THE EFFECT OF THE POLLUTION OF THE GROUND LAYER OF THE ATMOSPHERE ON THE ALBEDO

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Summary: A simple model is proposed suitable for studying the effect of the ground layer of the atmosphere, polluted by aerosol, on the albedo. This model is founded on solving the equation of transfer of radiative energy. The numerical results are discussed, particular attention being paid to the analysis of errors due to neglecting the multiple reflection of solar radiation on the aerosol particles. A method which would also include the multiple reflection is proposed, and the conditions under which the presence of the aerosol is responsible for an increase or decrease of the solar radiation balance on the Earth's surface, are analysed.

1. INTRODUCTION

One of the widely discussed problems in the present applied meteorology is the effect of aerosol particles, which are polluting the atmosphere in ever increasing numbers (a significant part of this being undoubtedly due to human activity), on the solar radiation balance near the Earth's surface. Of the series of papers, dealing with this topic in specialized literature in recent years, we should mention, e.g., [1—3]. The authors mostly reach the conclusion that the solar radiation balance near the Earth's surface may sometimes be decreased, at other times increased in individual local cases, depending on the physical and geographical conditions, as well as on the capability of the aerosol particles to reflect and absorb solar radiation and the local properties of the Earth's surface, specially the albedo. However, from the point of view of long-range climatic trends on a worldwide scale it is generally assumed that the increased presence of aerosols in the atmosphere will be reflected in an increase of the Earth's planetary albedo and thus in an overall decrease of the solar radiation balance with a subsequent cooling of the climate. In studying this problem a series of model studies are used, beginning with illustrative deliberation rather of a qualitative nature [1] and, so far, ending with complicated numerical models [3], the solution of which requires the use of the most sophisticated computers.

This paper ties up with [4], and an idealized model of the polluted ground layer is used, founded on solving the equation of transfer of radiative energy, also described in [4].

2. DESCRIPTION OF THE MODEL USED

For the sake of simplicity it is assumed that the Sun is always located in the zenith and \( I_1 \) is the flux of direct solar radiation, propagating through the atmosphere from top to bottom. It is also assumed that the atmospheric layer, extending from the Earth's surface to height \( H \), is polluted with aerosol particles which partly reflect and absorb the solar radiation. Scattering of radiation is not considered in the atmosphere above this layer. \( I_2 \) represents the flux of the solar radiation, reflected upwards from the aerosol particles, on the one hand, and from the Earth's surface on the other, assuming that radiation scattering upwards is isotropic.

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As in [4] we are able to compute, under the conditions mentioned, the magnitudes of the radiation fluxes $I_1$ and $I_2$ at height $z < H$ above the Earth's surface by solving the differential equations

\begin{align*}
(1) \quad dI_1(z)/dz &= (\alpha + \beta) I_1(z), \\
(2) \quad dI_2(z)/dz &= -(\alpha + \beta) q I_2(z) + \alpha I_1(z),
\end{align*}

where $\alpha$ and $\beta$ are the coefficients of reflection and absorption, respectively, in the ground layer, polluted by the aerosol, and $q = 1.66$ is the fictional optical mass. It can be proved [5] that in the case of radiative fluxes, dispersed isotropically, the magnitude of the flux may be substituted formally by the intensity of the ray which passes through the atmosphere so that the appropriate optical mass is close to 1.66.

The coefficient of reflection is defined as the ratio of the amount of the solar radiation per unit time scattered by a unit volume of the polluted atmosphere to all directions, making an angle of more than $\frac{1}{2}\pi$ with the original ray, and the amount of radiation per unit time incident at this unit volume. Analogously, the coefficient of absorption $\beta$ represents the ratio of the amount of radiation absorbed in a unit volume per unit time and the amount of incident radiation. The signs on the r.h.s. of Eqs (1) and (2) have been chosen with regard to the fact that for the radiative flux $I_1$ downwards $dz < 0$ and in (2), on the contrary, $dz > 0$, because the radiative flux $I_2$ is oriented upwards.

According to [4], the solutions of Eqs (1) and (2) can be found in the form

\begin{align*}
(3) \quad I_1(z) &= C_1 \exp \left[ \int (\alpha + \beta) dz \right], \\
(4) \quad I_2(z) &= \exp \left[ - \int q(\alpha + \beta) dz \right] \int x I_1(z) \exp \left[ \int q(\alpha + \beta) dz \right] dz,
\end{align*}

where $C_1$ is an integration constant which can be determined from condition

\begin{equation}
(5) \quad I_1(H) = I_0,
\end{equation}

$I_0$ representing the magnitude of the flux of the direct solar radiation entering the polluted layer at height $z = H$. If we assume that $\alpha$ and $\beta$ are independent of the vertical co-ordinate $z$ for $z < H$, (3) and (4) can be adjusted to read

\begin{align*}
(6) \quad I_1(z) &= C_1 \exp [(\alpha + \beta) z], \\
(7) \quad I_2(z) &= \alpha C_1 [(\alpha + \beta) (1 + q)]^{-1} \exp [(\alpha + \beta) z] + G_1 \exp [-q(\alpha + \beta) z].
\end{align*}

The integration constant $G_1$ in (7) is then determined from the boundary condition for the Earth’s surface ($z = 0$),

\begin{equation}
(8) \quad I_2(0) = A I_1(0),
\end{equation}

where $A$ is the albedo of the Earth's surface.