The Apparent Bluing of Aerosols Near Clouds

Contributors

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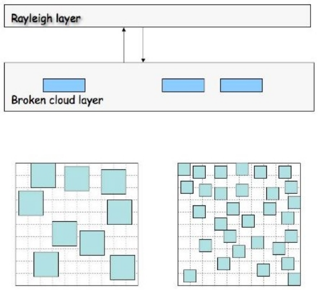
Research Highlight

Numerous studies based on satellite observations have reported a positive correlation between cloud amount and aerosol optical thickness (AOT). This positive correlation can be explained as a result of physical phenomena such as the humidification of aerosols in the relatively moist cloud environment or a transition between aerosol and clouds where the cloud signature is weak (evaporation and/or activation of cloud drops) and the distinction between cloudy and cloud-free air becomes problematic. On the other hand, part of the correlation can result from remote sensing artifacts such as cloud contamination of the cloud-free fields of view used in the aerosol retrievals.

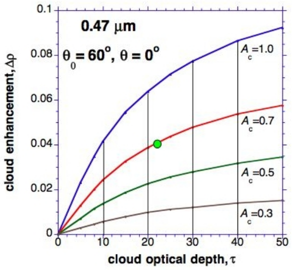
There are two ways that clouds affect the retrievals of aerosols: (i) the existence of small amounts of sub-pixel sized clouds in pixels identified as being cloud-free and (ii) an enhancement in the illumination of the cloud-free column through the reflection of sunlight by nearby clouds. When the pixels are relatively large, only the first type (cloud contamination) is considered. The second type (cloud adjacency effect) is more pronounced when satellite pixels are relatively small. Both cloud contamination and the cloud adjacency effect may increase substantially reflected radiation and thus lead to significant overestimates of the AOT. These two types of cloud effects, however, have different impacts on the retrieved AOT: sub-pixel clouds increase AOT by increasing the apparent contribution due to large particles (aerosol “coarse” mode), cloud adjacency mostly increases the apparent contribution due to small particles (aerosol “fine” mode). We have justified and quantified the second factor by using a simple stochastic cloud model to obtain the radiative flux reflected by broken clouds and comparing this flux with that obtained with the molecules in the atmosphere causing extinction, but no scattering.

A simple model was described for estimating the cloud-induced enhanced reflectances of cloud-free columns in the vicinity of clouds. The enhancement was assumed to be due entirely to Rayleigh scattering. For the shorter wavelengths where molecular scattering is relatively large, attributing the enhancement to the illumination of the Rayleigh scattering atmosphere by sunlight reflected from nearby clouds proved reasonable for scenes with dark surfaces, broken, low-level cumulus clouds, and an aerosol layer below the cloud tops. The enhancement in Rayleigh scattering was estimated using a stochastic cloud model (Fig. 1) to obtain the radiative flux reflected by broken clouds and comparing this flux with that obtained with the molecules in the atmosphere causing extinction, but no scattering.

The results of numerical simulations of the enhancement are in relatively good agreement with the simple model, although the model underestimates somewhat the enhancement for the particular scenes studied, cumulus cloud fields retrieved from collocated moderate-resolution imaging spectroradiometer (MODIS) and Atmosphere-Surface Turbulent



(upper panel) A schematic two-layer model of a broken cloud field and Rayleigh scatterers. (lower panel) An example of the Poisson distribution of broken cloud fields with cloud fraction Ac = 0.3 for a 10 by 10 km area. For a cloud vertical thickness of 1 km, the left lower panel has cloud aspect ratio # = 0.5, and the right lower panel has # = 1.



Cloud-induced enhancement ## and cloud optical depth for four cloud fractions, Ac = 1.0, 0.7, 0.5, and 0.3. The aspect ratio is # = 1, and the surface is black. As an example, the filled circle indicates the expected cloud-free radiance enhancement due to nearby clouds with #= 22 and Ac = 0.7.

Exchange Research (ASTER) images over a biomass burning region in Brazil.

The one-layer Poisson stochastic cloud model uses cloud optical depth, droplet single scattering albedo and scattering phase function, cloud fraction, cloud aspect ratio, and surface albedo to estimate reflectances for broken cloud fields. The optical depth and cloud fraction are given in the MODIS Cloud Product. They can be used as a first approximation to quantify the cloud-induced enhancement from precalculated look-up-tables (see Fig. 2, for an example). The cloud aspect ratio is not readily available but the error due to an incorrect cloud aspect ratio is 5-20% excluding very low sun and small cloud fractions. For clouds distributed in space according to a Poisson distribution, the average distance from a cloud-free pixel to the nearest cloud is determined uniquely by cloud fraction and cloud aspect ratio.

The assumption that the enhancement of the cloud-free column is due to molecular scattering leads naturally to a larger increase of AOT for shorter wavelengths, or to a "bluing" of aerosols near clouds. As a result, in contrast to cloud contamination by sub-pixel clouds, the cloud adjacency effect will increase the apparent aerosol "fine" mode fraction rather than the "coarse" mode fraction. We showed that the enhanced illumination of cloud-free columns is a key part of characterizing aerosol properties in the vicinity of clouds. In satellite based studies of cloud-aerosol interactions, changes in the properties of the aerosol due to the cloud environment must be separated from the apparent changes that come from three-dimensional cloud-radiative transfer effects on the retrieved aerosol properties.

Reference(s)

Marshak, A., G. Wen, J.A. Coakley, L.A. Remer, N.G. Loeb, and R.F. Cahalan, 2008. A simple model of the cloud adjacency effect and the apparent bluing of aerosols near clouds. J. Geophys. Res., 113, D14S17, doi: 10.1029/2007JD009196.

Working Group(s)

Radiative Processes