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POTENTIAL PHYSICAL PROCESSES EXPLAINING THE OBSERVED SPECTRAL SIGNATURE OF CLOUDY COLUMN SOLAR RADIATION ABSORPTION

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1. INTRODUCTION

Considerable debate has taken place over the last few years concerning the absorption of solar radiation within the atmosphere, in both cloud-free and cloudy conditions (e.g., Stephens and Tsay, 1990). Comparisons between modeled solar radiation absorption and observations suggest that the models underestimate the amount of radiation absorbed by the atmosphere with and without clouds (Ramanathan et al. 1995, Kato et al.). Solving this issue is crucial for climate model predictions, since the amount of solar radiation absorbed by the atmosphere strongly influences the dynamics of both the atmosphere and ocean and the exchanges of heat between the two media.

Gautier et al., 1999 showed that the spectral characteristics of the absorption of solar radiation in an atmosphere containing clouds on October 30, during the 1997 ARESE experiment. The objective of the present paper is to use these observations, together with radiative transfer modeling results, to better understand the physical processes giving rise to the observed spectral absorption.

1. OBSERVATIONS

Two aircraft, flying above and below clouds, were equipped with identical Radiation Measurement System (RAMS) and a Total Direct Diffused Radiometer (TDDR), measuring solar irradiance at seven spectral bands (approximately 10 nm wide) centered at 0.500, 0.862, 1.064, 1.249, 1.501, 1.651 and 1.750 µm (Valero *et al.*, 1997a). Nadir viewing spectral reflectance (0.418 - 1.096 µm) was also obtained from observations made by the Scanning Spectral Polarimeter (SSP) on the highest aircraft. Only the spectral data are used in this study.

2. MODEL

Two models, with 1-D and a 3-D,characteristics, but with the same physics and the same spectral resolution, have been used in this study. First, the 3-D model developed by O'Hirok and Gautier, 1998z) has been run with ARESE observations to evaluate the consistency between the different sets of spectral observations (Gautier et al., 1999). The second, a 1-D radiative transfer model SBDART (Ricchiazzi et al., 1998), has been used to diagnose the physical processes involved in solar radiation absorption. The 3-D model has been used to simulate observed fluxes for a synthesized cloud field that mimics the observed field. The variability of the cloud liquid water distribution field was derived from downwelling flux observations obtained from the TDDR at 0.500 µm. The field is presented on Fig. 1. . The mean liquid water LWP is 302 g m^{-2}. The cloud droplet radius distribution has an average r_e of 7.3 µm and follows a modified gamma size distribution. The corresponding mean cloud optical depth, τ, is 63.

Both models used cloud droplet single scattering albedo, extinction efficiency and phase function computed directly from Mie theory. Pressure, temperature, and water vapor vertical profiles were derived from soundings at the CART site while ozone amount was obtained from surface observations.

3. MODEL AND OBSERVATIONS COMPARISONS

4.1 Spectral variations of Absorption

Comparisons of albedo and transmission were presented in Gautier et al.,(1999). They showed that the 3-D model was reasonably representative of the radiative environment that existed on 10/30/97. The model was, therefore, used to interpolate between discrete measurements and to compute the flight-averaged spectral column absorption. The results are compared with values computed from the aircraft observations on Fig. 2. Significant differences exist between the computed and the observed absorptance with the better agreement for the shorter wavelengths regions (0.500 and 0.946 µm), and a large difference at 1.06 µm and for the three longest wavelengths of the TDDR (1.5, 1.651 and 1.750 µm).

4.2 Modified Absorption Spectral Variations

The difference between the observations and the model results presented above could be an indication that the model is unable to represent the absorption that is occurring in reality. Some of this absorption could result from uncertainties in the measurements, but the accuracy noted by the instrument providers is smaller than the unexplained absorption. In order to quantitatively determine the properties needed, we have modified the input parameters to our model, in such a way as to minimize the difference between modeled and observed absorption. This resulted in a maximization of the modeled absorption, while keeping the input data within realistic bounds. The results from these changes are presented in Fig. 3. The best fit between modeled and observed absorption has required a slight change in aerosol optical depth (from 0.12 to 0.15), single scattering albedo (from 0.938 to 0.82) and asymmetry factor (from 0.67 to 0.61). For the cloud droplet properties the best fit required a small increase in cloud optical depth (a factor of 1.09) and a large increase in co-albedo by a factor 3.

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The agreement between modeled and observed absorption with these tuned parameters is now very good for almost all wavelengths with an exception at 1.06 µm, where the modeled absorption is still much smaller than that observed.

4. PHYSICAL PROCESSES POTENTIALLY ENHANCING ABSORPTION

To investigate the processes that could play a role in enhancing absorption on the day analyzed, our 1-D model has been used. A series of sensitivity studies has been performed for each of the candidate processes discussed below. The reference case (nominal conditions used for the 3-D computations), as well as the TDDR observations, are plotted on each of the graphs presenting the results of the sensitivity studies.

5.1 Aerosol Properties

The low values of aerosol single scattering albedo and asymmetry factor required to reconcile the modeled with the observed values in the short wavelength region suggest a type of aerosol more absorbing than typical rural aerosol. This is in agreement with other indirect results for the CART site in clear sky conditions. Ricchiazzi et al. (1999) had to introduce small, highly absorbing (soot-like) particles in their computations to match clear sky diffuse observed irradiance with that modeled. Using the same aerosol particle,s the present computations agree with the observations at the shortest wavelengths, as shown on Fig. 4.

5.2 Cloud Droplet Co-Albedo

To reconcile observed and modeled absorption at longer wavelengths, very absorbing cloud droplets are needed. Their co-albedo must be 3 times that of pure water. Excluding instrumental problems with the TDDR as the reason for this high co-albedo value, we performed sensitivity studies to assess the origin of this absorption, from which we report on two of them.

First, we computed the spectral absorption properties for droplets containing soot in their core. As found by other authors, Fig. 5 shows that soot containing particles are not an acceptable solution for the shorter wavelengths.

A second sensitivity studies was performed this time with drizzle (100 µm water particles) in different locations. The results from these studies, presented on Fig. 6, indicate that a layer of drizzle of optical thickness 2 would be sufficient to match the observations. Drizzle layers were observed over parts of the flight (Pat Minnis, personal communication), however the corresponding amount of water seems too large for the cloud layer observed.

5. MISSING PHYSICS

Besides the physics needed to explain the observed cloud co-albedo, the only remaining missing one is that that would explain the observed enhanced absorption at 1.06 µm. Since this feature is present in both spectral data sets analyzed here, we have a certain level of confidence in its validity. This spectral region corresponds to the absorption by O_2-O_2 dimers. Recently updated absorption coefficients (Susan Solomon, personal communication) produces too small an absorption value to explain the enhanced absorption derived.

6. SUMMARY AND CONCLUSION

The results presented here have shown that the spectral signature of absorption in a cloudy layer could be duplicated (except for the 1.06 µm region) with a rather sophisticated radiative transfer model, if the absorption by both aerosol and cloud droplets was enhanced. In the case of aerosol, highly absorbing (imaginary part of refractive index between 0.1 and 0.01), small (2 - 5 nm) particles dramatically improved the match between observations and model computations. Duplication of the observed cloud absorption required a thin layer of drizzle (large droplets). The only feature remaining unexplained at this time is the enhanced absorption at 1.06 µm.

These results are only based on one day of observations and need to be verified. This study suggests the need for additional co-located broadband and spectral observations in clear and cloudy sky conditions in different atmospheric regimes. In-situ aerosol and cloud droplet microphysical measurements will be crucial to unravel the role of these particles in the "enhanced absorption" issue. Finally, accurate absorption measurements are needed at 1.06 µm to understand observed absorption in that spectral region.

8. REFERENCES

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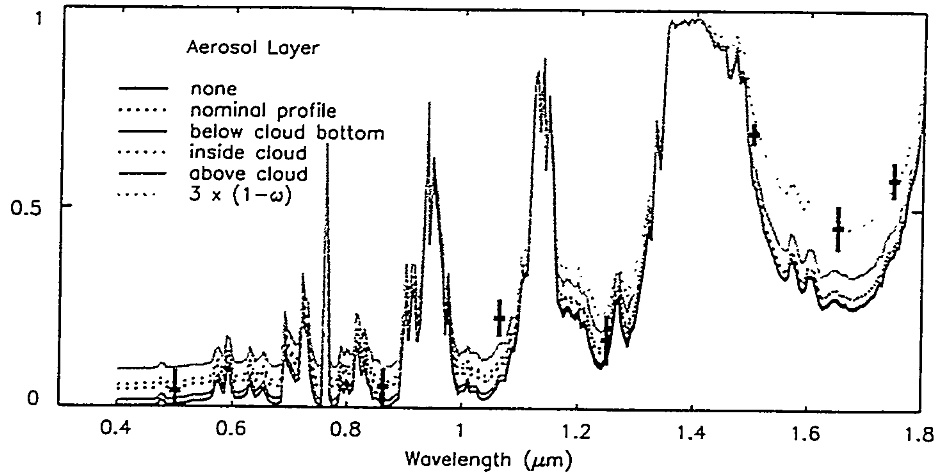

Fig 4. Spectral Variations of Absorption for an aerosol layer composed of small absorbing particles

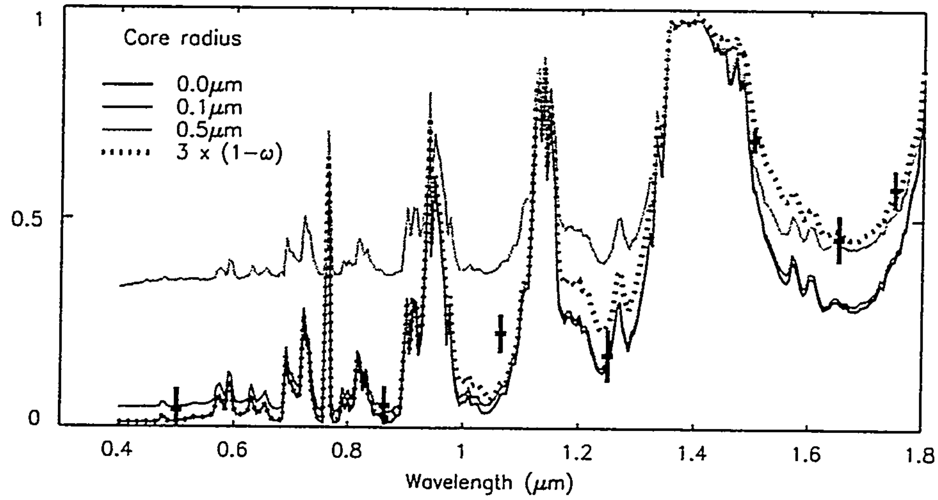

Fig 5. Spectral Variations of Absorption for cloud droplets with soot-containing core of different radius

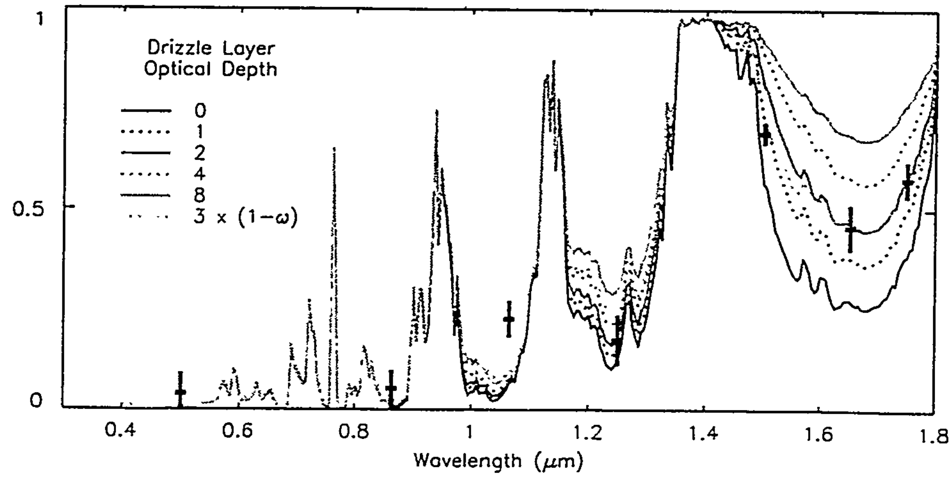

Fig 6. Spectral Variations of Absorption for drizzle layer of different optical depth