Distribution of Radiation Density in a Homogeneous Cloudy Layer

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The program block (Monte-Carlo method) allowing calculating radiation density in homogeneous and non-uniform clouds is developed for a homogeneous layer with various factors and phase functions of scattering the field of radiation density are calculated. On the basis of the calculated data the parameterization formulas of the characteristics of a radiation field are estimated. The angular distributions of intensity in fluxes of the radiation, which have left the cloud layer, are presented.

Abstract

Recently significant amount of problems connected to radiation distribution in a scattering volume is solved by formal consideration of photon distribution on lengths of trajectories in the cloud volume. The separate photon trajectories are traced, along which the absorption is acting. Such an approach allows solving both direct and inverse problems of radiation propagation. Thus, in a number of cases there are some simple parameters connected to photon distribution. Effective length of photon distribution trajectories is related to number of such parameters.

However, contraction of information of all set of photon trajectories in a cloud to one effective trajectory is accompanied by a certain error. If the absorbing substance is distributed in the cloud system non-uniformly then identical on length photon trajectories can correspond to different absorption. For a satisfactory decision of the task in this case it is necessary to know distribution of radiation density in the cloud.

In the present work using Monte-Carlo method, an analog modeling of distribution of radiation density in a homogeneous cloudy layer are made. The configuration of the two-dimensional (2D) density field is constructed.

The concrete algorithm of calculation is as following. For every photon its trajectory in a cloud up to the moment of leaving the cloud layer is traced. The trajectory consists of a number of different lengths of free path between the acts of scattering at cloud particles. Length of free path is defined as Rand/σ, where Rand is the uniformly distributed random number from a range [0, 1], chosen using the random-number generator, σ - volumetric scattering factor of cloud particles. The scattering in each act occurs according to the phase function typical for droplets. The absorption is involved through the single scattering albedo. If photon leaves through the upper boundary of the layer its trajectory is related to the reflected flux; if it leaves through the lower boundary its trajectory is ascribed to a flux transmitted through the cloud.

Described above analog modeling of light propagation in a cloud can be visualized using following technique. Having the position of each scattering point we can represent it at a screen using monochrome colored (e.g., red) pixels. Brightness of the pixel depends on number of scattering acts it has been involved in. So, field of these differently "heated" pixels represents 2D distribution of radiation density in the cloud. Further, since curves of equally heated pixels can be interpreted as the light energy front, then step by step rendering of field of pixels allows to study in dynamics both light propagation and distortion of the energy front. Real intensity of each closer to center red isoline is 256 times higher than previous one. The changing of radiation density field (three consequent states separated with different time intervals) during light propagation presented at Figure 1 (photons start at zenith angle 0 degrees).

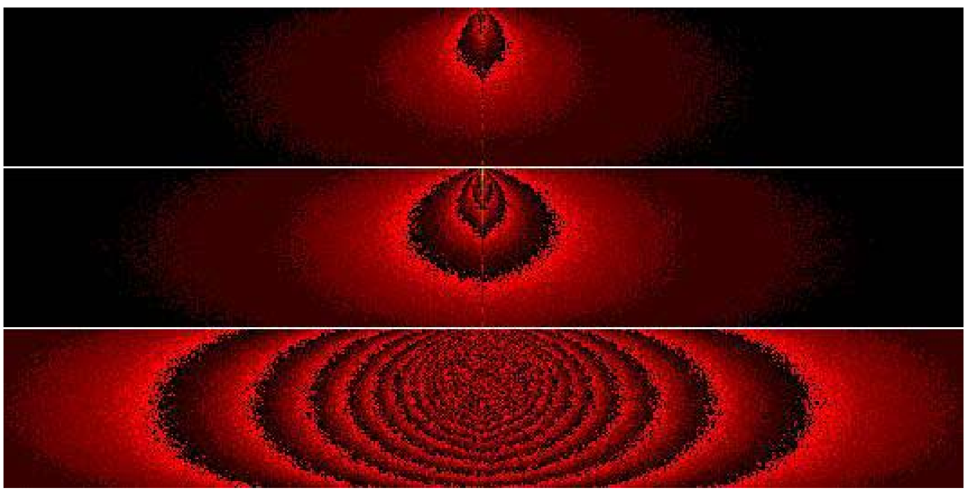

Figure 1. Three consequent states of radiation density in a cloud. Zenith angle of photons incidence is 0°.

Also, cases when photon starts at various zenith angles (for example at 30° as at Figure 2) were considered.

Photon output into both lower and upper hemisphere at various output angles was analyzed. At Figure 3 the angular distributions of radiation intensity (expressed in relative units) in the flux of light transformed by the cloud layer is presented for different optical depths τ (zenith angle is 0°).

It is seen at this (see Figure 4) that for semitransparent clouds the form of the calculated angular distribution corresponds well to the form of the phase function of light scattering for cloud model C1 (Deirmendjan 1971).

At Figure 5 the vertical profiles of radiation density in a cloudy layer are presented for various length L of free path. Here the density of radiation at the upper boundary of a cloud is equal to unity. The calculations show that the maximum of radiation density in the flux passed through a cloud is in the

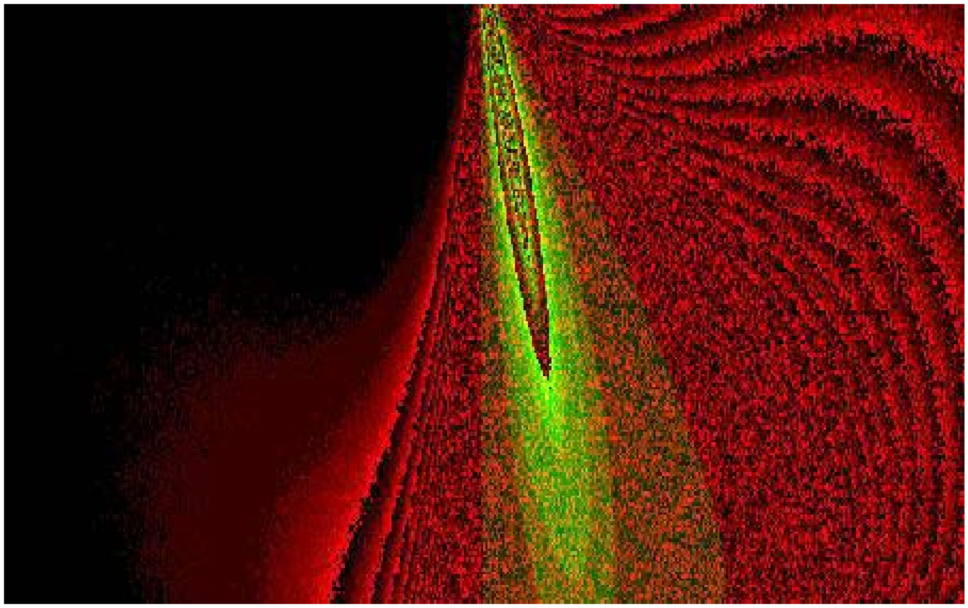

Figure 2. Radiation density in a cloud. Photon incidence angle is 30°.

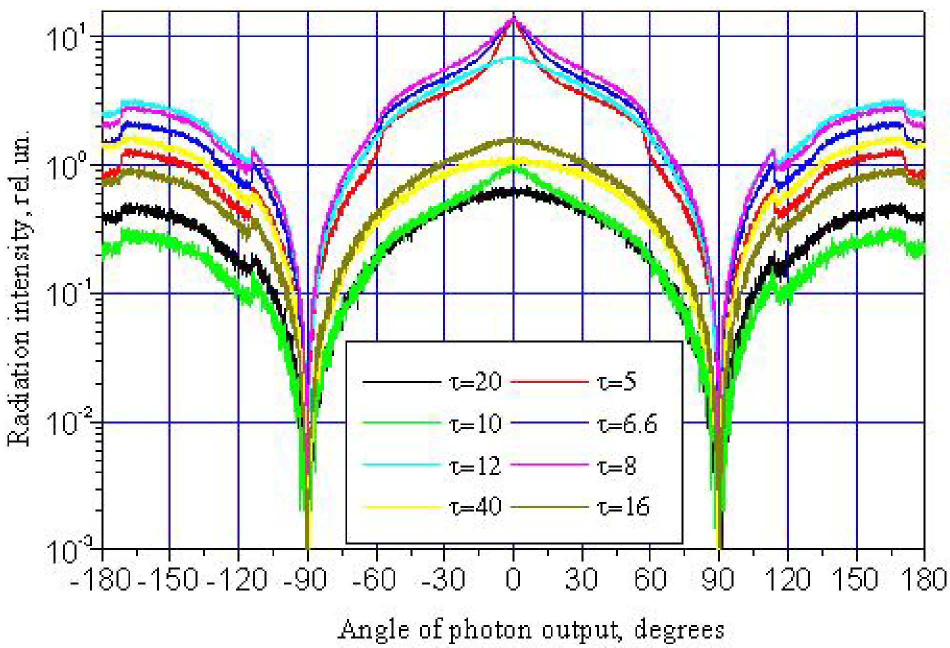

Figure 3. Radiation intensity vs. photon output zenith angle at different optical depths τ. Angular ranges: (-180, -90) and (90, 180) correspond to upper hemisphere and (-90, 90) corresponds to lower one. Photon incidence zenith angle is 0°.

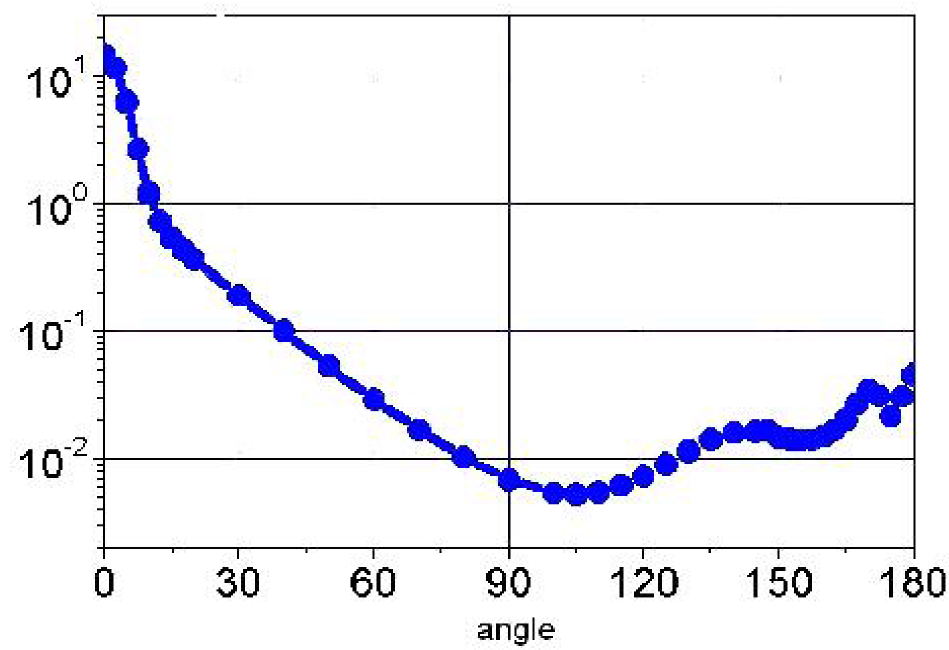

Figure 4. Phase function of light scattering for cloud model C1 (Deirmendjan 1971).

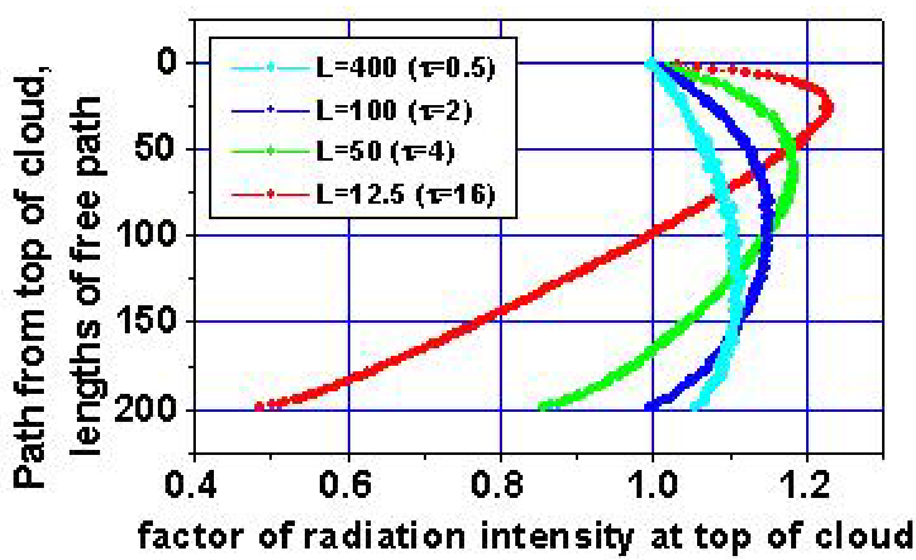

Figure 5. Vertical profiles of radiation density in a cloud layer at different lengths of free path L.

middle of the cloud layer and practically does not depend on absorption. In the reflected flux the density maximum is observed near the top of the cloud layer, the closer to it the more absorption.

From all viewpoints it is clear that if the cloud layer is composed of two layers separated by an interval, the value of radiation density in the integral would be equal to its value on the borders of layers that adjacent to the interval. Therefore by results of calculations for one cloud layer it is easy to reconstruct distribution of density for the cloud system consisting of two or more layers.

One of the basic results is that at sounding a cloud at a small visual angle the horizontal sizes of volume of a cloud can be estimated to be approximately equal to the size of a cloud in the vertical.

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Reference

Deirmendjan, D., 1971