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VISIBLE FLUX VARIATIONS ACROSS FINITE CLOUDS

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ABSTRACT

A new radiative transfer model has been developed to compute visible flux variations across and within finite clouds of varying shapes. The technique has much of the versatility of Monte-Carlo models, as well as the speed of the analytical finite cloud models.

INTRODUCTION

Quantitative and qualitative uses of visible satellite data have been hampered by the present deficiences of radiative transfer theories. An underlying explanation of what causes the brightness variations of clouds observed in satellite images is lacking. Much of the theoretical work dealing with cloud scattering of light has dealt with plane-parallel homogeneous clouds. However, satellite measurements of cloud brightness are contrary to the plane-parallel results. Monte-Carlo simulations by McKee and Cox (1974) using cubic clouds have shown that the three dimensional character of the cloud is important in the scattering of visible light. Reynolds et al. (1978) have shown the height to width ratio effect predicted by finite cloud models agrees with satellite observed cloud brightness. Wendling (1977) has shown that the striations on the cloud top can influence the amount of scattered light, while McKee and Klehr (1978) showed similar results for a turret on top of a cubic cloud.

The above studies used Monte-Carlo simulations of finite clouds. While the Monte-Carlo technique is well suited to studies with finite cloud boundries, it is a very expensive and time consuming method. Faster analytical finite cloud methods have been developed, such as the delta-Eddington approximation to the radiative transfer equation by Davies (1978), but these models are constrained to a limited number of homogeneous geometric shapes and cannot handle problems such as cloud top texture or liquid water inhomogeneities within a cloud.

Building Block Finite Cloud Model

A new approach, conceptually similar to a three dimensional doubling or adding method, has been developed. The starting point of this model is the scattering properties of a small cuboid determined from a Monte-Carlo model. These initial cuboids are then stacked together, and the interaction between the cubes solved for. The simplest case of this method uses a Monte-Carlo simulation with an input flux illuminating one face of a cube to determine the percent of the input flux which exits the top, sides, and bottom surfaces. These initial cubes are then stacked together. The output fluxes from interior cubes are the input fluxes for their neighboring cubes. If there are N cubes, then a system of 6N linear equations are defined. By specifying the fluxes at the exterior boundries of the cloud, the equations can be solved using algebraic or iterative techniques. An iterative technique based on Newton's method was used in this study because of its speed and ease of solving large systems of equations. Running time of the model with a larger cloud formed from 1000 smaller cubes was approximately 30 seconds on a UNIVAC 1110. The non-vertical incidence of light was handled by decomposing the incident flux into vertical and horizontal components, and applying these fluxes normal to the top and side faces.

An error analysis of the model showed three main sources of error; the limited number of angles allowed, the discrete representation of gradients, and the convention of decomposing non-vertical incident flux into normal components. The errors associated with the discrete representation of gradients were shown to be small (generally less than 10%), but the limited number of angles caused significant problems in dealing with strong anisotropic scattering. Clouds with optical dimensions larger than 20 had errors of less than 10%, but smaller clouds had errors of up to 50%. While the building block model is not as accurate as Monte-Carlo models, it is generally comparable in accuracy with other rapid three dimensional multiple scattering models.

Model Results

The model has been used to investigate some of the finite cloud effects which can be associated with cloud brightness patterns observed by satellites. For homogeneous cube-shaped clouds with optical dimensions of 100, the model showed a brightness variation across the cloud with sharp gradients near the edges and a reasonably uniform brightness pattern across the top center regions of the cloud. As the sun was shifted toward the side of the cloud, the brightest part of the cloud top shifted toward the sunlit side. The model was also used to investigate the possibility of developing correction factors for applying plane parallel solutions to finite cloud situations. The model showed that the center portions of a finite cloud show the most consistent correction factors because the center is farthest from the edge effects. However, even the center values of the cloud departed significantly from plane parallel solutions so that care must be taken in applying plane parallel solutions to any part of a cloud.

The model was used to investigate the effects of liquid water inhomogeneities within a cloud. A concentration of liquid water at the cloud top (but still maintaining a flat top) will affect the scattered light by showing up as a bright spot for the overhead sun case. For large solar zenith angles the liquid water inhomogeneity had very little effect on the scattered light. When the liquid water concentration was placed lower down into the cloud, the bright spot diminished rapidly. When the liquid water concentration was an optical thickness 25 (about a kilometer) below the cloud top, the bright spot completely disappeared.

The model was also used to investigate the effects of cloud structure. For an overhead sun a cloud top turret appeared darker than the parent cloud. When the sun was near the horizon, the turrets appeared as bright spots. Cloud shapes such as approximate cylinders, truncated spheres, inverted paraboloids, and cubes all showed varying albedo relationships to solar zenith angle. The figures with the smaller cloud top dimension (even though the maximum dimensions were the same) showed lower albedoes for the overhead sun. For larger solar zenith angles, the albedos of the different shapes showed a greater similarity than for the overhead sun. Attempts at trying to model aircraft flux measurements of clouds showed that simulations using geometric shapes which closely resemble the observed shapes gave the best representation of the observed flux patterns.

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