Original Research Article

Challenging the Greenhouse Effect Specification and the Climate Sensitivity of the IPCC

ABSTRACT

The greenhouse effect concept has been developed to explain the Earth’s elevated temperature. The prevailing theory of climate change is the anthropogenic global warming theory, which assumes that the greenhouse (GH) effect is due to the longwave (LW) absorption of 155.6 Wm^{-2} by GH gases and clouds. The actual warming increase to 33 °C of the Earth’s surface temperature according to the present GH effect definition is the infrared downward LW radiation of 345.6 Wm^{-2} emitted by the atmosphere. The atmosphere’s temperature is the key element behind this radiation. According to the energy laws, it is not possible that the LW absorption of 155.6 Wm^{-2} by the GH gases could re-emit downward LW radiation of 345.6 Wm^{-2} on the Earth’s surface. In this study, the GH effect is 294.5 Wm^{-2}, including shortwave radiation absorption by the atmosphere and the latent and sensible heating effect. This greater GH effect is a prerequisite for the present atmospheric temperature, which provides downward radiation on the surface. Clouds’ net effect is 1% based on the empirical observations. The contribution of CO_2 in the GH effect is 7.3% corresponding to 2.4 °C in temperature. The reproduction of CO_2 radiative forcing (RF) showed the climate sensitivity RF value to be 2.16 Wm^{-2}, which is 41.6% smaller than the 3.7 Wm^{-2} used by the IPCC. A climate model showing a climate sensitivity (CS) of 0.6 °C matches the CO_2 contribution in the GH effect, but the IPCC’s climate model showing a CS of 1.8 °C or 1.2 °C does not.

Keywords: Greenhouse effect; climate change; Earth’s energy balance; climate sensitivity; climate model

1. INTRODUCTION

The comprehensive article of Henderson and Henderson-Sellers [1] starts the history of "the greenhouse effect" with Fourier, Tyndall, and Arrhenius and ends at the present time. The definition of the GH effect emerged in the present form and quickly stabilized in the beginning of the twentieth century. Since that time, the anthropogenic global warming (AGW) theory is based on the increased GH effect caused by rising concentrations of GH gases [2] and recently by clouds. The important moment in the climate change science was the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. In its first assessment report [3], the GH effect was described to have been caused by trace gases, which absorb terrestrial radiation and re-emit radiation to the surface, thereby increasing the temperature. In its fourth assessment report [4], IPCC writes: "*Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect.*"

In the report AR5 of IPCC [2], there is only one sentence about the CO_2 contribution to the GH effect: *"Water vapour is the primary greenhouse gas in the Earth's atmosphere. The contribution of water vapour to the natural greenhouse effect relative to that of carbon dioxide (CO_2) depends on the accounting method but can be considered to be approximately two to three times greater"* (p. 666). In a way IPCC seems to keep this matter insignificant. The contribution of CO_2 is essential, and the GH effect is a very profound phenomenon in climate change science and can be used to test the results of climate models.

The contributors of the GH effect according to the published research studies are the absorbers of longwave (LW) radiation, which are the main GH gases and clouds. There are only a few comprehensive studies on this subject [2-10]. The author has recognized three studies applying all-sky conditions [7, 8, 10]. In these studies, the percentages of three main contributors vary: for water, they range from 38% to 80.7%; for carbon dioxide (CO_2) from 12.9% to 26%; and for clouds from 1% to 39%. It should be noticed that in all studies above, the percentages of GH factors have been calculated from the LW absorption value, which varies from 125 Wm^{-2} to 158.3 Wm^{-2} [6-10].

The main objective of this study is to analyze the GH contribution effects of different sky conditions and new contribution effects that had not been considered in the earlier studies. Energy fluxes of different sky conditions are needed in the GH effect analysis. Therefore, the Earth's annual mean energy budget has been updated.

2. Earth's energy balance

The author has updated the former energy balance for clear, cloudy, and all-sky conditions [11] utilizing the latest observed outgoing LW radiation values [12] at the top of the atmosphere (TOA) for clear sky and all-sky conditions during 2000–2010. Some other flux value updates are needed, and they have been explained in detail along with the uncertainties Table A1 of Appendix. The tables of Appendix have been referred by using letter A and a number.

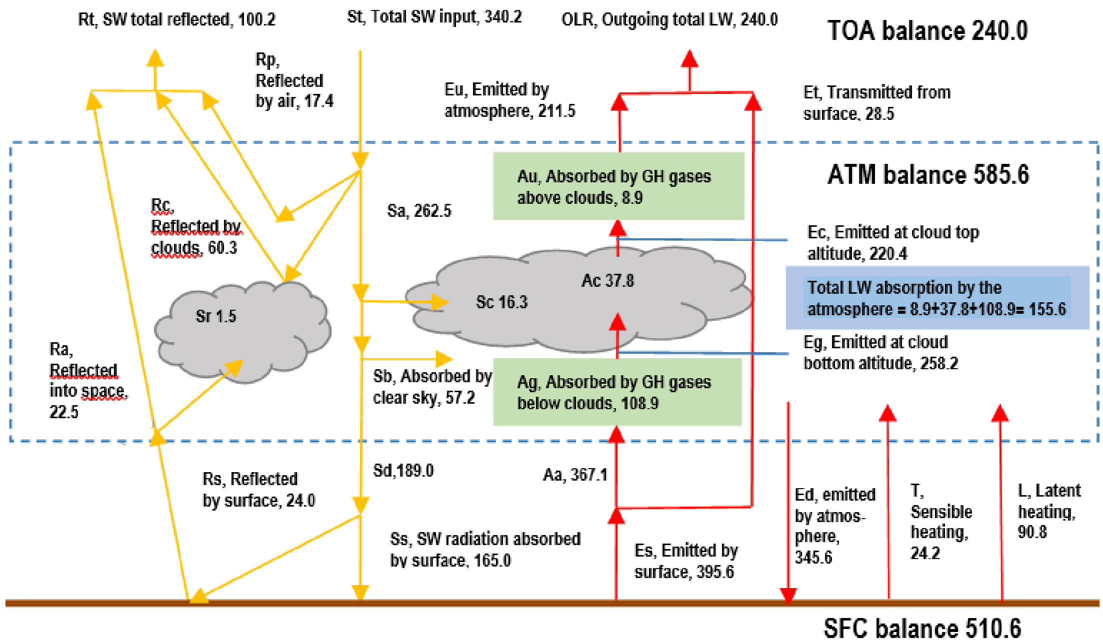

Figure 1. Earth's energy balance and flux values (Wm^{-2}) in all-sky conditions.

Based on the observations [13-15] the cloud base and top values, 1.6 and 4.0 km, have been used. The absorption values below the cloud cover depend on the surface temperatures of the different skies [16]. The author has applied average global temperature, pressure, and the concentration profiles of GH gases of the year 2015. The Spectral Calculator application [17] has been used for spectral analyses. The GH gas concentrations have been modified from the GH gas profiles of the Polar Summer of the Spectral Calculator. The water profile has been adjusted in such a way that the total precipitable water (TPW) is 2.6 cm. In this application the HITRAN line data version 2012 was available [18] and the coefficients in the water continuum model are also updated [19]. The calculations have been carried in such a way that the absorption values of different skies can be calculated below and above the cloud cover.

3. Greenhouse effect

3.1 Greenhouse effect definitions

In addition to the IPCC's definition, Hartmann [19] summarizes the final details of the GH effect in this way*: "Most of this emitted infrared radiation is absorbed by trace gases and clouds in the overlying atmosphere. The atmosphere also emits radiation, primarily at infrared wavelengths, in all directions. Radiation emitted downward from the atmosphere* *adds to the warming of Earth's surface by sunlight. This enhanced warming is termed the greenhouse effect.*" In the present climate, the direct solar insolation on the surface is 165 Wm^{-2} and downward LW radiation emitted by the atmosphere is 345.6 Wm^{-2}, showing the magnitude of the GH effect.

The conclusion of the prevailing GH effect definitions is this: the warming of the atmosphere is caused mainly by GH gases and clouds that absorb the LW radiation emitted by the Earth's surface. On the other hand, according to these references, the real warming impact of the GH effect is the same as the LW radiation emitted by the atmosphere back to the Earth's surface. LW absorption in the atmosphere is only a pre-phase in the process of transforming the absorption energy into radiation energy emitted by the atmosphere to the surface.

Thinking about the very basic feature of the GH phenomenon, it does not matter how the atmosphere warms up but the essential element in the GH effect is the existence of the atmosphere. Interesting enough, Swedish meteorologist Nils Ekholm [20] used the term "Greenhouse effect," describing it in this way: "*The other is that the atmosphere, absorbing but little of the insolation and the most of the radiation from the ground, receives a considerable part of its heat store from the ground by means of radiation, contact, convection, and conduction, whereas the earth's surface is heated principally by direct radiation from the sun through the transparent air.*" Ekholm was not aware that most of the ground heat originates from the GH effect (about 67.7%). Otherwise, he was obviously the first to realize that the atmosphere also receives energy from sources other than the absorption of LW radiation.

3.2 Shortwave absorption and longwave absorption warming effects

The Earth receives solar insolation of about 240 Wm^{-2} and emits an energy flux with the same magnitude into space. GH gases, aerosols and clouds in the atmosphere absorb 75 Wm^{-2}, and thus, 165 Wm^{-2} directly warms the surface. The same kind of absorption by a magnitude of 155.6 Wm^{-2} happens to LW radiation emitted by the Earth's surface. But according to climate change scientists, there is a big difference in transforming these absorption energies into warming effects on the surface. In both cases, the absorption energies must find ways to increase surface temperature.

The temperature impact of SW absorption is simply the magnitude of this absorption, 75 Wm^{-2}. Nobody has ever claimed that the whole downward flux emitted by the atmosphere is due to the SW absorption; the absorbed SW radiation 75 Wm^{-2} is just a part of the downward LW radiation 345.6 Wm^{-2} emitted by the atmosphere. According to the present practice, this is not a mechanism in the LW absorption, but the downward LW flux 345.6 Wm^{-2} is totally due to the LW absorption only. This goes against the physical laws. SW and LW absorption/reradiation processes in the atmosphere have no physical difference.

3.3 Spectral analysis calculations

Absorption processes in the atmosphere can be analyzed by spectral calculations. Applying the average atmospheric conditions as defined in Section 2, the total absorption flux calculated in the troposphere is 303.31 Wm^{-2} in the clear sky conditions. The downward flux emitted by the atmosphere can be calculated using the same atmospheric conditions but no GH gas concentrations. The result is 307.06 Wm^{-2}, having a 1.2% difference from the absorption flux value. This result means that the downward LW flux magnitude depends only on the temperature of the atmosphere as it should be per Eq. (1) of Planck because there is no LW flux radiating from space to the Earth's surface. Figure 19 by Miskolczi [21] depicts the downward LW flux and shows that it is zero at the TOA, then it starts to sharply increase in the troposphere and reaches the maximum value at the surface following the atmospheric temperature profile.

It is not a coincidence that the magnitudes of the total absorption and downward radiation flux are almost the same. Hundreds of simulations [21] with different atmospheric structures showed that these two fluxes are equal. Kirchoff's radiation law states that they are equal in radiation balance conditions. The small differences are well inside the uncertainty limits of the flux observations.

In clear sky conditions, the LW absorption value is 128.1 Wm^{-2} (Table A3) and the total energy flux value absorbed by the atmosphere is 249 Wm^{-2} (Table A5). By using the relationship 128.1/249, the GH effect of 33 □C can be estimated to be 16.98 □C due to the LW absorption and 16.02 □C due to other factors. If the other factors were causing this much warming, the surface and atmospheric temperature profile would be 16.98 □C lower than the present 15 □C. Another test calculation was carried out in the average atmosphere applying this lower temperature -1.98 □C, and the result was a downward LW flux 177.82 Wm^{-2}. Because the total downward flux was 307.06 Wm^{-2}, the difference of these two fluxes is 129.34 Wm^{-2}. It is very close to the LW absorption value 128.1 Wm^{-2}, the difference being only 0.9%. These spectral calculations confirm that the LW flux value cannot create the downward LW flux emitted by the atmosphere, but the other factors are needed to maintain the atmospheric temperature profile.

The counter argument against the traditional calculation basis of GH effect could be that anyway the total absorption of LW radiation in the atmosphere is totally due to the GH gases. It is true but it is not the whole truth. The total absorption value in the clear sky is 310.9 Wm^{-2} and the reduction of the total absorption by removing CO_2 from the atmospheric composition would be 20.1 Wm^{-2}. It means that the contribution of CO_2 to the total absorption in clear sky conditions would be only 6.5 % and in all-sky conditions even less. There is no essential difference to the result of the traditional method in Table 1.

One could ask, where is the impact of SW absorption, latent and sensible heating, if the total absorption of LW radiation is due to the GH gases only? The absorption of GH gases depends strongly on the temperature and also on the pressure of the atmosphere. The impact of these other elements of GH phenomenon have their effects in this calculation method in their contributions to the atmospheric temperature and pressure profile. In all-sky conditions the sum of the energy fluxes of latent heating, sensible heating and SW absorption is 190.0 Wm^{-2} and the same of LW absorption by GH gases is 155.6 Wm^{-2}. These figures show the portions what these elements have in maintaining the atmospheric temperature profile. It means that the contribution of the LW absorption in maintaining the temperature profile is 100*155.6/345.6 = 45.0 %.

The observed atmospheric temperature profile is normally used in calculating the total LW absorption without considering the contributing factors maintaining this profile. It may lead to the wrong conclusion that the atmospheric temperature profile is due to the LW absorption by the GH gases only, which not true.

3.4 Other energy fluxes warming the lower atmosphere

The GH effect is a physical-chemical phenomenon in which the lower part of the atmosphere warms up. Every object or matter warmer than absolute zero emits radiation always and at all wavelengths. Planck's law dictates that the Earth's surface emits radiation with detectable energy intensity from 3 to 100 μm:

$$E = (8\P hc)/\lambda^5 * 1/(e^{(hc/kT)-1}) \quad (1)$$

where E is the energy radiated per unit volume by a cavity of a blackbody, h is Planck's constant, c is the speed of light, k is the Boltzmann constant, and T is the absolute temperature. Planck's law means that the material of the atmosphere in emitting radiation depends only on the temperature of the atmosphere, and it is not able to separate the warming effects of different sources.

The present GH effect definition ignores other sources that warm up the atmosphere. For example, the SW radiation emitted by the Sun and absorbed by the atmosphere is 75 Wm^{-2}, which is 31.3% of the total SW energy flux absorbed by the Earth (Figs. 1 and 2). This portion of SW radiation radiates on the surface from the atmosphere and is part of the LW radiation emitted by the atmosphere.

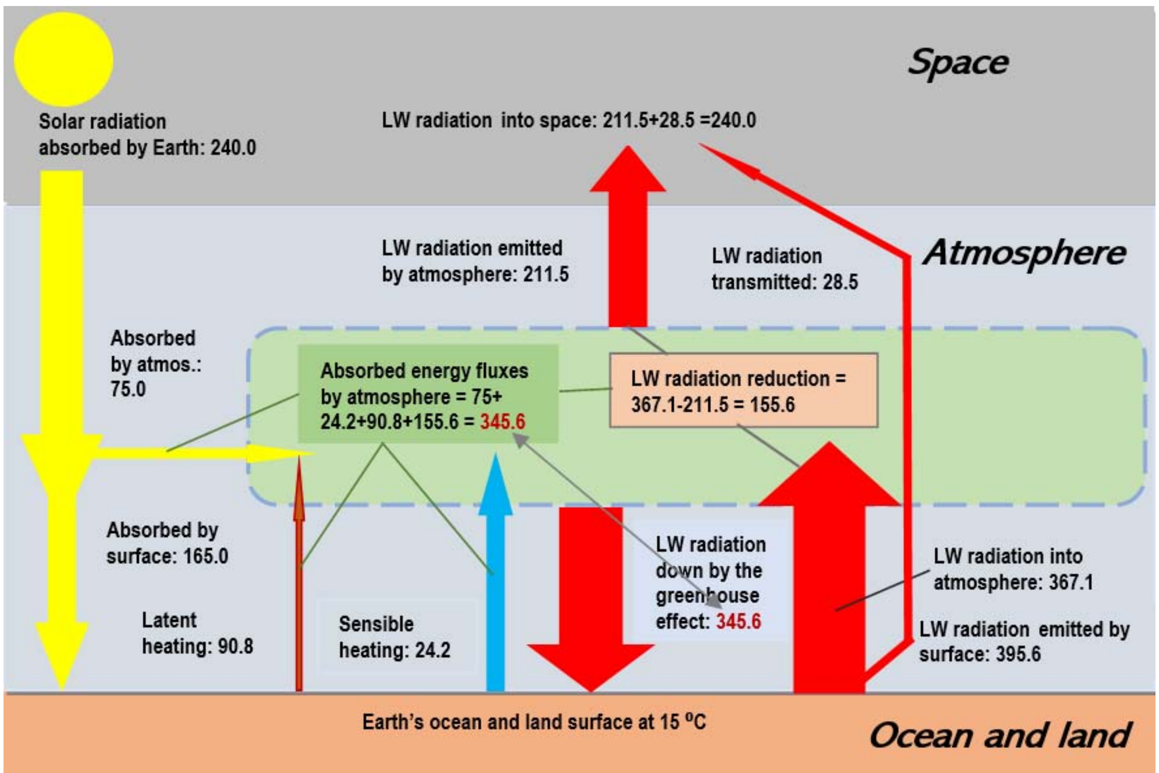

Figure 2. Energy fluxes contributing to the greenhouse effect in all-sky conditions (Wm^{-2}).

Thinking about the very basic feature of the GH phenomenon, it does not matter how the atmosphere warms up. Climate change scientists have ignored the warming effect of SW absorption by the atmosphere in calculating the GH effect. It has been accepted as an energy source in energy balance calculations, but not in GH effect calculations. Nowadays, we know quite exactly how much energy the atmosphere receives as the insolation, sensible heat, and latent heat. The sum of these sources is 75.0+90.8+24.2 = 190.0 Wm^{-2}, 22% greater in the all-sky conditions than the LW absorption by GH gases and clouds (155.6 Wm^{-2}) – total absorption by the atmosphere being 345.6 Wm^{-2}. The LW absorption according to Kiehl & Trenberth [7] is only 125 Wm^{-1}, because they have used an atmospheric model containing only 50 % absolute water vapor found in the average global atmosphere. This low LW absorption value is the main reason for an unrealistically high CO_2

contribution (26 %) of their study. In the updated energy balance the LW absorption is 155 Wm^{-2} by Trenberth et al. [22]. The same value of Schmidt et al. [8] is 155 Wm^{-2} and the Stephens et al. [12] 158.3 Wm^{-2}.

There is no physical reason to leave these three energy sources out of the GH effect calculations. The first law of thermodynamics states that the energy of an isolated system can be transformed from one form to another but can be neither created nor destroyed. According to its temperature, the warmed-up matter of the atmosphere emits LW radiations into all directions, including the Earth's surface. It has no meaning as to how the matter has received and maintained its temperature. It is true that only GH gases can absorb LW radiation, but according to the physical radiation law, every matter emits thermal radiation above absolute zero temperature according to its temperature. As shown by the spectral analysis, the atmosphere with the present temperature profile without any GH gases would emit the same LW radiation downward.

Climate change scientists have ignored the warming effects of energy sources other than the LW absorption by GH gases. In doing so, they accept that the total LW radiation to the Earth's surface is 345.6 Wm^{-2} and that it has been caused solely by GH gases and clouds, which absorb 155.6 Wm^{-2} from the thermal radiation emitted by the Earth's surface. The result of this interpretation is that the absorption by GH gases and clouds have caused the Earth's surface to become 33 □C warmer. This approach does not consider a physical contradiction in that an energy source of 155.6 Wm^{-2} cannot create an energy flux of 345.6 Wm^{-2}, which has the real warming effect on the Earth's surface.

There are two options to resolve this problem. We could specify that the GH effect is only a portion of the total warming effect of the atmospheric downward LW radiation: 33 □C * (155.6/345.6) = 14.9 □C. This could not be the full solution, however, because the total GH effect is really the magnitude of the downward LW radiation by the atmosphere, as specified by the present GH effect term. Any energy flux warming the atmosphere is thus an integral part of the Earth's GH effect.

3.5 The greenhouse effect of all contributing factors

The Earth's gross energy balance shows that the all-sky atmosphere balance value is 585.6 Wm^2 because it includes the LW radiation 211.5 Wm^{-2} emitted into space and the LW radiation 28.5 transmitted into space. The net energy absorbed by the atmosphere is 585.6 – 211.5 – 28.5 = 345.6 Wm^{-2}.

The author has calculated the GH effect using all energy sources, including SW absorption and latent and sensible heating. The GH gas contributions have been calculated by removing a GH gas in question from the atmospheric model in the Spectral Calculator application [17]. One of the most essential features of our planet is, that the oceans cover 70% of the surface area and provide humidity into the atmosphere, which plays the key role in the GH phenomenon.

The cloud absorption values for SW insolation are 27.0 Wm^{-2} and 17.8 Wm^{-2} according to the energy balance for cloudy and all-sky conditions. The contributors of the SW absorption for the clear sky case [23] are water 77.2%, ozone 19.5%, CO_2 2.3%, aerosols 1.9%, and methane and nitrogen oxide 0.7%. Based on the energy balance analysis, the overall absorption values caused by LW absorption (Wm^{-2}) only of different skies are clear sky 128.1, cloudy sky 167.8, and all-sky 155.6. The absorption effect of water in different skies is the difference between the overall GH absorption minus the sum of the GH gas absorptions.

The absorption of SW radiation is caused by GH gases, aerosols and by clouds. The results of the all-sky conditions are summarized in Table 1. The details of the SW and LW flux calculations are in Appendix Tables A2-A6.

Table 1. Greenhouse effects according to individual contributors in all-sky conditions.

Contributor	SW absorption, Wm^{-2}	LW absorption, Wm^{-2}	Total Wm^{-2}	Net contribution, %	Net contribution, °C	Gross contribution, %
Water	43.5	90.9	134.4	45.6	14.9	38.9
Latent heating	0.0	90.8	90.8	30.8	10.0	26.3
Sensible heating	0.0	24.2	24.2	8.2	3.0	7.0
Carbon dioxide	1.3	20.1	21.4	7.3	2.4	6.2
Ozone	11.0	6.9	17.9	6.1	2.0	5.2
Clouds	0.0	2.8	2.6	0.9	0.3	15.5
Methane & Nitrogen oxide	0.4	1.8	2.2	0.7	0.2	0.6
Aerosols	1.0	0.0	1.0	0.3	0.1	0.3
Total	57.2	237.5	294.5	100.0	33.0	100.0

Table 1 shows the contributions of two different approaches, which could be called a *Net GH effect* and a *Gross GH effect*. The Gross GH effect considers only the positive absorption effects of clouds, but the Net GH effect considers the real surface temperature effects of clouds based on the observations. The results show that water is the main contributor, consisting of a vapor effect of 45.6% and a latent heating effect of 30.8%, for a total of 76.4%. The contribution effect of CO_2 is 7.3%. This low contribution means that the total GH effect of the CO_2 concentration 400 ppm is only 2.4 □C.

The major controversial contributor is the GH effect of clouds. Most research studies [12,16, 24-28] show that *cloud forcing* has a negative impact on the surface temperature, varying from -17 to -30 Wm^{-2}. Two often referenced studies [7-8] show that clouds have a positive GH contribution of +25%, and +39% in the GH effect. These figures suggest that more cloudiness means higher GH effect and thus higher surface temperature. This is in direct conflict with the general cloud forcing impact.

The reason for this conflict originates from the two opposite effects of clouds on radiation. Clouds reduce the incoming SW radiation effect from 287.2 Wm^{-2} in the clear sky to 240 Wm^{-2} in all-sky, and thus the change is -47.2 Wm^{-2}. At the same time, the GH effect increases from 128.1 Wm^{-2} to 155.6, and thus the change is +27.4 Wm^{-2}. The net effect is cooling by -19.8 Wm^{-2}.

If only the positive radiative forcing effects of clouds are accounted for by increasing the GH effect, it does not give the right response to the surface temperature impact. This temperature effect is the main reason to assess the GH effect: what is the GH effect on the surface temperature and what are the portions of individual contributors? There is a study by Ollila [10] showing a very small positive cloud effect of 1%. This is based on the emitted radiation values of clear sky 394.1 Wm^{-2} and all-sky 395.6 Wm^{-2} [16]. These values correspond to the black surface temperatures 15.6 °C and 15.9 °C, which means that the all-sky surface temperature is 0.3 □C higher than that of clear sky.

4. Effect on climate change models

4.1 The simple climate model of the IPCC

These results have an effect on the climate change models. IPCC uses both ECS (Equilibrium Climate Sensitivity) and TCS (Temporary Climate Sensitivity) concepts and summarizes the differences in AR5, p. 1110 [2]: *"ECS determines the eventual warming in response to stabilization of atmospheric composition on multi-century time scales, while TCR determines the warming expected at a given time following any steady increase in forcing over a 50- to 100-year time scale."* IPCC has changed the TCS to TCR (Transient Climate Response). On page 1112 of AR5, IPCC [2] states that *"TCR is a more informative indicator of future climate than ECS."*

IPCC [2] has applied the radiative forcing (RF) model and the positive water feedback as a combination of

$$dT = \lambda * RF, \qquad (2)$$

where dT is the global surface temperature change (K) starting from the year 1750 and λ is the climate sensitivity parameter ($K/(Wm^{-2})$. The λ value is 0.5 $K/(Wm^{-2})$ per IPCC [4]. The RF value can be calculated according to the CO_2 concentration using Eq. (3) by Myhre et al. [29]. It has been used by the IPCC as well as by General Climate Models (GCMs)

$$RF = 5.35 * \ln(C/280) \qquad (3)$$

where C is the CO_2 concentration (ppm). This simple model is applicable to calculate the TCS value as well as the temperature response for the scenarios up to 1370 ppm CO_2 concentration. The simple model of Eq. (2) and (3) gives a TCS value of 1.85 □C. It can be compared to the IPCC's latest report AR5 [2], which shows TCS between 1.0 □C and 2.5 □C, meaning an average value of 1.75 □C. In Table 2, AR5 [2] is the average value of TCS/TCR of the 30 most complicated GCMs, and the value is 1.8 C. There is also the third TCR/TCS value calculated by GCMs [2] in section 8.6.2.3 of the AR5: "*It can be estimated that in the presence of water vapor, lapse rate and surface albedo feedbacks, but in the absence of cloud feedbacks, current GCMs would predict a climate sensitivity (±1 standard deviation) of roughly 1.9 □C ± 0.15 □C*." Considering these slightly different TCS values of IPCC, the simple model is a justified model that can be used to calculate the warming values of different CO_2 and other GH gas concentrations.

In Table 2, the AR5 [2] is the average λ value 1.0 $K/(Wm^{-2})$ for the ECS of 30 GCMs, which means that the simple climate model according to Eq. (2) is applicable to both TCR and ECS calculations. As referenced above, in TCR calculations, λ includes the feedback effects of water vapor, lapse rate, and surface albedo. In the AR4, the IPCC [4] writes: "*The diagnosis of global radiative feedbacks allows better understanding of the spread of equilibrium climate sensitivity estimates among current GCMs. In the idealized situation that the climate response to a doubling of atmospheric CO_2 consisted of a uniform temperature change only, with no feedbacks operating (but allowing for the enhanced radiative cooling resulting from the temperature increase), the global warming from GCMs would be around 1.2 °C.*" This statement means that the λ value 0.324 would give a warming value of 1.2 °C for the RF value of 3.7 Wm^{-2} due to the CO_2 warming effects only.

4.2 Climate sensitivity parameter according to the Earth's energy balance

The simplest calculation method of the climate sensitivity parameter λ is based on the total energy balance of the Earth by equalizing the absorbed and emitted radiation fluxes

$$SC(1\text{-}\alpha) * (¶r^2) = sT^4 * (4¶r^2), \qquad (4)$$

where SC is the solar constant (1361 W/m^2), α is the total albedo of the Earth, s is the Stefan-Boltzmann constant ($5.6704*10^{-8}$), and T is the temperature (K). The temperature value T can be solved using

$$T = (SC * (1 – \alpha) (4s))^{0.25}, \qquad (5)$$

where T is the temperature corresponding to the emitted longwave (LW) flux in the atmosphere. The average albedo according to Table S1 values is (100.2 Wm^{-2}) / (340.2 Wm^{-2}) = 0.295. Using this albedo value, the temperature T would be -17.1 °C (=255.4 K). According to Planck's equation, this temperature corresponds to an LW radiation flux of 239.8 Wm^{-2}, which is very close to the actual observed outgoing longwave radiation flux of 240.2 Wm^{-2} used in the energy balance calculations of this study. The most common magnitude of the GH effect is 33 °C, which means that the surface temperature would be 15.9 °C, and this value is the same as the black surface temperature of the surface emitted radiation flux [16].

The term SC(1-α)/4 is the same as the net radiative forcing (RF), and therefore, Eq. (4) can be written as $RF = sT^4$. When this equation is derived, it will be $d(RF)/dT = 4sT^3 = 4(RF)/T$. The ratio d(RF)/dT can be inverted, transforming it into λ:

$$dT/(d(RF)) = \lambda = T/(4RF) = T/(SC(1\text{-}\alpha)) = 255.40 / (1361 *(1\text{-}0.295)) = 0.264 K/(Wm^{-2}). \qquad (6)$$

This λ value means that there is no water feedback according to the Earth's energy balance analysis.

4.3 Reproduction of the radiative forcing of carbon dioxide

The radiative forcing (RF) of CO_2 according to Myhre et al. [29] has been reproduced applying two simulation tools available in the network, namely the Spectral Calculator [17] and the Modtran [30]. The parameters and choices applied in Modtran simulations are depicted in Table A8. The atmospheric temperature and GH gas profiles are the same as those specified in the Earth's energy balance calculations of Appendix.

The spectral calculations have been carried out from the surface to an altitude of 70 km. In these calculations, a few iterations are needed in both calculation tools in order to find the surface temperature, which compensates the increased absorption caused by a CO_2 increase (393 ppm, 560 ppm, and 1370 ppm) bringing the OLR flux exactly to the same the OLR (outgoing LW radiation) flux caused by a CO_2 concentration of 280 ppm. Because both the OLR change and the temperature change are calculated at the same time, the λ value can be easily calculated. The cloudy sky values are calculated using the Modtran simulations, which show about a 30% lower OLR change than the clear sky simulations. This relationship has been used to estimate the cloudy sky values of Spectral Calculator simulations. The IPCC's AR5 report [2] summarizes that according to several studies, the overall reduction of RF values in cloudy sky conditions is 25% lower than the clear sky values on average.

The results of the simulations carried out by the Modtran and Spectral Calculator are summarized in Table 2.

Table 2. The radiative forcing and warming values of different CO_2 concentrations (reference level 280 ppm). The clear sky values are calculated by Spectral Calculator and cloudy skies by Modtran.

Sky	ΔOLR, Wm^{-2}	ΔT, °C
	CO_2, 393 ppm	
Clear	1.29	0.28
Cloudy	0.90	0.22
All-sky	1.03	0.24
	CO_2, 560 ppm	
Clear	2.69	0.66
Cloudy	1.88	0.51
All-sky	2.16	0.56
	CO_2, 1370 ppm	
Clear	6.29	1.60
Cloudy	4.39	1.23
All-sky	5.04	1.36

Myhre et al. [29] have concluded that the absorption of solar radiation in the troposphere yields a positive RF at the tropopause and a negative RF in the stratosphere, contributing to a net cooling effect of CO_2 absorption of -0.06 Wm^{-2} for the concentration change from 280 ppm to 381 ppm. The absorption calculations of solar radiation [10] in the atmosphere from 0 to 70 km show a very small net warming effect of CO_2 increase. Therefore, the solar radiation warming effects due to CO_2 concentration changes have not been included in the RF calculations.

The logarithmic fitting gives the following equation between RF values and CO_2 concentrations in Table 2:

$$RF = 3.12 * \ln(C/280). \qquad (7)$$

The coefficient of correlation is 0.99987, showing an almost perfect fit. The different results in comparison to the equation (3) of Myhre et al. [29] have been analyzed in the discussion section.

A sensitivity analysis for λ has been carried out. Using the Spectral Calculator simulation, a CO_2 concentration of 393 ppm gives a λ value of 0.230 K/(Wm^{-2}) and 1370 ppm gives a λ value of 0.269 K/(Wm^{-2}). The OLR value 233 Wm^{-2} gives a λ value of 0.270 K/(Wm^{-2}), and the OLR value 240 Wm^{-2} gives a λ value of 0.265 K/(Wm^{-2}). According to Spectral Calculator analysis, the RF value for a CO_2 concentration of 560 ppm is 2.16 Wm^{-2}, CS is 0.576 °C, and λ is 0.267 K/(Wm^{-2}). Using a CO_2 concentration of 560 ppm in Modtran simulations, the RF is 1.834 Wm^{-2}, the CS is 0.49 °C, and λ is 0.267 K/(Wm^{-2}). The variation of λ is relatively small, but λ is not invariant. The Modtran calculation results are not as accurate and reliable as the Spectral Calculator results because the atmospheric conditions of Modtran cannot be specified with the same accuracy as in Spectral Calculator. The final choice for the climate sensitivity parameter λ is 0.27 K/(Wm^{-2}), and the (transient) climate sensitivity can be rounded to 0.6 °C.

4.4 Fitting the simple climate models into the greenhouse effect

In Figure 3a, two cases have been depicted: a) a red curve according to the TCS value of 1.2 °C representing the IPCC model for CO_2 warming effects only and b) a green curve according to equation (7), and λ value of 0.27 K/(Wm^{-2}) without positive water feedback. The direct humidity measurements do not show the constant relative humidity either [10].

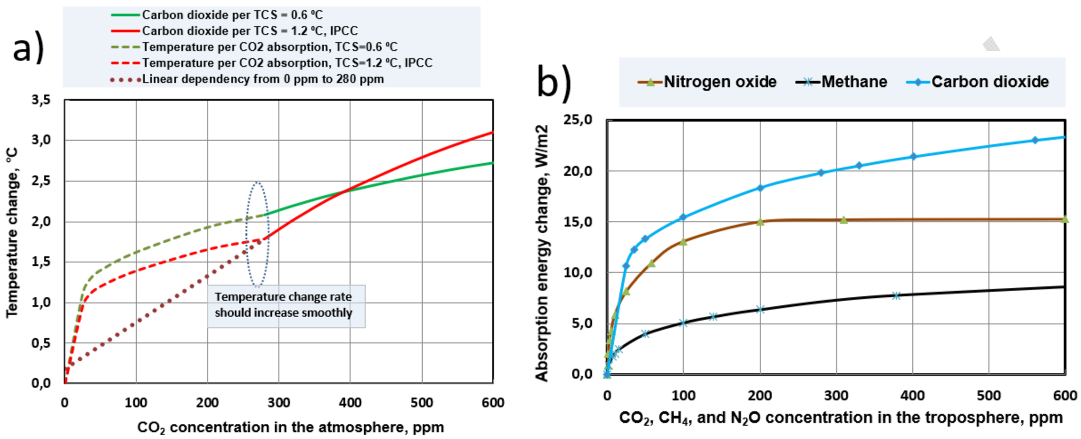

Figure 3. Warming effects of CO_2 according to the new greenhouse effect of CO_2 being 2.4 □C in 2014 (400.9 ppm). **(a)** CO_2 warming effects from 280 ppm onward are per a green curve, TCS = 0.6 □C, and per IPCC (2013), a red curve, TCS = 1.2 □C. **(b)** The absorption values of carbon dioxide, methane, and nitrogen oxide. The detailed numerical values of the absorption and warming calculations are in Table A7 of Appendix.

The calculation basis of curves in Figure 3a are on the Eqs (2), (3), and (7) for CO_2 concentration 280 ppm onward. These CO_2 warming impact curves have been adapted to give a total warming value of 2.4 □C caused by the CO_2 concentration of 400.9 ppm as shown in this study. The warming change from CO_2 concentration 0 ppm to 280 ppm (dashed curves) is based on the absorption decrease by spectral calculations in Figure 3b. The detailed numerical values of the absorption and warming calculations are in Table A7 of SM.

The absorption of GH gases follows the general rules of absorption, which means that increasing concentrations from zero upward has the strongest effect in the beginning. This behavior can be noticed also in the absorption curves of methane and nitrogen oxide. The starting phase approximately follows the Beer-Lambert law, which states that absorbance depends linearly on the concentration and path length. When the concentration increases, this relationship is no longer valid. There is a very nonlinear dependency from 20 to 100 ppm for CO_2, and thereafter the relationship is slightly nonlinear after 280 ppm, which can be approximated by a logarithmic relationship very well.

It should be noticed that these kind of absorption calculations have been applied by many researchers [7-10] to quantify the GH effects of GH gases. The temperature effects based on the absorption may differ slightly from temperature effects calculated based on the outgoing LW radiation change at the top of the atmosphere. The absorption change curve shows reliably the general feature of the temperature change as CO_2 concentration increases, because temperature change should decrease smoothly without any sharp transition point to another mode.

The absorption values of CO_2 as depicted in Figure 3b, have been transformed into warming values (dashed line curves) in Figure 3a using conversion factors. These factors have been calculated so that the CO_2 absorption by concentration 280 ppm gives the same warming value as the curve in question according to Eqs (2), (3), and (7). If the climate model is correct from 280 ppm onward, there should be no sharp change at this concentration.

A red curve according to the IPCC model gives warming values that are too high as illustrated in Figure 3a, because the warming rate change is not smooth at the concentration of 280 ppm. The dotted straight line in Figure 3 illustrates the linear growth rate in the case of TCS=1.2 □C from 0 to 280 ppm. It shows that a linear growth rate would almost match the curve point from 280 ppm onward, but as Figure 4 shows, it would strongly violate the general behavior of the absorption rate of CO_2 because there should be a strong nonlinear part from 20 ppm to 100 ppm.

The IPCC model with λ value 0.324 $K/(Wm^{-2})$ gives the TCS value 1.2 □C. It cannot be fitted into the general behavior of the CO_2 absorption either. The curve of the model (TCS = 0.6 □C) according to Eq. (7) of this study shows a smooth feature of a warming rate without a transition point at the 280 ppm. IPCC [2] has estimated that the actual temperature increment from 1880 to 2012 has been 0.85 □C, p. 5 of SPM. According to IPCC (2013) the radiative forcing value for the same time period has been 2.34 Wm^{-2}, which gives 1.17 °C warming being 37.7 % greater than the observed temperature.

4.5 Positive water feedback or not in the atmosphere

The climate models referred by the IPCC apply positive water feedback as reported in AR5 [2, p.207]: "*In summary, radiosonde, GPS and satellite observations of tropospheric water vapor indicate very likely increases at near global scales since the 1970s occurring at a rate that is generally consistent with the Clausius-Clapeyron relation (about 7% per degree Celsius) and the observed increase in atmospheric temperature.*" This assumption of the Clausius-Clapeyron (C-C) relation should also mean constant relative humidity (RH).

The C-C equation provides the relationship between the saturation water pressure and the temperature. The atmosphere is not saturated with water vapor, but RH varies globally between 35% and 80% depending on the altitude. There is no scientific basis to apply the C-C relationship to atmospheric conditions.

Figure 4 depicts the satellite temperatures [31] and absolute humidity trends [32] from 1979 to 2019.

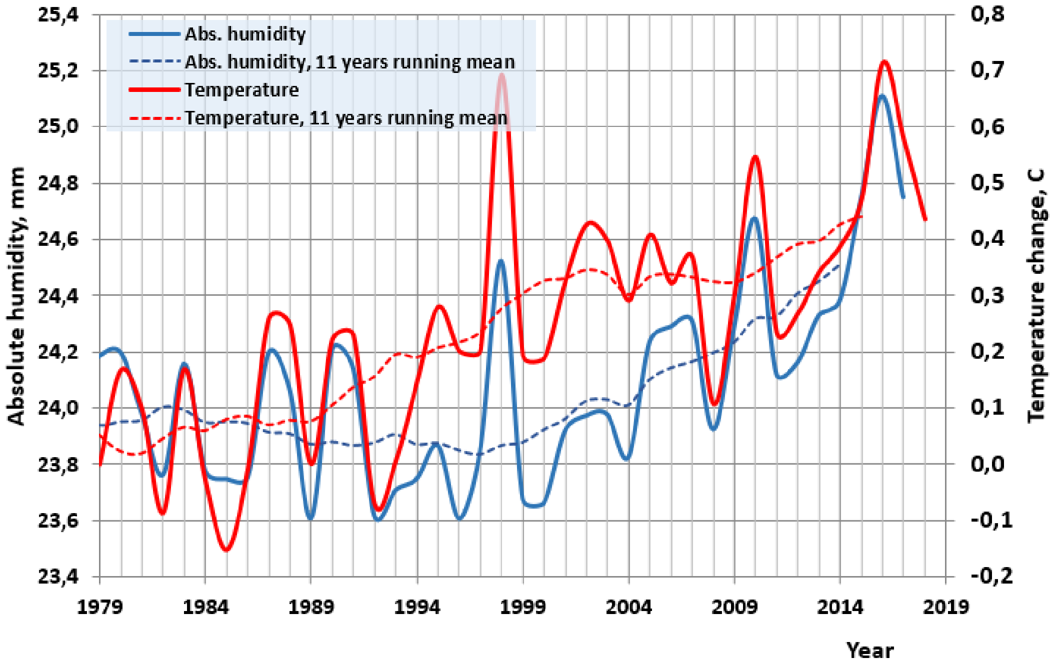

Figure 4. The satellite temperature and absolute humidity trends.

It can be noticed that absolute humidity does not follow temperature changes according to the C-C relationship. For example, during 1982–2002, the temperature has been steadily increasing, but absolute humidity has a decreasing trend.

5 Validation of calculations

Simple linear model according to equation (2) has been used for calculating the warming values of CO_2 changes. Because the emitted radiation depends on the temperature according to Planck's law, which is nonlinear as presented in equation (1), it can cause errors. Figure 4 depicts the surface temperature changes according to RF changes from 0 to 5 Wm^{-2} in both ways. Figure 5 shows in an illustrative way that the error for the potential RF changes in using linear model is insignificant.

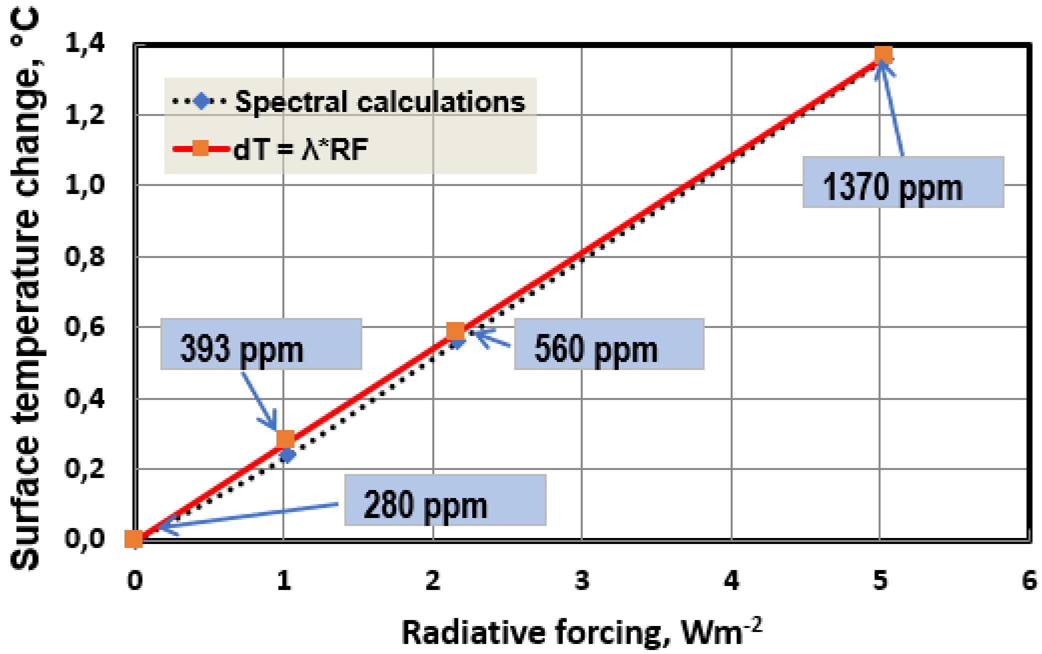

Figure 5. The dependency of the surface temperature on the radiative forcing (RF) according to spectral calculations and to linear relationship T = λ * RF.

The synthesis analysis by Stephens et al. [33] shows an average value of 314.2 Wm^{-2} in 13 independent observation-based studies for the downward LW flux on the surface. The value of the same flux of this study model is 310.9 Wm^{-2}, meaning a difference of 1.0%. The LW radiation flux at TOA in the clear sky conditions according to spectral calculations of this study is 265.3 Wm^{-2}. The same flux value based on the NASA CERES satellite observations [12] from 2000–2010 is 266.4 Wm^{-2}. The difference is 0.4%. These uncertainties are much smaller than the uncertainties of the observed flux values. These values mean that the atmospheric model of this study used in the spectral calculations, describes very accurately the radiation fluxes of the real atmosphere.

The total absorption values of Gross GH effect are 312.8 Wm^{-2} for clear sky, 363.9 Wm^{-2} for cloudy sky, and 345.6 Wm^{-2} for all-sky according to spectral analysis method. The downward radiation fluxes emitted by the atmosphere (also close to empirical values) in the energy budget calculation are 318 Wm^{-2}, 359.8 Wm^{-2}, and 345.6 Wm^{-2}. The total absorption (including SW and LW absorption) of all-sky 345.6 Wm^{-2} is the sum of the following contributors in Wm^{-2}: water 134.4, latent heating 90.8, clouds 53.7, sensible heating 24.2, CO_2 21.4, ozone 17.9, methane & nitrogen oxide 2.2, and aerosols 1.0. It is not a coincidence that the figures of the total absorption and downward radiation flux are almost the same as Kirchoff's radiation law states that they are equal in radiation balance conditions. The small differences are well inside the uncertainty limits of the fluxes. The LW absorption by GH gases only cannot create the emitted fluxes by the atmosphere.

The absorption values above the cloud cover for different skies are the same. In the energy balance analysis, the absorption values of clouds in cloudy sky and all-sky conditions are 49.6 Wm^{-2} and 37.8 Wm^{-2}, and the spectral calculations show the corresponding values to be 52.4 and 35.8 Wm^{-2}. These differences of -2.8 and +2.0 Wm^{-2} are well inside the uncertainty values of individual flux values, which show a typical uncertainty of ±7 Wm^{-2}.

6 Discussion and conclusion

The atmosphere emits LW radiation according to its temperature, but the LW absorption 155.6 Wm^{-2} is not capable of creating the observed downward LW radiation of 345.6 Wm^{-2}. Other factors are needed in the GH effect to explain this gap, and they are SW absorption by GH gases and sensible and latent heating. These fluxes disappear into the atmosphere in the present GH effect definition, leaving no effect on the atmospheric temperature and downward radiation for these fluxes. Together, these four factors perfectly explain the downward LW radiation, which has the real warming effect on the surface. The new GH effect definition explains the radiation fluxes and elevated surface temperature without contradicting the physical laws. All four factors have an essential role in maintaining the atmospheric temperature profile, which defines downward LW flux according to Planck's law. This study shows that the increase of 33 □C is due to the downward LW radiation effect of 294.5 Wm^{-2}. This figure is not the same as the observed downward LW radiation flux of 345.6 Wm^{-2} emitted by the atmosphere because the clouds simultaneously increase LW absorption and decrease solar insolation. Additionally, all-sky conditions prevail only during short time periods, and the observed surface temperatures do not correspond to the observed radiation fluxes due to the long-time delays of the climate system.

The reason for the small positive temperature effect of 0.3 °C of the all-sky situation in comparison to that of the clear sky is in the dynamic time delays of the atmospheric and ocean/land processes. When the clear sky turns into cloudy sky, changes in radiation fluxes happen almost immediately, because the longest time constant of the atmosphere is only about 2.7 days [34]. The time constant of land is 1.04 months and of the ocean mixing layer 2.74 months [34-35].

The major positive effect of the cloudy sky is due to the cloud cover during the nighttime, which radically reduces the cooling rate of the surface in comparison to the clear sky. This means that during the first few days, the temperature effect of the cloudy sky is slightly positive, but eventually the cloudy sky always results in a lower surface temperature. In a real climate, cloudiness fluctuates continuously from clear sky to cloudy sky in relatively short periods of only a few days. That is why during the changing sky conditions, the all-sky generally gives a small positive warming effect. At the same time, it should be noticed, for example, that a long-term (> 1 week) increased cloudiness always results in a lower surface temperature [11].

The contribution of CO_2 is only 7.3% in the GH effect, which means that the sole CO_2 effect of 1.2 □C or 1.8 °C calculated by GCMs applied by IPCC cannot be fitted into the total GH effect of CO_2. The value of 1.2 □C is not in line with the statement from the IPCC (2013 p. 666) stating that "*the contribution of water vapor to the natural greenhouse effect relative to that of carbon dioxide (CO_2) depends on the accounting method but can be considered to be approximately two to three times greater.*" This means that the warming effect of CO_2 would be between 1.8 □C/2 = 0.9 □C or 1.8 □C/3 = 0.6 □C, which are much lower values than 1.2 □C. The author has no explanation for this discrepancy in the IPCC values. The IPCC model including the GH effect and feedbacks shows about 37.7% too much surface warming at the end of 2012. The climate model, which can be fitted into the total GH effect, shows 0.3 □C warming by CO_2 by 2017. Therefore, other forces are needed to explain the major part of present warming.

If a climate model using the positive water feedback were applied to the GH effect magnitude of this study, it would fail worse than a model showing a TCS value of 1.2 °C. If there were a positive water feedback mechanism in the atmosphere, there is no scientific grounding to assume that this mechanism would start to work only if the CO_2 concentration exceeds 280 ppm, and actually, the IPCC does not claim so.

The AGW theory emphasizes the role of CO_2. In this theory the contribution of CO_2 has been considered higher than its contribution calculated by the method of removing its impact in spectral calculations. The basis for this increased effect is that the atmosphere, if CO_2 were removed from it, would cool and much of water vapor would rain out. This would cause more raining, and this would cause further cooling resulting even glaciated snowball state [2]. Schmidt et al. [8] have used the average value of minimum and maximum effects of CO_2 absorption, which is an “ad hoc” method without a clear scientific basis. However, majority of CO_2 contribution studies have applied the method of removing the GH gas in question [7, 9-10, 21] in spectral calculations. The spectral analysis method takes into consideration the overlapping absorption frequencies/wavelengths. That is why this method shows what is the contribution of each GH gas in the present climate in a precise way. The RF values of CO_2 concentration changes according to different research studies [29, 34–35] have been depicted in Figure 6.

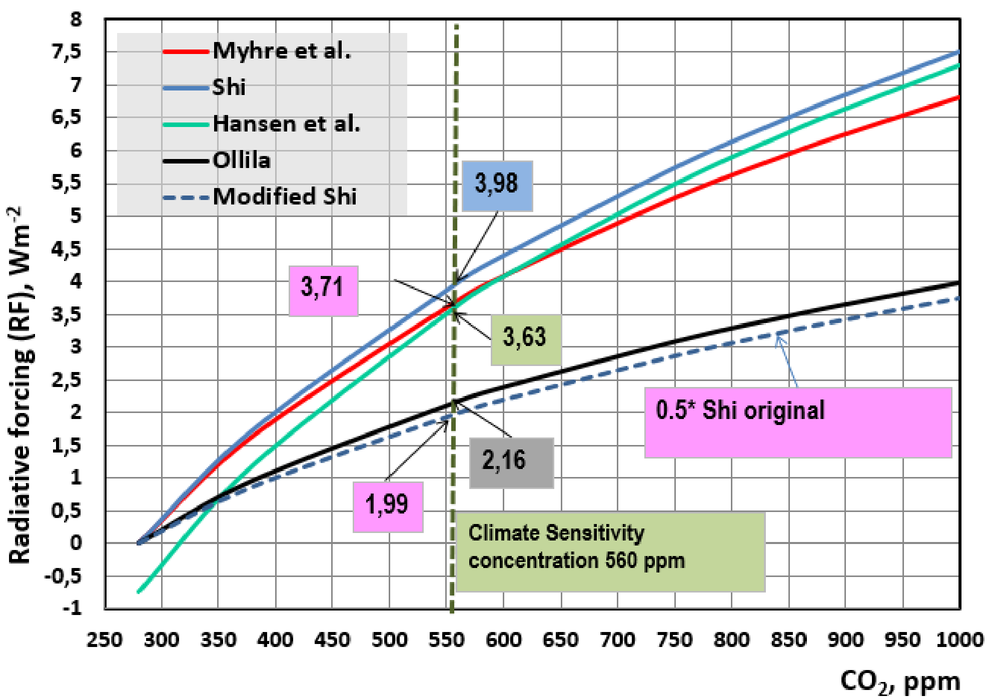

Figure 6. Radiative forcing (RF) curves of carbon dioxide according to different research studies [29, 34-35] and this study.

Because Myhre et al.’s [29] study does not show the actual total atmospheric water vapor amount, and because the applied atmospheric water vapor profile is not accessible in the common databases, it is impossible to find a reason between the reproduction of this study (equation [7]) and equation (3)). Shi [37] has used positive water feedback in his calculations, and his curve is very close to the curve by Myhre et al. [29], but if the RF values are multiplied by 0.5 to remove the positive water feedback, the curve is very close to the equation of this study.

COMPETING INTERESTS

The author has declared that no competing interests exist.

REFERENCES

[1] Henderson MDH, Henderson-Sellers A. History of greenhouse effect. Progr Phys Geography Earth and Environ 1990;14:1-18.

[2] IPCC. The Physical Science Basis, Chapter 8.1. Working Group I Contribution to the IPCC Fifth Assessment Report. Cambridge University Press, Cambridge; 2011.

[3] IPCC. The Physical Science Basis, Policymakers summary, Climate change, The IPCC scientific assessment. Cambridge University Press, Cambridge; 1990.

[4] IPCC. The Physical Science Basis, Chapter 1.5, Working Group I Contribution to the IPCC Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge; 2007.

[6] Pierrehumbert RT. Infrared radiation and planetary temperature. Phys Today 2011;64:33-38.

[6] Michell JFB. The “greenhouse” effect and climate change. Rev Geophys 1989;27:115-139.

[7] Kiehl JT, Trenberth KE. Earth’s annual global mean energy budget. Bull Amer Meteor Soc 1997;90:311-323.

[8] Schmidt GA, Ruedy RA, Miller RL, Lacis AA. Attribution of the present-day total greenhouse effect. J Geophys Res 2010;115,D20106:1-6.

[9] Ollila A. The roles of greenhouse gases in global warming. E&E 2012;23:781-799.

[10] Ollila A. Warming effect reanalysis of greenhouse gases and clouds. Phys Sci Int J 2017;13:1-13.

[11] Ollila A. Dynamics between clear, cloudy and all-sky conditions: cloud forcing effects. J Chem Biol Phys Sc 2013;4:557-575.

[12] Stephens GL, Wild M, Stackhouse Jr PW, L’Ecuyer T, Kato S, Henderson DS. An update on Earth’s energy balance in light of the latest global observations. Nat Geosc 2012;5:691-696.
[13] Chernykh IV, Alduchov OA, Eskridge RE. Trends in low and high cloud boundaries and errors in height determination of cloud boundaries. Bull Amer Meteor Soc 2001;82:1941-1947.

[14] Wang J, Rossow WB, Zhang Y. Cloud vertical structure and its variations from a 20-yr global rawinsonde dataset. J Climate 2000;13:3041-3056.

[15] Kokhanovsky AA, Rozanov VV, Lotz W, Bovensmann H, Burrows JP. Global cloud top height and thermodynamic phase distributions as obtained by SCIAMACHY on ENVISAT. Int J Rem Sens 2011;28:836-844.

[16] Zhang Y, Rossow WB, Lacis AA, Oinas V, Mischenko MI. Calculation of radiative fluxes from the surface to top of atmosphere based on ISCCP and other global data sets: Refinements of the radiative model and the input data. J Geophys Res 2004;109:1149-1165.

[17] Gats Inc. Spectral calculations tool; 2015. http://www.spectralcalc.com/info/help.php.

[18] HITRAN. Harvard-Smithsonian Center for Astrophysics, The HITRAN (high-resolution transmission molecular absorption) data base; 2018. https://www.cfa.harvard.edu/hitran/.

[19] Mlawer EJ, Payne VH, Moncet J-L, Delamere JS, Alvarado MJ, Tobin DC. Development and recent evaluation of the MT_CKD model of continuum absorption. Phil Trans Ser A Math Phys Eng Sc 2012;370:2520-25.

[19] Hartmann DL. Global Physical Climatology, Elsevier Science, USA; 2015.

[20] Ekholm N. On the variation of the climate of the geological and historical past and their causes. Quart J Royal Meteor Soc 1901;27:1-62.

[21] Miskolczi FM. Greenhouse effect and IR radiative structure of the Earth’s atmosphere. Int J Environ Res Public Health 2010;7:1-27.

[22] Trenberth KE, Fasullo JT, Kiehl JT. Earth’s global energy budget. Bull Amer Meteor Soc 2009;90:311-324.

[23] Ollila A. Clear sky absorption of solar radiation by the average global atmosphere. J Earth Sc Geotech Eng 2015;5:19-34.

[24] Ohring G and Clapp PF. The effect of changes in cloud amount on the net radiation at the top of the atmosphere. J Atm Sc 1980;37:447-454.

[25] Harrison EF, Minnis P, Barkstrom BR, Ramanathan V, Cess RD, Gibson GG. Seasonal variation of cloud radiative forcing derived from Earth radiation budget experiment. J Geophys Res 1990;95:18687-18703.

[26] Ardanuy PE, Stowe LL, Gruber A, Weiss M. Shortwave, longwave, and net cloud-radiative forcing as determined from Nimbus 7 observations. J Geophys Res 1991;96(D10):18537-18549.

[27] Loeb HG, Wielicki BA, Doelling DR, Smith GL, Keyes D, Kato S, Manalo-Smith N, Wong T. Toward optimal closure of the Earth's top-of-atmosphere radiation budget. J Climate 2009;22:748-766.

[28] Raschke E, Ohmura A, Rossow WB, Carlson BE, Zhang Y-C, Stubenrauch C, Kottek M, Wild M. Cloud effects on the radiation budget based on ISCCP data (1991 to 1995). Int J Clim 2005;25:1103-1125.

[29] Myhre G, Highwood EJ, Shine KP, Stordal F. New estimates of radiative forcing due to well mixed greenhouse gases. Geophys Res Lett 1998;25: 2715-2718.

[30] Berk A, Bernstein LS, Robertson DC. Modtran; 2017. A moderate resolution model for lowtran 7. http://forecast.uchicago.edu/Projects/modtran.orig.html.

[31] UAH MSU dataset; 2019. https://www.nsstc.uah.edu/data/msu/v6.0/tlt/uahncdc_lt_6.0.txt.

[32] NCEP/NCAR Reanalysis; 2019. https://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl.

[33] Stephens GL, Wild M, Stackhouse Jr PW, L'Ecuyer T, Kato S, Henderson DS. The global character of the flux of downward longwave radiation. J of Climate 2011;25:2329-2340.

[34] Kauppinen J, Heinonen JT, Malmi PJ. Major portions in climate change: Physical approach. Int Rev Phys 2011;5:260-270.

[35] Stine AR, Huybers P, Fung IY. Changes in the phase of the annual cycle of surface temperature. Nature 2009;457:435-441.

[36] Hansen J, Gung I, Lacis A, Rind D, Lebedeff S, Ruedy R, Russell G, Stone P. Global Climate Changes as Forecast by Goddard Institute for Space Studies, Three Dimensional Model. J Geophys Res 1998;93: 9341-9364.

[37] Shi G-Y. Radiative forcing and greenhouse effect due to the atmospheric trace gases. Science in China (Series B) 1992;35:217-229.

Appendix

The energy balance calculation bases are explained, and the values are depicted in Table A1. The detailed values of SW absorption for all-sky conditions are in Table A2, and the values of LW absorption in Table A3. The absorption flux values of the Gross GH effect for different skies are tabulated in Tables A4–A6. The absorption and warming values of different carbon dioxide, methane and nitrogen oxide concentrations are shown in Table A7.

Earth's energy balance

The energy flux values in Table A1 are based on six different methods as marked[1-6]:

- The direct observations[1]
- Equation $F_{all\text{-}sky} = 0.34*F_{clear\ sky} + 0.66*F_{cloudy\ sky}$ based on the average cloudiness of 66%[2]
- Spectral calculations[3]
- Energy balance requirements for surface, atmosphere, and TOA[4]
- Adding or subtracting fluxes[5]
- Four different calculation basis[6] as explained below:

1) SW flux reflected by the air in the cloudy sky (Rp). Reflected flux has been assumed to be dependent upon the amount of air molecules. The amount of air mass above the average cloud top (4 km) is 62% of the total air mass. Because the reflected radiation by air cannot take place in or below clouds, the Rp flux of the cloudy sky can be estimated to be 0.62*23 Wm^{-2} = 14.4 Wm^{-2}.
2) SW absorption by a clear sky in cloudy and all-sky conditions (Sb). There are no measured or calculated values available for SW fluxes absorbed by a clear sky in cloudy and all-sky conditions. The author has calculated these fluxes using an iteration method. Two iterations were needed and only the final results are represented in the flux table. The Sx represents the downward flux, which is calculated by subtracting reflection fluxes with Rc and Rp values from SWin. The clear sky absorption-% = 100 * Sb/Sx = 100 * 69/317 = 21.77. This percentage has been used in calculating the air absorption for cloudy and all-sky conditions, and the values are clear sky = 52.3 and cloudy sky = 57.2.
3) Absorbed flux by clouds (Sr) from the reflected flux by surface (Rs). The Sc values can be calculated as differences between the Si values and Sb values, which produce the values Sc = 24.7 for cloudy sky and Sc = 16.3 for all-sky. The cloudy sky absorption-% = 100 * Sco/Sxo = 100 * 24.7/240.4 = 10.28%, and all-sky absorption-% = 100 * Sca/Sxa = 16.3/262.5 = 6.2%. Using these absorption-% values, the absorption fluxes Sr of reflected flux Rp can be calculated. The results for cloudy sky are Sr = 2.3 and for all-sky Sr = 1.5. The calculated values for Rc, Rp, and Ra can be checked by calculating the reflected fluxes at TOA and that their sum is the same as the measured values Rt for different skies.
4) Sensible heating (T) and latent heating (L) values are based on three calculation bases utilizing an iteration procedure: a) the sum of T+L must match the balance value of the "surface out," b) the relationship between the T values of clear sky/cloudy sky is the same as Ss values of clear sky/cloudy sky, and c) the relationship between the L values of clear sky/cloudy sky is the same as the "surface out" balance values of clear sky/cloudy sky. The pseudo flux values of Ss are the effective values of SW radiation absorbed by the surface. They are pseudo values because Earth can never reach the real balance for incoming SW radiation flux on the surface. This is due to the long dynamic delays of the ocean and the land.

Table A1. Earth's energy balance for clear, cloudy, and all-sky conditions (Wm^{-2}).

SW radiation budget		Clear	Cloudy	All-sky	Uncertainty
SW total radiation from the sun	SWin	**340.2**[1]	**340.2**[1]	**340.2**[1]	±0.1
Total reflected SW rad. = Rc+Rp+Ra	Rt	**53.0**[1]	**119.3**[1]	**100.2**[1]	±2
SW flux reflected by clouds	Rc	0.0[1]	85.4[5]	60.3[4]	±10
SW flux reflected by air	Rp	23.2[4]	14.4[6]	17.4[2]	±10
SW flux downwards Sx = St-Rc-Rp	Sx	317.0[5]	240.4[5]	262.5[5]	±10
SW absorption by clear sky	Sb	69.0[3]	52.3[6]	57.2[6]	±10
SW absorption of Sx flux by cloudy sky	Sc	0.0[1]	24.7[4]	16.3[2]	±5
Sw insolation (Sx) absorbed by atmosphere	Si	69.0[3]	77.0[5]	73.5[5]	±10
Reflected flux (Rs) absorbed by clouds	Sr	0.0[1]	2.3[6]	2.3[6]	±0.5
Total absorption of SW rad. absorbed by atm.	Sa	69.0[3]	79.3[5]	75.0[5]	±10
SW radiation downwards to surface	Sd	248.0[5]	163.4[5]	189.0[5]	±10
SW radiation reflected by surface	Rs	29.8[1]	21.8[1]	24.0[1]	±3
Reflected Rs flux into space. Ra = Rs-Sr	Ra	29.8[1]	19.5[5]	22.5[5]	±3
SW radiation absorbed by surface	Ss	**218.2**[5]	**141.6**[5]	**165.0**[5]	±6
Net SW radiation = St - Rt	NSR	287.2[5]	220.9[5]	240.0[5]	±0.4
SW rad. absorbed by clouds & surface	ASR	**287.2**[5]	**220.9**[5]	**240.0**[5]	±0.4
Surface in:					
SW radiation absorbed by surface (pseudo)	Ss	197.0[4]	149.3[2]	165.0[1]	±6
Downward radiation emitted by atmosphere	Ed	318.0[3]	359.8[2]	345.6[1]	±9
SFC-balance		**515.0**[5]	**509.1**[5]	**510.6**[5]	±10
Surface out:					
Sensible heating	T	29.4[6]	22.2[6]	24.2[4]	±7
Latent heating	L	91.5[6]	90.5[6]	90.8[2]	±10
LW radiation emitted by surface	Es	394.1[3]	396.4[3]	395.6[3]	±5
SFC-balance		**515.0**[5]	**509.1**[5]	**510.6**[5]	±10
Atmosphere in:					
SW absorption by clear sky	Sb	69.0[3]	52.3[6]	57.2[6]	±10
Total SW absorption by cloudy sky	Sa	0.0[1]	79.3[5]	17.8[5]	±6
Sensible heating	T	29.4[6]	22.2[6]	24.2[4]	±7

Latent heating	L	91.5[6]	90.5[6]	90.8[2]	±10
LW radiation absorbed by atmosphere	Aa	310.9[3]	396.4[3]	367.1[3]	±10
LW radiation transmitted from surface to space	Et	83.2[3]	0.0[3]	28.5[3]	±6
ATM-balance		**584.0[5]**	**588.4[5]**	**585.6[5]**	±10
Processes inside the atmosphere:					
LW rad. absorbed by GH gases below clouds	Ag	107.5[3]	109.3[3]	108.9[3]	±7
LW radiation emitted by GH gases at cloud bottom	Eg	203.4[5]	287.1[5]	258.2[5]	±7
LW radiation absorbed by clouds or GH gases	Ac	11.7[4]	49.6[4]	37.8[4]	±7
LW radiation emitted by cloud top altitude	Ec	191.7[5]	237.5[5]	220.4[5]	±4
LW rad. absorbed by GH gases above clouds	Au	8.9[3]	8.9[3]	8.9[3]	±3
Total absorption by GH gases	At	128.1[5]	167.8[5]	155.6[5]	±7
Atmosphere out:					
LW radiation emitted by GH gases at TOA	Eu	182.8[5]	228.6[5]	211.5[5]	±12
Downward radiation emitted by atmosphere	Ed	318.0[3]	359.8[2]	345.6[1]	±9
LW radiation transmitted from surface to space	Et	83.2[3]	0.0[3]	28.5[3]	±4
ATM-balance		**584.0[5]**	**588.4[5]**	**585.6[5]**	±10
TOA:					
LW radiation emitted by GH gases at TOA	Eu	182.8[5]	228.6[5]	211.5[5]	±12
LW radiation transmitted from surface to space	Et	83.2[3]	0.0[3]	28.5[3]	±6
OLR		**266.0[1]**	**228.6[5]**	**240.0[1]**	±0.4

Table A2. SW absorption fluxes for clear, cloudy, and all-sky conditions (Wm^{-2}) by spectral analysis method.

SW absorption	Clear sky	Cloudy sky	All-sky
Water	52.4	39.8	43.5
Carbon dioxide	1.6	1.2	1.3
Ozone	13.2	10.0	11.0
Methane & Nitrogen oxide	0.5	0.4	0.4
Aerosols	1.3	1.0	1.0
Clouds	0.0	27.0	17.8
Total absorption	69.0	79.3	75.0

Table A3. LW absorption fluxes for clear, cloudy, and all-sky conditions (Wm^{-2}) by spectral analysis method.

LW absorption	Clear sky	Cloudy sky	All-sky
Water	98.8	86.8	90.9
Carbon dioxide	20.1	20.1	20.1
Ozone	7.2	6.8	6.9
Methane & Nitrogen oxide	2	1.7	1.8
Aerosols	0	0	0.0
Clouds	0	54.4	35.9
Total absorption	128.1	169.8	155.6

Table A4. Gross greenhouse effect in all-sky conditions (Wm^{-2}) by spectral analysis method.

	SW absorption	LW absorption	Total	Contribution, %	Contribution, °C
Water	43.5	90.9	134.4	38.9	12.83
Latent heating	0.0	90.8	90.8	26.3	8.67
Clouds	17.8	35.9	53.7	15.5	5.13
Sensible heating	0.0	24.2	24.2	7.0	2.31
Carbon dioxide	1.3	20.1	21.4	6.2	2.04
Ozone	11.0	6.9	17.9	5.2	1.71
Methane & Nitrogen oxide	0.4	1.8	2.2	0.6	0.21
Aerosols	1.0	0.0	1.0	0.3	0.10
Total	75.0	270.6	345.6	100.0	33.00

Table A5. Gross greenhouse effect in clear sky conditions by spectral analysis method.

	SW absorption Wm^{-2}	LW absorption Wm^{-2}	Total Wm^{-2}	Contribution %	Contribution □C
Water	52.4	98.8	151.2	48.3	15.95
Latent heating	0.0	91.5	91.5	29.3	9.65
Clouds	0.0	0	0.0	0.0	0.00
Sensible heating	0.0	29.4	24.2	7.7	2.55
Carbon dioxide	1.6	20.1	21.7	6.9	2.29
Ozone	13.2	7.2	20.4	6.5	2.15
Methane & Nitrogen oxide	0.5	2	2.5	0.8	0.26
Aerosols	1.3	0.0	1.3	0.4	0.14
Total	69.0	249	312.8	100.0	33.00

Table A6. Gross greenhouse effect in cloudy sky conditions (Wm^{-2}) by spectral analysis method.

	SW absorption Wm^{-2}	LW absorption Wm^{-2}	Total Wm^{-2}	Contribution %	Contribution □C
Water	39.8	86.8	126.6	34.8	11.48
Latent heating	0.0	90.5	90.5	24.9	8.21
Clouds	27.0	54.4	81.4	22.4	7.38
Sensible heating	0.0	22.2	24.2	6.7	2.19
Carbon dioxide	1.2	20.1	21.3	5.9	1.93
Ozone	10.0	6.8	16.8	4.6	1.52
Methane & Nitrogen oxide	0.4	1.7	2.1	0.6	0.19
Aerosols	1.0		1.0	0.3	0.09
Total	79.4	282.5	363.9	100.0	33.00

Table A7. The absorption change caused by the concentration changes of carbon dioxide, methane, and nitrogen oxide in the average global atmosphere conditions.

Carbon dioxide			Methane			Nitrogen oxide		
ppm	dE, Wm^{-2}	dT, □C	ppm	dE, Wm^{-2}	dT, □C	ppm	dE, Wm^{-2}	dT, □C
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	10.69	1.19	1.77	0.89	0.09	0.31	0.86	0.09
35	12.26	1.36	7.26	1.77	0.19	1.32	2.04	0.21
50	13.32	1.48	10.00	2.04	0.21	3.32	3.35	0.35
100	15.44	1.72	15.49	2.47	0.26	5.32	4.28	0.45
200	18.35	2.04	50	3.96	0.42	10.32	5.90	0.62
280	19.80	2.20	100	5.07	0.53	25.00	8.15	0.86
379	20.51	2.28	139	5.65	0.59	58.32	10.94	1.15
410	21.40	2.38	200	6.35	0.67	100	13.07	1.37
560	23.01	2.56	379	7.77	0.82	200	14.99	1.57
800	24.92	2.77	1400	11.37	1.19	310	15.20	1.60