A New Basic 1-Dimension 1-Layer Model Obtains Excellent Agreement With the Observed Earth Temperature

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Abstract. The Earth radiation and energy budget is calculated by a manifold of rather complex Global Circulation Models. Their outcome mostly cannot identify radiation in the atmosphere or energy budget relations. Therefore it is reasonable to look at more basic models to identify the main aspects of the model results. The simplest one of all of those is a 1-dimensional 1-layer model. However, most of these models - two are discussed here - suffer the drawback that they do not include essential contributions and relations between the atmospheric layer and the Earth. The 1-dimensional 1-layer model presented here integrates sensible and latent heat, the absorption of solar radiation in the atmosphere and the direct emission of the long wave radiation to space in addition to the standard correlations. For the atmospheric layer two different long wave fluxes are included, top of atmosphere to space and bulk emission to Earth. The reflections of long wave radiations are taken into account. It is shown that this basic model is in excellent agreement with the observed integrated global energy budget.

Key words: : Earth energy budget; 1-dimensional 1-layer model; sensible and latent heat; long wave radiation

1 Introduction

The Earth radiation and energy budget is calculated by a manifold of Global Circulation Models [1]. These are very complex and their results mostly cannot be plainly identified to understand the integral radiation or energy budget relations. Therefore it is reasonable to look at basic models to identify the main aspects. *Kiel* and *Trenberth* [2], [6] used a 1-dimensional 3-layer model with different top of atmospheric layer fluxes and those from the bulk atmospheric layer for the evaluation of the measured data. The results for their integral global energy budget are widely accepted as a reference.

A quite elementary model is the 1-dimensional 1-layer model presented by Schneider and Mass [5], and from other authors following the approach from *Liou* [4]. Schneider and Mass did not take into account the absorption of solar radiation by the atmosphere nor the sensible and latent heat. Their model used only one temperature for the top of atmosphere and for the long wave radiation to the Earth, and their equation for thermal equilibrium was expressed by the basic formula

$$R \cdot dT_E/dt = (1 - a) \cdot S_0/4 + \varepsilon_E \cdot F_{IR\downarrow} - F_{IR\uparrow} \qquad (1)$$

The problems associated with this oversimplification are thoroughly discussed by *Kramm* and *Dlugi* [3]. These authors correctly criticized Eq. (1) because the absorption of solar radiation in the atmosphere and/or the sensible and latent heat emitted by Earth are completely neglected. They finally improved the model of Schneider and Mass by including the sensible and latent heat and the absorption of solar radiation by the atmosphere. However, also this corrected model [3] shows substantial drawbacks. *Kramm* and *Dlugi* used only one temperature T and one integral emissivity ε_A for the lower and upper part of the atmospheric layer (Eqs. A19, A20 in Ref. 3). This is not feasible because of the big difference between the long-wave radiation from the top of the atmosphere and the down-welling infrared radiation to the Earth from the lower atmosphere [2], [6]. Furthermore, the direct emission of the long wave radiation from Earth to space was wrongly taken into account by a term $-(1-\varepsilon_a)\cdot\varepsilon_E\cdot T_E^4$ (p. 152 and Eq. A18 in Ref. 3) that disappears for $\varepsilon_a = 1$. This was the reason why *Kramm* and *Dlugi* for the mean Earth temperature obtained $T_E = 268\ K$ (Figure 15 in Ref. 3). This disagrees with the observed value $T_E = 288\ K$. *Kramm* and *Dlugi* calculated the mean temperature of the atmosphere $T_A = 255\ K$. In their paper this value is independent of the integral absorbtivity of the atmosphere with respect to solar radiation (A_a in Figure 15 of Ref. 3), which seems rather odd. Furthermore *Kramm* and *Dlugi* used the same latent and sensible heat of 92 W/m^2 for the whole temperature range of TE down to the freezing temperature of 268 $K \approx -5\ ^0C$. This is not feasible as is demonstrated in Figure 3 where we show the temperature dependence of Q on T_A. *Kramm* and *Dlugi* used the incompatibility of their model results with observed values as an argument that their model (the improved model of *Schneider* et al.) reveals "no evidence for the existence of the so-called atmospheric greenhouse effect, if realistic empirical data are used".

2 Applied methods

A basic 1-dimensional 1-layer model with different atmospheric and top of atmosphere long wave radiation fluxes and temperatures, including the reflections of the long wave radiation at the surface of the Earth and atmosphere can correctly reproduce the observed global average surface temperatures and radiation fluxes, if all emission and absorption processes are accurately introduced into the model. The model and the interrelations of the model presented here are shown schematically in the following Figure 1:

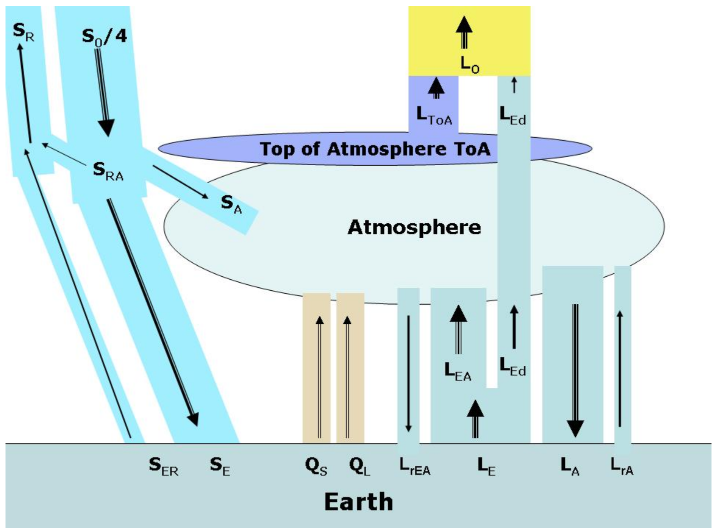

Fig. 1. Fluxes applied in the 1-dimensional 1-layer model of this paper. The abbreviations are for short wave: S_0 - Incident solar flux (1365 W/m^2) , S_R - Total reflected flux, S_{RA}- Reflected by atmosphere, S_A -Absorbed by atmosphere, S_{ER} -Reflected by Earth, S_E - Absorbed by Earth. For long wave: L_{ToA}- Emitted from top of atmosphere, L_{Ed} - Directly emitted from Earth, L_{EA} - Emitted by Earth and absorbed by atmosphere, L_{rEA} - Emitted by Earth and reflected by atmosphere, L_A - Emitted by atmosphere and absorbed by Earth, L_{rA} - Emitted by atmosphere and reflected by Earth, L_O - Outgoing long wave radiation, Q_S, Q_L: Sensitive and latent heat, $Q = Q_S + Q_L$

The model depicted in Figure 1 is a 1-dimensional 1-layer model which integrates sensible and latent heat, the absorption of solar radiation and the direct emission of the long wave radiation to space. The reflection of long wave radiation from the surface and atmosphere is taken into account. For the atmospheric layer two different long wave fluxes are included, from top of atmosphere to space and bulk emission to Earth. Direct emission to space of the reflected atmospheric back radiation to Earth is not considered, because it is assumed that the reflected spectrum fits completely into the absorption bands of the greenhouse gases. The following relations hold as they can be deducted from Figure 1:

$$0 = S_0/4 - S_R - L_{ToA} - L_{Ed} \tag{2}$$

$$0 = S_A - L_A + L_{rA} - L_{ToA} + L_{EA} - L_{rEA} + Q \tag{3}$$

$$0 = S_E - S_{ER} - L_{EA} + L_{rEA} - L_{Ed} + L_A - L_{rA} - Q \tag{4}$$

Additionally the following connections are evident:

$$L_E = L_{EA} + L_{Ed} \tag{5}$$

$$S_R = S_{RA} + S_{ER} \tag{6}$$

$$\alpha = (S_{RA} + S_{ER})/(S_0/4) \tag{7}$$

$$\alpha_A = S_A/(S_0/4) \tag{8}$$

$$S_E = S_0/4 - S_{RA} - S_{ER} - S_A = S_0/4 \cdot (1 - \alpha - \alpha_A) \tag{9}$$

$$d = L_{Ed}/L_E \tag{10}$$

$$L_0 = L_{ToA} + L_{Ed} = L_{ToA} + d \cdot L_E \tag{11}$$

$$r_{EA} = L_{rEA}/L_{EA} \tag{12}$$

$$r_A = L_{rA}/L_A \tag{13}$$

The following relations result

$$0 = (1 - \alpha) \cdot S_0/4 - L_O \tag{14}$$

$$0 = \alpha_A \cdot S_0/4 - L_A \cdot (1 - r_A) - L_{ToA} + L_{EA} \cdot (1 - r_{EA}) + Q \tag{15}$$

$$0 = (1 - \alpha - \alpha_A) \cdot S_0/4 - L_E \cdot (1 - r_{EA} - d \cdot r_{EA}) + L_A \cdot (1 - r_A) - Q \tag{16}$$

From ERBE (Earth Radiation Budget Experiment) data [2] and [6] and references cited therein, a value for $L_0 = 241$ W/m^2 and $L_{ToA} = 199$ W/m^2 was evaluated. As it can be seen in the above relations, we connect the long wave radiation fluxes. As a consequence, the equations are independent of absorption and emission coefficients. From Eq. (2), Eq.(5), Eq. (6), Eq.(7), Eq. (15), and Eq. (16), one obtains (see also Figure 1)

$$L_E = ((1 - \alpha) \cdot S_0/4 - L_{ToA})/d \tag{17}$$

$$L_A = [L_E \cdot (1 - r_{EA} \cdot (1 + d)) - (1 - \alpha - \alpha_A) \cdot S_0/4 + Q]/(1 - r_A) \tag{18}$$

The dependence of L_E in Eq. (17) and L_A in Eq. (18) on the fraction $d = L_{ED}/L_E$ is shown in Figure 2. For the calculation of L_A it is assumed that $r_{EA} = (1 - \varepsilon_A) = 0$ and $r_A = (1 - \varepsilon_E) = 0$, which is in agreement with the energy and radiation balance scheme of *Kiel* and *Trenberth* [2], [6], who neglected the reflexion of long wave radiation from the surface of the Earth and from the atmosphere. For the absorption values we also followed *Trenberth* [6] with $\alpha_A = 0.23$ and $\alpha = 0.3$.

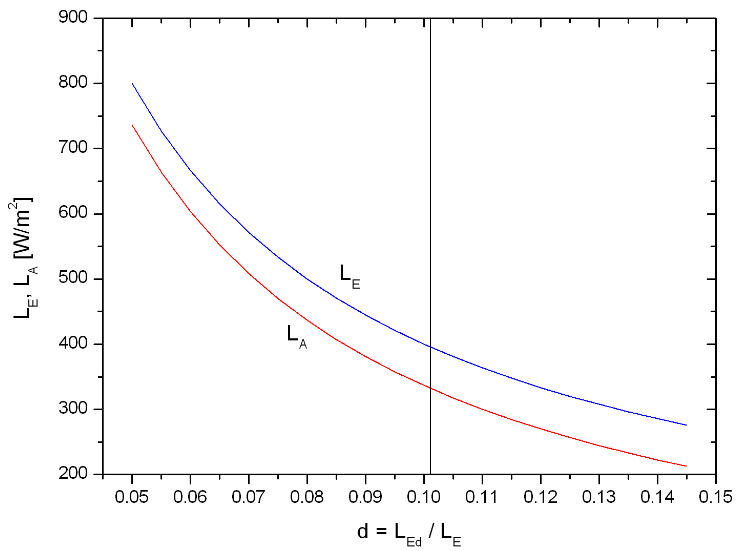

Fig. 2. The long-wave flux L_A (red) emitted by the atmosphere and absorbed by the Earth (back radiation, see Figure 1) and $L_E = L_{EA} + L_{Ed}$ (blue) as a function of d $= L_{Ed} / L_E$. The vertical line marks the value of d = 0.101, which corresponds to the observed values of Trenberth [6]

The corresponding temperatures are calculated according to Stephan-Boltzmann and assuming a gray body for Earth and atmosphere (ε - emission coefficients, σ - Stephan-Boltzmann constant):

$$\varepsilon_A \cdot \sigma \cdot T_A^4 = L_A \tag{19}$$

$$\varepsilon_E \cdot \sigma \cdot T_E^4 = L_E \tag{20}$$

$$\varepsilon_{ToA} \cdot \sigma \cdot T_{ToA}^4 = L_{ToA} \tag{21}$$

With the values (see Ref. 6) Q = 97 W/m^2, L_{ToA} = 199 W/m^2, $\alpha_A = 0.23$, and d = 0.101 the mean global temperature T_E, L_A and L_E are reproduced with $r_{EA} = (1 - \varepsilon_A) = 0$, ($\varepsilon_A$=1), $r_A = (1 - \varepsilon_E) = 0$, ($\varepsilon_E$=1). This is evident, as *Kiel* and *Trenberth* [2], [6] did not take into account the reflexion of long wave radiation from the Earth and atmosphere. Our model of course is capable of calculating these values with non zero reflexions of long wave radiation to atmosphere or surface.

$L_A = 333\ W/m^2$ (see Figure 2)
$L_E = 396\ W/m^2$ (see Figure 2)

$T_E \approx 289\ K$ (Eq. (20))
$T_A \approx 277\ K$ (Eq. (19))

In addition, if we assume ε_{ToA}=1, $T_{ToA} \approx 243\ K$ results.

The mean atmospheric temperature T_A as a function of α_A can be evaluated from Eqs. (18) and (19). In very good approximation the function is linear

$$T_A = 75.04 \cdot \alpha_A + 257\ \ K \tag{22}$$

Obviously the value for T_A is strongly dependent on α_A in disagreement with the results from *Kramm* and *Dlugi* [3], who calculated the mean temperature of the atmosphere as T_A = 255 K, independent of the integral absorption of the atmosphere with respect to the short wave radiation of the sun.

Figure 3 shows the T_E temperature dependence of Q = Q_S + Q_L (sensible and latent heat) and of the mean atmospheric temperatur T_A with α = 0.3, α_A = 0.23, r_{EA}=r_A=0, d = 0.101, evaluated with the Eqs. (17) - (20). The Albedo of clouds and surface of the Earth have not been changed as function of temperature, although a strong dependence must be expected as well. Unfortunately there exists no detailed calculation or any Ansatz from more complex global circulation models.

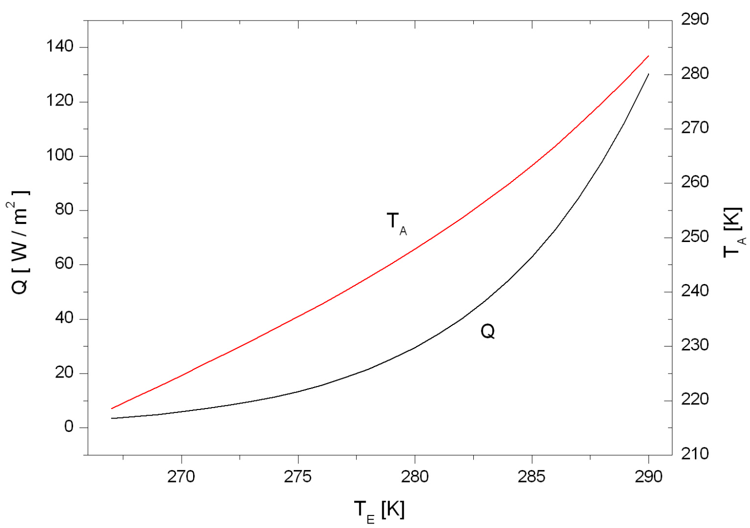

Fig. 3. Temperature dependence of Q = Q_S + Q_L (sensible and latent heat) and of the mean atmospheric temperatur T_A with α = 0.3, α_A = 0.23, r_{EA}=r_A=0, d = 0.101. It was assumed that the temperature dependence of Q is proportional to the absolute humidity resulting in Q = 7 W/m^2 and T_A = 227 K for an Earth temperature of T_E = 271 K.

Within our model the effect of a radiative forcing can be deduced. From the values given by *Trenberth* [6] the ratio

$$L_{Ed}/L_0 = 0.167 \tag{23}$$

is determined. Assuming an additional radiative forcing RF = ΔL_0 as described by IPCC AR4 and a corresponding partition of RF after readjustment to radiative equilibrum as in Eq. (23)

$$\frac{L_{Ed}}{L_0} = \frac{\Delta L_{Ed}}{\Delta L_0} = 0.167 \tag{24}$$

holds. Eq. (10) with d = 0.101 can be written as

$$\Delta L_{Ed}/\Delta L_E = 0.101 \tag{25}$$

For a doubling of CO_2 the IPCC asumes RF = 3.7 W/m^2. RF = ΔL_0 together with Eq. (24) and Eq. (25) yield

$$\Delta L_E = (0.167/0.101) \cdot RF = 6.12 \;\; W/m^2 \tag{26}$$

The unturbed state is L_E = 396 W/m^2. This and Eq. (20) result in $T \approx 289.1\ K$. The perturbed state, however, is $L_E + \Delta L_E$ = 402.12 W/m^2 that yields $T \approx 290.2\ K$. As a result, the change of the surface temperature of the Earth induced by 3.7 W/m^2 radiative forcing (doubling of CO_2) is $T \approx 1.1\ K$, which is in good agreement with the IPCC value [1] without feedback.

3 Conclusion

This paper demonstrates that a basic 1-dimensional 1-layer model with different atmospheric and top of atmosphere long wave radiation fluxes and temperatures, and including the reflections of the long wave radiation at the surface of the Earth and atmosphere can reproduce with excellent agreement the observed global average surface temperatures and radiation fluxes. This requires that all emission and absorption processes are correctly introduced into the model. In particular the direct emission of long wave radiation from Earth to space and the temperature dependence of latent and sensible heat have to be taken into account. Our model yields a change in the surface temperature of the Earth of roughly 1.1 ^{o}C for an additional radiative forcing of 3.7 W/m^2 - caused for instance by a hypothetical doubling of the present CO_2 concentration in the atmosphere -, which is in good agreement with the appropriate IPCC value, if no feedback amplification (or attenuation) is considered.

References

1. AR4, IPCC (2007),
http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

2. J. T. Kiehl and K. E. Trenberth, Earths Annual Global Mean Energy Budget, *Bulletin of the American Meteorological Society* **78**, No. 2 (1997)
3. G. Kramm and R. Dlugi, On the Meaning of Feedback Parameter, Transient Climate Response, and the Greenhouse Effect: Basic Considerations and the Discussion of Uncertainties, *The Open Atmospheric Science Journal* **4** (2010)
4. K. N. Liou, An introduction to atmospheric radiation - 2nd edn., *Academic Press* (2002)
5. S. H. Schneider and C. Mass, Volcanic dust, sunspots, and temperature trends, *Science* **190**, 741 (1975)
6. K. E. Trenberth, J. T. Fasullo and J. T. Kiehl, Earths Global Energy Budget, *American Meteorological Society (BAMS)*, March 2009