High Speed Cloud Optical Depth Retrievals from a Narrow Field of View, Narrowband, Shortwave, Zenith Pointing Radiometer

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Introduction

The Atmospheric Radiation Measurement (ARM) Program has recently deployed a new, shortwave, Narrow Field of View (NFOV) Zenith radiometer at the Southern Great Plains (SGP) facility. The instrument measures the Zenith NFOV radiance at 870 nm, with a 10-nm full-width at half-maximum (FWHM) and field of view (FOV) of 5.7°. Data from this instrument are simulated using a simple Monte Carlo radiative transfer model. From these simulations, the zenith, NFOV, cloud optical depth for liquid water clouds is retrieved.

Procedure

A Monte Carlo radiative transfer model is applied as shown in Figure 1 to simulate the signal received by the NFOV sensor. The model assumes a plane-parallel cloud with a uniform size distribution of cloud drops. These cloud drops are assumed to have a single-scattering albedo, ϖ_0, of 0.999 and assume a Henyey-Greenstein phase function asymmetry factor, g, of 0.875.

Monte Carlo radiative transfer calculations are performed for a range of solar zenith angles (SZAs) and cloud layer properties (Danielson and Moore 1969). A lookup table, shown graphically in Figure 2, is used to convert measurements of nadir radiance to cloud optical depth. For the December 20 case, the model is run for a range of μ_0 from 0.2 to 0.5, where μ_0 is the cosine of the SZA. In the case of a simple plane-parallel geometry, the nadir radiance is a double valued function of optical depth.

From the lookup table, we produce a time series of zenith optical depth with a temporal resolution of 1 Hz. At this temporal resolution, even low clouds are oversampled.

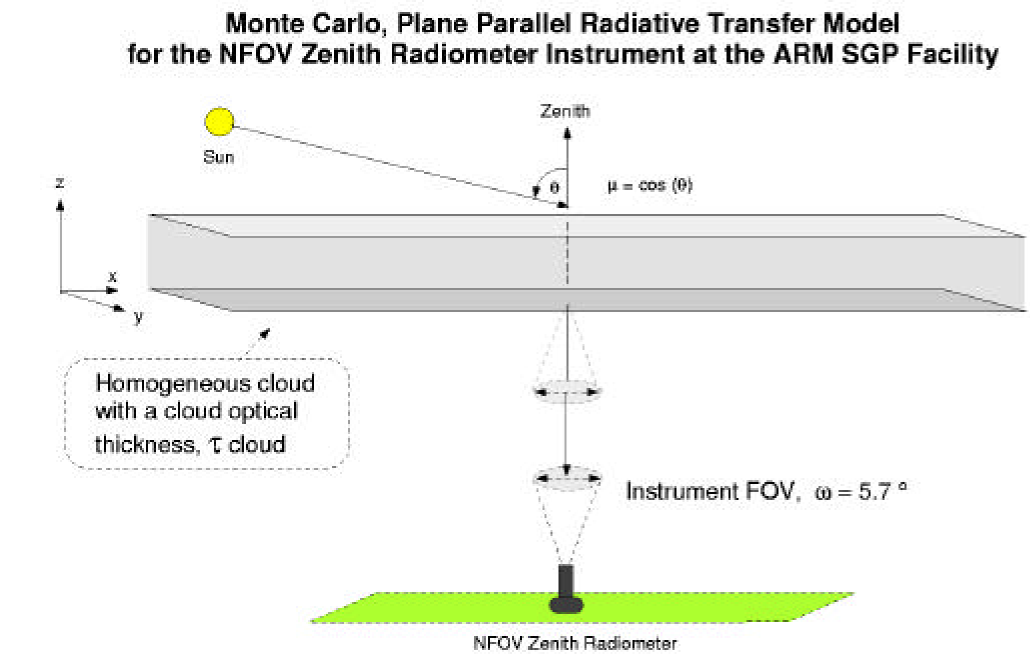

Figure 1. The conceptual model used to simulate the radiative transfer for the clouds in the December 20, 1998, case study.

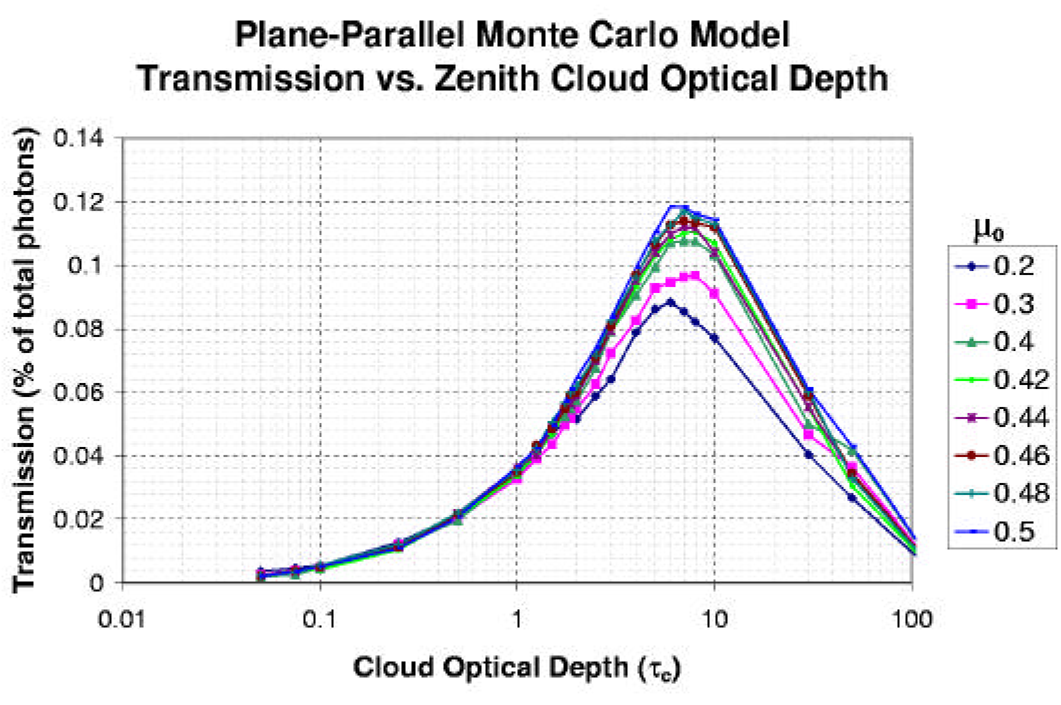

Figure 2. Monte Carlo model simulated transmission into a zenith 5.7° NFOV cone for a range of zenith cloud optical depths, $\tau_{c,}$ versus the cosine of the SZAs, μ_0.

Case Study: December 20, 1998

A deck of warm stratus covered the ARM SGP site for 12 hours starting at 12Z. Figure 3 shows that Millimeter Wave Cloud Radar (MMCR) and Ceilometer estimated cloud base at 300 m and cloud top at 1500 m to 2000 m yielding a cloud deck 1200-m to 1700-m thick (Clothiaux et al. 1994). Atmospheric profiles over the SGP, shown in Figure 4, indicate that for cloud levels, temperatures were above 273°K, at least for the onset of the stratus deck. The MMCR did not detect clouds above this stratus deck after 12Z. The NFOV Zenith radiometer and Microwave Radiometer (MWR) signals are shown in Figure 5.

Figure 6 shows the derived zenith cloud optical depths, τ_c, where τ_0 is greater than 0.3. For this particular case, the derived τ_c was assumed to be the larger of the two potential solutions along the radiance curve. The first three hours indicate τ_c between 30 and 55. The second three hours indicate τ_c ranging from 65 to 85. There probably was some drizzle present in the second three-hour period. However, rain rate instruments during this period did not indicate any measurable precipitation.

Figure 7 shows the results of a rapid radiation transfer model (RAPRAD) using the values of τ_c, 14Z profile in Figure 4 and cloud boundaries derived from Figure 3. The calculations are compared to measurements of the downwelling solar flux by the Baseline Surface Radiation Network (BSRN). For this preliminary study, the results match up quite well.

Conclusions

For this stratus case, the cloud optical depths when used in RAPRAD produce reasonable fluxes as measured by the BSRN. Although this is very preliminary work, these results indicate the potential for deriving high temporal resolution cloud properties from this simple, NFOV, narrowband radiometer measurement.

Future Work

Potential improvements to retrieval include:

- In order to deduce which of the two cloud optical depths is correct for a given scenario, an analysis of the concurrent MWR radiances and the broadband, downward solar flux measurements is planned.

- The retrieval matrix can be improved by increasing the number of SZAs and increasing the photon count per run to solidify the model statistics.

- Different cloud-atmosphere radiative transfer models will be explored as alternatives to the Monte Carlo to improve the calculation speed.

- A simple ice cloud model will be explored.

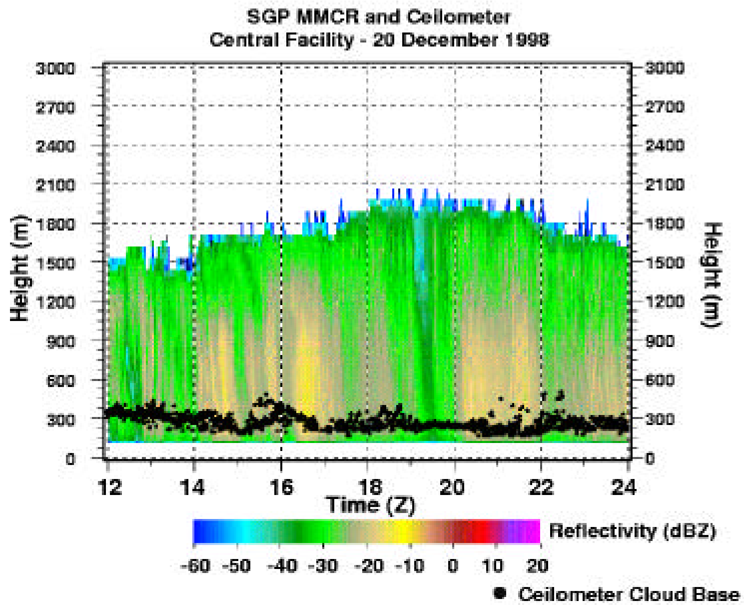

Figure 3. MMCR and Ceilometer best estimate of cloud boundaries at the ARM SGP central facility for December 20, 1998.

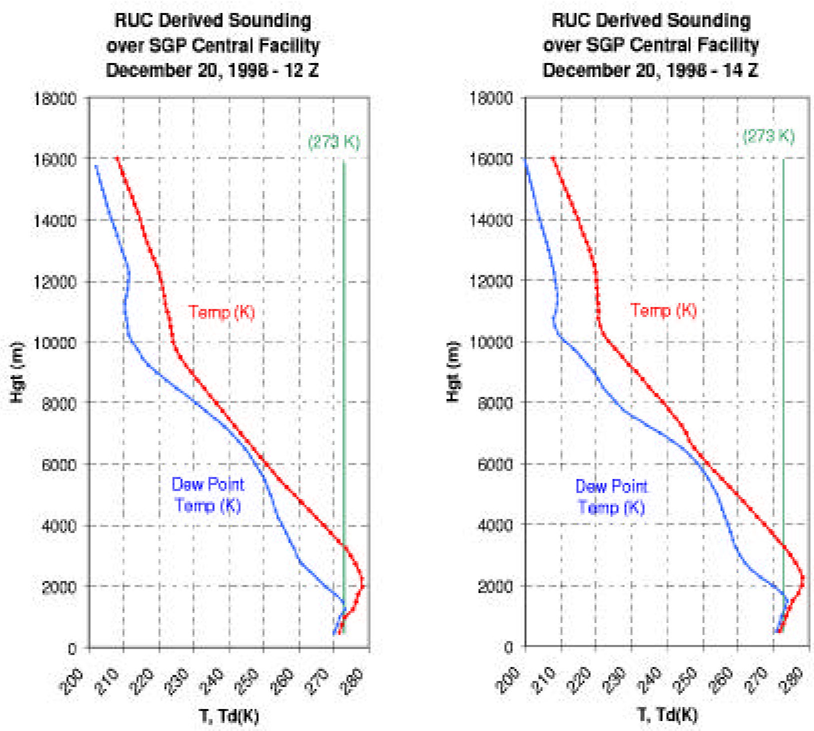

Figure 4. Rapid Update Cycle (RUC) model derived profiles of the vertical structure above the ARM SGP central facility at 12Z and 14Z on December 20, 1998. Notice that at cloud levels (300 m to 2000 m) that the temperature was above 273°K. Note: There were no radiosondes available from the SGP on this date.

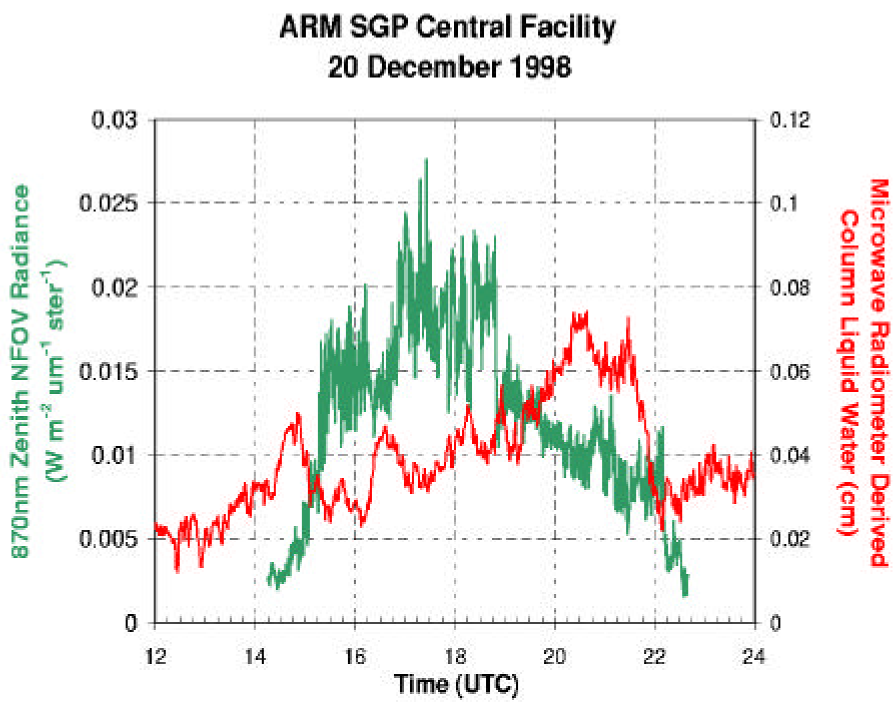

Figure 5. The NFOV radiance and the MWR derived column water.

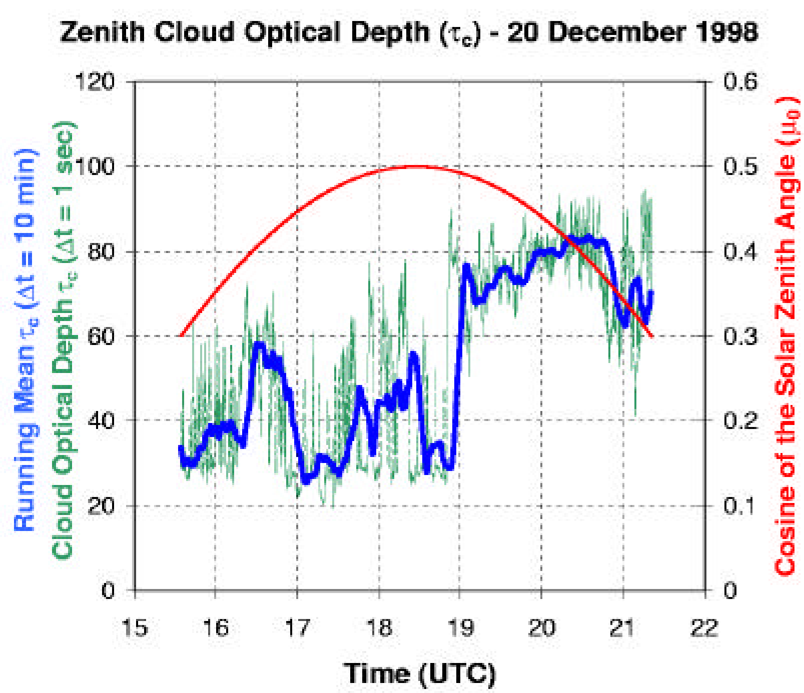

Figure 6 $_c$) for the December 20, 1998, case where τ_0 is greater than 0.3.

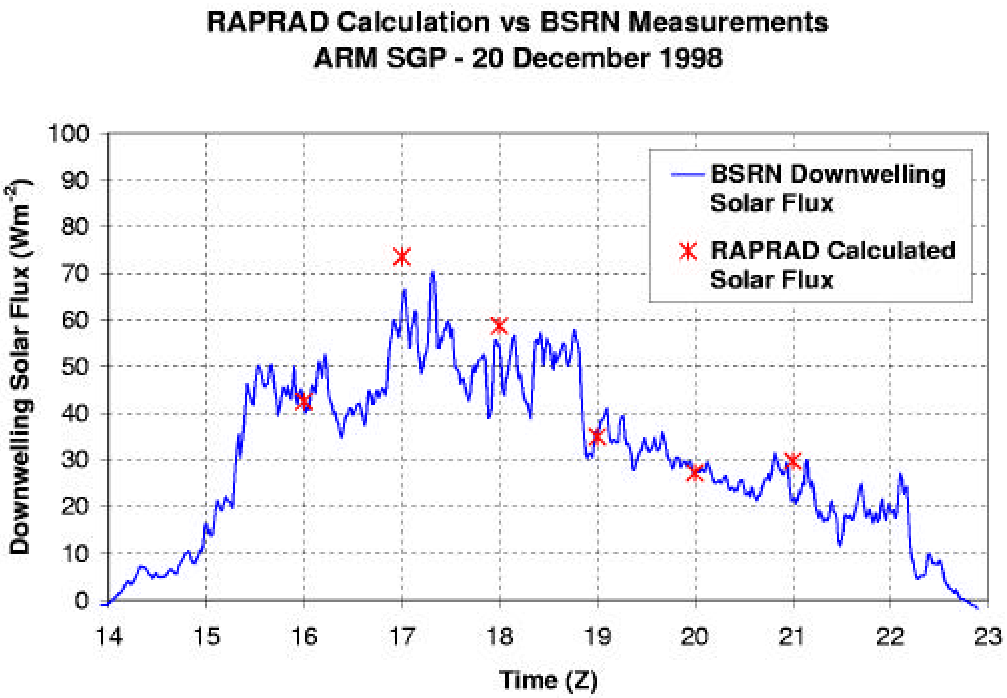

Figure 7. Results from the RAPRAD compared to measurements of the downwelling solar flux by the BSRN.

The temporal signal from the NFOV radiometer will be explored as a means of obtaining cloud structure information.

Acknowledgments

The author wishes to thank John Schmeltzer at the Pacific Northwest National Laboratory for information regarding the operation and calibration of the NFOV instrument.

References

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