An Explanation of Global Warming without Supercomputing

(revised version)*

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Abstract

A new analytic solution of the radiative transfer equation is proposed. It is an extension of the semi-gray model developed by Weaver and Ramanathan. We consider the two regions of thermal spectra independently. In the first the infrared absorption (or radiation) is only due to water vapor. In the second both water vapor and carbon dioxide are active. The pre-industrial values of the corresponding two optical depths are determined so as to reproduce the global average temperature and the infrared spectrum observed by satellite spectrometer. Then, assuming that the optical depth of carbon dioxide is proportional to its concentration but the optical depth of water vapor is invariable, we can reproduce the climate change after 1850 AD fairly well. Consequently, it is found that the climate sensitivity never exceeds 6 °C. The result is consistent to recent investigations. It is therefore concluded that the anthropogenic global warming is severely limited because the Earth is a water planet.

1 Introduction

Now, it is well known that most of climate scientists attribute the climate change since the industrial revolution to the growing concentration of carbon dioxide (CO_2) from fossil fuel burning. Their *consensus* [1,2,3] on this anthropogenic global warming (AGW) is essentially based on the results of elaborate and enormous computer simulations as seen in Figure 9.5 on the 4th Assessment Report (AR4) [4] of Intergovernmental Panel on Climate Change (IPCC). In this respect we also note the following statement by Dr. Weart in Ref. [5]:

> I often get emails from scientifically trained people who are looking for a straightforward calculation of the global warming that greenhouse gas emissions will bring. . . . The history reveals how the nature of the climate system inevitably betrays a lover of straightforward answers. . . . Physics is rich in phenomena that are simple in appearance but cannot be calculated in simple terms. Global warming is like that.

*I have largely improved mp_arc 10-163. However, the main results and conclusions are retained.

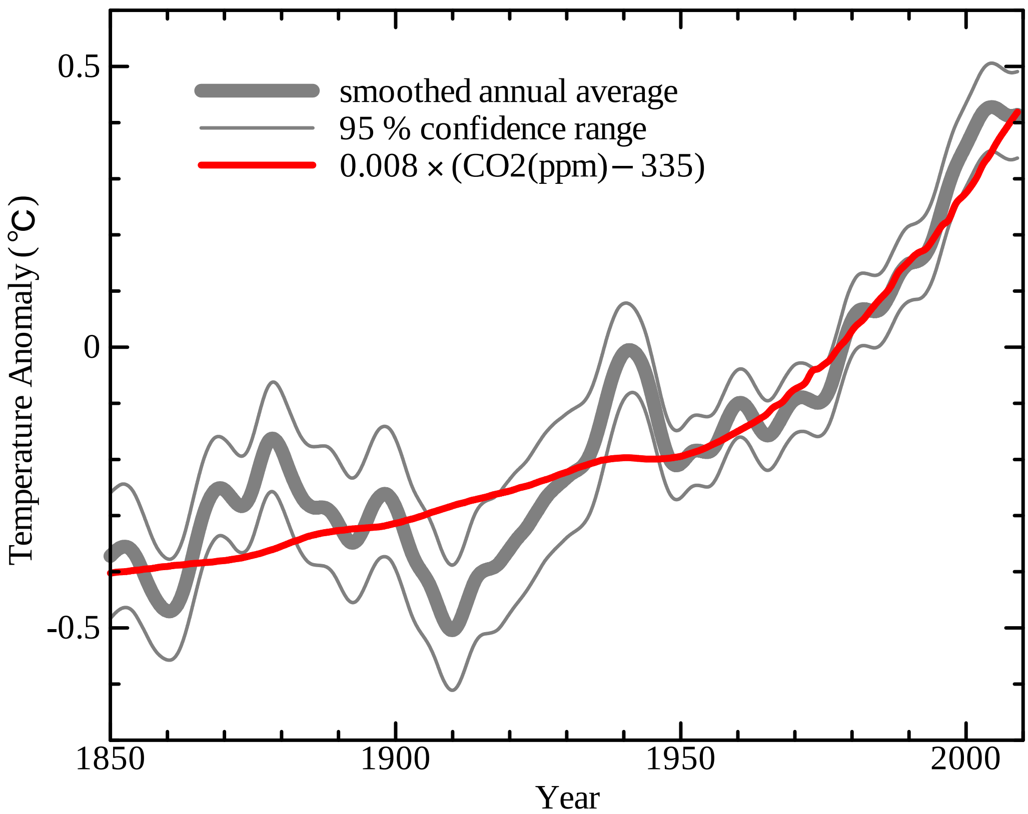

Figure 1: The gray curves are the observed temperature anomalies in Met Office Hadley Centre observations datasets [6]. The red curve is the calculated result of $0.008 \times (n - 335)$, where n is CO_2 concentration (ppm) from Carbon Dioxide Information Analysis Center (CDIAC) [7] and National Oceanic and Atmospheric Administration (NOAA) [8].

However, there will be not a few physicists who do not agree with him. See the red curve in Fig. 1. There is simple and clear correlation between the temperature anomaly and the increase in CO_2. (Here, the anomaly means the difference from an average temperature between 1961 and 1990.) Contrary to the climate scientists, some physicists will expect from the result that the global warming can be calculated in relatively simple terms only on the basic theory of greenhouse gas (GHG). Of course, if the scientists warn the world against AGW, they have a duty to illustrate AGW in simple terms. In the present work I challenge a straightforward calculation of global warming and want to verify that the science never betrays a lover of straightforward answers.

2 Extension of Ramanathan's semi-gray model

The atmospheric absorption of infrared radiation (IR) from the earth surface and the atmospheric back-radiation to the surface is formulated in the theory of radiative transfer. The basic equation is the following Schwarzschild equation [9,10]:

$$\cos\theta \, \frac{d\,I_\lambda}{d\,\tau_\lambda} = I_\lambda - B_\lambda\,(T)\,, \tag{1}$$

where I_λ is the intensity of radiation with wavelength λ, τ_λ is the corresponding optical depth, $B_\lambda\,(T)$ is the Plank function of temperature T and θ is the zenith angle of the direction of radiation. Under the approximation of plain-parallel gray atmosphere, Eq. (1) is solved analytically and the surface air temperature is given by

$$T\,(\tau^*)^4 = \frac{2+3\,\tau^*}{4}\,T_e^{\,4}, \tag{2}$$

where τ^* is the total optical depth of atmosphere and $T_e = 255\,\mathrm{K}$.

Equation (2) however has a serious drawback. The surface air temperature diverges when the atmosphere is a black body. But, if the temperature of black body is infinite, the Kirchhoff law, on which the Schwarzschild equation is based, has not been found. Surprisingly, climate scientists have ignored this inconsistency until Weaver and Ramanathan [11] have resolved the problem in 1995. They modified the gray model so as to take into account the spectral window in thermal spectrum and obtained the following result in place of Eq. (2):

$$T\,(\tau^*)^4 = \frac{2+3\,\tau^*}{4+3\,(1-\beta)\,\tau^*}\,T_e^{\,4}, \tag{3}$$

where the fraction $1-\beta \simeq 0.3$ of total thermal spectrum is transparent to thermal radiation. (It is noted that β in the present work corresponds to $1-\beta$ in Ref. [11].)

However, the Weaver-Ramanathan semi-gray model is not beyond the original gray model in the sense that it does not distinguish CO_2 from the other GHGs. Because the atmospheric greenhouse effect is mainly due to water vapor and CO_2 but the AGW is due to the growing concentration of the latter, we have to consider the greenhouse effects of water vapor and CO_2 independently so as to investigate the AGW.

For the purpose we divide the opaque fraction $\beta \simeq 0.7$ of total thermal spectrum into two regions:

$$\bar{I}_I = \int_{\lambda_1}^{\lambda_2} I_\lambda\,d\lambda, \tag{4}$$

$$\bar{I}_{II} = \int_{\lambda_3}^{\lambda_4} I_\lambda\,d\lambda, \tag{5}$$

where CO_2 is active only within $\lambda_3 \le \lambda \le \lambda_4$ while water vapor is active over $\lambda_1 \le \lambda \le \lambda_2$ and $\lambda_3 \le \lambda \le \lambda_4$. Although in fact the thermal window cuts the absorption spectrum of water vapor into two regions, we have expressed Eq. (4) in single term for simplicity. This is not a problem because in the present work we assume that in each of the spectra I and II the optical depth is independent on wavelength.

Then, we integrate Plank function similarly:

$$S_I \equiv \pi \int_{\lambda_1}^{\lambda_2} B_\lambda(T)\, d\lambda \ = \beta_I \, \sigma \, T^4, \tag{6}$$

$$S_{II} \equiv \pi \int_{\lambda_3}^{\lambda_4} B_\lambda(T)\, d\lambda = \beta_{II} \, \sigma \, T^4, \tag{7}$$

where σ is the Stefan-Boltzmann constant. The sum of β_I and β_{II} equals to β in Eq. (3):

$$\beta = \beta_I + \beta_{II}. \tag{8}$$

In the present work, it is assumed that β_I, β_{II} and β are independent on temperature according to Ref. [11].

Next, we use the Eddington approximation:

$$S_I \simeq \pi \left(C_I^{(0)} + C_I^{(1)} \, \tau_I \right), \tag{9}$$

$$S_{II} \simeq \pi \left(C_{II}^{(0)} + C_{II}^{(1)} \, \tau_{II} \right). \tag{10}$$

Consequently, the upwelling and downwelling fluxes are given by

$$F_I^{\uparrow\downarrow} (\tau_I) = \pi \left(C_I^{(0)} + C_I^{(1)} \tau_I \right) \pm \frac{2\,\pi}{3} \, C_I^{(1)}, \tag{11}$$

$$F_{II}^{\uparrow\downarrow} (\tau_{II}) = \pi \left(C_{II}^{(0)} + C_{II}^{(1)} \tau_{II} \right) \pm \frac{2\,\pi}{3} \, C_{II}^{(1)}, \tag{12}$$

where the signs of the second terms in the right hand sides are + for upwelling and − for downwelling flux, respectively.

Because there are no downwelling fluxes at the top of atmosphere (TOA), we have the following two conditions of terrestrial radiative equilibrium:

$$\begin{aligned}\left[F_I^{\uparrow} (\tau_I = 0) + F_I^{\downarrow} (\tau_I = 0) \right] + \left[F_{II}^{\uparrow} (\tau_{II} = 0) + F_{II}^{\downarrow} (\tau_{II} = 0) \right] + (1 - \beta)\, \sigma \, T_g^4 \\ = 2\,\pi \left[C_I^{(0)} + C_{II}^{(0)} \right] + (1 - \beta)\, \sigma \, T_g^4 \ = \ \sigma \, T_e^4,\end{aligned} \tag{13}$$

$$\begin{aligned}\left[F_I^{\uparrow} (\tau_I = 0) - F_I^{\downarrow} (\tau_I = 0) \right] + \left[F_{II}^{\uparrow} (\tau_{II} = 0) - F_{II}^{\downarrow} (\tau_{II} = 0) \right] + (1 - \beta)\, \sigma \, T_g^4 \\ = \frac{4\,\pi}{3} \left[C_I^{(1)} + C_{II}^{(1)} \right] + (1 - \beta)\, \sigma \, T_g^4 \ = \ \sigma \, T_e^4,\end{aligned} \tag{14}$$

where T_g is the surface temperature.

From Eqs. (6) and (9) the temperature at TOA is

$$\sigma\,T\left(\tau_I = 0\right)^4 = \pi\,\frac{C_I^{(0)}}{\beta_I}, \tag{15}$$

while from Eqs. (7) and (10) it is

$$\sigma\,T\left(\tau_{II} = 0\right)^4 = \pi\,\frac{C_{II}^{(0)}}{\beta_{II}}. \tag{16}$$

Because of $T\left(\tau_I = 0\right) = T\left(\tau_{II} = 0\right)$, from Eq. (13) we have

$$C_I^{(0)} = \frac{1}{2\,\pi}\,\frac{\beta_I}{\beta}\,\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right], \tag{17}$$

$$C_{II}^{(0)} = \frac{1}{2\,\pi}\,\frac{\beta_{II}}{\beta}\,\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right]. \tag{18}$$

On the other hand, from Eqs. (6) and (9) the surface air temperature is

$$\sigma\,T\left(\tau_I^*\right)^4 = \pi\,\frac{C_I^{(0)} + C_I^{(1)}\,\tau_I^*}{\beta_I}, \tag{19}$$

while from Eqs. (7) and (10) it is

$$\sigma\,T\left(\tau_{II}^*\right)^4 = \pi\,\frac{C_{II}^{(0)} + C_{II}^{(1)}\,\tau_{II}^*}{\beta_{II}}. \tag{20}$$

Because of $T\left(\tau_I^*\right) = T\left(\tau_{II}^*\right)$, from Eq. (14) we have

$$C_I^{(1)} = \frac{3}{4\,\pi}\,\frac{\beta_I\,\tau_{II}^*}{\beta_I\,\tau_{II}^* + \beta_{II}\,\tau_I^*}\,\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right], \tag{21}$$

$$C_{II}^{(1)} = \frac{3}{4\,\pi}\,\frac{\beta_{II}\,\tau_I^*}{\beta_I\,\tau_{II}^* + \beta_{II}\,\tau_I^*}\,\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right]. \tag{22}$$

Consequently, the upwelling and downwelling fluxes at any optical depth are

$$F_I^{\uparrow}\left(\tau_I\right) + F_{II}^{\uparrow}\left(\tau_{II}\right) = \left(1 + \frac{3}{4}\,\tau\right)\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right], \tag{23}$$

$$F_I^{\downarrow}\left(\tau_I\right) + F_{II}^{\downarrow}\left(\tau_{II}\right) = \frac{3}{4}\,\tau\,\sigma\left[T_e^4 - (1-\beta)\,T_g^4\right], \tag{24}$$

where

$$\tau = \frac{\beta_I\,\tau_{II}^*\,\tau_I + \beta_{II}\,\tau_I^*\,\tau_{II}}{\beta_I\,\tau_{II}^* + \beta_{II}\,\tau_I^*}. \tag{25}$$

The radiative equilibrium is really satisfied.

Then, from the radiative equilibrium condition at surface

$$F_I^{\downarrow}(\tau_I^*) + F_{II}^{\downarrow}(\tau_{II}^*) + \sigma T_e^4 = \sigma T_g^4, \tag{26}$$

the surface temperature is given by

$$T_g^4 = \frac{4 + 3\,\tau^*}{4 + 3\,(1-\beta)\,\tau^*}\, T_e^4, \tag{27}$$

where

$$\frac{1}{\tau^*} = \frac{\beta_I}{\beta}\frac{1}{\tau_I^*} + \frac{\beta_{II}}{\beta}\frac{1}{\tau_{II}^*}. \tag{28}$$

Utilizing this equation, Eq. (25) is rewritten as

$$\frac{\tau}{\tau^*} = \frac{\beta_I}{\beta}\frac{\tau_I}{\tau_I^*} + \frac{\beta_{II}}{\beta}\frac{\tau_{II}}{\tau_{II}^*}. \tag{29}$$

Substituting Eqs. (17) and (21) into Eq. (9) and using Eq. (27), we have

$$T\,(\tau_I)^4 = \frac{2 + 3\,(\tau^*/\tau_I^*)\,\tau_I}{4 + 3\,(1-\beta)\,\tau^*}\, T_e^4. \tag{30}$$

Similarly, substituting Eqs. (18) and (22) into Eq. (10) and using Eq. (27),

$$T\,(\tau_{II})^4 = \frac{2 + 3\,(\tau^*/\tau_{II}^*)\,\tau_{II}}{4 + 3\,(1-\beta)\,\tau^*}\, T_e^4. \tag{31}$$

Then, from Eqs. (30) and (31), we have

$$\beta_I\,\sigma\,T\,(\tau_I)^4 + \beta_{II}\,\sigma\,T\,(\tau_{II})^4 = \beta\,\sigma\,T\,(\tau)^4\,, \tag{32}$$

where

$$T\,(\tau)^4 = \frac{2 + 3\,\tau}{4 + 3\,(1-\beta)\,\tau^*}\, T_e^4. \tag{33}$$

This gives the temperature profile of atmosphere. Consequently, the surface air temperature is given by the same form as Eq. (3).

Finally, the above results are easily generalized by using

$$\beta = \beta_I + \beta_{II} + \beta_{III} + \cdots\,, \tag{34}$$

$$\frac{1}{\tau^*} = \frac{\beta_I}{\beta}\frac{1}{\tau_I^*} + \frac{\beta_{II}}{\beta}\frac{1}{\tau_{II}^*} + \frac{\beta_{III}}{\beta}\frac{1}{\tau_{III}^*} + \cdots\,, \tag{35}$$

$$\frac{\tau}{\tau^*} = \frac{\beta_I}{\beta}\frac{\tau_I}{\tau_I^*} + \frac{\beta_{II}}{\beta}\frac{\tau_{II}}{\tau_{II}^*} + \frac{\beta_{III}}{\beta}\frac{\tau_{III}}{\tau_{III}^*} + \cdots\,, \tag{36}$$

in place of Eqs. (8), (28) and (29), respectively.

3 Analyses and Discussion

Now, we apply the extended Ramanathan's semi-gray model to AGW. For the purpose the values of β_I and β_{II} should be determined. First, we choose $\beta = 0.7$ according to Ref. [11]. Second, β_{II} is determined as follows:

$$\beta_{II} = \left(\pi \int_{\lambda_3}^{\lambda_4} B_\lambda(T)\, d\lambda\right) \Big/ \left(\sigma T^4\right) = 0.2, \tag{37}$$

where $\lambda_3^{-1} = 800\,\mathrm{cm}^{-1}$, $\lambda_4^{-1} = 600\,\mathrm{cm}^{-1}$ and $T = 300\,\mathrm{K}$. (In the present work we take into account water vapor and CO_2 but O_3 is not considered.) Consequently, $\beta_I = 0.5$.

Here, we adopt a phenomenological approach. The values of $\tau_I^*(n_0)$ and $\tau_{II}^*(n_0)$ at the pre-industrial level of CO_2 concentration $n_0 = 280\,\mathrm{ppm}$ are determined in a phenomenological way. Two conditions are necessary. As a first we reproduce the average surface air temperature $T_s = 288\,\mathrm{K}$ in terms of Eq. (3). Consequently, $\tau^*(n_0)$ is determined as follows:

$$\tau^*(n_0) = \frac{2}{3}\,\frac{2\,T_s^4 - T_e^4}{T_e^4 - (1-\beta)\,T_s^4} = 2.94. \tag{38}$$

For another condition we note the terrestrial radiation spectrum around $15\mu m$ CO_2 band from satellite observations. It is globally reproduced by the blackbody radiation of brightness temperature $T_r \simeq 215\,\mathrm{K}$. (For instance, see Fig. 8.3 in Ref [12].) This condition is expressed by

$$F_{II}^{\uparrow}(\tau_{II} = 0) = 2\,\beta_{II}\,\frac{1 + \tau^*/\tau_{II}^*}{4 + 3\,(1-\beta)\,\tau^*}\,\sigma\,T_e^4 = \beta_{II}\,\sigma\,T_r^4. \tag{39}$$

Because of $[\,T_e^4 - (1-\beta)\,T_s^4\,]^{1/4} \simeq T_r$, Eq. (39) is suitable to determine $\tau_{II}^*(n_0)$ although the satellite observation is far later than the industrial revolution:

$$\tau_{II}^*(n_0) = \frac{2\,\tau^*(n_0)\,T_e^4}{[4 + 3\,(1-\beta)\,\tau^*(n_0)]\,T_r^4 - 2\,T_e^4} = 4.33. \tag{40}$$

Substituting Eq. (40) into Eq. (28) we have

$$\tau_I^*(n_0) = \frac{2\,\beta_I\,\tau^*(n_0)\,T_e^4}{2\,(\beta_{II} + \beta)\,T_e^4 - \beta_{II}\,[4 + 3\,(1-\beta)\,\tau^*(n_0)]\,T_r^4} = 2.6. \tag{41}$$

Next, we assume $\tau_{II}^* - \tau_I^* = \tau_{\mathrm{CO2}}^*$. Then, using the data of CDIAC [7] and NOAA [8] the post-industrial value of τ_{CO2}^* is calculated as follows:

$$\tau_{\mathrm{CO2}}^*(n) = \frac{n}{n_0}\,\tau_{\mathrm{CO2}}^*(n_0)\,, \tag{42}$$

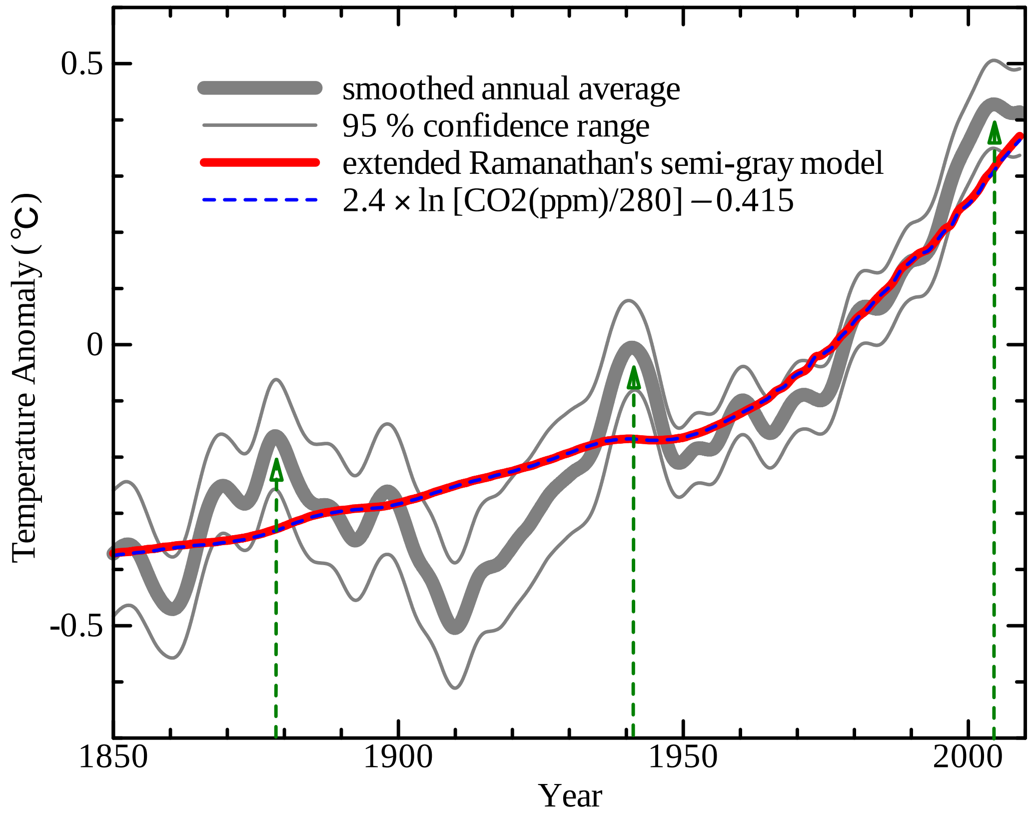

Figure 2: The gray curves are the same as Fig. 1 while the red curve is the result of the extended Ramanathan's semi-gray model. The blue dashed curve is the calculation of $2.4 \times \ln\left(n/n_0\right) - 0.415$. The green dashed arrows indicate the peaks in natural periodic climate oscillations of 60-years cycle.

where n is the post-industrial value of CO_2 concentration. On the other hand, we assume that τ_I^* is invariable:

$$\tau_I^*\left(n\right) = \tau_I^*\left(n_0\right). \tag{43}$$

Then, substituting the values of $\tau_I^*\left(n\right)$ and $\tau_{II}^*\left(n\right) = \tau_I^*\left(n\right) + \tau_{\mathrm{CO2}}^*\left(n\right)$ into Eq. (28), the post-industrial value of $\tau^*\left(n\right)$ is calculated. Finally, substituting the resultant value into Eq. (3) the climate change due to the increase in CO_2 is calculated.

The result is shown in Fig. 2. Although we have compared our calculation with the combined land-surface air temperature and sea-surface temperature rather than the pure land-surface air temperature, the comparison is reasonable because the brightness temperature T_r in Eq. (39) has a constant value of 215 K whether the radiation is from land or sea. It is found that the global warming trend is well reproduced by a simple analytic model.

According to IPCC, the so-called radiative forcing is given by $5.35 \times \ln\left(n/n_0\right)$ [13] and so the temperature anomaly due to AGW is also proportional to $\ln\left(n/n_0\right)$. As shown by the blue dashed curve in Fig. 2, our result really presents the logarithmic behavior. This indicates that our simple model is comparable with IPCC prediction.

It is well known that the recursive effect referred to as feedback in literature plays a crucial role in AGW. (For instance, see Fig. 6 in Ref. [14].) Is there the feedback in our model? According to IPCC, the so-called climate sensitivity without feedback is given by [15]

$$\frac{T_s}{4\,\sigma\,T_e^4} \times (5.35 \times \ln 2) = 1.1°\mathrm{C}. \tag{44}$$

On the other hand, our model predicts the climate sensitivity of 1.7 °C. The difference between the two values should be attributed to the feedback. Well then, where is the feedback in our model? Because the optical depths $\tau_I^*\,(n_0)$ and $\tau_{II}^*\,(n_0)$ have been determined from observations, $\tau_{\mathrm{CO2}}^*\,(n_0)$ naturally contains the feedback of pre-industrial level. (In this sense, the optical depths determined by Eqs. (40) and (41) are different from their original definitions.) On the other hand, the prescription (42) appropriately extrapolates the feedback to post-industrial level. This is the reason for the successful result in Fig. 2.

The success of our model using a constant value of τ_I^* imposes a crucial limitation on AGW. If the CO_2 concentration becomes extremely large $\tau_{II}^* \gg \tau_I^*$, from Eq. (28) the total optical depth has a limit $\tau^*\,(n \to \infty) = (\beta/\beta_I)\,\tau_I^*\,(n_0) = 3.64$. Consequently, there is an upper limit of surface air temperature due to AGW:

$$\lim_{\tau_{II}^* \to \infty} T\,(\tau^*) - (288\,\mathrm{K}) = \left[\frac{2\,\beta_I + 3\,\beta\,\tau_I^*\,(n_0)}{4\,\beta_I + 3\,\beta\,(1-\beta)\,\tau_I^*\,(n_0)}\right]^{1/4} \times (255\,\mathrm{K}) - (288\,\mathrm{K}) = 6.4\,°\mathrm{C}. \tag{45}$$

Now, we can see that the AGW is severely limited because the Earth is a water planet. Although the recent report [16] warns the world that adding 1km to the CO_2 fog layer will heat the surface climate by 6.5 °C, no matter how much released CO_2 is from fossil fuel burning, the global warming of 6.5 °C is impossible.

Of course, 6.4 °C is the limit of greenhouse effect. If the atmospheric pressure becomes as much high as on Venus, the value is meaningless. However, the CO_2 concentration never becomes infinite. Although in our model the surface air temperature rises by 6 °C at $n = 50\,n_0$, such a high concentration will be never realized from fossil fuel burning. Even then, only 2% of atmosphere is composed of CO_2. Moreover, the increase in CO_2 from fossil fuel burning decreases O_2. Therefore, even if the temperature rises up to 6 °C from the loose anthropogenic CO_2 emission, the component and pressure of atmosphere on the Earth are completely different from those on Venus. Consequently, we can see that Eq. (45) is valid.

Since Article 2 [17] of the United Nations Framework Convention on Climate Change (UNFCCC) warned against the dangerous anthropogenic interference (DAI) with the climate system so as to avert irreversible climate catastrophe, it has been circulated among scientists, economists and policymakers [18,19,20] that the threshold for DAI is 2 °C global warming from pre-industrial level. Moreover, some scientists alarm [21, 22,23] that the present CO_2 concentration already represents DAI. However, the recent investigation [24] reveals that a peak Antarctic interglacial temperature was at least 6 °C higher than that of the present day. The value is almost the same as the upper limit of AGW. This indicates that the AGW never destroys the terrestrial ecosystem until it cannot return to the pre-industrial state. It is therefore unlikely that such an alarmism as DAI has a reliable scientific basis.

Equation (45) also indicates that the climate sensitivity never exceeds 6 °C. This conclusion is consistent with Refs. [25,26]. Although most of studies referred in Table 9.3 on AR4 [4] predict the climate sensitivities being much larger than 6 °C, it is unlikely that their values are realized. (Fairly speaking, the recent work [27] criticizes that Ref. [25] does not convincingly reduce the large uncertainty of climate sensitivity remaining in previous observationally based studies.) Moreover, the elaborate and enormous computer simulations of AGW [28] also predict high climate sensitivities as much as 11.5 °C. This suggests that the computer simulations output unphysical results.

Because our model is only based on the fundamental theory of GHG, it cannot reproduce the climate oscillation from natural cause. It is therefore concluded that the outstanding climate changes around 1880, 1940 and 2000 indicated by the green dashed arrows in Fig. 2 are the naturally caused periodic climate oscillations of about 60-years cycle. This conclusion is consistent with the analysis in Ref. [29]. On the other hand, as seen in FAQ. 3.1 on AR4 [4] the IPCC regards the rapid warming after 1980 as a prominent evidence for AGW. Is the view of IPCC right? The elaborate and enormous computer simulations should take into account natural forcing on climate change in contrast to our simple model. Nevertheless, as seen in Fig. 9.5 on AR4 [4] the IPCC cannot reproduce the outstanding warming [30,31] centered at 1940. This indicates that the computer simulations are not yet successful in elucidating natural climate oscillation. Moreover, no observation of global warming after 2000 [32,33] strongly suggests that the rapid warming before 2000 is not AGW but a result of natural climate oscillation. It is therefore likely that our simple analytic model is more consistent than the elaborate and enormous IPCC report.

The IPCC concludes [4] that the climate sensitivity is likely to lie between 2 °C and 4.5 °C with a most likely value of approximately 3 °C. Because 2 °C is now believed to be the DAI threshold value, it is a crucial problem whether the climate sensitivity is above or below 2 °C. In this sense, our model, which predicts the climate sensitivity of 1.7 °C, is clearly opposite to IPCC. However, as seen in the above discussion, there is no scientific reason to prefer the elaborate and enormous IPCC report to our simple model. Moreover, the investigations [26,34] after AR4 never exclude our prediction. It cannot be denied that the IPCC may overestimate AGW.

4 Summary and Conclusion

An eminent climate scientist Dr. Goody says in his famous textbook [35] as follows:

> Recent history has demonstrated that such complex numerical calculations may be flowed; they may yield unphysical results and equally competent investigators can disagree. An outsider can make no judgment. ... Although numerical methods may be essential for accurate numbers, a valuable level of understanding of atmospheric problem can also be achieved with approximate equations.

Another eminent climate scientist Dr. Ramanathan emphasizes at the beginning of Ref. [11] as follows:

> Simple models of complex systems have great heuristic value, in that their results illustrate fundamental principles without being obscured by details.

I fully agree with these statements and so have tried to illustrate fundamental principles of AGW without being obscured by details. The Ramanathan's semi-gray model has been extended so as to take into account the greenhouse effects by both water vapor and CO_2. The pre-industrial values of the corresponding two optical depths are determined phenomenologically from the global average temperature and the terrestrial radiation in the absorption band of CO_2. Their post-industrial values are determined by assuming that the optical depth of CO_2 is proportional to its concentration but the optical depth of water vapor is invariable. Then, we have calculated the global average surface air temperature. The result is remarkable. The observed temperature anomaly can be reproduced fairly well. We have to note that the model has no adjustable parameters to the anomaly. Therefore, we can say as follows. *Physics is rich in phenomena that are simple in appearance and so can be calculated in simple terms. Global warming is like that.*

The success of our model, in which the optical depth of water vapor has a constant value, gives an additional insight on AGW. It is found that the climate sensitivity never exceeds 6 °C. The AGW is severely limited because the Earth is a water planet. Consequently, most of works referred in IPCC AR4 are ruled out because they predict much higher values of climate sensitivity. We have also found that the rapid increase in temperature after 1980 is the naturally caused periodic climate oscillation of 60-years cycle. Consequently, most of computer simulations referred in IPCC AR4 are ruled out because they predict that the rapid warming is a clear evidence for AGW. It is therefore likely that the IPCC exaggerates AGW.

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