OPTICAL THICKNESS OF WINTER CLOUDS FROM GROUND-BASED
VISIBLE IMAGES

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1 ABSTRACT
Here we study the possibility of evaluating the optical thickness of winter clouds from ground-based imagery used as a flexible and inexpensive remote sensing tool. The use of terrestrial photography, which allows high temporal and spatial resolution is an economic approach, complementary to satellite imagery. Furthermore, the combination of both techniques, satellite and ground-based photography, may enhance the quality of the satellite data [1]. The main problem in such an approach is the need to take into account the effects of scattering and extinction of radiation through the atmosphere. The atmospheric corrections are obtained using models that also involve data on the horizontal visibility and other meteorological parameters.

The method presented here is based on relative photometric measurements in the visible spectral band of the clouds and of an isotropic reflecting white surface. The fresh snow cover, which practically satisfies the conditions for an etalon diffuse reflector is used. The brightness of clouds and of the etalon is obtained from digital photography taken at the earth surface and its validation on fresh snow cover in mountains. The proposed method for ground-based measurements of the optical thickness of clouds has been applied to winter clouds above the city of Sofia.

2 THEORETICAL CONSIDERATIONS
The advantage of ground-based observations of clouds as compared to satellite ones is in the possibility of measuring the attenuation of solar radiation through the clouds, which in turn depends exponentially on the optical thickness. Consequently, it is necessary to have the values of the solar radiation incident at cloud top and emergent from cloud base. The latter quantity is inferred from surface observations of the lowermost cloud layer. For evaluation of the amount of solar radiation we use an isotropic reflecting white surface, the brightness of which is related to the solar irradiance according to the Lambert’s law. Practically, the fresh snow cover can be considered as an ideal Lambert reflector.

2.1 Camera Validation and atmospheric corrections
We make use of a basic measurement of the brightness of a fresh snow cover during clear cloudless sky state in the mountains at altitude \( h_m = 2200 \) m above sea level – the Rezena peak in Vitosha mountain near the city of Sofia. It is needed as a reference value serving for the “energetic calibration” of the camera. The images of the mountain fresh snow cover are taken on 20 March 2006 at solar zenith angle of near 43°, which is sufficient to ignore the bi-directional reflectance of the snow. For the brightness of a normal to the sun etalon surface in the mountains due to the attenuated direct solar radiation we have:

\[
L_{em} = k L_s, \quad k = \frac{\Omega_s}{\pi} \exp \left( -T_a \frac{h_m - H_a}{\cos z_s} \right)
\]

where \( L_s \) is the extra atmospheric brightness of the solar disk, \( T_a \) is the vertical optical thickness of the upper atmospheric layer between heights denoted as arguments, \( H_a \) is for the upper limit of the earth atmosphere, \( \Omega_s \) is the solid angle subtended by the solar disk at the Earth (\( \Omega_s \approx 6.8 \times 10^{-5} \) sr), and \( z_s \) is the zenith angle of the sun during the measurements. Because of the unevenness of the relief for the value of the quantity \( L_{em} \) is taken the maximum of the measured snow brightness.

The constant \( k \) is determined using approved models for computation of the molecular optical thickness of the almost clear of aerosol upper atmosphere. From [2] and elsewhere we find that the total volume coefficient of molecular scattering for the visible spectral range represented by the wavelength 0.55 \( \mu \text{m} \) for standard atmospheric conditions at
sea level can be taken equal to 0.012 km\(^{-1}\). After the necessary corrections for temperature and pressure at ground level, we make also correction for altitude referring to exponentially distributed molecular atmosphere with density scale height equal to 9.3 km. As a result we obtain that the vertical optical thickness of the upper atmosphere during the measurement is \(T_a\left(h_m, H_a\right) = 0.069375\) that corresponds to the vertical atmospheric transmittance of 0.933. The coefficient \(k\) in Eq. (1) is evaluated to 1.97\times10^{-5}.

The ground-based measurements of the brightness of the cloud base are strongly influenced by the lower atmosphere in the presence of aerosols. In winter, the haze and fog are a common occurrence, and we have to account for the optical characteristics of the atmosphere during the observations. The total volume scattering coefficient of the atmosphere, which is the sum of the corresponding quantities for the atmospheric constituents – molecules and aerosols - is determined from the data about the horizontal visibility. The corrections for the molecular extinction have been described just above. The changes of the visibility are due mainly to the particular content of aerosols. We obtain the total aerosol volume scattering coefficient at ground level excluding the contribution of the molecular component. The model calculations for altitude distribution of the aerosol density refer to exponentially decreasing function with scale height taken as 1.2 km [2]. The needed meteorological parameters (visibility, pressure, temperature and so on) and astronomical data for the solar position during the measurements are taken from on-line data about the city of Sofia at websites: [http://bulgarian.wunderground.com/global/stations/15614.html](http://bulgarian.wunderground.com/global/stations/15614.html) and [http://www.nrel.gov/midc/apps/solpos.pl](http://www.nrel.gov/midc/apps/solpos.pl), respectively.

Theoretically, equation (1) is very useful for evaluation of the optical thickness of clouds from ground-based measurements. It is needed to apply in most of the cases concerning the winter clouds because the sky is mostly cloudy or fully overcast almost all the time and there is not any possibility to measure the incident at the earth surface solar irradiation. Below we present the considerations used for evaluation of the optical thickness \(T\) of clouds observed during the past winter.

2.2 Visible Solar Disk

During the past winter, often occurred the phenomenon called “filtered sun effect”, when the skies are mostly cloudy, but the solar disk is sharply outlined through the clouds. Neglecting the vertical thickness of the cloud layer with respect to the height of the entire atmospheric envelope (which is about 100 km of height), the measured brightness of the solar disc visible through the cloud can be represented as

\[
L_{fi} = L_s \exp\left(-\frac{T_a(0, H_a)}{\cos z_s}\right) \exp(-T),
\]

where \(T\) is the cloud optical thickness, the quantity that is looking for. From Eq. (1) follows that

\[
T = \ln\left(\frac{L_{cm}}{kL_{fi}}\right) - \frac{T_a(0, H_a)}{\cos z_s}. \tag{2}
\]

The physical meaning of the relation in Eq. (2) is that the optical thickness of the cloud is expressed as the difference of the optical thickness of the atmosphere including the cloud and that of the clear of cloud atmosphere for the same direction of observation. Depending on the atmospheric conditions, when the air is very clear, the first term on the right side in (2) may be much higher/larger then the second one, say in proportion 16:1.

2.3 Thick Clouds

The sun disc is not visible behind a thick cloud when the skies are mostly cloudy and/or fully overcast. Because of their great optical thickness, such types of clouds present multiple-scattering problems. The tendency of multiple scattering is to average out the sharp variations in scattered intensities with the angle of observation [2]. Considering the cloud as an ideal diffuser, the cloud optical thickness can be expressed by the measured brightness of the cloud base \(L_c\) in direction to the sun in the following way:

\[
T = \ln\left(\frac{L_{cm}}{k\pi L_c}\right) - \frac{T_a(0, H_a)}{\cos z_s}. \tag{3}
\]
In winter, the texture of the cloudiness is usually regularly distributed over the skies. The variations of the brightness in the image taken in direction to the sun are representative for the range of optical thickness of all clouds.

3 RESULTS AND CONCLUSIONS

For calculating the brightness data, a weighted mean value is formed from the channels red, green and blue. The values of the brightness codes in the image are read by means of a software product specially created for the purpose. The camera specific settings such as shutter-speed time, aperture and focus are taken into account for converting of the digital image codes into values of brightness.

Unfortunately, the dynamic range of the available amateur camera is smaller than the dynamic range of the scenes and some shadow and highlight details are lost. In our opinion this fact results in the underestimated values of the cloud optical thickness obtained by now. For example, the cloud optical thickness may reach the value 16 when the solar disk is sharply outlined and is not much brighter then the surrounding cloud [2], while according to our estimates the sun disk is not visible through cloud of optical thickness greater then 9.5. Moreover, only compressed JPEG files with unknown tonal curve are given. An attempt to apply decompression would lead to another loss of information. Yet, the obtained values of the optical thickness of clouds are reasonable and the tendencies indicating the consistency of the proposed approach are displayed. Below some examples are given.

Picture 1. The sky is fully overcast by almost uniform cloud layer. The presence of light aureole around the sun disc is indicative of the smaller cloud thickness, evaluated to 6.16.

Picture 2. The sun disk is not much brighter then the surrounding cloud, which optical thickness is evaluated to 9.3.

Picture 3. The sun disk is not visible behind the darker cloud at the top of the picture. The optical thickness of the cloud is evaluated to 10.9.

Picture 4. Because of the different settings of the camera, the optical thickness (11.7) of the upper cloud is greater then that in Picture 3.

For computation of the atmospheric corrections in measurements particular software program is made. Depending on the input data about horizontal visibility, temperature, pressure, and solar zenith angle, the second term in the right side of Eqs. (2) or (3) indicate values between 0.74 and 5.08, which are comparable to the evaluated optical thickness of some clouds.
We would like to mention that in case of smaller cloud or if there is a thinner area in the cloud, the strong single scattered forward solar radiation gives additional “noise” brightness to the measurement that cannot be neglected. Such relatively narrow angular range not exceeding 30°, the measurement may be read at approximately such distances from the sun. In order to assure the same optical thickness of the atmosphere as for the direction to the sun, the remote area of the cloud base must be situated along the almucantar, i.e. remote approximately horizontally.

![Image](image1.png)

**Picture 5.** The circle indicates the area of the cloud just in front of the sun. Because of the influence of the single scattered solar light the brightness of this area is 1.5 times greater than the brightness of area denoted by square.

![Image](image2.png)

**Picture 6.** Panoramic view of the site in the Vitosha mountain during the calibration of the camera on a fresh snow. The dark sky is indicative of the purity of the atmosphere from aerosols.

Our first results may be not completely satisfactory mainly due to the poor dynamic range and to the rest insufficiencies of the used digital camera. Nevertheless, the results are encouraging. Presumably, in theory the camera is considered as a photometric device. In order to approach this requirement, the camera must give at least uncompressed RAW data format of pictures, as well as it must allow for large range of aperture values.

4 **ACKNOWLEDGEMENT**
The Bulgarian National Scientific Fund supports the present work by the contract NZ 1414.

5 **REFERENCES**