J.P1.12 A METHOD FOR THE DETERMINATION OF CLOUD PARAMETERS USING NIGHTTIME MODIS IMAGES

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1. ABSTRACT

A method is presented for determining the optical thickness, effective particle radius and temperature of stratiform water cloud layers from infrared measurements. The method is based on a forward radiative transfer model combined with a numerical inversion technique called "*scatter* search". We present results which show that the radiative model proposed is able to explain the brightness temperatures detected by the MODIS sensor in the infrared spectral channels. The method is applied to satellite data coincident with the DYCOMS-II field campaign. Comparison with in-situ measurements show that the retrieval is capable of detecting relative variations in droplet size, although retrieved droplet effective radii are smaller than aircraft measured values.

2. INTRODUCTION

Satellite remote sensing techniques have shown the capability to measure climatically important cloud parameters on a global scale. The retrieval of cloud optical and microphysical properties from AVHRR or AVHRR-like wavelengths has been the focus of many studies (Arking and Childs, 1985, Nakajima and King, 1990, Nakajima and Nakajima, 1995). However, most of these techniques are limited to daytime data, because they rely on the fact that the cloud visible reflectivity is mainly governed by optical thickness, while the radiance received in an absorbing band is primarily a function of droplet size. During nighttime, the retrieval procedure is more complex, because the radiances received in the middle and thermal infrared bands depend on all cloud parameters. Methods applied during nighttime (Baum et al., 1994, Pérez et al., 2000, González et al., 2002), use temperature differences between channels 3, 4 and 4,5. These methods are based on the fact that the optical properties of clouds are different at each wavelength examined. In addition, these techniques could be improved with the data provided by next generation satellites. For example, the MODIS sensor on board EOS-AM1 (Terra) satellite which provides information in 36 spectral bands, 16 of them in the region 3 -14 µm. Below, we propose a method to retrieve cloud properties using these infrared channels. In Section 3, we present the theoretical radiative transfer model used to simulate Top of Atmosphere (TOA) brightness temperatures from cloud and atmospheric parameters. In Section 4, we describe the numerical method used to invert the theoretical model . Then, in Section 5 we present the sensitivity analysis performed to the method and after that, in Section 6 we show the results of applying the procedure to actual data. Finally, in Section 7, a summary is presented.

3. THEORETICAL TRANSFER MODEL

In this section we describe the radiative transfer model used to simulate the radiances at TOA from cloud parameters and atmospheric conditions. The model presented here consists of a 3 layers atmosphere above a sea-surface with an emissivity of 1, and an homogeneous cloud layer located at a height "h" over this surface. The cloud is assumed to be within an absorbing and emitting atmosphere considered composed only of water vapour following a known vertical profile, obtained through standard atmospheric models, soundings or using the MODIS profile retrieval algorithm (Menzel and Gumley, 1998). Although the normalized water vapour distribution is assumed to follow this profile, the total amount is an input to the model. These assumptions limit the number of channels to be used in the procedure, since some of the MODIS infrared channels are strongly affected by other gaseous species such as CO_2, N_2 or O_3. In our case, the selected bands are: 20 (3.660–3.840 µm) ,21 (3.929-3.989) ,22 (3.929-3.989), 29 (8.400-8.700) ,31(10.780-11.280 µm). We have also discarded those channels strongly affected by the "striping effect" detector noise (although residual striping remains in some channels).

The stratiform cloud layer, assumed plane-parallel, is composed of spherical water droplets, modelled using a gamma size distribution (Hansen and Travis, 1974), represented with the effective radius r_{eff} defined as:

$$r_{eff} = \frac{\int_0^\infty r^3 n(r) dr}{\int_0^\infty r^2 n(r) dr} \qquad (1)$$

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In addition, the geometrical cloud thickness and the total number of particles are expressed using the optical thickness τ, defined as:

$$\tau = \int Q_e(r/\lambda)\pi r^2 n(r)\,dr\,\Delta h \qquad (2)$$

This parameter will be specified at 0.55µm and the corresponding optical thickness at whatever wavelength λ is scaled according to the ratio of the extinction cross section:

$$\tau(\lambda) = \frac{Q_{ext}(\lambda)}{Q_{ext}(0.55\mu m)}\,\tau(0.55\mu m) \qquad (3)$$

For each droplet distribution, the single scattering properties are computed using Mie scattering theory (Wiscombe, 1980), while the model used for the solution of the radiative transfer equation in the cloud layer is an optimised form of the discrete ordinates method called DISORT (Stamnes et al., 1988, Tsay et al., 1990), which includes the effects of multiple scattering, absorption and emission within the layer. Therefore, from cloud layer properties, effective radius, optical thickness and cloud temperature and the total water vapour amount in the column, we can simulate the radiances in the TOA assuming known the surface temperature. This sea surface temperature is determined using a traditional split-window technique using clear-sky pixels.

Using this theoretical model, multiple simulations have been carried out to observe the sensitivity of each spectral channel to variations in the cloud and atmospheric parameters. Figure 1 shows some results of these simulations where we have displayed the channels more sensitive to each parameter. We have presented these results in terms of brightness temperature differences (BTD's) between channels, keeping as reference the channel 31 temperature. As expected, the scattering processes predominate in the mid-infrared region, and absorption in the thermal infrared. In addition, we can observe how the atmospheric water vapour absorption can be inferred from channels located in the water vapour absorption bands, such as channel 29. In these figures, we have superimposed actual satellite data corresponding to one of the flight days (Rf06) of DYCOMS-II field experiment (Stevens et al., 2002). The theoretical model brackets the data distribution in the selected infrared channels.

4. INVERSION PROCEDURE

Given the forward radiance model, the next step is the determination of the model parameters from the spectral satellite radiances. Due to the complexity of the direct model, the inversion must be done numerically. We defined a cost function that accounts for the differences between simulated and satellite measured brightness temperatures:

$$Cost = \sum_i \left(T_{model,i} - T_{satellite,i}\right)^2,\quad i=\{20,21,22,29,31\} \qquad (4)$$

Thus, for every pixel, the retrieved cloud properties are those which minimize this function.

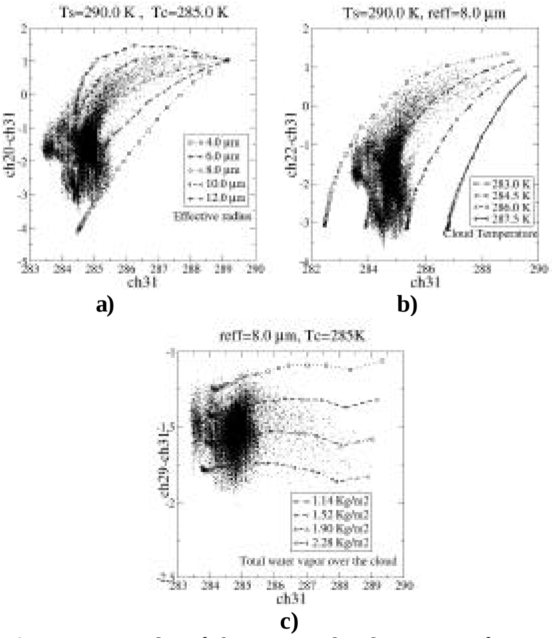


Figure 1. Results of the proposed radiative transfer model simulations applied to Flight Rf06. a) Effect of variations in effective radius on $BTD_{20\text{-}31}$. b) Sensitivity of $BTD_{22\text{-}31}$ to variations in cloud temperature and c) behaviour of $BTD_{29\text{-}31}$ upon varying the water vapour total amount over the cloud.

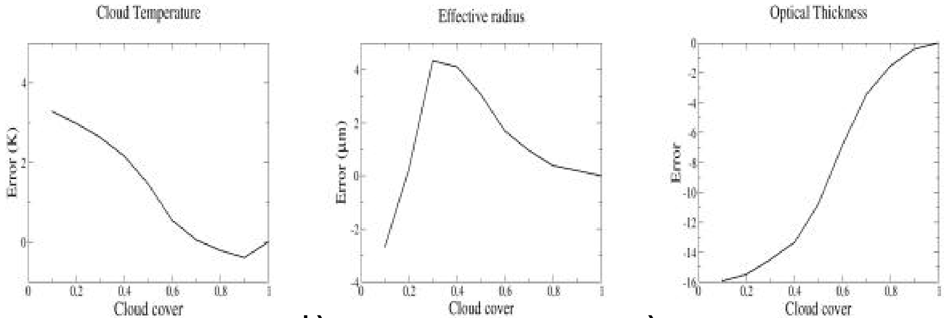
The cost function possesses a single global minimum and multiple local minima. To cope with these local extremes we have selected a method called "*scatter search*" (Glover et al., 2002) which can be considered an evolutionary technique similar to genetic algorithms, with the contrast that it provides unifying principles for joining solutions based on generalized path constructions in Euclidean space. So, from each pair of individual solutions generated initially, linear combinations are calculated to generate new solutions. From all the members of the new population, two criteria are applied to choose the survivors: both high quality (those that provide the lower values of the cost function), and diversity (those with the largest distances to the best solutions)

An heuristic process is applied to improve the solutions, using a classical Nelder and Mead's simplex method. After a few generations, the method finds the set of parameters that minimize the cost function.

5. SENSITIVITY ANALYSIS

The uncertainties in determining the cloud parameters can be categorized as originating in either the model used to compute the theoretical TOA temperatures or in the physical uncertainties due to instrument errors and atmospheric effects. In this section, we focus on the analysis of model uncertainties. The other uncertainties have been evaluated in Pérez et al., 2000.

As we described in Section 3, two assumptions were made in the radiative model: The determination of the sea-surface temperature and the fully cloudy pixel assumption. We have carried out simulations to evaluate the impact of these considerations. From these simulations, we can deduce that the largest errors appear in those situations where partially cloudy pixels are assumed to be fully cloudy, while errors introduced by uncertainties in the determination of sea temperature are smaller. In figure 2 we show the errors in the retrieved parameters varying the cloud cover from 0.1 to 1. We can observe that large errors occur for cloud fraction less than 80%.



a) **b)** **c)**

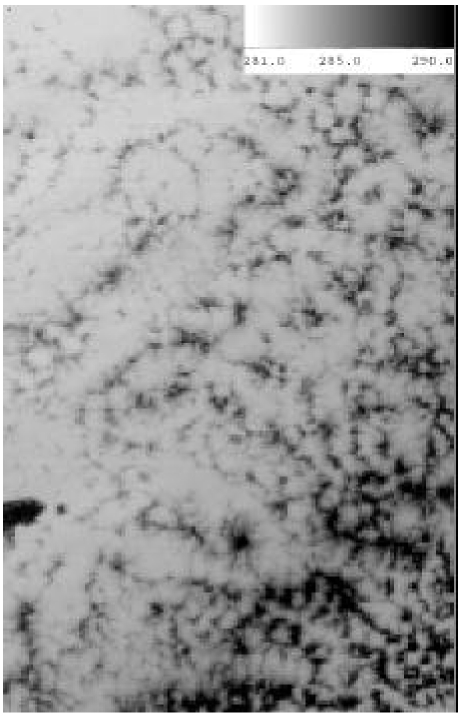
Figure 2. Errors in the retrieved parameters for cloud covers varying from clear-sky to totally covered pixels a) Cloud Temperature, b) Effective radius, c) Optical thickness.

6. RESULTS

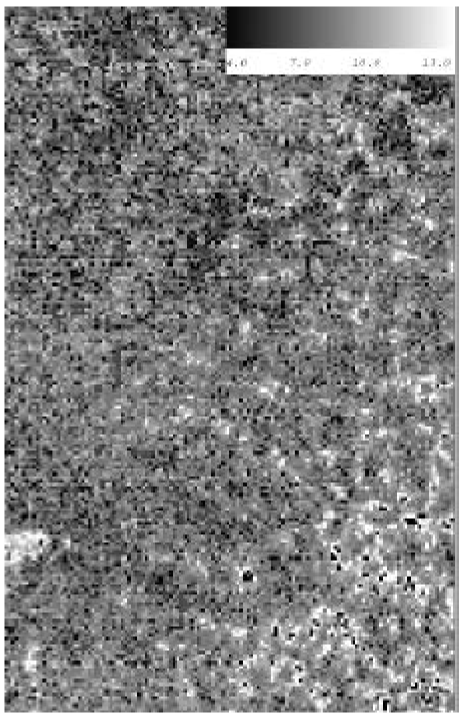
The described method was applied to satellite images for which almost-coincident airborne observations were obtained during the DYCOMS-II field experiment. Figure 3 shows the results obtained applying this procedure to the MODIS image corresponding to Rf05 flight, July 18th, 2001, (figure 3.a). Note some noise in the retrieved images, due to "striping" present in some of the selected channels, which considerably affects the retrieval procedure.

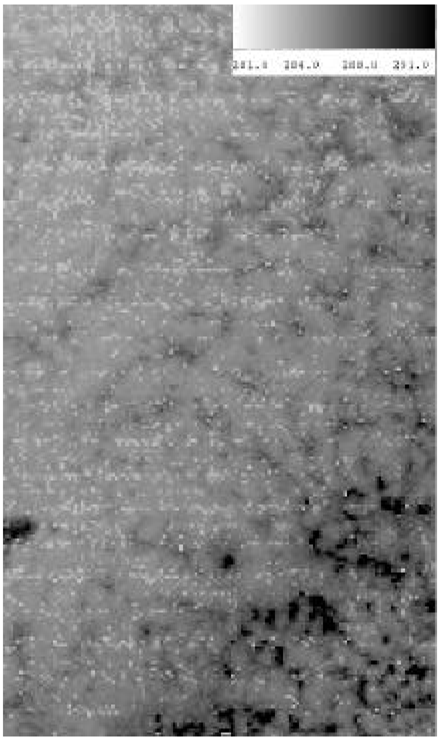
Furthermore, analysing the retrieved effective radius, we observe that the retrieved values are homogeneous (about 8 μm) except in linear tracks in where the values decrease to 6μm, consistent with the existence of ship tracks in the scene. Moreover, we can observe that the largest retrieved effective radius correspond to those partially cloudy pixels which, as we discussed in the previous section, is a consequence of the sensitivity of the method to cloud cover.

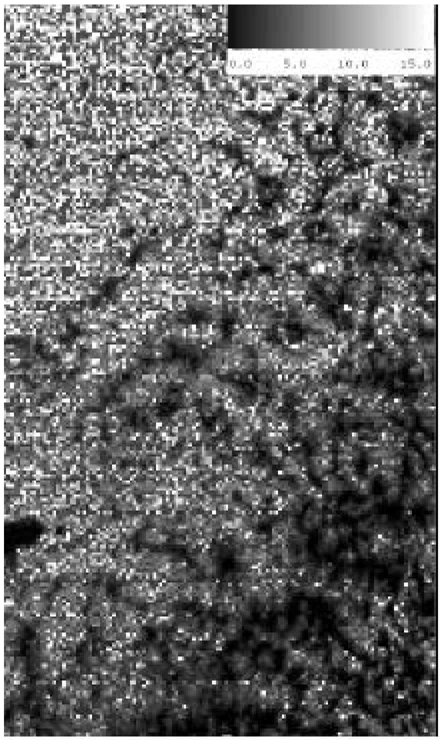
a)



b)




c)



d)

Figure 3. Retrieved cloud parameters from Rf05 Modis image: a) Calibrated brightness temperatures in channel 31 (10.8 μm), b) Retrieved cloud droplet effective radius, c) Cloud temperature and d) Optical thickness.

The retrievals were compared with in-situ measurements (not shown), finding that retrieved droplet radius are smaller than those measured by aircraft near cloud top, while cloud temperature corresponds with cloud top measurements. Detailed comparisons are presented at http://www.lct.ull.es/ogden.

7. SUMMARY

In this work we present a method to retrieve cloud parameters optical thickness, effective droplet radius and cloud temperature using exclusively infrared MODIS images. The method was applied to near-coincident aircraft measurements carried out during the DYCOMS-II field campaign finding that, in general, although the method provides droplet sizes smaller than those measured in-situ, it is able to follow the relative changes in droplet sizes. However, further studies are required.

8. REFERENCES

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