Impact of vertical and horizontal inhomogeneity on solar reflected radiance

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Abstract

Remote sensing of cloud parameters from a cloudy atmosphere is usually based on the assumption of plane parallel homogeneous clouds. Indeed, using this assumption in radiative transfer calculations for the solar spectral band leads to both random and systematic errors when infering cloud physical properties from radiance measurements. Cahalan et al. (1994) for example showed an underestimation of satellite based retrieved cloud optical thickness.

On the other hand radiative transfer calculations with a 3D representation of clouds show significant correlations between reflected solar radiance and cloud optical thickness for optically thin clouds only. This implies that a remote sensing of microphysical cloud parameters like cloud optical thickness or cloud particle radius as proposed by Nakajima and King (1990) must fail for most cloud occurences unless additional information of spatial cloud structure is available.

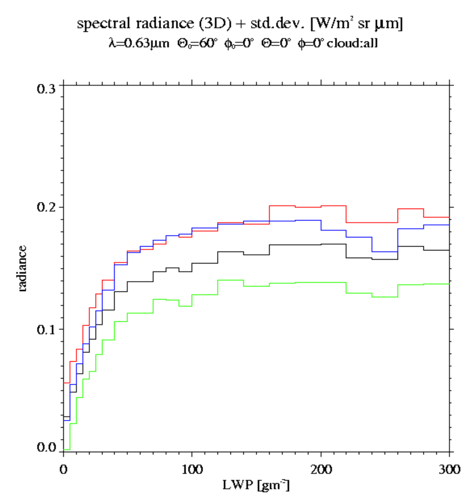


fig. 1: liquid water path vs. radiance for 3D cloud field

The present study accounts for cloud inhomogeneities in ground based and satellite based cloud remote sensing. Special attention is drawn to the impact of the vertical and horizontal cloud variability on the solar reflected radiances. The use of multichannel cloud remote sensing of effective radius and especially cloud optical thickness is investigated.

Model

The Monte-Carlo radiative transfer code MC-UNIK (Macke et al. 1999) is used to calculate monochromatic radiance fields of the various cloud scenarios. For reasons of variance reduction and computing time, applications as proposed by Barker et al. (2003) are implimented. The 'Local Estimate method', which is used in MC-UNIK, allows accurate calculations of reflected radiance fields for each wavelength and spatial weighting functions.

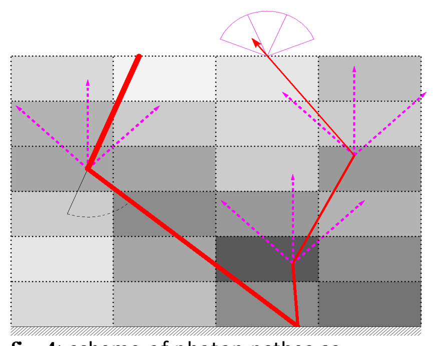


fig. 4: scheme of photon pathes as simluated in MC-UNIK

The method provides an allocation of reflected sunlight to each cloud layer or box where the scattering has taken place.

The 'Local Estimate Method' takes into account that a part of the photons is scattered directly into the detector at each scattering process. These photons are attenuated along the optical thickness between the scattering location and the detector.

The total reflected radiance as measured at the detector is a sum-up of all these portions during all scattering processes along the photon's history. To calculate vertical and horizon-tal weighting functions in a more efficient way, MC-UNIK has been further extended towards a backward scheme (MC-UNIK-BW). The detector can be placed every where below or above the cloud field. Therfore both ground based and satellite based measurement can be simlulated.

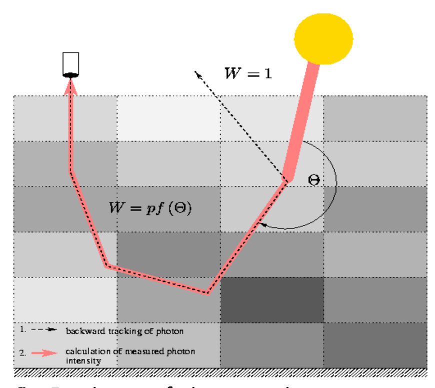


fig. 5: scheme of photon pathes as simluated in MC-UNIK-BW

Calculations for a 1D cloud

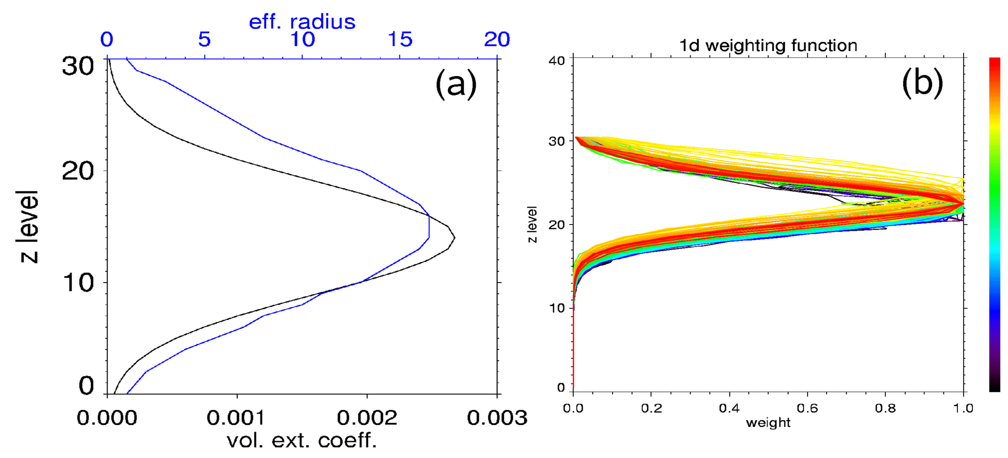


fig. 6: (a) vertical profile of vol. extinction coeff. and (b) associated spectral vertical weighting functions; (Θ_0, ϕ_0) = (0.0,0.0); (Θ, ϕ) = (0.0,0.0)

- MC-UNIK calculations of spectral highly resolved weighting functions ($\Delta\lambda$ = 0.025 µm).
- Most information of reflected radiance originates from upper portions of the cloud. (fig. 6)
- Only little spectral change in vertical weighting function. (fig. 6)
- Variation in vertical profile of extinct. coeff. while keeping τ fixed leads to different reflectances. (fig. 7)
- Reflected radiance is highly sensitive to changes in upper parts of the cloud. (fig. 7)
- Variation of both extinction and effective radius leads to increased reflectance. (fig. 7)

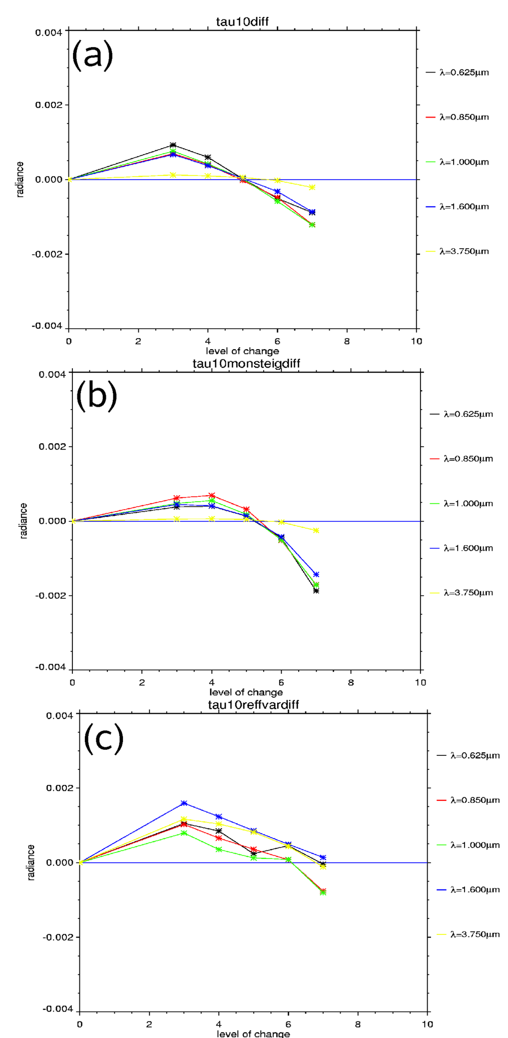


fig. 7: difference in refl. radiance vs. 'level of change' for (a) homogeneous profile with fixed r_{eff}, (b) stratified profile with fixed r_{eff} and (c) homogeneous profile with variable r_{eff}. Variation of extinction coeff +10% while optical thickness is kept fixed. (τ=10.0; (Θ_0, ϕ_0) = (60.0,0.0); (Θ, ϕ) = (0.0,0.0))

Clouds

For this study one- (1D), two- (2D) and three dimensional (3D) cloud fields are used.

For the 1D case a cloud column with a vertical profile of volume extinction coefficient β_x is applied. This profile is based on artifical Gaussian profiles that mimicks specific vertical distributions. For each layer a specific effective radius is used to obtain scattering and absorption properties.

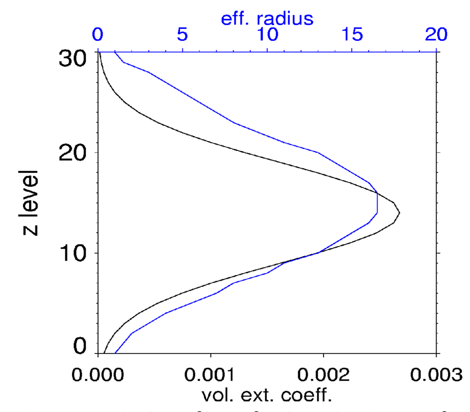


Fig. 2: vertical profiles of vol. extinction coef. (black), and effective radius (blue).

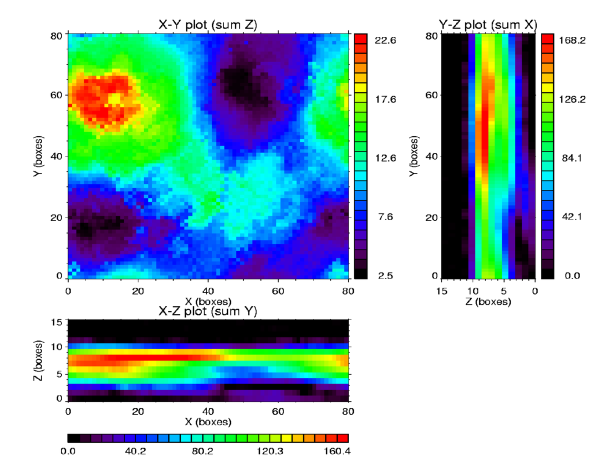


fig. 3: optical thickness distribution of 3D cloud field. sum-up in direction of third axis.

The Iterative Amplitude Adapted Fourier Transform Method (IAAFT) enables to create three dimensional cloud fields with predefined statistical properties (Venema et al. 2004). These statistical inputs originate from 1D measurements of liquid water path and cloud liquid water content as for example measured during the BBC campaign in Cabauw, The Netherlands, 2001. Like the 1D case the 3D cloud fields are described by extinction coefficient and effective radius specified for each grid box.

The 2D cases are generated as slices of the 3D cloud fields. These are used for a more distinct demonstration of effects due to inhomogeneities and in order to save computing time during the radiative transfer calculations.

Calculations for a 2D cloud

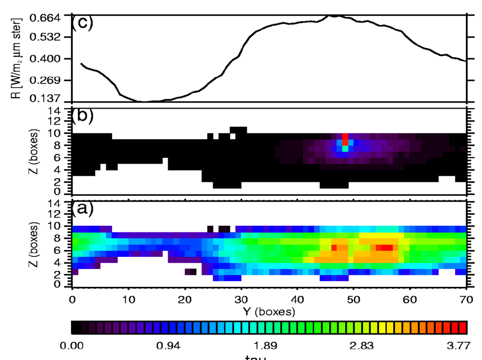
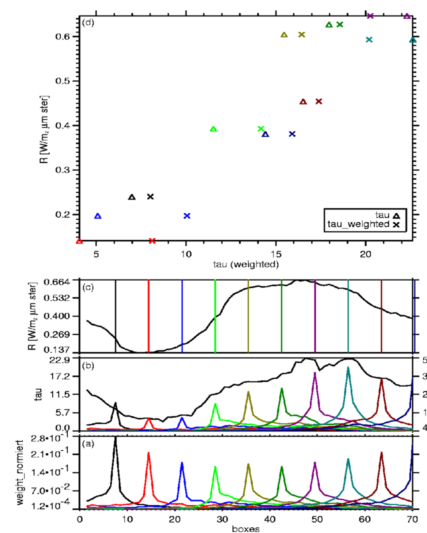


fig. 8: (a) distribution of optical thickness, (b) distribution of weighting functions and (c) associated radiance field.

- Volume of influence on solar reflectance is small and depends strongly on solar and viewing zenith angle.
- Photons leaving the cloud contain information on the cloud structure only from the very upper part of the cloud and a very nearby area around the leaving location. (fig. 8)

- Comparison of the weighting function belong-ing to each detector with entire field of optical thickness provides 'true' optical thickness. (fig. 9)
- Mean 'true' optical thickness contains informa-tion of all cloud areas contributing to reflected radiance. (fig. 9)


(d) mean (true) optical thickness vs. reflected radiance

(c) reflecetd radiance and detector positions

(b) optical thickness and weighted optical thickness

(a) normalized weighting functions

fig. 9: results for 10 detectors:

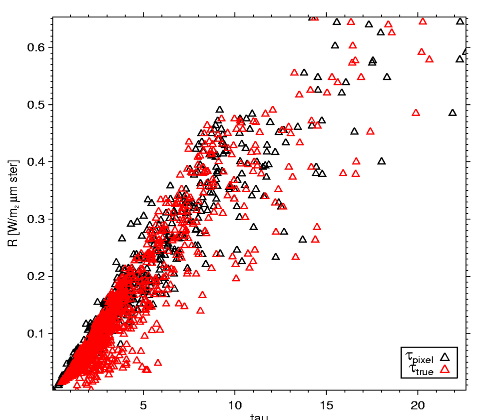


fig. 10: mean (true) optical thickness vs. reflected radiance

- This combination enables to describe the radiance - cloud relation not only on pixel-scale but with respect to the whole area.
- Consideration of volume of influence leads to a slight improvement in the relation between reflected radiance and optical thickness. (fig. 10)
- Nevertheless the entire 3d effect can not be explained. Additional information is required.

Outlook

- To enable remote sensing with respect to the entire 3D effects additional information is required.
- The variance in the radiance field alone (structure functions) is not sufficient.
- Accelerated MC-UNIK enables to account for more cases of sophisticated cloud model (e.g. IAAFT or GESIMA (Eppel et al. 1995)) results.
- Non-linear regressions like Neural Networks will be used to find correlations between reflected radiance and cloud properties with respect to sun and viewing geometry.

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