RETRIEVAL OF CLOUD OPTICAL PROPERTIES FROM AVHRR FOR USE IN A COMBINED PROCESSING OF AVHRR AND AMSU

A. Thoss, R. Bennartz and J. Fischer
Institute for Space Sciences
Free University of Berlin
Germany

1 INTRODUCTION

High resolution AVHRR data can be used to explain signatures measured in HIRS and microwave fields of view. Techniques determining the cloud cover within the HIRS field of view to improve the quality of temperature and humidity soundings are widely used. The aim of this study is to prepare for a more detailed use of multispectral data in visible, IR and microwave frequencies. NOAA-K will be the first satellite on which such a large range of frequencies will be flown, which will yield easily accessible global data sets for all frequencies. The spectral information contained in AVHRR data shall be used to help explain signatures which will be detected in AMSU fields of view. A final algorithm will have to merge spectral and spatial information gained from AVHRR for AMSU-A and AMSU-B fields of view. The interest of this study, and a compagnion paper in this volume by Bennartz et.al., is mainly to concentrate on cloudy and precipitating cases. A lot of climatologically valuable information on cloudiness, liquid water content (LWC), precipitation and microphysical cloud parameters will be contained in this data, even for cases which will have to be rejected for sounding.

This part of the study concentrates on radiative transfer simulations of AVHRR channels for liquid water cases only. Extensive use is made of the scattering properties in the solar frequencies. For retrieval of microphysical parameters the usefulness of both the 3.7μm and 1.6μm channels is evaluated. As a measure of the microphysical information content it is investigated, how well the effective cloud droplet radius can be retrieved from simulated AVHRR data under different assumptions about sensor noise.

2 METHOD

2.1 Radiative Transfer Model

The radiative transfer model used for the simulations is the matrix operator model of the Institute for Space Sciences. It is an adding and doubling model for plane parallel media for the solar and infrared part of the spectrum (Redheffer,1962, Plass et al 1973, Wiscombe 1976, Fischer and Grassl 1991). The advantage of the method is that all orders of scattering are treated simultaneously, and it is thus also applicable to optically thick media. Despite this, simulations are still time consuming.

Calculations can be performed azimuthally resolved for a range of viewing and sun geometries. In this study only nadir viewing angles have been considered for different sun zenith angles. The absorption by atmospheric gases is treated by an exponential sum fit of transmission functions (Armbruster and Fischer, 1996). The transmissions themselves have been calculated from the Hitran92 database. The continuum absorption is parametrized in a similar way as in MODTRAN, with slightly higher absorption for the water vapour continuum.

2.2 Simulations for AVHRR Channels

Simulations have been performed for NOAA-11 channels ch1 (0.57 - 0.70μm), ch4 (10.35 - 11.30μm) and ch5 (11.4 - 12.4μm) using halfpowerpoints. The 3.7μm channel (here termed channel 3b in correspondence to the nomenclature of NOAA-K) had to be approximated more precisely using simulations for 0.1μm intervals between 3.5 - 4.0μm and folding the results with the filterfunction. For NOAA-K the 1.6μm channel has been simulated using halfpower points (1.58 - 1.64μm). About 500 simulations were performed for water clouds in a midlatitude summer atmosphere over ocean (albedo set to zero for all channels). The effective radius was assumed to be constant within the cloud and varied between 2μm and 20μm in steps of 2μm. Cloud top height was varied randomly between 200m to 4000m, cloud geometrical thickness varied between 100m and 1500m. Cloud optical thickness was varied randomly between 1 and 55 for a reference wavelength of 0.55μm. Extinctions higher than 30/km were excluded, which resulted in maximum liquid water contents of 0.5g/m^3.

2.3 Retrieval of Optical Thickness and Effective Radius

AVHRR channel 1 at 0.635μm is predominantly influenced by the cloud optical thickness (see Figure 2). The functional relationship between the optical thickness and upward radiance has been approximated by a polynominal fit of the 6th degree for different classes of sun zenith angles (see Figure 1 for a sun zenith angle of 35^o). Channel 3a at 1.6μm and - to a lesser degree - channel 3b at 3.7μm are influenced by both the optical thickness and effective radius (Figure 2). The solar component of the radiance is approximated by linear regressions for different classes of optical thickness and sun zenith angles. For the 3.7μm channel a considerable part of the radiation stems from thermal emission. Applying an algorithm to real data, this thermal part will have to be estimated and corrected. For the simulated data, a correction of the thermal part of radiance in channel 3b was achieved by performing a bilinear regression to the channels 4 and 5. However, without using prior knowledge of the effective radius, the simulated and estimated thermal radiance in channel 3b only have a correlation coefficient of 0.73. Correlations improve drastically to 0.93 and better if the effective radius was known. The retrieval thus consisted of the following steps:

- 1) Add gaussian noise to the simulated radiances
- 2) Retrieve the optical thickness from channel 1
- 3) Estimate thermal part of the radiance of channel 3b from the thermal channels 4 and 5 and substract it from the total radiance

- 4) Retrieve the effective radius from channel 3a or 3b respectively

Iterating between retrieval steps two to four did not yield better results for the retrieval of effective radius, despite the uncertanties for thermal correction of channel 3b.

The noise was added according to the specifications given in Table 1. Two retrieval scenarios were performed:

- Add a gaussian noise which is constant in radiance (constant noise)
- Add a gaussian noise according to the signal/noise ratio

The constant noise scenario is more realistic if only sensor noise is considered. However, other effects like uncertainties in the calibration of the visible channels, are not yet accounted for. To evaluate the potential of the different channels for physically meaningful retrievals, it would be advantageous if noise specifications were published which span the whole range of expected radiance values.

Channel	Noise Specification
1	S/N 9:1 @ 0.5% Albedo
3a	S/N 20:1 @ 0.5% Albedo
3b	S/N 0.12K @ 300K
4	S/N 0.12K @ 300K
5	S/N 0.12K @ 300K

Table 1 : Noise specifications for AVHRR channels assumed in this study

3 RESULTS

The principle dependencies of the radiances on the effective radius for the solar part of the spectrum can be seen in Figure 2. For effective radii smaller than $4\mu m$ there are ambiguities for low optical thickness. They can be found for both $1.6\mu m$ and $3.7\mu m$. They are caused by the behaviour of Mie scattering particles. For a size parameter of about five, the extinction efficiency is close to its maximum. This behaviour shows most clearly when there is a significant amount of single scattering, as can be found for low optical thickness. Because of these ambiguities, effective radii of $2\mu m$ have been excluded from the original simulated data set. Another limiting factor was found for high sun zenith angles when using the $3.7\mu m$ channel (see Figure 3). In these cases the signal from the reflected solar radiance was as low as the thermal correction applied, and all information on cloud microphysics was lost due to the uncertanties in correction and the very small solar signal. Results displayed here are therefore restricted to a realistic range of sun zenith angles between 19.0^0 and 66.5^0. Figures 4 and 5 show the retrieval results for effective radius under the "constant noise" assumption. Retrievals are more accurate for the $1.6\mu m$ channel, with a standard deviation for the effective radius of $1.6\mu m$ compared to 2.0 μm for the $3.7\mu m$ channel. However, retrieval results depend strongly on the noise characteristics and noise level assumed. If the signal/noise scenario is assumed, the quality of the retrieval from channel 3b is only marginally affected (by a less accurate estimation of optical thickness from channel 1), but the effective radius retrieval from channel 3a becomes almost useless with a standard deviation of 3.5μm (Figures 6 and 7). If both channel 3a and 3b were available simultaneously, only a slight improvement is seen in the retrieval of the effective radius in the constant noise scenario for the water clouds simulated here (standard deviation 1.5μm compared to 1.6μm for channel 3a alone). Again, these results depend crucially on both the noise assumed and on the quality of the thermal correction applied to channel 3b.

4 FUTURE WORK

The simulation data set used here will have to be extended to cases for ice clouds and mixed ice/water clouds. Some preliminary simulations showed that there is some potential to discriminate between pure water and ice clouds in both the 1.6μm and 3.7μm channels. The applicability of the simulation results will also be tested on NOAA-11 AVHRR data. A final simulation data set will then be composed to cover the same cases, including precipitation, for both AVHRR and AMSU channels (for independent AMSU simulations see paper of Bennartz et. al. in this volume).

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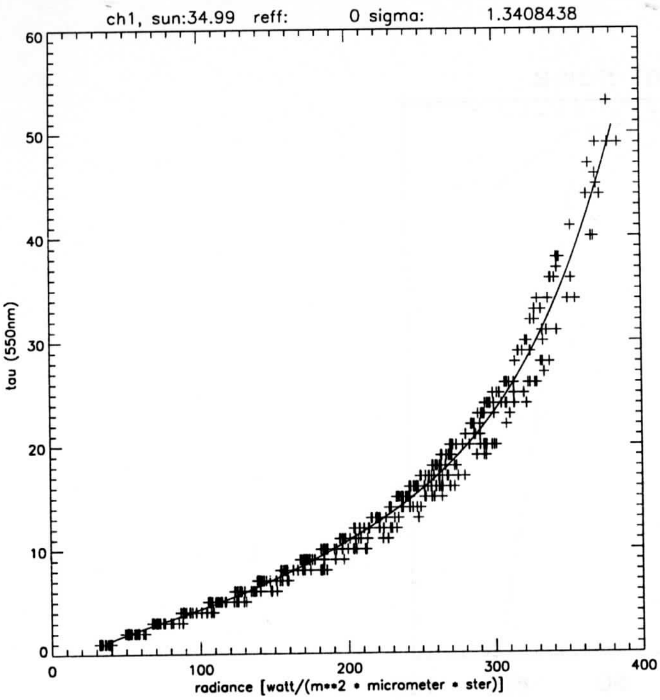

Figure 1 : Simulated radiance AVHRR channel 1 versus optical thickness for all effective radii from 4μm to 20μm and a sun zenith angle of 35^o.

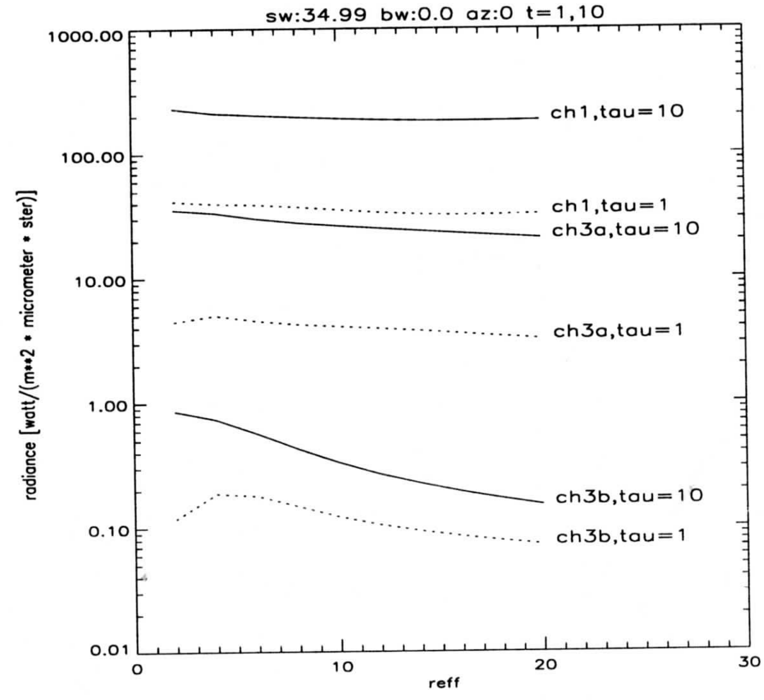

Figure 2 : Simulated solar radiance for AVHRR channels 1,3a and 3b at a sun zenith angle of 35^o for optical depth=10 (solid lines) and 1 (dotted lines).

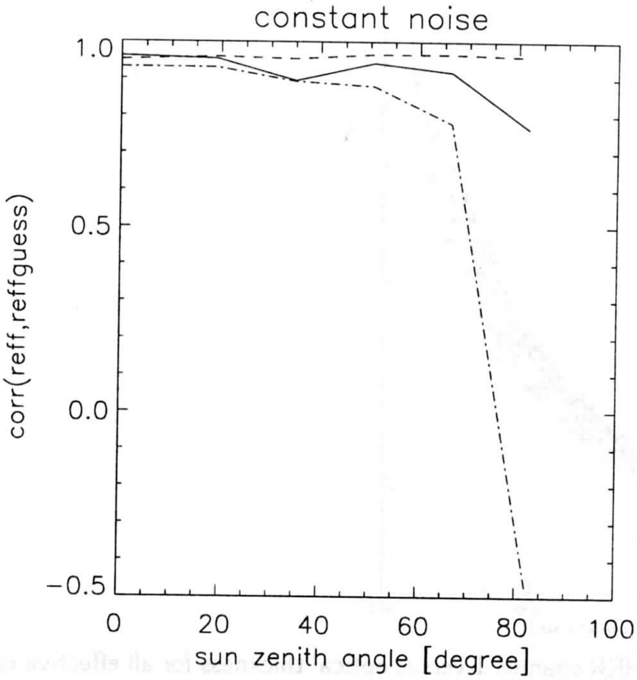

Figure 3 : Correlation of simulated and retrieved effective radius under constant noise assumption for different sun zenith angles. Dashed: channel 3a, solid: channels 3a and b together, dash-dotted: channel 3b. All data in channel 3b is corrected for thermal emission .

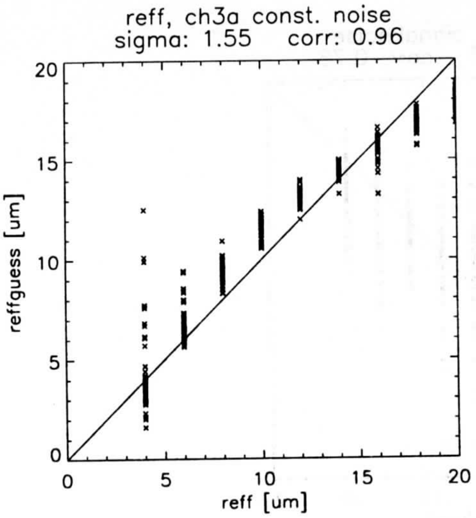

Figure 4 : Simulated versus retrieved effective radius for sun zenith angles between 19°- 66.5°. Effective radius retrieved from channel 3a under constant noise assumption.

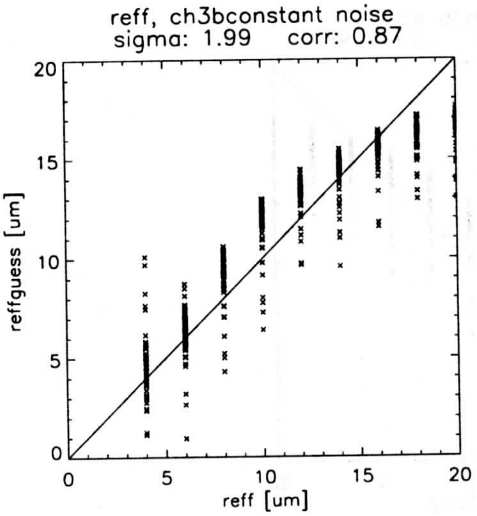

Figure 5 : Same as figure 4 but for thermally corrected channel 3b.

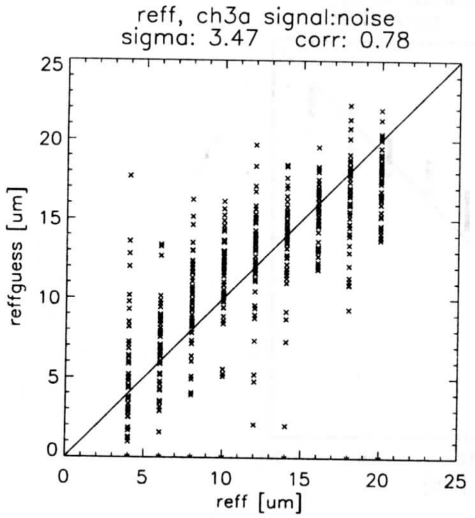

Figure 6 : Same as figure 4 but for signal:noise assumption.

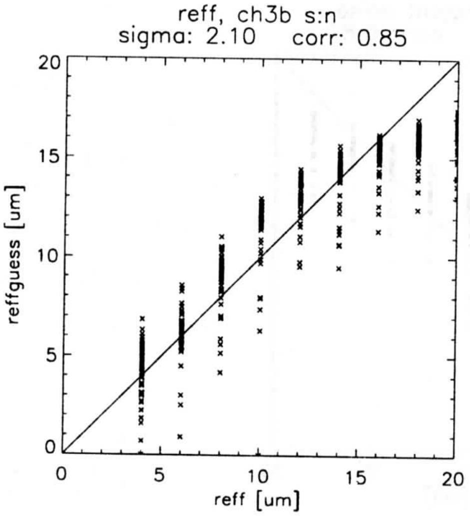

Figure 7 : Same as figure 5 but for signal:noise assumption.

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