ON THE CONFUSION OF PLANCK FEEDBACK PARAMETERS

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ABSTRACT

The Planck feedback parameter λ_0 is the most fundamental quantity in the theory of global warming, because the surface temperature change $\Delta T_{s,0}$ is calculated by—(radiative forcing due to CO_2 doubling)/λ_0 in the absence of feedbacks other than that of surface temperature change. The following three groups of Planck feedback parameters are found in the literature depending on the choice of temperature T_s and the outgoing long wave radiation (OLR) at the top of atmosphere in equation of $\lambda_0 = -4OLR/T_s$, which is derived from the Stefan-Boltzmann Law.

GROUP A: $T_s = 288K$ and OLR = 231–243W/m^2 $\lambda_0 = -3.21 - -3.37(W/m^2)/K$
GROUP B: $T_s = 255K$ and OLR = 242W/m^2, $\lambda_0 = -3.8(W/m^2)/K$
GROUP C: $T_s = 288K$ and OLR = 492–514W/m^2 $\lambda_0 = -6.8 - -7.1(W/m^2)/K$

This study shows that λ_0 of GROUP C is a theoretically relevant choice for T_s and OLR, rather than those of GROUP A and GROUP B, while the IPCC adopted λ_0 of GROUP A. Although the surface temperature change ΔT_s is 3.0K with $\lambda_0 = -3.21(W/m^2)/K$ for CO_2 doubling when lapse rate ,water vapor, surface albedo and cloud feedbacks are included in the IPCC AR4, it is shown to be 0.5–0.75K with $\lambda_0 = -6.8(W/m^2)/K$ in the present study.

Since the IPCC overestimates the threat of carbon dioxide by 4–6 times, the revaluation will be needed for the CO_2 reduction policies in terms of cost and potential hazards.

1. INTRODUCTION

Climate sensitivityΔT_s indicates the change in the global mean surface temperature T_s when the concentration of atmospheric CO_2 is doubled from the pre-industrial level of 280 ppm to 560 ppm. It is expressed as the product of the climate sensitivity parameter Λ and the radiative forcing due to CO_2 doubling ΔQ, namely $\Delta T_s = \Lambda \times \Delta Q$ [Cess et al., 1990].

The climate system reacts to this external forcing through the various feedback processes, such as the change in surface temperature, lapse rate, water vapor concentration, surface albedo, as well as the cloud amount and its properties [Bony et al., 2006; Soden et al., 2006]. Therefore, two types of climate sensitivity and their corresponding parameters can be defined as follows.

(a) Climate sensitivity $\Delta T_{s,0}$ and climate sensitivity parameter Λ_0 without feedbacks other than change in surface temperature, which is called Planck feedback.
(b) Climate sensitivity ΔT_s and climate sensitivity parameter Λ with the feedbacks of surface temperature, lapse rate, water vapor, surface albedo and cloud.

Schlesinger proposed a linear model of the climate system as follows [Schlesinger, 1986].

$$N = N\ (E_i, T_s, I_j) \text{ and } I_j = I_j(T_s) \tag{1}$$

Then,

$$⊿N = \partial N/\partial E_i \times ⊿E_i + \partial N/\partial T_s \times ⊿T_s + \partial N/\partial I_j \times dI_j/dT_s \times ⊿T_s \tag{2}$$

Here in the formula,

N: the net energy flux at the top of atmosphere (TOA) The sign of flux is plus when the flux is downward.
E_i: the vector of external variables to the climate system such as atmospheric CO_2 concentration.
I_j: the vector of internal variables in the climate system other than T_s such as lapse rate, water vapor concentration, surface albedo, cloud amount and its properties.
$⊿Q$: the external forcing defined as $⊿Q = \partial N/\partial E_i \times ⊿E_i$
λ_0: the Planck feedback parameter defined as $\lambda_0 = \partial N/\partial T_s$
λ_j: the feedback parameter of internal variable j defined as $\lambda_j = \partial N/\partial I_j \times dI_j/dT_s$

Since $⊿N$ is 0 when equilibrium is reached in response to the external forcing $⊿Q$, the change in global mean surface temperature $⊿T_s$ can be expressed as follows [Bony et al., 2006].

$$⊿T_s = -⊿Q/(\lambda_0 + \lambda_{LR} + \lambda_{WV} + \lambda_A + \lambda_C) = -⊿Q/\lambda = \Lambda \times ⊿Q \tag{3}$$

Here, $\lambda = \lambda_0 + \lambda_{LR} + \lambda_{WV} + \lambda_A + \lambda_C$
λ_{LR}: lapse rate feedback parameter
λ_{WV}: water vapor feedback parameter
λ_A: surface albedo feedback parameter
λ_C: cloud feedbacks parameter

From Eq. (3), with $\lambda_j = 0$, climate sensitivity $⊿T_{s,0}$ is expressed as follows in the absence of feedbacks other than the change in surface temperature [Bony et al., 2006].

$$⊿T_{s,0} = -⊿Q/\lambda_0 = \Lambda_0 \times \Delta Q \tag{4}$$

Furthermore, the following equations are derived from the above equations [Bony et al., 2006].

$$\Lambda = -1/\lambda \quad \text{and} \quad \Lambda_0 = -1/\lambda_0 \tag{5}$$

$$⊿T_s = ⊿T_{s,0} \times \lambda_0/\lambda = ⊿T_{s,0} \times 1/(1 - g_{LR} - g_{WV} - g_A - g_C) \tag{6}$$

Here, g_{LR} : lapse rate feedback gain $-\lambda_{LR}/\lambda_0$
g_{WV}: water vapor feedback gain $-\lambda_{WV}/\lambda_0$
g_A: surface albedo feedback gain $-\lambda_A/\lambda_0$
g_C: cloud feedbacks gain $-\lambda_C/\lambda_0$

In calculating the climate sensitivity $⊿T_s$, the Planck feedback parameter λ_0 is the most fundamental and influential, because it determines $⊿T_{s,0}$, as well as the feedback gains. The sign of λ_0 is negative for the negative Planck feedback [Bony et al., 2006; Soden, et al., 2006], although the opposite sign is utilized in some literature [Wetherald et al., 1988].

2. λ_0 DEDUCED FROM MODEL STUDIES

Manabe et al., reported $\Delta T_{s,0} = 1.3$K for CO_2 doubling utilizing a radiative- convective model (RCM) with a fixed critical lapse rate of 6.5 K/km for convective adjustment, fixed absolute humidity, fixed cloud altitude, fixed cloud cover, fixed cloud optical depth and fixed surface albedo [Manabe et al., 1964; Manabe et al., 1967]. Although the radiative forcing due to CO_2 doubling ΔQ is not shown in their paper, it can be estimated as $3.5W/m^2$ from the general circulation model (GCM) study incorporating the same RCM [Manabe et al., 1975], which yields $\lambda_0 = -2.7(W/m_2)/K$.

Hansen et al., obtained $\Delta T_{s,0} = 1.2$K utilizing an RCM with the same characteristics as that of Manabe et al., with $\Delta Q = 4.0W/m^2$ [Hansen et al., 1981], which corresponds to $\lambda_0 = -3.3(W/m_2)/K$.

Schlesinger also conducted an RCM study showing $\Delta T_{s,0} = 1.3$K with $\Delta Q = 4.0\ W/m_2$ to obtain a climate sensitivity parameter Λ_0 of $0.3K/(W/m^2)$ [Schlesinger, 1986], which means that $\lambda_0 = -3.3(W/m^2)/K$.

Although the above three RCM studies show that λ_0 is around $-3(W/m^2)/K$, the computation results of an RCM strongly depend on the various parameterizations such as critical lapse rate for convective adjustment, cloud layer, cloud height, cloud temperature and cloud optical depth [Schneider, 1975; Hummel et al., 1981; Lindzen et al., 1982; Somerville et al., 1984; Schlesinger, 1986]. For instance, Hummel et al., obtained a 25 – 60% smaller surface temperature change ΔT_s utilizing a moist adiabatic lapse rate than the ΔT_s with the constant 6.5K/km lapse rate used in the above three RCM studies. This will reduce λ_0 from $-3(W/m^2)/K$ to $-4(W/m^2)/K$ – $-7.5(W/m^2)/K$ when the same degree of reduction is applied for $\Delta T_{s,0}$.

Ramanathan et al., pointed out that a constant 6.5K/km lapse rate is too large for the lower troposphere in his investigations of the actual behavior of the lapse rate at that height [Ramanathan et al., 1978], implying that the moist adiabatic lapse rate is the more realistic parameterization than the constant 6.5K/km lapse rate. In conclusion, an RCM study cannot furnish a Planck feedback parameter λ_0 which can serve as the theoretical basis of atmospheric science.

3. λ_0 CALCULATED WITH THE STEFAN-BOLTZMANN LAW

Eq. (7) expresses the radiation budget N of the earth at the top of the atmosphere (TOA), utilizing the solar constant S_0, the albedo of the earth α and the outgoing long wave radiation OLR [Bony et al., 2006].

$$N = (S_0/4)(1 - \alpha) - OLR \tag{7}$$

Therefore, the Planck feedback parameter λ_0 can be calculated by Eq. (8).

$$\lambda_0 = \partial N/\partial T_s = -\partial OLR/\partial T_s \tag{8}$$

Based on experimental data for OLR as a function of surface temperature and surface albedo measured by satellites, Cess expressed OLR with the modified Stefan-Boltzmann equation as follows [Cess, 1976].

$$OLR = \varepsilon_{eff}\sigma T_s{**}4 \tag{9}$$

Here, ε_{eff}: the effective emissivity of the surface-atmosphere system
σ: the Stefan-Boltzmann constant

From Eq. (9), λ_0 was obtained by differentiation as follows with the assumption that ε_{eff} is a constant [Cess, 1976].

$$\lambda_0 = -\partial OLR/\partial T_s = -4\varepsilon_{eff}\sigma T_s{**}3 = -4OLR/T_s \tag{10}$$

In the Eq. (9), Cess took $T_s = 288K$ and $\varepsilon_{eff} = 0.6$ to obtain OLR = 233 (W/m^2), which gives the following λ_0 and Λ_0[Cess, 1976].

$$\lambda_0 = -4OLR/T_s = -4 \times 233/288 = -3.3\ (W/m^2)/K \qquad \Lambda_0 = 1/3.3 = 0.3K/(W/m^2)$$

Cess et al., reconfirmed the calculation with $T_s = 288K$ and OLR = 240W/m^2 [Cess et al., 1990]. Wetherald et al., and Tsushima et al., followed Cess's procedures to obtain substantially equivalent results [Wetherald et al., 1988; Tsushima et al., 2005].

The above four studies furnish $\varDelta T_{s,0} = 1.2K$ utilizing 4W/m^2 for the radiative forcing due to CO_2 doubling [Hansen et al.,1981]. Since this is revised to 3.7W/m^2 in the IPCC TAR, the Planck feedback parameter λ_0 is changed slightly from -3.3(W/m^2)/K to -3.21(W/m$_2$)/K in the 14 GCMs studied for the IPCC AR4 in order to guarantee that $\varDelta T_{s,0} = 1.2K$ [Soden et al., 2006].

Bony et al., pointed out that the combination of $T_s = 288K$ and OLR = 233–243 W/m^2 did not coincide with the Stefan-Boltzmann Law. They proposed that $T_s = 255K$ and $\lambda_0 = -3.8$(W/m^2)/K, which means that OLR = 242W/m^2 [Bony et al., 2006]. However, T_s should be 288K based on the definition of λ_0 as shown in Eq. (2) and (8). Therefore, their proposed values failed when tested mathematically.

Schlesinger calculated the climate sensitivity Λ_0 using Eq. (11) with $T_s = 288K$, solar constant $S_0 = 1370W/m^2$ and surface albedo $\alpha = 0.3$ obtaining $\Lambda_0 = 0.3$ K/(W/m^2), which corresponds to $\lambda_0 = -3.3$(W/m^2)/K [Schlesinger, 1986].

$$\Lambda_0 = T_s/(1 - \alpha)S_0 \tag{11}$$

Equation (11) is derived from Eq. (7), (9) and (10) as follows.
From Eq. (7) and (9), the following equation is obtained.

$$N = (S_0/4)\,(1 - \alpha) - \varepsilon_{eff}\sigma T_s{}^{**}4 \tag{12}$$

At equilibrium, the following equation is obtained, since N is 0.

$$\varepsilon_{eff}\sigma T_s{}^{**}4 = (S_0/4)(1 - \alpha) \tag{13}$$

Equation (11) can be derived from Eq. (10) and (13) as follows.

$$\lambda_0 = -4 \times (S_0/4T_s)(1 - \alpha) = -(S_0/T_s)(1 - \alpha) = -1/\Lambda_0$$

$$\Lambda_0 = T_s/(1 - \alpha)S_0 \tag{11}$$

Based on the above analysis, whether Cess's and Schlesinger's calculations are correct or not depends on Eq. (9), assuming that ε_{eff} is a constant.

According to the annual global mean energy budget [Kiehl et al., 1997], OLR can be expressed as follows.

$$OLR = F_{s,r} + F_{s,e} + F_{s,t} + F_{sun} - F_b \tag{14}$$

Here, $F_{s,r}$:	surface radiation	$390 W/m^2$
$F_{s,e}$:	surface evaporation	$78 W/m^2$
$F_{s,t}$:	surface thermal conduction	$24 W/m^2$
F_{sun}:	short waves absorbed by the atmosphere	$67 W/m^2$
F_b:	back radiation	$324 W/m^2$
OLR:	outgoing long wave radiation	$235 W/m^2$

From Eq. (9) and (14), the following equations are obtained.

$$\varepsilon_{eff}\sigma T_s{}^{**}4 = \varepsilon_{eff}F_{s,r} = F_{s,r} + F_{s,e} + F_{s,t} + F_{sun} - F_b \tag{15}$$

$$\varepsilon_{eff} = 1 + (F_{s,e} + F_{s,t})/F_{s,r} + (F_{sun} - F_b)/F_{s,r} \tag{16}$$

Therefore, ε_{eff} is not a constant but a complicated function of T_s and the internal variables I_j, which can not furnish the differentiation of Eq. (9) to obtain Eq. (10).

Based on the above arguments, we can conclude that Cess's and Schlesinger's calculations as well as that of Bony et al., can not be allowed as mathematically feasible in obtaining the genuine Planck feedback parameter.

4. λ_0 IN THE PRESENT STUDY

From Eq. (8) and (14), the Planck feedback parameter λ_0 is calculated by Eq. (17) referring to the linear model of the climate system expressed by Eq. (2).

$$\lambda_0 = -\partial OLR/\partial T_s = -d(F_{s,r} + F_{s,e} + F_{s,t})/dT_s - \partial(F_{sun} - F_b)/\partial I_j \times (dI_j/dT_s) \tag{17}$$

Here, I_j is the vector of the internal variables in the climate system.

Since the second terms are the climate feedback parameters of the internal variables I_j, they are zero when Planck feedback parameter λ_0 is calculated. Thus, Eq. (17) is reduced to Eq. (18) utilizing the Stefan-Boltzmann Law.

$$\lambda_0 = -d(F_{s,r} + F_{s,e} + F_{s,t})/dT_s = -4(F_{s,r} + F_{s,e} + F_{s,t})/T_s \tag{18}$$

As shown above, $F_{s,r} = 390W/m^2$: $F_{s,e} = 78W/m_2$: $F_{s,t} = 24W/m^2$

Thus, λ_0 can be calculated by Eq. (18) as follows.

$$\lambda_0 = -4 \times (390 + 78 + 24)/288 = -4 \times (390 + 102)/288 = -6.8(W/m^2)/K$$

Ramanathan obtained $\Delta T_{s,0} = 0.50K$ with $\Delta Q = 3.5W/m_2$ for the direct heating of CO_2 doubling, which gives $\Lambda_0 = 0.14K/(W/m^2)$ or $\lambda_0 = -7.1(W/m^2)/K$ [Ramanathan, 1981]. In this study, the flux of evaporation $F_{s,e}$ plus thermal conduction $F_{s,t}$ is $124W/m^2$, when the radiation flux $F_{s,r}$ is $390W/m_2$. Strictly speaking, $(F_{s,e} + F_{s,t})$ is a different function of T_s from $F_{s,r}$ as shown in Newell et al., for tropical seas [Newell et al., 1979]. However, the Stefan-Boltzmann Law is applied to $(F_{s,r} + F_{s,e} + F_{s,t})$ in Eq. (18) as a first approximation [Ramanathan, 1981].

The following table shows a comparison between the present study and the data in the literature . Based on the argument presented in section 3, GROUP C is the theoretically relevant choice for T_s and OLR, while GROUP A and GROUP B can not be allowed on mathematic bases.

	T_s K	OLR W/m_2	$-\lambda_0$ $(W/m^2)/K$	Λ_0 $K/(W/m^2)$
(GROUP A)				
Cess, 1976	288	233	3.3	0.3
Schlesinger, 1986	288	*)	3.3	0.3
Wetherald et al., 1988	288	243**)	3.37	0.3
Cess et al., 1990	288	240	3.3	0.3
Tsushima et al., 2005	288	238**)	3.3	0.3
Soden et al., 2006	288	231**)	3.21***)	0.31***)
(GROUP B)				
Bony et al., 2006	255	242****)	3.8	0.26
(GROUP C)				
Ramanathan, 1981	288	390 + 124**)	7.1	0.14
Present study	288	390 + 102	6.8	0.15

*) Solar constant $S_0 = 1370W/m_2$ and surface albedo $\alpha = 0.3$ in Eq. (11)

**) Calculated by Eq. (10) with $T_s = 288K$

***) Averaged value of the 14 GCMs calculations for the IPCC AR4[Soden et al., 2006]

****) Calculated by Eq. (10) with $T_s = 255K$

5. COMPARISON WITH THE IPCC AR4 AND OBSERVATIONAL DATA

Finally, the present study will be compared with the calculations of the 14 GCMs for the IPCC AR4 [Soden et al., 2006], in terms of $\Delta T_{s,0}$ and ΔT_s for CO_2 doubling. The comparison will be made utilizing the averaged values of λ_{LR}, λ_{WV}, λ_A and λ_C from the IPCC AR4 [Soden et al., 2006].

	IPCC AR4 [Soden et al.,2006]	Present study
λ_0	$-3.21(W/m^2)/K$	$-6.8(W/m^2)/K$
λ_{LR}	$-0.84(W/m^2)/K$	$-0.84(W/m^2)/K$
λ_{WV}	$1.80(W/m^2)/K$	$1.80(W/m^2)/K$
λ_A	$0.26(W/m^2)/K$	$0.26(W/m^2)/K$
λ_C	$0.69(W/m^2)/K$	$0.69(W/m^2)/K$
ΔQ	$3.7W/m^2$	$3.7W/m^2$
$\Delta T_{s.0}$	1.2K	0.54K
ΔT_s	3.0K	0.75K

Climate sensitivity ΔT_s is 3K in the IPCC AR4, while it is 0.75K in the present study. A comparison will be made with observational data to investigate which value is more plausible.

(1) According to the annual global mean energy budget [Kiehl et al., 1997], natural greenhouse energy can be expressed as $(F_b - F_{sun})$ utilizing the same notation as Eq. (14), which furnishes a natural greenhouse effect of 33K. Therefore, the climate sensitivity ΔT_s and its parameter Λ is calculated as follows utilizing the same radiative forcing ΔQ of $3.7W/m_2$ due to CO_2 doubling as the IPCC AR4.

$$\Lambda = 33K/(F_b - F_{sun}) = 33K/(324 - 67)W/m^2 = 33K/257W/m^2 = 0.13K/(W/m^2)$$

$$\Delta T_s = 0.13K/(W/m^2) \times 3.7W/m^2 = 0.5K$$

Since climate change is a perturbation in the natural greenhouse effect due to CO_2 doubling, this calculation is the most reliable method in evaluating climate sensitivity among the various observational methods.

(2) From eight natural experiments, Idoso obtained $\Delta T_s = 0.4K$ or less for CO_2 doubling [Idoso, 1998]. Natural experiment 4 is substantially equivalent to method (1).

(3) Based on data analysis from the Pinatubo event, Douglass et al., found that Λ is $0.22K/(W/m^2)$, which gives $\Delta T_s = 0.8K$ with $\Delta Q = 3.7W/m^2$ [Douglass et al., 2006].

(4) Raval et al., obtained a sensitivity of $0.3K/(W/m_2)$ or $-3.3(W/m_2)/K$ for $G_{clear} = \sigma T_s{**}4 - OLR_{clear}$ by ERBE measurements on the open ocean [Raval et al., 1989]. Utilizing the notation of Eq. (14), G_{clear} can be expressed as follows.

$$G_{clear} = F_{s,r} - (F_{s,r} + F_{s,e} + F_{s,t} + F_{sun} - F_b) = (F_b - F_{sun}) - (F_{s,e} + F_{s,t}) \quad (19)$$

Since $(F_b - F_{sun})$ is the true greenhouse effect as shown in method (1), G_{clear} does not include the flux of surface evaporation and thermal conduction, which have a smaller range of sensitivity than radiation [Newell et al., 1979]. Furthermore, the relative humidity depends strongly on the large scale circulation which governs the distribution of water vapor with the strongest greenhouse effect [Held et al., 2000]. Therefore, it is to be concluded that the sensitivity obtained by Raval et al., is not the proper one to use in calculating the climate sensitivity ΔT_s.

(5) Gregory et al., obtained a climate sensitivity distribution curve having its maximum at 2K based on the sea temperature rise reported by Levitus et al. [Levitus et al., 2001; Gregory et al., 2002]. However, these results are not reliable since measurement problems exist in the data in Levitus et al. [Gouretski et al., 2007].

Based on the above argument, we concluded that the climate sensitivity $\Delta T_s = 0.75K$ in the present study was good coincident with the observed values of 0.4 – 0.8K. It is overestimated by the IPCC AR4 as $\Delta T_s = 3K$ since the Planck feedback parameter λ_0 is $-3.21(W/m^2)/K$,which is not mathematically feasible. ΔT_s in the present study is 0.25K larger than the 0.5K obtained using method (1), which is the most reliable value. The discrepancy can be attributed to the overestimation of water vapor feedback in the IPCC AR4 [Minschwaner et al., 2004]. Furthermore, Lindzen proposed the possibility of negative water vapor feedback which diminishes climate sensitivity [Lindzen, 1990; Lindzen et al., 2001]. He also pointed out that the observed surface warming was far less than the calculated values using GCMs [Lindzen, 2007], which is in accordance with the present paper.

As to the overall effect of the various feedbacks, the following calculation shows that it is neutral or slightly negative .

$$\Delta T_s \text{ by method (1)}/\Delta T_{s,0} \text{ in the present study} = 0.50/0.54 = 0.93$$

This might be the cause of the stability in the present climate, though Earth's climate has experienced the Medieval Warm Period and the Little Ice Age due to fluctuations in solar activity.

6. CONCLUSION

The Planck feedback parameter λ_0 is the most fundamental quantity in the theory of global warming, because the surface temperature change $\Delta T_{s,0}$ is calculated by–(radiative forcing due to CO_2 doubling)/ λ_0 in the absence of feedbacks other than the changes in surface temperature. The following three groups of Planck feedback parameters are found in the literature depending on the choice of the temperature T_s and the outgoing long wave radiation (OLR) at the top of atmosphere in the equation of $\lambda_0 = -4OLR/T_s$, which is derived from the Stefan-Boltzmann Law.

GROUP A: $T_s = 288K$ and $OLR = 231–243W/m^2$	$\lambda_0 = -3.21 - -3.37(W/m^2)/K$
GROUP B: $T_s = 255K$ and $OLR = 242W/m^2$,	$\lambda_0 = -3.8(W/m^2)/K$
GROUP C: $T_s = 288K$ and $OLR = 492–514W/m^2$	$\lambda_0 = -6.8 - -7.1(W/m^2)/K$

The present study shows that λ_0 of GROUP C is the theoretically relevant choice for T_s and OLR rather than that of GROUP A or GROUP B, while the IPCC adopted λ_0 of GROUP A. Although the surface temperature change ΔT_s is 3.0K with $\lambda_0 = -3.21(W/m^2)/K$ for CO_2 doubling when lapse rate ,water vapor, surface albedo and cloud feedbacks are included in IPCC AR4, it is 0.5 – 0.75K with $\lambda_0 = -6.8(W/m^2)/K$ in the present study.

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