of major showers, such as Quadrantids (Link and Robley, 1971), Orionids (Mateshvili and Mateshvili, 1988) and η-Aquarids (Mateshvili et al., 1997) during the return of parent comet Halley, and others. In late 1990s and early 2000s the observations were basically focused on the return of Leonids parent comet, which occurs once in 33 years producing the burst of activity up to several thousands and dozens of thousands meteors per hour. The twilight sky background increase was detected during the Leonids burst

*Corresponding author. Tel.: +7 495 333 4011; fax: +7 495 333 5178.
E-mail addresses: ugol@tanatos.asc.rssi.ru (O.S. Ugolnikov), imaslov@iki.rssi.ru (I.A. Maslov).

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period in 1998 (Mateshvili et al., 1999) and 1999 (Mateshvili et al., 2000).

Method used in cited papers was based on the assumption that all observational properties of the twilight sky are related with the atmosphere layers illuminated by straight solar radiation at a given time. This is so-called single-scattering approximation. While this is a reasonable assumption during the daytime, it encounters serious problems during twilight, when the solar emission is transferred along optically thick tangent path in the lower atmosphere layers. Possible sufficient contribution of multiple scattering in the twilight background was noticed in Fesenkov (1923) and became the subject of detailed analysis in Rozenberg (1966) (see also references therein). Although the estimation of multiple scattering contribution during the light twilight period was principally correct, it was sufficiently underestimated later, during the dark twilight period with SZA $>95^{\circ}$, when multiple scattering starts to take over the single scattering.

The contribution of multiple scattering during different twilight stages was estimated by polarization observations in Ugolnikov (1999) for the wavelength 356 nm. Then in Ugolnikov and Maslov (2002) the same was done for the number of bands in the visible part of spectrum. As it was shown, the multiple scattering contribution near the sunrise (or sunset) rises from about 30% in the red spectral region up to 60% in violet one in the case of stable clear skies. Being almost constant until the SZA of 94–95°, the multiple scattering contribution increases after that, practically reaching 100% at the SZA of 98–99°. These results were confirmed by the numerical solution of radiative transfer equation made by vector code MCC++ (Postylyakov, 2004). Correct numerical account of multiple scattering, which became available recently, leads to satisfactory agreement of twilight background intensity and polarization calculations with the observational data (Ugolnikov et al., 2004; Patat et al., 2006). The total domination of multiple scattering in the dark period of twilight (SZA about 99–100°) can be also proved by simple observational analysis (see Section 3).

If the meteoric dust appears in the upper atmosphere, the corresponding scattering fraction will be observed on the background of multiple scattering forming in the other layers of the atmosphere. The intensity of this background depends on the transparency and scattering properties of these lower atmospheric layers not only at the observation place, but also along the whole trajectory of photons diffusion. Such dependence is quite complicated, and the clear sky intensity changes from twilight to twilight. It is the basic problem during the separation of single and multiple scattering based on the intensity measurements only. Detection of meteoric dust and estimation of particle density based on intensity comparison for different twilight periods with single-scattering model may lead to systematical errors.

More exact approach to this problem was suggested in Mateshvili and Rietmeijer (2002) and used in Padma Kumari et al. (2005) for the analysis of Leonids meteoric dust in early 2000s. The basic observational parameter there is not the twilight background intensity, but its logarithmic derivative by the effective altitude of single scattering. Rapid variations of such value during the twilight are interpreted as the influence of meteoric dust layer at the corresponding altitude. It is correct since the multiple scattered background cannot have short-period variations during the twilight. The method is effective for detection of dense meteoric dust layers, but the numerical estimations need the multiple scattering properties to be taken into account, which is a quite complicated problem.

The primary goal of this work is to present and discuss a new method of meteoric dust detection in the upper atmosphere based on the polarization measurements of the twilight sky. Since the polarization properties differ substantially for the various twilight components (single Rayleigh scattering, single aerosol scattering, multiple scattering), polarization measurements are the independent and effective tool to disentangle between them, as already noticed in Fesenkov (1966). Polarization method was used to distinguish between single and multiple scattering (Ugolnikov, 1999; Ugolnikov and Maslov, 2002), to detect and investigate the aerosol scattering in the troposphere (Ugolnikov and Maslov, 2005b). It is quite sensitive, being able to detect weak optical features in the atmosphere, invisible for the intensity probes. It can work in the case of moonlit twilight. In this work this method will be applied to the Leonids meteoric dust layer investigation in 2002, the last year of strong Leonids burst after the 1998 perihelion of parent comet, 55P/Temple–Tuttle.

2. Observations and dust fall conditions

Polarization observations of twilight sky background were conducted in Crimean Laboratory of Sternberg Astronomical Institute (Crimea, Ukraine, 44.7°N, 34.0°E, 600 m a.s.l.). The observational device was the wide-angle CCD camera ($8^{\circ}\times 6^{\circ}$) directed to the zenith with rotating polarization filter. The data were averaged over the square $1^{\circ}\times 1^{\circ}$. The observations were carried out in the wide spectral band with effective wavelength 525 nm. This band is close to Johnson–Cousins V band, for the stars magnitudes in nighttime images we have $(m-V)=0.06\cdot(B-V)$. The polarization given by the filter is practically linear (better than 99.9%) in this spectral band. The measurements started during the day, when the Sun was still above the horizon (SZA about 87°), and continued deep into the night, and, then, till the same SZA in the morning. The most of the data were obtained during the Leonids activity epoch in 2002.

In order to investigate the meteoric dust inflow at a given location on Earth, it is necessary to check its local conditions for the shower maximum being considered, a check which is unfortunately missing in a number of published papers. The maximum time and activity of Leonids in 2002 were successfully predicted by Lyytinen