5.3 RETRIEVAL OF BOUNDARY LAYER CLOUD PROPERTIES USING INFRARED SATELLITE DATA DURING THE DYCOMS-II FIELD EXPERIMENT

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1. ABSTRACT

This work presents a method to retrieve the optical thickness, effective particle radius and cloud temperature of low-level marine clouds from night-time satellite imagery. The method uses a direct radiative transfer model to simulate the radiances detected by the MODIS infrared channels and a numerical procedure based on evolutionary techniques to invert the model. The method was applied to MODIS datasets for which almost-coincident airborne observations were conducted during the DYCOMS-II field experiment carried out off the coast of southern California during July 2001. The retrieved parameters were compared to in situ measurements showing that, despite the large vertical variations in measured sizes, the method is able to provide particle sizes representative of the cloud layer.

2. INTRODUCTION

Clouds play a crucial role in the planetary energy budget, reflecting the solar radiation and absorbing the longwave thermal emission from the earth surface. Therefore, it is important to understand cloud optical and microphysical properties to describe the cloud-radiation interaction and to include them in global climate models (GCMs) which will allow to evaluate the importance of the indirect effect of clouds on climate change.

However, due to the high spatial and temporal variability of clouds, the analysis of data remotely sensed by satellites is the only tool available to provide these parameters on a global scale. So, multiple studies on the retrieval of the cloud parameters using airborne or spaceborne measurements have been developed.

Although many different techniques have been developed to infer optical thickness and effective particle radius from NOAA-AVHRR radiometric measurements (Nakajima and King, 1990, Baum et al., 1994, Perez et al., 2000)., most 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.

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However, a new generation of satellites specifically designed for the study of climate change, such as the EOS-AM1 (Terra), may provide information that will allow us to improve extend these retrieval techniques. In this work, we analyze the applicability of a proposed method to retrieve cloud parameters from MODIS night-time imagery. In the next section, we present the radiative transfer model used to solve the "direct problem". In the Section 4, the procedure for the model inversion is described. The retrieved results are presented in the Section 5 The sixth section contains a summary.

3. RADIATIVE TRANSFER MODEL

The retrieval of cloud parameters rely heavily on the modeled top of the atmosphere (TOA) brightness temperatures. We assume an atmospheric model consisting of three layers located over a sea-surface acting as a black body . The top and bottom layers are assumed to be composed only of water vapour. We assume that the temperature and water vapour vertical profiles are known, through standard atmospheric models, soundings or using the MODIS profile retrieval algorithm (Menzel and Gumley, 1998). Although the normalized water vapour distribution is supposed to follow this profile, the total amount is an input to the model. The middle layer is a plane-parallel cloud composed by spherical liquid water droplets. To characterize this layer of optical thickness τ, we assume that droplet concentration in the cloud follows a gamma size distribution with an effective radius r_{eff} and effective variance σ_{eff} (Hansen and Travis, 1974). Multiple scattering processes inside the cloud are evaluated using the "DISORT" discrete ordinates method (Stamnes et al., 1988)

We select MODIS channels sub ject only to water vapour absorption, and have also discarded those channels strongly affected by the "striping effect" detector noise (although residual striping remains in some channels). The selected channels were: 20 (3.660–3.840 μm) , 21 (3.93-4.00) , 22 (3.93-4.00) , 29 (8.40-8.70) , 31(10.78-11.28 μm).

We performed radiative transfer calculations to infer theoretical brightness temperatures that would result from given cloud particle size distributions, optical depths and cloud temperatures, given a sea-surface temperature and a total amount of water vapour in the atmosphere. The results of these simulations have been expressed in terms of brightness temperature differences (BTD's) taking as reference the temperatures in channel 31 (10.8 µm). Multiple simulations have been carried out for a large variety of input parameters and the results obtained have been compared with actual satellite data (http://www.lct.ull.es/Blmeet/trans_model.html). From the inspection of these simulations, we can deduce that the proposed model is able to explain the radiances received in the selected MODIS infrared channels.

4.MODEL INVERSION.

In order to obtain cloud parameters from nighttime MODIS data, it is necessary to invert the proposed radiative model. Due to its complexity, this inversion must be performed numerically. First, we build a look-up-table with the cloud optical properties (emissivity, transmissivity) in the selected MODIS channels for a wide range of the input parameters. Then, we define a cost function that accounts for the differences between the simulated and satellite measured brightness temperatures. The retrieved cloud parameters are those that minimize this cost function.

After verifying the behaviour of the cost function, which presents multiple local minima, we conclude that is necessary to choose a numerical technique insensitive to local extremes. We selected an evolutionary method called "*scatter search*" (Glover et al., 2000) which provides unifying principles for joining solutions in every evolutionary step. These new generated solutions are improved using a classical Nelder and Mead's simplex method and the best and most diverse solutions are chosen as the new population. After a few generations, this procedure returns the set of parameters for the global minimum.

5.RESULTS AND SENSITIVITY ANALYSIS

The described procedure was applied to the three case studies during Dycoms-II field campaign where almost-coincident satellite passes and in situ aircraft data were available These cases correspond to flights Rf02, Rf05 and Rf06. For each of them, the method was applied to a box including the flight area, and 3 new images were generated, one for each of the cloud retrieved parameters. MODIS images and retrieved parameters are shown in http://www.lct.ull.es/Blmeet/Dycomsii/Dycomsii.html . As a first conclusion, we can observe that similar conditions were present in these case studies, with an homogeneous cloud layer covering the selected area. Furthermore, the retrieved images present horizontally periodic noise as a consequence of the residual "striping effect" noise present in some of the channels used in the retrieval.

Table 1 shows the mean values retrieved for these days, so as the mean values measured by the FSSP-100 instrument during the flight "*leg*" nearer to the Terra overpass, which in these cases correspond to the initial stage (1-2 hours after take-off). However, these results cannot be compared directly to in-situ measurements due to the vertical variation of cloud droplet size.

In http://www.lct.ull.es/Blmeet/Dycomsii/aircraft.html , we present an approximate vertical droplet size distribution obtained using in situ measured data in different legs and in the transition between legs. The figure indicates that while the retrievals capture the relative variations in effective radius, they are consistently smaller than the in-situ values measured near the top

Concerning the cloud temperature, we observe that retrieved values show good agreement with those measured near the cloud top. Also, from the Rf06 case study we can evaluate the effect of ship tracks on clouds, observing droplet sizes of 8µm decrease to 6µm in the region affected by ships, with the mean optical thickness of 4 increasing to 8 in the same region.

In order to evaluate the sensitivity of the model to uncertainties in model parameters, we carried out simulations assuming uncertainties in cloud cover (percentage of pixel covered by cloud) and sea surface temperature, which is determined from clear sky pixels. In http://www.lct.ull.es/Blmeet/Dycomsii/sensitivity.html we show some of these results emphasizing that the largest errors appear in those partially cloudy pixels. This effect can be also seen in the case studies, where large effective radius values appear in the border of clear-sky pixels.

6.SUMMARY

In the present work, a method to retrieve cloud parameters, based on the inversion of a radiative transfer model, is proposed . The method has been applied to DYCOMS-II field campaign showing good agreement in the retrieved parameters. Nevertheless, although this technique seems applicable to cloud parameter retrieval, further studies are necessary.

Flight	Retrieved Tc	In-situ Tc	Retrieved r_{eff}	In-situ r_{eff}
Rf02	284.8	285.1	7.8	8.5
Rf05	283.5	282.7	8.3	13.5
Rf06	284.6	284.6	8.2	NA

Table1.- Comparison of retrieved and measured parameters.

7.References

B.A. Baum, R.F. Arduini, B.A. Wielicki, P. Minnis, and S. Tsay, 1994: Multilevel cloud retrieval using multispectral HIRS and AVHRR data: Nighttime oceanic analysis, J. G. R., 99, 5499-5514.
Glover,F., M.Laguna and R.Martí, 2002: *Theory and Applications of Evolutionary Computation: Recent Trends*, A. Ghosh and S. Tsutsui (Eds.), Springer-Verlag,
J.E. Hansen, and L.D. Travis, 1974: Light scattering in planetary atmospheres, Space Sci. Rev, 16, 527-610..
Menzel, P. and L. E. Gumley, 1998: *MODIS atmospheric profile retrieval algorithm theoretical basis document*, ATBD MOD-07, NASA GSFC, 32 pp
Nakajima, T. and M.D. King, 1990: Determination of optical thickness and effective particle radius of clouds from reflected solar radiation measurements, J. Atmos. Sci., 47, 1878-1893.
Pérez, J.C., F. Herrera, F. Rosa, A. González, M. A. Wetzel, R. D. Borys, and D. H. Lowenthal, 2000: Retrieval of marine stratus cloud droplet size from NOAA-AVHRR nighttime imagery, Rem. Sens. Environ., **73**, 31-45.
Stamnes, K., S. Tsay, W. Wiscombe, and K. Jayaweera, 1988: Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media", Appl. Opt., **27**, 2502-2509.