Atmospheric research and meteoric dust detection by the all-sky polarization measurements of the twilight sky

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The paper describes the results of wide-field polarization measurements of scattered emission in the upper atmosphere during the dark period of twilight. The field of single scattering gives the possibility to retrieve the temperature profile of the mesosphere and to estimate the contribution of dust particles. The increase of dust concentration was noticed during the Perseids shower activity period in 2013. The maximum of dust depolarization effect precedes the visual Perseids maximum but it is in good agreement with the meteor activity index in the nearby location.

1 Introduction

The mesosphere of the Earth is the worst-investigated layer of the atmosphere owing to its physical properties and impossibility of long series of *in situ* measurements. Neither planes or balloons nor spacecrafts can fly through this layer. The principal way of exploration are optical remote measurements, both from space and from the ground.

The mesosphere is also the place of possibly fastest climate changes on the Earth. Greenhouse gases (like carbon dioxide) creating the “global warming” effect near the ground start the opposite process of radiative cooling above 70 km. The negative temperature trend is not well-known due to absence of long-term measurements, but different estimations listed in (Beig, 2003) give the values up to -1K per year.

The fast cooling of the mesosphere is the most probable reason for noctilucent cloud (NLC) appearances in Europe in late XIX century. The clouds consist of water ice requiring the temperature to be below 150K at altitudes ~85 km. The condensation nuclei are the tiny meteoric dust particles.

The twilight method of the mesosphere remote sensing can be effective for a temperature profile retrieval (if the scattering is Rayleigh-dominated) and for the scattering medium investigations including the meteoric dust detection and investigations. This can be done if the polarization of the twilight sky is measured together with the intensity. Polarization data also help to separate the multiple scattering which is a basic problem of the twilight analysis.

2 Observations

The method of single and multiple scattering separation and retrieval of scattering matrices depending on the altitude require a rich set of simultaneous intensity and polarization measurements over a large number of sky points during the whole twilight period. This can be successfully performed by an all-sky camera designed for polarization measurements (see Figure 1). First two lenses (1 and 2) create the infinitely remote image of the sky with the zenith angle up to 70°. The visible size of the image is reduced by a factor of 10, and collimated rays cross the polarization filter. Lens 3 creates the secondary sky image on the CCD.

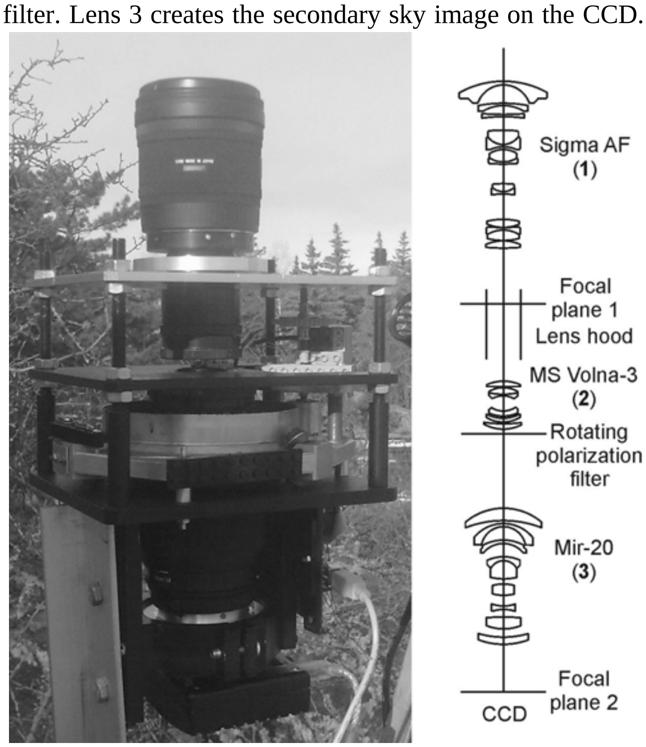

Figure 1 – All-sky polarization CCD-camera and its principal optical scheme.

Observations started in 2011 at a point (55.2° N, 37.5° E), southwards from Moscow. The measurements are carried out in a spectral band with effective wavelength equal to 540 nm.

A detailed description of the measurements and of the method of multiple scattering separation are made in (Ugolnikov and Maslov, 2013). The same paper also contains the results of temperature analysis. The accuracy of simple measurement is about 5K, the values are in good agreement with space measurements by TIMED/SABER and EOS Aura/MLS instruments.

3 Meteoric dust detection

Most parts of meteoric mass entering the vicinity of the Earth is burned or moderated in the mesosphere. The meteor products can create the dust layers at different altitudes. Additional twilight sky brightness during the major shower maxima was found in a number of papers starting from (Link and Robley, 1971). But the numerical procedure of dust detection required the multiple scattering separation which was a very difficult problem in the XX century.

The accuracy of detection of difficult twilight background components can be sufficiently increased using the polarization data. The meteor dust is being searched as the decrease in single scattering polarization. The detailed description of the procedure can be found in (Ugolnikov and Maslov, 2014). The basic parameter calculated from the observational data is the polarization characteristic q:

$$q = p(\theta) / p_R(\theta) \quad (1)$$

Here p and p_R are measured and the Rayleigh (molecular) polarization of a single light scattering by the angle θ. This parameter is close to unity in a pure gas condition and decreases in the case of dust appearance.

Figure 2a shows the values of q in the atmospheric layer above 80 km for the observations performed in 2011-2013. We see that this value is a little bit less than the unity for most of the dates showing the possible effect of the sporadic dust. A remarkable minimum is seen during August 2013. It is probably related with the Perseids shower.

However, a detailed picture for August (Figure 2b) shows that the temporal depolarization profile is shifted to the earlier dates compared to the traditional Perseids visual maximum, but in very good agreement with television data for the same year and from a nearby location (Kartashova, 2014). We should notice that the visible maximum on the 12th of August is defined by large particles, and the dust layer is formed by a small fraction, which activity profile is not well-known. Some peaks prior and after were noticed in (Bel'kovich and Ishmukhametova, 2006) and they can also coincide with depolarization effects.

The analysis is showing that the dust causing the additional scattering and depolarization effect has a maximum concentration at the altitudes decreasing from 83 to 81 km during the Perseids activity. It is also close to the NLC typical altitudes, which is not a surprise knowing the physical relation between these phenomena.

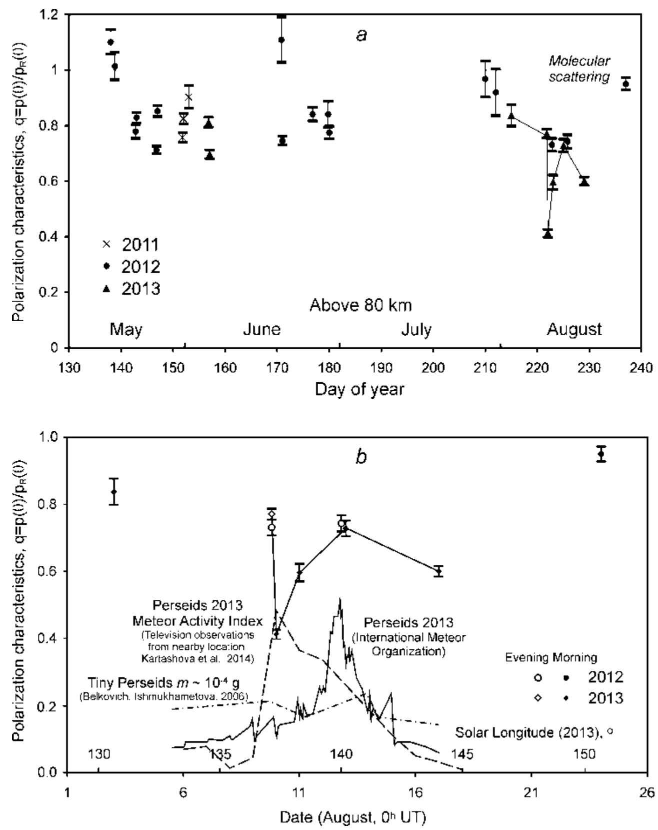

Figure 2 – Single scattering characteristics depending on the date in summer (a) and in August (b) compared to the Perseids activity profiles.

4 Conclusion

Twilight analysis remain an effective tool to solve the different problems of the middle and the upper atmosphere physics. When multiple scattering is correctly separated, the data can be used for temperature analysis, meteoric dust detection and noctilucent cloud particles investigation.

The effects of the dust inflow can be seen for the major showers like the Perseids. A difference in dust inflow and the temporal meteor activity profiles is possible. This is related to different profiles for large and small particles, the last one not being too well-known.

All-sky cameras used for scattering analysis during twilight can also be used for meteor registrations during the night. However, the polarization filter and the multi-lensed optics required for correct polarization measurements reduce the sensitivity of the camera.

Acknowledgement

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