VOL. 14, NO. 3, FEBRUARY2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

TWO LAYERS CLOUD RADIATIVE FORCING MODEL

Ronnachai Nanthochot[1], Dusadee Sukawat[2] and Warisa Yomsatieankul[1]
[1]The Department of Mathematics, Faculty of Science, King Mongkut's University of Technology Thonburi, Pracha Uthit Road, Bang Mod, Thung Khru, Bangkok, Thailand
[2]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Pracha Uthit Road, Bang Mod, Thung Khru, Bangkok, Thailand
E-Mail: warisa.yom@mail.kmutt.ac.th

ABSTRACT

The cloud radiative forcing (CRF) plays an important role in the climate system for physical, dynamical, chemical and biological processes. The CRF value effects the overall and the distribution of energy between the atmosphere and the surface. In this study, the CRF value is analyzed from one-layer to consider in two-layer cloud by adding the cloud between the top of atmosphere (TOA) and the cloud at one-layer. There are three experiment cases of longwave, shortwave and net two-layer cloud radiative forcing. The results show that the CRF value depends on cloud optical depth and cloud top altitude of each layer in case of longwave. The CRF value depends on only cloud optical depth of each layer on a case of shortwave. In net CRF, the CRF value depends on the cloud optical depth and cloud top altitude of each layer. The CRF value depends on the low-cloud more than high-cloud. For all cases, the results can be concluded that the CRF values of two-layers CRF model give the similar results compared with the radiative transfer model.

Keywords: cloud optical depth, cloud radiative forcing, cloud top altitude, one layer cloud, two layers clouds.

INTRODUCTION

Cloud has enormous influence on Earths energy balance, climate and also weather. The ever-changing distribution of cloud is one of the most interesting feature of the Earth. There are many aspects indicated the kind of cloud. Some clouds sustain the cooling effect of the earth and others support the heating effect of the earth. The system of cloud also drives the storms move cross the planet and transport the energy between the warm and the cold areas. A small changing in the luxuriance or location of clouds can change the climate caused greenhouse gases, aerosol produced by human or the other future associate with the global change [1, 2, 3]. As mentioned previously, the different kind of cloud affects on unequal climate. The value that indicate the incidence of the different cloud are important value that are the cloud radiative forcing (CRF) value.

Cloud radiative forcing (CRF) is the difference between net irradiances measure the average atmospheric conditions and those measured in the mists of clouds for a similar locale and time period. It depends jointly on the measure of cloud display and the affectability of radiation to cloud amount. It may be apportioned into the reflection of cloud to some of longwave forcing term of the sun's radiation back into space (longwave forcing). Consequently, clouds help contain the radiation (shortwave forcing). The mix of which ordinarily brings about a negative net compelling when referenced to the top of the atmosphere. While the meaning of cloud radiative compelling as far as normal estimated esteems is unambiguous, the connection between cloud radiative constraining and the balance impacts of mists on atmosphere, particularly on surface temperature, is a confounded subject [4, 5, 6, 7, 8].

The reaction of CRF relates convective movement and a forced atmosphere bother is in this way basic for our understanding of climate change, but shows no consistency in either sign or magnitude among different climate models in climate perturbation experiments [9, 10, 11, 12]. Regardless of its incredible utility, CRF and its variation with temperature in investigations of cloud feedbacks not sufficient for completely understanding cloud-radiation interactions and their effects on climate. Additionally, advance requires relating CRF to other cloud properties, for example, cloud fraction and cloud albedo. Despite it has been for quite some time perceived that CRF is related intimately to cloud fraction and cloud albedo and some efforts have been devoted to exploring their relationships [13, 14]. The quantitative relationship between CRF, cloud fraction and cloud albedo remains elusive. The parts of cloud division and cloud albedo in shaping the Earth's climate had actually been investigated before the introduction of CRF already in the 1970s and keep on defying tasteful comprehension and parameterization [15, 16]. The CRF can be evaluated by comparing the actual surface radiative flux to the flux during an equivalent clear-sky scene. The Arctic clouds have a warming effect on the surface, except for a period in the summer when the sun is highest and surface albedo is lowest [17, 18, 19].

The different CRF value is the different cloud type and the characteristic of cloud. Corti and Peter (2007) have presented a simple one-layer CRF model for understanding the radiation between cloud coverage and the earth's energy balance. The CRF model is studied the CRF value from the reflection of cloud by the different between cloud and clear sky. The CRF value consists of both longwave and the shortwave radiation. The CRF value on the one-layer CRF model depends on the different between the cloud optical depth and cloud top altitude [19]. Wang *et al.* (2000) studied the one-layer and multilayer of cloud. Globally, 58% of clouds are single-layered and 42% are multi-layered; almost 67% of the layers are two-layered clouds. Then, this paper extends the model from a one-layer CRF model to a two-layer CRF model using the different between the cloud optical depth and cloud top altitude in each layer [20].

ONE-LAYER CLOUD RADIATIVE FORCING

The difference between the radiation budget components for the average cloud conditions and cloud-free conditions is CRF. Much of the interest in CRF relates to its role as a feedback process in the present period of global warming [21]. The CRF model is separated in to two path by the magnitude of wavelength. CRF model consists of longwave CRF and shortwave CRF. The long wave radiation is as a wavelength greater than $4\mu m$ whereas the shortwave radiation has a wavelength between 0.4 and $4\mu m$ [22]. The one-layer CRF model of the longwave CRF, CRF^{LW}, and the shortwave CRF, CRF^{SW}, are the difference of the radiation between the cloud and cloudless sky [19].

Longwave radiative forcing in one-layer cloud

In order to formulate the longwave CRF model, there are four main assumptions. Firstly, the cloud is a semi-transparent blackbody. Secondly, cloudless sky radiation is based on the surface temperature. Thirdly, the cloud is a plane parallel model. Finally, cloud emissivity depends solely on optical depth. At the TOA, longwave radiative forcing consists of only upwelling fluxes and assumes that the earth is not a black body at uniform temperature T_{srf}. The net longwave radiative flux (F^{LW}) can then be approximated by the Stefan-Boltzmann law as follows:

$$F^{LW} = \sigma T_{srf}^{4} \tag{1}$$

where σ is the Stefan-Boltzmann constant and T_{srf} is the earth's surface temperature. In fact, the earth is not a blackbody, the atmosphere absorbs and emits longwave radiation depending on the water vapour and CO_2 content. In the case of a cloudless sky as shown in Figure-1 (left) and remembering the second assumption of the model, longwave radiative flux F_{clr}^{LW} is approximated by:

$$F_{clr}^{LW} \approx \sigma^* T_{srf}^{k^*} \tag{2}$$

where $k^*$and σ^* are two parameters obtained by applying regression analysis. For more detail see Raval et al. 1994 and Allan et al. 1999 [7,23]. The values of k^* and σ^* are $k^* = 2.528$ and $\sigma^* = 1.607\times10^{-4}\, wm^{-2}k^{-2.528}$, respectively [19].The cloud influence on, F^{LW}, is approximated by the semi-transport black body. This means that longwave radiation is lost by emission.

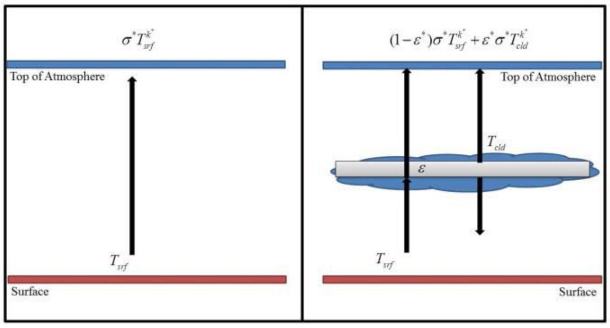

Figure-1. The plane parallel model of the outgoing long wave radiation in a cloudless sky (left) and for a cloudy sky (right).

For the cloudy sky as shown in Figure-2 (right), the emissivity ε indicates the transparency of the cloud. It is the ratio of the radiation emitted by the cloud and a black body at the same temperature. The expression of longwave radiation flux of the cloudy sky, F_{cld}^{LW}, can be written as:

$$F_{cld}^{LW} \approx (1-\varepsilon^*)\sigma^* T_{srf}^{k^*} + \varepsilon^* \sigma^* T_{cld}^{k^*} \tag{3}$$

where T_{cld} is the cloud top temperature, k^* and σ^* can be determined just like the cloudless sky calculation. To evaluate ε^*, the last assumption of the model is applied, which stated that cloud emissivity depends on optical depth and follows Stephens et al. (1990) [24]. The parameter ε^* is then approximated by

$$\varepsilon^* \approx 1 - e^{-\delta^* \tau} \tag{4}$$

where $\delta^* = 0.75$ [24].

Now CRF^{LW} can be calculated as the differences between F_{clr}^{LW} and F_{cld}^{LW}:

$$CRF^{LW} = F_{cld}^{LW} - F_{clr}^{LW} \approx \sigma^*(T_{srf}^{k^*} - T_{cld}^{k^*})(1-e^{-\delta^*\tau}). \tag{5}$$

Shortwave radiative forcing in one-layer cloud

The shortwave CRF equation consists of three assumptions. Firstly, the atmosphere absorbs the shortwave above the cloud only. Secondly, the cloud does not absorb shortwave radiation. Finally, the upward shortwave radiation transmitted by the cloud isotropic.

ARPN Journal of Engineering and Applied Sciences

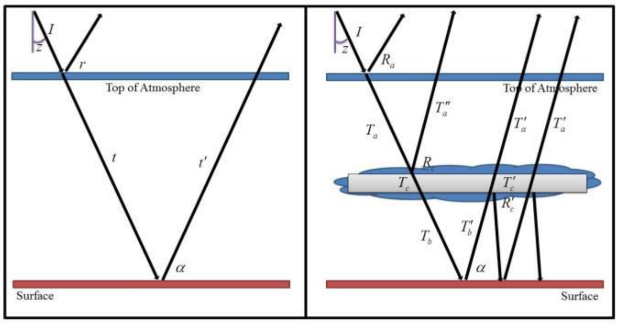

Figure-2. The plane parallel model of the outgoing shortwave radiation in a cloudless sky (left) and for a cloudy sky (right).

In the case of the clear sky as shown in Figure-2 (left), the solar flux, I, depends on the solar zenith angle Z, described as $I = S\cos(Z)$, where S is the solar constant. The shortwave radiative flux of the cloudless sky, F_{clr}^{SW}, is approximated by:

$$F_{clr}^{SW} = I(1 - r - tt'\alpha). \tag{6}$$

where r is the reflection by the atmosphere. The solar flux crosses the atmosphere with transmittance (t) and reflects at the surface albedo (α). The transmittance for the outgoing diffuse is t'. The short wave of the cloudy sky is shown in Figure-2 (right). The shortwave radiation of the cloudy sky, F_{cld}^{SW} is approximated by:

$$\begin{aligned} F_{cld}^{SW} = I(1 - R_a - R_c T_a T_a'' - \alpha T_a T_a' T_b T_b' T_c T_c' \\ - (1 + \alpha R_c' T_b'^2 + \alpha^2 R_c'^2 T_b'^4 + \ldots)). \end{aligned} \tag{7}$$

where R_a is the reflection of the TOA. The reflection of cloud is R_c for the incoming radiation and R_c' for the outgoing radiation. The reflectance and two-way transmittance of the atmosphere above the cloud are assumed to be the same for both the cloudy and cloudless sky, $R_a = r$ and $T_a T_a' = T_a T_a'' = tt'$. The approximation value of tt' depends on the atmosphere composition and the solar zenith angle. Corti T. and Peter T. (2009) approximated $tt' = 0.73$ [19]. The atmosphere reflection and absorption rise above the cloud, $T_b = T_b' = 1$ and the shortwave radiation is not absorb by the cloud feature, $T_c = 1 - R_c$. Then F_{cld}^{SW} can be rearranged to:

$$F_{cld}^{SW} = I(1 - r - tt'\alpha - (1-\alpha)tt'\frac{R_c - \alpha R_c'}{1 - \alpha R_c'}). \tag{8}$$

Baker (1997) estimated the reflection of the cloud, R_c and R_c' by:

$$R_c = \frac{\tau_{eff}}{\gamma^* + \tau_{eff}} \tag{9}$$

$$R_c' = \frac{2\tau}{\gamma^* + 2\tau} \tag{10}$$

where the parameter γ^* is 7.25 [25,26,27,28], and $\tau_{eff} = \tau / \zeta$. ζ is the cosine of zenith angle, $\zeta = \cos(z)$. R_c can be expressed as:

$$R_c = \frac{\tau / \zeta}{\gamma^* + \tau / \zeta}. \tag{11}$$

The net shortwave cloud radiative forcing, CRF^{SW}, is the difference between F_{cld}^{SW} and F_{clr}^{SW} expressed as:

$$CRF^{SW} = F_{cld}^{SW} - F_{clr}^{SW} = -Itt'^*(1-\alpha)\frac{R_c - \alpha R_c'}{1 - \alpha R_c'}. \tag{12}$$

Net cloud radiative forcing

The net cloud radiative forcing (CRF^{NET}) is the summation of CRF^{SW} and CRF^{LW} as follows:

$$\begin{aligned} CRF^{NET} \approx \sigma^*(T_{srf}^{k^*} - T_{cld}^{k^*})(1 - e^{-\delta^*\tau}) \\ - Itt'^*(1-\alpha)\frac{R_c - \alpha R_c'}{1 - \alpha R_c'}. \end{aligned} \tag{13}$$

TWO-LAYER CLOUD RADIATIVE FORCING

In this study, the one-layer CRF model to a two-layer CRF model by inserting the cloud layer between TOA and the cloud in the one-layer CRF model to better represent a real-world scenario of cloud coverage. To formulate the two-layer CRF model, the assumptions of the longwave and shortwave for the one-layer CRF model are applied. The two-layer CRF model is more complex than the one-layer model because radiation interacts between the two cloud layers. For simplicity, this study name upper cloud for the upper layer and low cloud for the lower layer.

Longwave two-layer cloud radiative forcing

For the cloudless sky, longwave radiation flux is the same as Equation 2. To extend the two layers, by add the layer of cloud between the TOA and the low cloud as shown in Figure-3.

ARPN Journal of Engineering and Applied Sciences

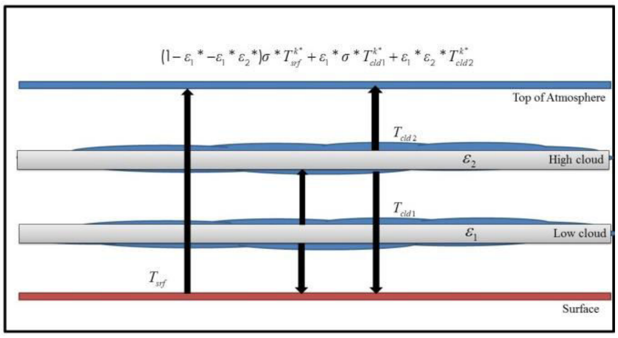

Figure-3. The plane parallel model of outgoing longwave radiation for the two-layer CRF model.

The approximation of longwave radiation two-layer cloud scenario is expressed as:

$$F_{cld}^{LW} \approx (1-\varepsilon_1*)(1-\varepsilon_2*)\sigma*T_{srf}^{k*} + \varepsilon_1*(1-\varepsilon_2*)\sigma*T_{cld1}^{k*} + \varepsilon_2*\sigma*T_{cld2}^{k*} \tag{14}$$

where T_{cld1} is the cloud top temperature for the lower cloud layer, T_{cld2} is the cloud top temperature for the upper cloud layer, ε_1* is the emissivity of the lower cloud and ε_2* is the emissivity of the upper cloud.

The net longwave CRF is the difference between the radiative flux value of the cloud and cloudless sky. The net longwave CRF is approximated by:

$$CRF^{LW} \approx (\varepsilon_1*+\varepsilon_1*\varepsilon_2*)\sigma*T_{srf}^{k*} - \varepsilon_1*\sigma*T_{cld1}^{k*} - \varepsilon_1*\varepsilon_2*T_{cld2}^{k*} \tag{15}$$

Shortwave two-layer cloud radiative forcing

In the case of a cloudless sky, shortwave radiative flux is the same as Equation 6 whereas the cloudy sky is extended by adding the layer of cloud between the TOA and lower cloud as shown in Figure-4.

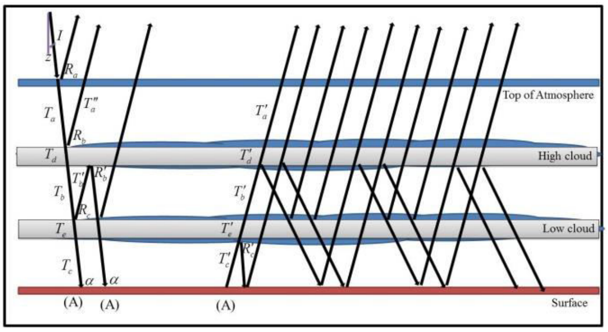

Figure-4. The plane parallel model of outgoing shortwave radiation for a cloudy sky on the two-layer CRF model.

The shortwave two-layer CRF model contains two assumptions. Firstly, this work assume that there are two events of reflection at the surface (α). The first surface reflection is radiation from the lower cloud layer to the surface. The second surface reflection is under the lower cloud. The second assumption is that shortwave CRF between upper and lower cloud layer doubles in surface reflection. The short wave CRF equation for the cloudy sky is created by:

$$F_{cld}^{SW} = I - IR_a - IR_bT_aT_a'' - IT_aT_dT_bR_cT_a'T_d' - IA - IT_aT_dT_b^2R_cT_b'^2R_b'T_a'T_d' - IR_cT_bT_b'(A) \tag{16}$$

where the term A is expressed as:

$$A = (T_aT_dT_bT_eT_c\alpha T_c'T_e'T_b'T_d'T_a' + T_aT_dT_bT_eT_c^2\alpha T_c'^2T_e'T_b'T_d'T_a' + T_aT_dT_b^2T_eT_c\alpha T_c'T_e'T_b'^2R_b'R_cT_d'T_a' + T_aT_dT_b^2T_eT_c^2\alpha^2T_c'^2T_e'T_b'^2R_b'R_cT_d'T_a' + T_aT_dT_b^2T_e^2T_c^2\alpha^2T_c'^2T_e'^2T_b'^2R_b'T_d'T_a' + \ldots)$$

Rearrange term A to get

$$A = (T_aT_dT_d'T_a'(\sum_{i=1}^{\infty}T_b^iT_e^iT_c^i\alpha^iT_c'^iT_e'^iT_b'^iR_b'^{(i-1)}) + T_aT_dT_d'T_a'R_c'(\sum_{i=1}^{\infty}T_b^iT_e^iT_c^{(i+1)}\alpha^{(i+1)}T_c'^{(i+1)}T_e'^{(i+1)}T_b'^iR_b'^{(i-1)}) + T_aT_dT_d'T_a'R_c(\sum_{i=1}^{\infty}T_b^{(i+1)}T_e^iT_c^i\alpha^iT_c'^iT_e'^iT_b'^{(i+1)}R_b'^i) + T_aT_dT_d'T_a'R_cR_c'(\sum_{i=1}^{\infty}T_b^{(i+1)}T_e^iT_c^{(i+1)}\alpha^{(i+1)}T_c'^{(i+1)}T_e'^iT_b'^{(i+1)}R_b'^i)).$$

Using the infinite geometry series, term A can be changed to

$$A = (T_aT_dT_d'T_a'(\frac{T_bT_eT_c\alpha T_c'T_e'T_b'R_b'}{1-T_bT_eT_c\alpha T_c'T_e'T_b'R_b'}) + T_aT_dT_d'T_a'R_c'(\frac{T_bT_eT_c^2\alpha^2T_c'^2T_e'T_b'R_b'}{1-T_bT_eT_c\alpha T_c'T_e'T_b'R_b'}) + T_aT_dT_d'T_a'R_c(\frac{T_b^2T_eT_c\alpha T_c'T_e'T_b'^2R_b'}{1-T_bT_eT_c\alpha T_c'T_e'T_b'R_b'}) + T_aT_dT_d'T_a'R_cR_c'(\frac{T_b^2T_eT_c^2\alpha^2T_c'^2T_e'T_b'^2R_b'}{1-T_bT_eT_c\alpha T_c'T_e'T_b'R_b'}))$$

where R_a is the reflection at the TOA. The reflection of the upper cloud layer is R_b for the incoming radiation and R_b' for outgoing radiation. The incoming radiation and the outgoing radiation reflection of the lower cloud layer are R_c and R_c'., T_a, T_a' and T_a'' are the transmission from the upper cloud layer and T_b and T_b' are the transmission between the two cloud layers. While T_c and T_c' are the transmission between the lower cloud and earth's surface.

VOL. 14, NO. 3, FEBRUARY2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

T_d and T_e are the transmission of radiation through upper and lower cloud layer.

The net shortwave CRF is the difference between the CRF value of the cloud and cloudless sky. Net shortwave CRF is approximate by:

$$\begin{aligned} CRF^{SW} &= Itt'\alpha - IR_bT_aT_a'' - IT_aT_dT_bR_cT_a'T_d' - IA \\ &\quad - IT_aT_dT_b^2R_cT_b'^2R_b'T_a'T_d' - IR_cT_bT_b'(A) \end{aligned} \quad (17)$$

Net two-layer cloud radiative forcing

The summation between net longwave CRF (F^{LW}) and net shortwave CRF (F^{SW}) is the net two-layer CRF.

$$\begin{aligned} CRF^{NET} &= \{(\varepsilon_1 * + \varepsilon_1 * \varepsilon_2 *)\sigma * T_{srf}^{k*} - \varepsilon_1 * \sigma * T_{cld1}^{k*} \\ &\quad - \varepsilon_1 * \varepsilon_2 * T_{cld2}^{k*}\} + \{Itt'\alpha - IR_bT_aT_a'' \\ &\quad - IT_aT_dT_bR_cT_a'T_d' - IA \\ &\quad - IT_aT_dT_b^2R_cT_b'^2R_b'T_a'T_d' - IR_cT_bT_b'(A)\} \end{aligned} \quad (18)$$

Approximation parameters of the two-layer CRF model

All parameters in this section are used to find the CRF value for the two-layer CRF model. The emission of the lower cloud and upper cloud layers are calculated by $\varepsilon^* \approx 1 - e^{-\delta^*\tau_1}$ and $\varepsilon^* \approx 1 - e^{-\delta^*\tau_2}$ respectively. The parameters τ_1 and τ_2 are the cloud optical depth for the lower cloud and upper cloud layers, respectively. This work assume that the reflectance and two-way transmittance of the atmosphere above the cloud are the same in cloud and cloudless sky, $R_a = r$ and $T_aT_a' = T_aT_a'' = tt'$, which means atmospheric reflection and absorption occur only above the cloud. Thus $T_b = T_b' = 1$ for the upper cloud and $T_c = T_c' = 1$ for the lower cloud. The estimates for the reflection at the top of the upper cloud and lower cloud layer are $R_b = (\tau_2/\zeta)/(\gamma * + \tau_2/\zeta)$ and $R_c = (\tau_1/\zeta)/(\gamma * + \tau_1/\zeta)$, respectively. The expression of reflection below the upper cloud layer is $R_b' = (2\tau_2)/(\gamma * + 2\tau_2)$ and that below the lower cloud layer is $R_c' = (2\tau_1)/(\gamma * + 2\tau_1)$.

The incoming short wave solar radiation is not absorbed in the lower cloud, thus $T_e = 1 - R_c$ and in the upper cloud, $T_d = 1 - R_b$. Moreover, the outgoing short wave solar radiation is not absorbed in the lower cloud, thus $T_e' = 1 - R_c'$ and for the upper cloud $T_d' = 1 - R_b'$.

In the radiative transfer calculation, the surface temperature, T_{srf} to $299K$, surface albedo to 0.05, the upper cloud layer at 7 Km, the lower cloud layer at 5 Km, T_{cld} of $256K$ corresponding to $6.25km$ altitude are specified and the solar radiation as found in daily mean equinox condition at the equator is $\zeta = 0.636$ and $I = 435Wm^{-2}$. [19]

RESULTS AND DISCUSSIONS

This study extends the one-layer cloud radiative forcing to the two-layers cloud radiative forcing with different cloud optical depth. Three cases of the longwave CRF value, the shortwave CRF value and the net CRF value are considered. The accuracy of the two-layers CRF model is compared with the radiative transfer model with the same cloud optical depth and the height of cloud in each layers. The radiative transfer model is studied the value of CRF by using the radiation equation that is more complex and more difficult than the two-layers CRF model in the processing of the cloud interaction in the atmospheres. The results of the two-layers CRF model show the value of cloud radiative forcing with the upper cloud at 7km height and of the lower cloud at 5km height.

Two-layers CRF model scenario

The results of the two-layers CRF model represent cirrus cloud features with the parameter $\gamma*$ =7.25. The results are shown in Figure-5 for the long wave CRF, Figure-6 for the shortwave CRF and Figure-7 for the net CRF on the two cloud layers.

Figure-5 illustrates the estimation of the long wave CRF for a two-layers cirrus cloud scenario under the tropical condition based on Equation 5. The cloud top altitude of 5km and 7km are translated to cloud top temperature according to the mean tropical temperature profile.

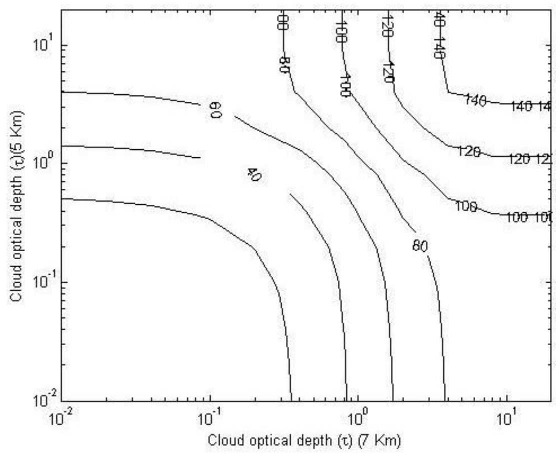

Figure-5. Values of longwave CRF (Wm^{-2}) for the two cloud layers.

Longwave CRF values vary based on the cloud optical depth value. The CRF values are increasing as the cloud optical depths are increasing. The positive longwave CRF values indicate that the clouds impact on longwave radiation acts to warm the Earth. In the case of longwave CRF ranging between $40Wm^{-2}$ to $80Wm,^{-2}$ the optical depth of the upper cloud layer (7km) is less than the optical depth of the lower cloud layer (5 km).

VOL. 14, NO. 3, FEBRUARY2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

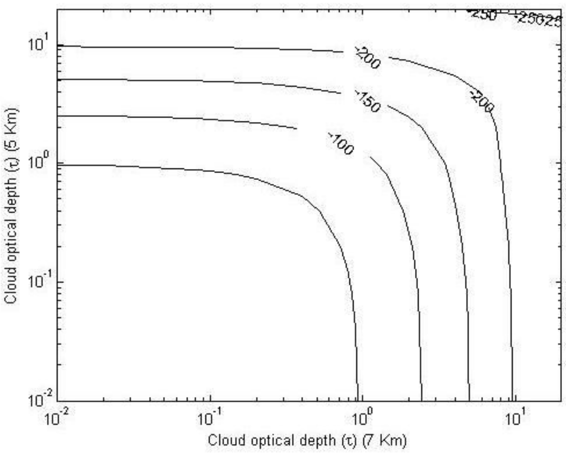

Figure-6. Values of shortwave CRF (Wm^{-2}) for the two cloud layers.

In Figure-6, the approximation CRF^{SW} depends on the cloud optical depth as in Equation 17.The shortwave CRF results are based on the higher cloud optical depth more than the smaller cloud optical depth of both the upper and lower cloud layer. The results show the negative values of the shortwave CRF.It means that the temperature of the earth is decreasing. The clouds therefor impact on shortwave radiation acts to cool the Earth.

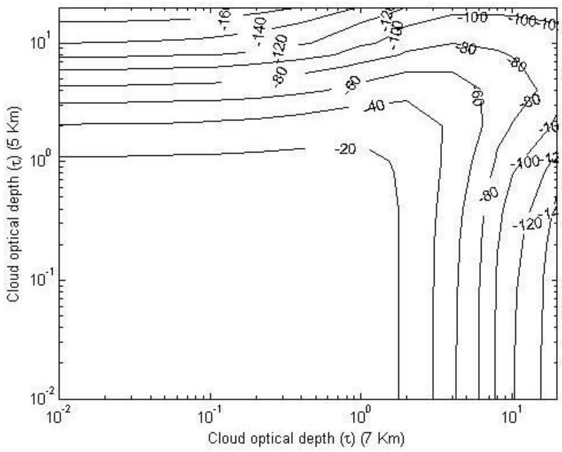

Figure-7. Values of the net CRF (Wm^{-2}) for both cloud layers.

The net cloud radiative forcing (CRF^{NET}) is the addition of CRF^{SW} to CRF^{LW} (Figure-7). From Figure-7, CRF^{NET} is negative under a small cloud optical depth. CRF^{NET} decreases when the cloud optical depth is increased. The results illustrate that the CRF values depend on the cloud optical depth of both the upper and lower cloud layer. Especially, the cloud optical depth of the lower layer is less than of upper cloud layer, when the net CRF value is $-20Wm^{-2}$.

Comparison between the two-layers CRF model and radiative transfer model

To compare our experimental results, the radiative transfer model [29, 30, 31] is utilized. The absolute different CRF values of the net CRF are demonstrated in Figure-8.

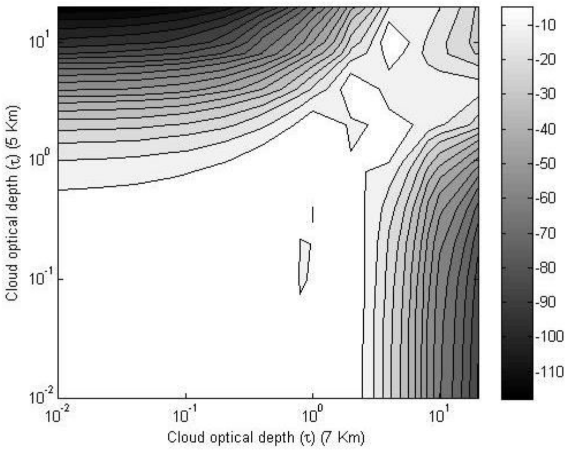

Figure-8. The difference in net CRF (Wm^{-2}) between the CRF model and radiative transfer model on the two cloud layers.

The absolute differences of the CRF values between the two models are small if the cloud optical depths of both lower and upper clouds are in the interval of $10^{-2} - 10^{0}$. It means that our model is only useful when cloud optical depth is less than 10^{0}. Also, the two-layers cloud radiative forcing model give the similar values of the CRF with the radiative transfer model in case of the same cloud optical depths although the value of cloud optical depth is greater than 10^{0}. For example, the CRF values between the Cloud radiative forcing model and radiative transfer model are similar at the same cloud optical depth (10^{1}) for each layers of cloud and the CRF values are different at the different cloud optical depth (10^{-1} and 10^{1}) for each layers of cloud. The overall agreement between estimated and calculated forcing is good.

CONCLUSIONS

This paper aims to present the formulation of a two-layers cloud radiative forcing model. The model consists of longwave and shortwave cloud radiative forcing. The experimental results are satisfied with the radiative transfer model when the cloud optical depth is within the range of $10^{-2} - 10^{0}$. The results can be utilized as a guideline for the geoengineer for studying the impact of cloud coverage on global temperature [32]. However, the cloud radiative forcing model has some disadvantages about the different cloud optical depth in each layers. The cloud radiative forcing model can analyze the characteristic value of CRF that is the result of the cloud optical depth changing in each cloud layer.

ACKNOWLEDGEMENTS

This research is supported by the grant from department of Mathematics, faculty of science, KMUTT and the PetchraPraJomKlao scholarship, KMUTT.

REFERENCES

[1] Justin G. 2015. Short Answers to Hard Questions about Climate Change. The New York Times. ISSN 0362-4331.

[2] Solomon S. Qin D. Maniny M. Chen Z. Marquis M. Avergt K.B. Tignor M. & Miller H.L. 2007. Climate Change 2007. Cambridge University Press. ISBN 978-0-521-8809-1.

[3] Morgan M. G. and Katharine Ricke. 2009. Cooling the Earth through Solar Radiation Management: The need for research and an approach to its governance. Department of Engineering and Public Policy Carnegie Mellon University.https://www.irgc.org/IMG/pdf/SRM_Opinion_Piece_web.pdf.

[4] Barkstrom B. R., E. F. Harrison and R. B. Lee III. 1990. Earth Radiation Budget Experiment: Preliminary seasonal results, Eos Trans. AGU. 71(9): 297-304.

[5] Bergman J. W. and H. H. Hendon. 1998. Calculating monthly radiative fluxes and heating rates from monthly cloud observations, J. Atmos. Sci. 55: 2471-3491.

[6] Bergman J. W. and H. H. Hendon. 2000. Cloud radiative forcing of the low-latitude tropospheric circulation. Linear Calculations, J. Atmos. Sci. 57: 2225-2245.

[7] Allan R. P. Shine K. P. Slingo, A. & Pamment J. A. 1999. The dependence of clear-sky outgoing long-wave radiation on surface temperature and relative humidity Q. J. Roy. Meteor. Soc. 125: 2103–2126.

[8] Chen, T. Rossow W. B. & Zhang Y. C. 2000. Radiative effects of cloud-type variations. J. Clim. 13: 264-286.

[9] Bony S, Dufresne J-L, Le Treut H, Morcrette J-J, Senior C. 2004. On dynamic and thermodynamic components of cloud changes. Clim Dyn. 22:71-86.

[10] Wyant MC, Bretherton CS, Bacmeister JT, Kiehl JT, Held IM, Zhao M, Klein SA, Soden BJ. 2006. A comparison of low-latitude cloud properties and their response to climate change in three agcms sorted into regimes using mid-tropospheric vertical velocity. Clim Dyn. 27(2-3): 261-279.

[11] Williams KD, Tselioudis G. 2007. GCM intercomparison of global cloud regimes: present-day evaluation and climate change response. Clim Dyn 29:231-250.

[12] Williams KD, Webb MJ. 2009. A quantitative performance assessment of cloud regimes in climate models. Clim Dyn. 33(1):141-157.

[13] Charlock T. P. and Ramanathan V. 1985. The albedo field and cloud radiative forcing produced by a general circulation model with internally generated cloud optics, J. Atmos. Sci. 42: 1408-1429.

[14] Harrison E. F., Minnis P., Barkstrom B. R., Ramanathan V., Cess R. D. and Gibson G. G. 1990. Seasonal variation of cloud radiative forcing derived from the Earth Radiation Budget Experiment, J. Geophys. Res. 95: 18687-18703.

[15] Arakawa A. 1975. Modelling clouds and cloud processes for use in climate models The Physical Basis of Climate and Climate Modelling (GARP Publication Series No 16) (Geneva: WMO/ICSU) pp. 81-97.

[16] Bony S. and Dufresne J. L. 2005. Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models Geophys. Res. Lett. 32 L20806.

[17] Curry J. A., and E. E. Ebert. 1992. Annual cycle of radiation fluxes over the Arctic Ocean: Sensitivity to cloud optical properties. J. Climate. 5: 1267-1280.

[18] Intrieri J. M., C. W. Fairall, M. D. Shupe, P. O. G. Persson, E. L Andreas, P. S. Guest and R. E. Moritz 2002. An annual cycle of Arctic surface cloud forcing at SHEBA. J. Geophys. Res. 107: 8039.

[19] Corti T. and Peter T. 2009. A simple model for cloud radiative forcing. Atmos. Chem. Phys. 9: 5751-5758.

[20] Wang J., Rossow W.B., and Zhang Y. 2000. Cloud Vertical Structure and Its Variations from a 20-Yr Global Rawinsonde Dataset. Journal of Climate. 13: 3041-3056.

[21] Steve Graham. 1999. Clouds &Radiation. The Earth's Climate System Constantly Adjusts. Retrieved 25 November 2016.

[22] Glickman T. S. 2000. Glossary of Meteorology. 2nd ed. American Meteorological Society. 855.

[23] Raval A.,Oort, A. H. and Ramaswamy V. 1994. Observed Dependence of Outgoing Longwave Radiation on Sea-Surface Temperature and Moisture. J. Clim. 7: 807-821.

[24] Stephens G. L. Tsay S. C. Stackhouse P. W. and Flatau P. J. 1990. The Relevance of the Microphysical and Radiative Properties of Cirrus Clouds to Climate and Climatic Feedback. J. Atmos. Sci. 47: 1742-1753.

[25] Baker M. B. 1997. Cloud microphysics and climate. Science. 276: 1072-1078.

[26] Ronnachai N. Dusadee S. and Warisa Y. 2016. Parameterization of Water Cloud of the Cloud Radiative Forcing Model. 3rd International Conference on Civil, Biological and Environmental Engineering (CBEE-2016). Phuket, Thailand. 12-13 December 2016: 117-120.

[27] Ronnachai N. Dusadee S. and Warisa Y. 2016. The Relationship between Cloud Optical Depth and Cloud Top Altitude on the Cloud Radiative Forcing Model. The 7th RMUTP International Conference on Science, Technology and Innovation for Sustainable Development: Challenges towards the green innovative society. The Sukosol, Bangkok, Thailand. 23-24 June 2016: 22-25.

[28] Alexander A. K. 2006. Cloud Optics. Springer. Atmospheric and Oceanographic Sciences Library. 34: 230-235.

[29] Fred G. R. 2015. LaRC Fu-Liou, 4th Ed. 12 January 2015.

[30] Fu Q. and Liou K. N. 1993. Parameterization of the Radiative Properties of Cirrus Clouds. J. Atmos. Sci. 50: 2008-2025.

[31] Fu Q. and Liou K. N. 1992. On the Correlated K-Distribution Method for Radiative-Transfer in Nonhomogeneous Atmospheres. J. Atmos. Sci. 49: 2139-2156.

[32] JP S. and Colin R. M. 2015. Optimal Sunshade Configurations for Space-Based Geoengineering near the Sun-Earth L1 Point. Plos one. 10(8).