A Simple Model for Cloud Radiative Transfer of West Atlantic Cumulus

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1.Introduction

Clouds are dominant components of the Earth's hydrological cycle. Clouds also play an important role in determining the Earth's radiation budget, and strongly influence the radiative transfer within the atmosphere. Clouds are equally important in atmospheric chemistry because they are involved in many chemical reactions and chemicals transport through precipitate. However, the modeling of clouds can be challenging due to their high degree of spatial variability, and the complexity of processes in atmosphere. Cumulus clouds are the type of cloud that typically exist in the lowest few kilometers of atmosphere surrounding Earth, thus is of great interest to researchers due to the proximity to the surface of the earth.

In this work, we investigate the cumulus in the West Atlantic area in terms of radiative flux and droplet concentration. By establishing models and making corresponding assumptions, we draw some conclusions on how radiative properties of are affected by droplet size distribution within the clouds. These simplified models will help us simulate the real process of radiative transfer, and develop better understanding of how this particular type of cloud in West Atlantic influence on the Earth's radiation budget.

2.Methods

2.1 Model for shortwave

When we calculate the transmissivity (T), reflectivity (R), and absorptivity (A) of western Atlantic cumulus, we use following formula (DeVault J E el al., 1983).

$$R(\mu) = (u^2 - 1)[\exp(\tau n) - \exp(-\tau n)]V^{-1},$$

$$T(\mu) = 4uV^{-1},$$

$$T + R + A = 1$$

where

$n(\mu) = \xi\mu^{-1},$

$$\xi(\mu) = (1 - \widehat{\omega_0})[1 - \widehat{\omega_0} + 2\widehat{\omega_0}\beta(\mu)]^{1/2},$$

$$u(\mu) = \xi(1 - \widehat{\omega_0})^{-1},$$

$$V(\mu) = (u + 1)^2 \exp(\tau n) - (u - 1)^2 \exp(-\tau n),$$

$$\mu = \cos(zenith),$$

τ is the optical depth, $\widehat{\omega_0}$is the single scattering albedo and $\beta$is the back-scattering fraction. For simplication, we assume $\beta = 0$, $\widehat{\omega_0}$=0.95(Takemura el al., 2002), zenith=45°. Besides, we take the 0.25 S_0 as incoming shortwave flux (Webster and Curry, 1999), where S_0 is the solar constant with the value of 1367 W/m^2. What's more, we use the height of cumulus base and top from de Roode S R el al.[1996], they are 500 meter and 1600 meter.

2.2 Methods for longwave

When calculating the infrared emissivity, we use equations below (G.L.Stephens, 1978):

$$\varepsilon \uparrow = 1 - \exp(-a_0 \uparrow * W), \qquad \varepsilon \downarrow = 1 - \exp(-a_0 \downarrow * W)$$

$$a_0 \uparrow = 0.130, \qquad a_0 \downarrow = 0.158$$

S_0 is defined as a mass absorption coefficient for total infrared flux. The value of S_0 is obtained by fitting. W is liquid water path. We neglect the cloud reflectivity because it only accounts for a few percent in longwave radiation (Yamamoto el al., 1970). The average of upward emissivity and downward emissivity is considered to be the emissivity of cumulus.

3. Results and analysis

The following table gives results of parameters based on Western Atlantic cumulus datasets.

Table 1 Results of parameters based on data of Western Atlantic cumulus from Marile´ Colo´n-Robles el al.[2006]

$N(\#cm^{-3})$	total number concentration of drops	207.1
$w_l(g\ kg^{-1})$	liquid water mixing ratio	0.24
$\bar{r}(\mu m)$	mean drop size radius	6.67
$r_e(\mu m)$	drop equivalent radius	7.52
$\sigma_{ext}(m^{-1})$	extinction cross section for shortwave radiation	0.062
$W_l(g\ m^{-2})$	liquid water path	339.8
τ_{ext}	optical depth for shortwave radiation	67.80

T	transmissivity for shortwave radiation	0.28
R	reflectivity for shortwave radiation	0.55
A	absorptivity for shortwave radiation	0.16
ϵ	emissivity for longwave radiation	~1

From the table we can see that the cumulus reflects more than half of the incoming shortwave radiation and emissivity for longwave radiation is almost 1.

Then we explored the relationship between the shortwave flux and the concentration of droplets in western Atlantic cumulus. The following figure is based on the model for western Atlantic cumulus (Section 2.1).

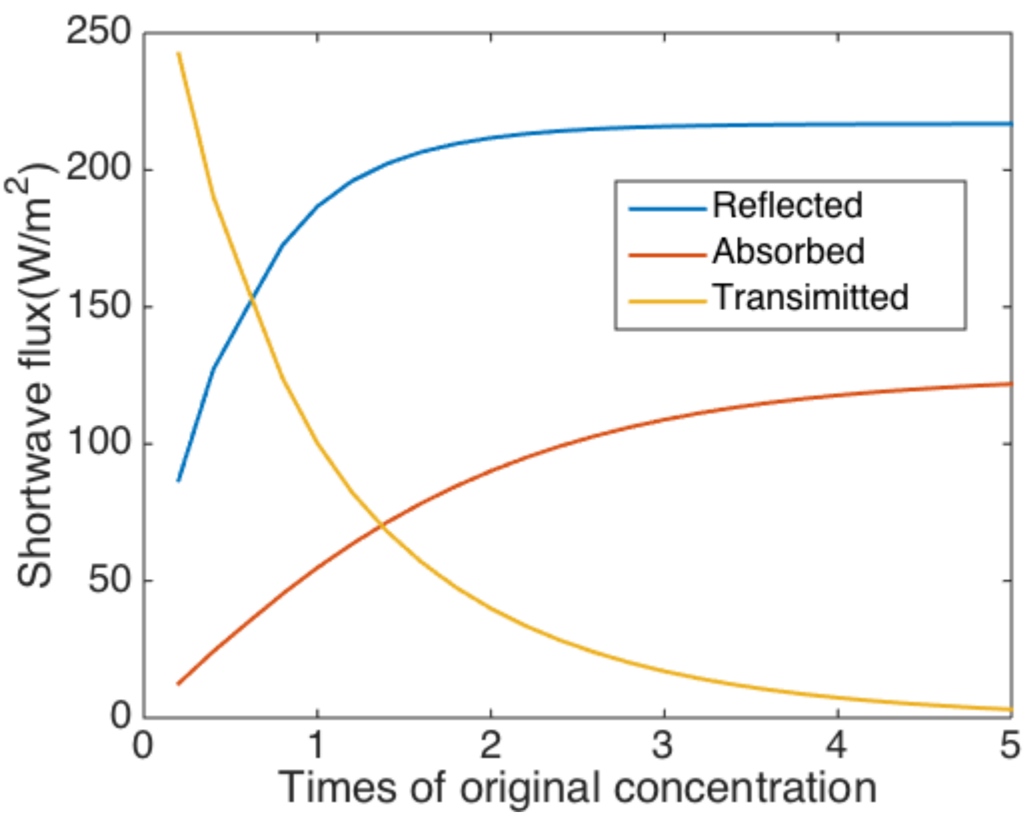

Fig 1. Shortwave flux variation with concentration

According to Fig. 1, we find that the solar radiation that is reflected and absorbed by the cloud increase with the concentration, while the transmitted part decreases with the concentration. We notices that when the concentration is halved, the transmitted part of solar radiation has great increase while the reflected part owing sharp decrease. After the concentration reaches 2 times of original value, the reflectivity barely increases with concentration, and nearly remains constant.

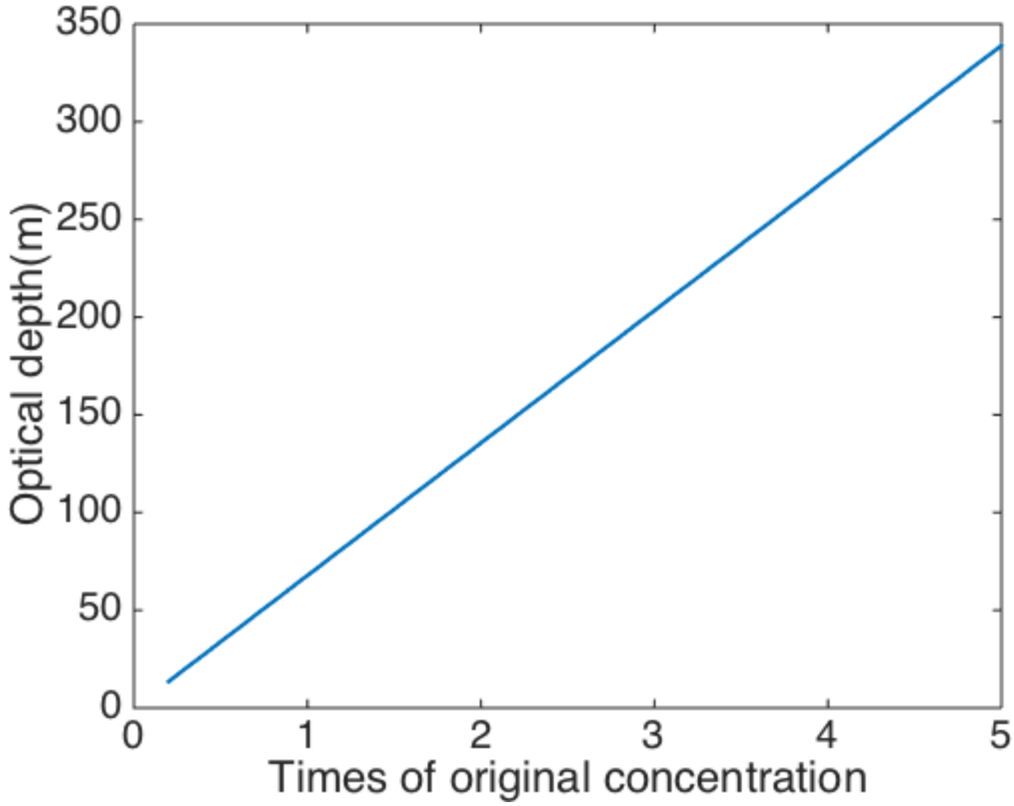

Fig 2. Optical depth variation with concentration

From Fig 2, we can find that optical depth increases linearly with the droplets concentration. Once the concentration increases, the optical depth will rise, thus the cumulus will reflect more shortwave radiation and let less shortwave radiation pass through.

For longwave radiation, the emissivity is approximately equal to 1 at the original concentration, which is a great value for emissivity. When we increase the droplets concentration, emissivity gets even closer to 1, which indicates that the cumulus emits nearly all longwave flux that it can emit.

4. Conclusion

From this study, we learned that droplets concentration casts a significant effect on the transmissivity, reflectivity, absorptivity and emissivity of cloud. With droplets concentration rising, optical depth will increase linearly, which contributes to more solar radiation reflection and longwave radiation emission of Western Atlantic cumulus. In this case, the surface will gain less solar radiation and more longwave radiation. Their ultimate effect on temperature of the earth is complex and remains to be explored. As a whole, our model provides a good way to simplify and study the role of cumulus in radiation transfer.

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