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Cloud Feedback Process in the annual variation of Earth Radiation Budget

Yoko TSUSHIMA [＊1，＊2]　Syukuro MANABE [＊1]

Cloud’s radiative feedback effect in the annual variation of global mean surface temperature ($\mathbf{T_S}$) has been analyzed using the satellite observation of radiative fluxes at the top of the atmosphere. It is found that clouds neither amplify nor dump the variation of $\mathbf{T_S}$. Cloud’s reflectivity and height do not change with $\mathbf{T_S}$. However in three general circulation models in which cloud microphysics is parameterized, cloud’s reflectivity and height increase with increasing $\mathbf{T_S}$.

Key Words : Cloud feedback process, Earth Radiation Budget Experiment, Annual variation of global mean surface temperature, Cloud Forcing

季節変動における地球の放射収支に対する雲の放射フィードバックの研究

對馬　洋子[＊3，＊4]　真鍋　淑郎[＊3]

季節変動における全球平均地表面温度($\mathbf{T_S}$)の変化に伴う雲の放射フィードバックを衛星データから解析した。雲は$\mathbf{T_S}$の変化を強めても弱めてもいない。雲の反射率・有効高度も$\mathbf{T_S}$の変化に伴い変化していない。一方，雲水量を予報している 3 つの大循環モデルでは雲の反射率・高度共に$\mathbf{T_S}$の増加に伴い増えている。

キーワード：雲の放射フィードバック，Earth Radiation Budget Experiment, 全球平均地表面温度の季節変動，雲の放射強制力

＊1　Frontier Research System for Global Change, Japan Marine Science and Technology Center
＊2　National Space Development Agency fo Japan
＊3　海洋科学技術センター　地球フロンティア研究システム
＊4　宇宙開発事業団

1. Introduction

The cloud radiative feedback process remains one of the most uncertain factors in projection of increase of earth surface temperature associated with global warming. For example, there are on going discussion about whether cloud albedo increases by increased cloud water content (Sommerville and Remer 1984, Tselioudis et al.1992). Using observational data, we estimate here the effect of the cloud feedback process upon the annual variation of global mean surface temperature (**T_S**). The purpose of this study is to see if cloud increases or decreases the annual variation of surface temperature. The results described below are compared with those obtained from GCM.

2. Annual variation of global mean surface temperature

Annual variation of global mean surface temperature increases as much as 4K from January to July (Fig. 1). This is as big as the surface temperature increase in a 2× CO2 experiment which was conducted using a GCM.It is attributable to a large inter-hemispheric difference of the coverages of continent and ocean with different heat capacites.

3. Formulation

Diffeutial of global mean annually normalized solar cloud forcing, longwave cloud forcing, annually normalized net cloud forcing change ($d\overline{CF_{SA}}$, $d\overline{CF_L}$, $d\overline{CF}$) is defined as follows.

$$d\overline{CF} = d\overline{CF_{SA}} + d\overline{CF_L} \quad (1)$$

$$d\overline{CF_{SA}} = \overline{dCF_S - \frac{\partial CF_S}{\partial S_0} dS_0} \quad (2)$$

S_0 and CF_S are solar insolation, solar cloud forcing . $\bar{x}$ denotes global mean of x.

4. Data and Analysis

ERBE S-9 data (ERBS+NOAA-9,10) from Feburary 1985 to January 1990 was used for top-of-the-atmosphere monthly mean annually normalized solar cloud forcing (CF_{SA}) and outgoing longwave cloud forcing (CF_L) (Harrison et al.1990). NCEP Reanalysis (Kalnay et al. 1996) monthly mean ground surface temperature was used for global mean surface temperature (**T_S**). ISCCP (Rossow

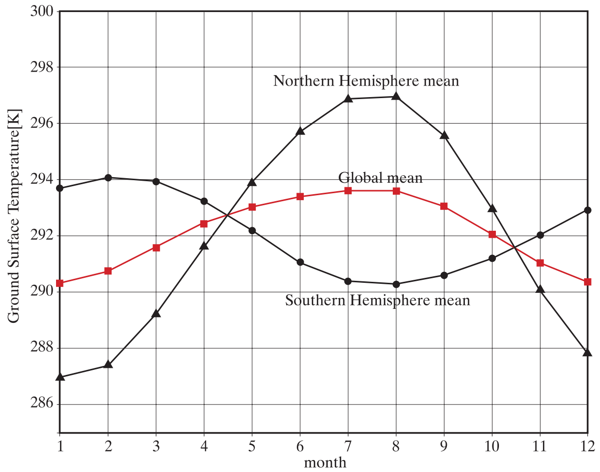

Fig. 1 Annual variation of Surface temperature[K]: Southern hemisphere, Northern hemisphere, global mean value

and Schiffer 1999) D2 data from January 1986 to Feburary 1993 (exclude Feburary 1987 to December 1987) was used for cloud cover. Monthly climatology has been made from these data. Globally averaged value is analysed, although the area is restricted to the region between 60S and 60N. Line regression has been done with 12 months of global mean surface temperature **T_S** and global mean annually normalized cloud radiative forcing $\overline{CF_{SA}}$, $\overline{CF_L}$. The results of GCM analysed in the present study are simulations performed as Atmospheric Model Intercomparison Project (AMIP) I (from January 1979 to December 1988). Results of the 3 models (CCSR/NIES, MPI, UKMO) with solar, longwave cloud forcing data in which prognostic cloud scheme are used have been analyzed.

5. Result from ERBE

It is found that there is no correlation between cloud radiative feedback and the annual variations of ground surface temperature both in solar and longwave radiation (Fig. 2a, Fig. 3a).

Cloud neither intensify nor damp the annual variation of **T_S**. With regard to global mean clud amount, it decreases with global mean surface temperature increases. When we see the dependency of $\overline{CF_{SA}}$ and $\overline{CF_L}$ per unit cloud amount (**Ca**.global mean) on **T_S**, they also have no correlation (Fig. 2b, Fig. 3b). Linear regression slopes are shown in the figures. The Small slope for annually normalized solar cloud forcing implies that the mean solar reflectivity of cloud hardly depends upon global mean surface temperature. The Small slope for longwave cloud forcing suggests that the mean cloud height changes little

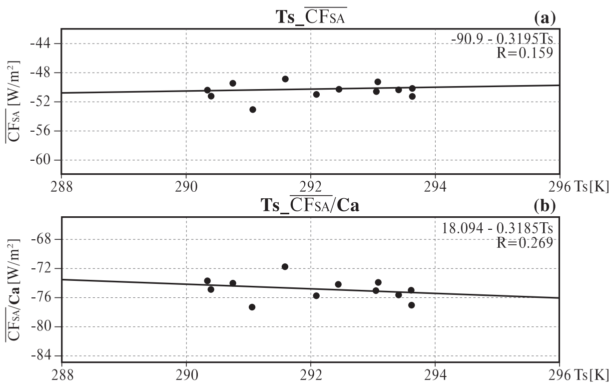

Fig. 2 Scatterplots of (a) $\overline{CF_{SA}}$ and $\mathbf{T_S}$, (b) $\overline{CF_{SA}}$ /**Ca** and $\mathbf{T_S}$.

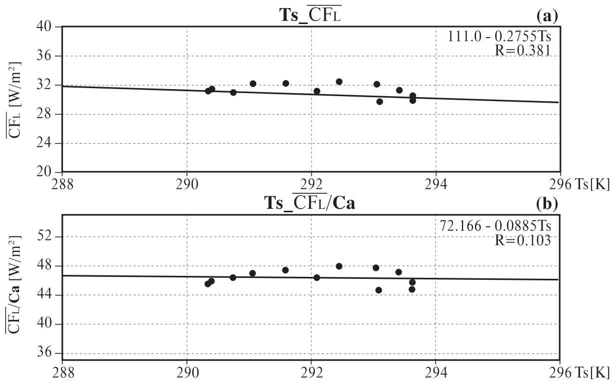

Fig. 3 Scatterplots of (a) $\overline{CF_L}$ and $\mathbf{T_S}$, (b) $\overline{CF_L}$ /**Ca** and $\mathbf{T_S}$.

with the increase of global mean surface temperature.

6. Result from GCM

In GCM, while strength of the correlation between cloud radiative feedback and the annual variation of the ground surface temperature is different in 3 models,intensification of both $\overline{CF_{SA}}$ and $\overline{CF_L}$ with the increasing of global mean surface temperature is found in spite of decreasing of cloud amount. As a result, $\overline{CF_{SA}}$ and $\overline{CF_L}$ per unit cloud amount get bigger with the surface temperature increase. Dependencies of $\overline{CF_{SA}}$ and $\overline{CF_L}$ per unit cloud amount(**Ca**) on gobal mean surface temperature in 3 models are shown in Fig. 4 and Fig. 5. In all 3 models, cloud reflectivity gets higher with increasing global mean surface temperature. As for longwave cloud forcing, greenhouse effect becomes stronger with global mean surface temperature increase.

7. Discussion

Our analysis of the annual variation of global radiation budget obtained from ERBE indicates that cloud neither amplifies nor damps the annual variation of global mean

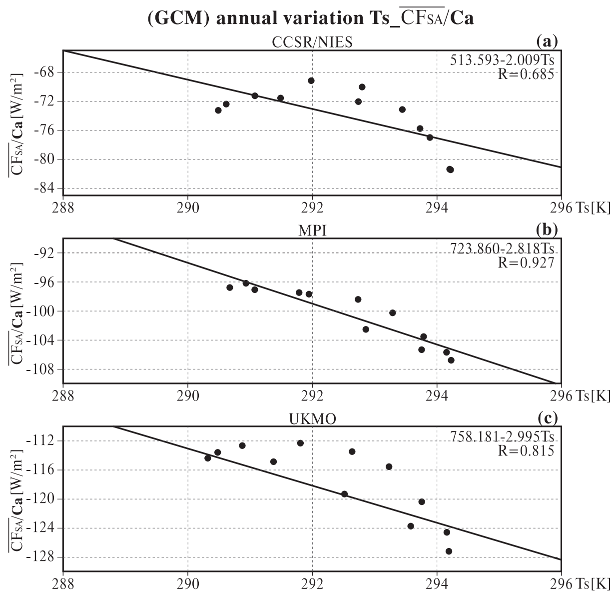

Fig. 4 Scatterplots of $\overline{CF_{SA}}$ and $\mathbf{T_S}$ in 3 models ((a)CCSR/NIES, (b)MPI, (c)UKMO).

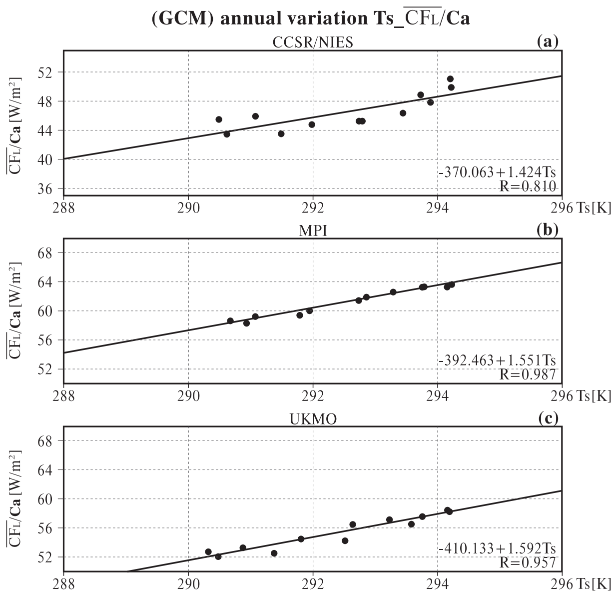

Fig. 5 Scatterplots of $\overline{CF_L}$ /**Ca** and $\mathbf{T_S}$ in 3 models ((a)CCSR/NIES, (b)MPI, (c)UKMO).

surface temperature. The analysis also indicates that the mean solar reflectivity of cloud and the mean cloud height hardly depends upon global mean temperature. However, in three general circulation models, in which cloud microphysics is parameterized explicitly, both cloud reflectivity and cloud effective height increase significanthly with increasing global mean surface tempreature. Slopes of global mean annually normalized cloud forcings to $\mathbf{T_S}$ are summarized in the Table1 and Table2.

	ERBE	CCSR/NIES	MPI	UKMO
$(d\overline{CF_{SA}}+d\overline{CF_L})/d\mathbf{T_S}$	– 0.138	– 0.064	– 0.765	+ 0.097
$d\overline{CF_{SA}}/d\mathbf{T_S}$	+ 0.139	– 0.496	– 0.697	– 0.052
$d\overline{CF_L}/d\mathbf{T_S}$	– 0.275	+ 0.432	+ 0.350	+ 0.131

Table 1. Slopes of $(d\overline{CF_{SA}}+d\overline{CF_L})/d\mathbf{T_S}$, $d\overline{CF_{SA}}/d\mathbf{T_S}$, $d\overline{CF_L}/d\mathbf{T_S}$ which are obtained from the least squares fit of the data. Units are [W/m^2/K].

	ERBE	CCSR/NIES	MPI	UKMO
$d\{(\overline{CF_{SA}}+d(\overline{CF_L}/\mathbf{Ca})\}/d\mathbf{T_S}$	– 0.406	– 0.585	– 1.267	– 1.414
$d(\overline{CF_{SA}}/\mathbf{Ca})/d\mathbf{T_S}$	+ 0.318	– 2.009	– 2.818	– 2.995
$d(\overline{CF_L}/\mathbf{Ca})/d\mathbf{T_S}$	– 0.088	+ 1.424	+ 1.551	+ 1.592

Table 2. Slopes of unit cloud amount's cloud forcings to $\mathbf{T_S}$: $d\{(\overline{CF_{SA}}+d(\overline{CF_L}/\mathbf{Ca})\}/d\mathbf{T_S}$: $d(\overline{CF_{SA}}/\mathbf{Ca})/d\mathbf{T_S}$, $d(\overline{CF_L}/\mathbf{Ca})/d\mathbf{T_S}$ which are obtained from the least squares fit of the data. Units are [W/m^2/K].

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