The Potency of Carbon Dioxide (CO_2) as a Greenhouse Gas

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Abstract

According to this study the commonly applied radiative forcing (RF) value of 3.7 Wm^{-2} for CO_2 concentration of 560 ppm includes water feedback. The same value without water feedback is 2.16 Wm^{-2} which is 41.6 % smaller. Spectral analyses show that the contribution of CO_2 in the greenhouse (GH) phenomenon is about 11 % and water's strength in the present climate in comparison to CO_2 is 15.2. The author has analyzed the value of the climate sensitivity (CS) and the climate sensitivity parameter (λ) using three different calculation bases. These methods include energy balance calculations, infrared radiation absorption in the atmosphere, and the changes in outgoing longwave radiation at the top of the atmosphere. According to the analyzed results, the equilibrium CS (ECS) is at maximum 0.6 °C and the best estimate of λ is 0.268 K/(Wm^{-2}) without any feedback mechanisms. The latest warming scenarios of Intergovernmental Panel on Climate Change (IPCC) for different CO_2 concentrations until the year 2100 include the same feedbacks as the 2011 warming i.e. only water feedback. The ECS value of 3.0 °C would mean that other feedback mechanisms should be stronger than water feedback. So far there is no evidence about these mechanisms, even though 40 % of the change from 280 ppm to 560 ppm has already happened. The relative humidity trends since 1948 show descending development which gives no basis for using positive water feedback in any warming calculations. Cloudiness changes could explain the recent stagnation in global warming.

Keywords

Strength of CO_2; Climate Change; Global Warming; Climate Sensitivity; Climate Sensitivity Parameter

Introduction

The CS is calculated based on the doubling of the CO_2 concentration from the pre-industrial concentration from 280 ppm to 560 ppm. Before calculating these future effects, climate science should find a good understanding of the effect of CO_2 on the present greenhouse (GH) phenomenon and on the warming starting 1750. It should be alarming that there is not even a broad consensus on these figures. The values of the CO_2 effect on GH phenomenon vary in scientific articles from 9% (Miskolczi and Mlynczak, 2004) to about 33% (Pierrehumbert, 2011).

The primary effect of increased CO_2 concentration occurs in the lower part of the atmosphere, where GH gases have absorbed 95% of the infrared radiation (IR) emitted by the earth's surface up to 2 km high (Ohmura, 1997; Ollila, 2012a). The secondary effect is that the outgoing longwave radiation (OLR) at the top of the atmosphere (TOA) is reduced, and IPCC names this OLR change (IPCC, 2007a) the radiative forcing (RF). Because the Earth must reach the radiative energy balance, the third effect is the increase in the surface temperature until the OLR is the same as the incoming shortwave (SW) radiation. The changes are so small that they can be analyzed only by computational methods.

The global mean surface temperature change can be calculated multiplying the RF change at TOA by climate sensitivity parameter (λ) according to IPCC (2007a). The value and accuracy of λ is critical in calculating the global warming value.

The objectives of this paper are to show that the potency of CO_2 as a GH gas is much lower than used by IPCC, that the CS is much lower than used by IPCC and finally that the global warming value is much lower than calculated by IPCC. The calculation methods are the same as used by IPCC, but the basic differences are the water content of the atmosphere and finally the relative humidity (RH) trends of the atmosphere.

The Strengths of Greenhouse Gases

IPCC (2013) claims 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." There are no references to any scientific papers supporting this claim. IPCC has referred in its 2007 report (IPCC, 2007a) to the article of Kiehl & Trenberth (1997). The author (Ollila, 2013a) has shown that using the same US Standard Atmosphere 76 with 12% less water he can get the same results: H_2O 60% and CO_2 26% (60/26 = 2.3). This atmosphere contains only 50 % of the real average global atmosphere (AGA), see Table 1. The author has concluded that the number "three times greater" could refer to the article of Pierrehumbert (2011), which says that CO_2 absorption is not close to saturation and its contribution in the tropical climate is about 33%. Pierrehumbert shows no detailed calculations – only the claim above.

TABLE 1. WATER PROFILES OF U.S. STANDARD ATMOSPHERE 1976 (USST 76) AND AVERAGE GLOBAL ATMOSPHERE (AGA). THE ACRONYM VMR IS VOLUME MIXING RATIO.

H_2O	USST 76	AGA	USST 76	AGA
alt, km	vmr	vmr	g/m³	g/m³
0	$7.750*10^{-3}$	$1.656*10^{-2}$	5.857	12.037
1	$6.070*10^{-3}$	$1.246*10^{-2}$	4.171	8.264
2	$4.630*10^{-3}$	$9.539*10^{-3}$	2.885	5.756
3	$3.180*10^{-3}$	$5.705*10^{-3}$	1.792	3.122
4	$2.160*10^{-3}$	$3.234*10^{-3}$	1.096	1.607
5	$1.400*10^{-3}$	$2.226*10^{-3}$	0.640	0.999
6	$9.250*10^{-4}$	$1.412*10^{-3}$	0.379	0.571
7	$5.720*10^{-4}$	$8.685*10^{-4}$	0.210	0.316
8	$3.670*10^{-4}$	$5.078*10^{-4}$	0.120	0.166
9	$1.580*10^{-4}$	$2.814*10^{-5}$	0.046	0.082
10	$7.000*10^{-5}$	$1.433*10^{-4}$	0.018	0.037
11	$3.610*10^{-5}$	$5.475*10^{-5}$	0.008	0.013
Precipitated water in cm's (prcm)			1.43	2.60

I have calculated the AGA profiles (Ollila, 2012a) by combining the values of three climate zones published by Ellingson et al. (1991) These profiles are available also in the Spectral Calculator program (Gats, 2014) which I have used in the spectral analyses of this paper.

The AGA's surface temperature is 15 °C, and the concentrations of the anthropogenic GH gases as measured in 2005: CO_2 393 ppm, CH_4 1.774 ppm, and N_2O 0.319 ppm) as reported by IPCC (2007b).

I have used one dimensional (1D) Polar Summer atmosphere values, modifying the profiles where needed. The temperature and pressure profiles of AGA are the same as Polar Summer values, but GH gas profiles have been adjusted to the 2005 values using scale factors.

In Fig.1, the absorption graphs of major GH gases are depicted up to 25 μm, because thereafter water can totally absorb all the IR radiation (Ollila, 2012a). The shaded green area gives a good image of the magnitude of CO_2 in the GH phenomenon. The total contributions of GH gases are up to 120 km calculated by the Spectral Calculator (Gats, 2014) and by the Hitran database of Harvard-Smithsonian Center for Astrophysics (2014): H_2O 82.2%, CO_2 11.0%, O_3 5.2%, and CH_4 0.8 % and N_2O 0.8%.

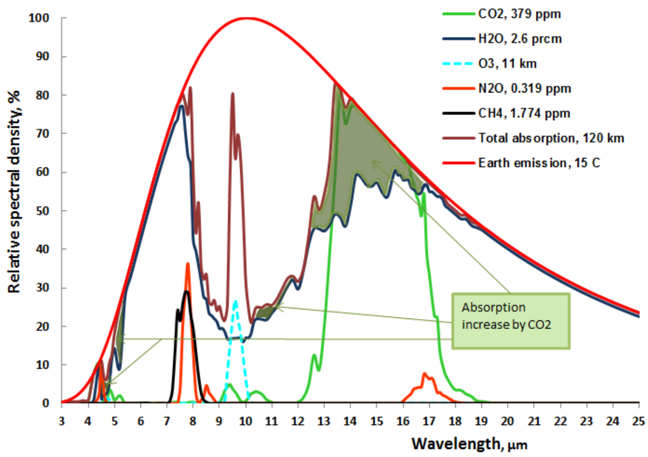

FIG 1. THE ABSORPTION BAND GRAPHS OF GH GASES IN THE ATMOSPHERE IN THE AGA CONDITIONS 2005. THE GREEN-SHADED AREAS INDICATE A TOTAL GH IMPACT OF CO_2 CONCENTRATION OF 379 PPM.

The curve of each GH gas in Fig.1 is calculated when it is the only gas in the AGA conditions. The real combined absorption of GH gases is not a simple summary of the band areas of single GH gases. The real total absorption can be calculated only when all the GH gases are present at the same time. The total absorption is depicted by the purple line. Therefore for example, the total absorption curve does not follow the green line of CO_2 absorption curve, because it is essentially caused by the total absorption of H_2O and CO_2 present at the same time in the atmosphere.

Some important conclusions can be drawn from the absorption graphs. The GH gases have different effects on the total absorption when compared to the absorption caused by water. Ozone pushes the total absorption curve effectively upward, but CH_4 and N_2O only minimally increase the total absorption in comparison to water absorption. The radiation flux transmitted into space in the clear sky conditions is 83.2 Wm^{-2}, and it is the only potential area for increased absorption caused by higher GH gas concentrations. In all-sky conditions, clouds absorb about 66% of the transmitted flux, and thus about 28.3 Wm^{-2} - that is, only about 7 % of the emitted LW radiation - escapes directly into space.

Because the effects of GH gases are very nonlinear, the above contributions are not the actual strengths of GH gases for the changes around the present concentrations. The author has calculated the relative strengths of GH gases (Ollila, 2013a) based on the increased IR absorptions from 1990 to 2005. The most important GH gas is water and its strength in respect to CO_2 impact (value = 1) is 15.2. The same values of other GH gases are: CH_4 0.144, N_2O 0.168, and O_3 0.629. Fig. 1 shows that any impact of GH gases that could actually increase warming must do it in the wavelength zone from 7.5 μm to 14 μm in the so-called atmospheric window.

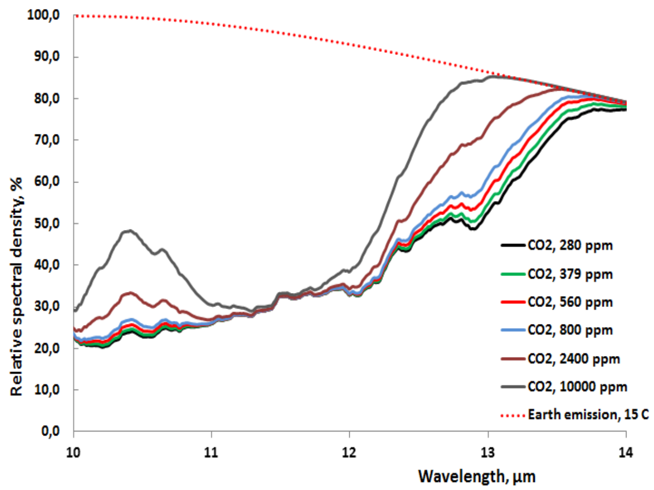

FIG. 2. THE TOTAL ABSORTION BAND GRAPHS FOR INCREASED CO_2 CONCENTRATIONS IN THE AGA 2012 CONDITIONS IN THE TROPOSPHERE.

In Fig. 2 are depicted absorption graphs for various CO_2 concentrations from 10 μm to 14 μm. In this wavelength zone 85-90% of absorption caused by increased CO_2 concentrations occurs. Even by eye, it is easy to estimate that the absorption area increase from 379 ppm to 560 ppm is almost the same as the area from 280 ppm to 379 ppm. The warming effect is directly proportional to the total area caused by the GH gases between the x-axis and the total emission curve of the GH gases.

The Climate Sensitivity According to the Earth's Energy Balance

The radiative forcing (RF change) at TOA has a linear relationship to the global mean surface temperature change ΔT_s if two equilibrium climate states are assumed:

$$\Delta T_s = \lambda RF \qquad (1)$$

IPCC states (2007a) that λ is a climate sensitivity parameter, which is nearly invariant parameter having a typical value about 0.5 K/(Wm^{-2}). This value is based on rather old calculations (Ramanathan et al., 1985) before 1985, at which time narrow-band models were applied and not the accurate line-by-line methods of today. IPCC no longer keeps the climate sensitivity parameter as a nearly invariant parameter like in AR4. In AR5 its value varies in broad limits. The value of the climate sensitivity parameter is 0.811 K/Wm^{-2} for the CO_2 forcing of 3.7 Wm^{-2} and the warming of 3.0 °C.

The author has used three different methods in calculating the CS and λ values. The simplest analysis of CS and λ is based on the total energy balance of the Earth by equalizing the absorbed and emitted radiation fluxes

$$SC(1-\alpha) * (\P r^2) = sT^4 * (4\P r^2), \qquad (2)$$

Where SC is solar constant (1368 W/m^2), α is the total albedo of the Earth, s is Stefan-Bolzmann constant ($5.6704*10^{-8}$), and T is the temperature (K). The temperature value of T can be solved:

$$T = (SC * (1 - \alpha) (4s))^{0.25} \qquad (3)$$

Where T is the temperature corresponding the emitted longwave (LW) flux in the atmosphere. The average albedo (Ollila, 2013b; Ollila, 2014) is (104.2 Wm^{-2})/(342 Wm^{-2}) = 0.30468. Using this albedo value, the temperature T would be -18.7 °C (=254.5 K). According to the Planck's equation, this temperature corresponds to LW radiation flux 237.8 Wm^{-2}, which is the actual average emitted LW radiation flux of the Earth. The most common reported global mean surface temperature is 15°C, which means that the greenhouse effect would be 33.7 K. The surface temperature T_s can be calculated by adding 33.7 K into T

$$T_s = T + 33.7 \qquad (4)$$

The term SC(1-α)/4 is the same as the net radiative forcing (RF) and therefore Eq. (2) can be written in the form 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:

$$dT/(d(RF)) = \lambda = T/(4RF)= T/(SC(1-\alpha)) \qquad (5)$$

In the all-sky conditions the total albedo flux 104.2 Wm^{-2} is the sum of the cloud reflected flux of 67.8 Wm^{-2}, the surface reflected flux of 22.7 Wm^{-2} and the air reflected flux of 13.7 Wm^{-2}. These values as well as the following three pairs of cloudiness and albedo values for clear, all-sky and cloudy sky conditions are based on energy balance analysis of global radiative fluxes (Ollila, 2013b; Ollila, 2014; Zhang et al., 2004; Bodas-Salcedo et al., 2008; Loeb et al., 2009): (0%, 53/342=0.155), (66%, 104.2/342=0.305), and (100%, 120/342=0.351). The second-order polynomial can be fitted through these points and the result is

$$\alpha = 0.15497 + 0.0028623 * CL - 0.000009 * CL^2 \quad (6)$$

where α is albedo and CL is cloudiness-%.

The differences between sky conditions are due to the degrees of cloudiness in different skies. This effect is generally called cloud forcing (CF). Normally the CF has been calculated at TOA as the difference between clear sky and all-sky conditions. Using the values of Ollila (2013b), the albedo flux change 53 - 104.2 = -51.2 Wm^{-2}. The outgoing LW radiation decrease is the difference between OLR fluxes, which is 259 - 237.8 = 21.2 Wm^{-2}. According to the most common definition, the CF is the sum of these two fluxes, which in this case is -30.0 W/m^2, a cooling effect. This value is close to the values used in other studies (Ohring and Clapp, 1980; Harrison et al., 1990; Ardanuy et al., 1991; Zhang et al., 2004; Raschke et al., 2005; Loeb et al., 2009; Stephens et al., 2012), which vary between -17.0 and -28 W/m^2 average being -23.4 W/m^2.

Spencer and Braswell (2011) have created a more complicated calculation method for cloud forcing by separating the effects and feedback of the clouds. Their final conclusion is that clouds have a negative impact on the surface temperature. Dressler (2010) has analysed the TOA radiation budget in response to short-term climate variations from the years 2000 to 2010, and his results showed positive feedback of the clouds. So the issue of cloud forcing still remains unclear without common acceptance and understanding but the big majority of CF studies show the cooling effect of cloudiness increase.

The specification of the CF can be criticized, because it is based on the instant radiation flux changes after a cloudiness change and it does not recognize the dynamic delays of the climate system. Ollila (2014) has concluded that the real CF is based on the SW radiation changes only, because the Earth has yet to reach the radiation flux balance according to the 1st law of thermodynamics, which means that the OLR flux must be the same as the net solar input flux. This approach would increase the CF values by about 46 % (Ollila, 2014b).

The equation (6) does not mean that only the total cloudiness changes can cause albedo changes. The changes of other reflected fluxes (by surface and air and by different cloud types) have their effects on the total albedo but the numerical effects are not known. The equation (6) is well established because it is based on the measured fluxes in the global scale.

When the changes in radiative forcing are known, the equations (2), (3), and (4) can be used in calculating T, ECS and λ values for the variations of RF and α. The climate sensitivity parameter calculated according equation (5) is 0.268 $K/(Wm^{-2})$.

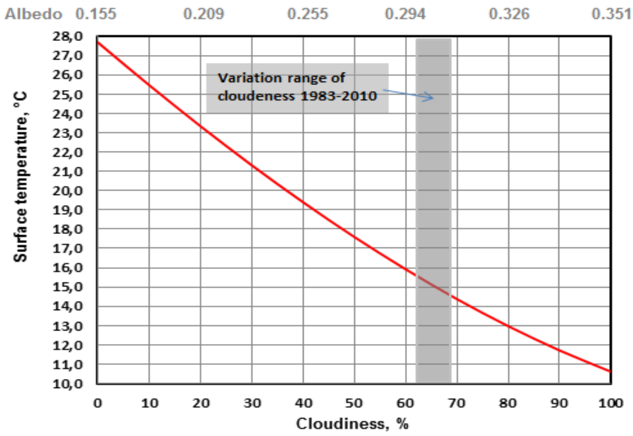

FIG. 3. THE SURFACE TEMPERATURE AS A FUNCTION OF CLOUDINESS ACCORDING TO THE ENERGY BALANCE EQUATIONS (2)…(6).

The surface temperature is very sensitive for the cloudiness and albedo changes of the Earth, as one can see in Fig. 3.

Climate Sensitivity According to Absorption and Longwave Radiation Changes

The author has also calculated the CS and λ values applying two simulation tools available in the network, namely Modtran (Berk et al., 2013) and the Spectral Calculator (Gats, 2014). The results are collected in Table 2. The all-sky conditions have been calculated by combining the clear and cloudy sky values (Bellouin et al., 2003; Ollila, 2013b):

$$(1-CL/100) * F_{clear} + (CL/100) * F_{cloudy} = F_{all\text{-}sky} \quad (7)$$

Where F is a radiation flux of a sky in question and CL is a cloudiness-%. Also temperatures of different skies are combined according to this equation.

The average global atmosphere's (AGA) surface temperature is 15 °C, and the concentrations of the anthropogenic GH gases measured in 2005 (AGA 2005) or in 2012 (AGA 2012) have been used. The GH gas concentrations (2005/2012) are: CO_2 (379/393 ppm), CH_4 (1.774/1.866 ppm), and N_2O (0.319/0.324 ppm), as reported by IPCC (2007c, 2013). The graphs in Fig. 1 and Fig. 2 are based on the AGA 2005 gas concentrations and Fig. 4 graphs are based on the AGA 2012 conditions. The parameters and choices applied in Modtran simulations, are depicted in Table 2.

TABLE 2. PARAMETERS AND CHOICES APPLIED IN MODTRAN SIMULATIONS

Parameter	Value
Tropospheric ozone	28 ppb
Stratospheric ozone scale	1
Water vapor scale	1.2384
Ground temperature offset	1 °C (T= 288.2 K)
Holding fixed	Water vapor pressure
Locality	Subarctic summer
Clear sky	No clouds or rain
Cloudy sky	Cumulus cloud base 0.66 km, top 2.7 km
Altitude	70 km

The CS and λ calculations are carried out 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 to 560 ppm, bringing the OLR flux exactly to the same the OLR 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 30 % lower OLR change than the clear sky simulations. This relationship has been used in estimating the cloudy sky values of Spectral Calculator simulations. IPCC's report AR5 (2013) summarizes that according to several studies, the overall reduction of RF values in cloudy sky conditions is in average 25 % lower than the clear sky values. The results of the simulations carried out by Modtran and Spectral Calculator are summarized in Table 3.

TABLE 3. CLIMATE SENSITIVITY AND CLIMATE SENSITIVTY PARAMETER CALCULATED IN AVERAGE GLOBAL ATMOSPHERE (AGA) AT TOA

Sky	ECS, °C	ΔOLR, Wm^{-2}	λ, $K/(Wm^{-2})$
	MODTRAN		
Clear	0.69	2.29	0.301
Cloudy	0.53	1.6	0.331
All-sky	0.584	1.834	0.319
	Spectral Calculator		
Clear	0.66	2.69	0.245
Cloudy	0.507	1.88	0.270
All-sky	0.559	2.16	0.259

The change of CO_2 concentration from 280 ppm to 560 ppm would increase the total absorption of shortwave (SW) radiation by 0.40 Wm^{-2} according to the 1D model simulations. This change alone would mean an essential warming impact, but the situation is not straightforward, because this absorption directly decreases the SW radiation reaching the surface.

Myhre et al. (1998) 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. On these bases the author has not included the solar radiation absorption changes of CO_2 into his calculations. The net effect of solar radiation absorption would slightly decrease the RF values of CO_2 according to the analyses of Myhre et al. (1998).

The clear sky OLR change 2.69 Wm^{-2} calculated by Spectral Calculator at the TOA is the sum of transmittance flux change 1.12 Wm^{-2} and the radiance flux change 1.57 Wm^{-2}. The OLR changes and the warming values of different CO_2 concentrations are summarized in Table 4. The global warming caused by the CO_2 concentration increase from 280 ppm to 393 ppm calculated through OLR change is 0.24 °C without water feedback.

The logarithmic fitting gives the following equation between RF values and CO_2 concentrations in Table 4:

$$RF = 3.12 * \ln(C/280), \quad (8)$$

Where RF is the radiative forcing in Wm^{-2}, C is the CO_2 concentration in ppm.

TABLE 4. 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

Using Spectral Calculator simulation, a CO_2 concentration of 393 ppm gives the λ value 0.230 and 1,370 ppm gives the λ value 0.269. According to several studies (Zhang et al., 2004; Bodas-Salcedo et al., 2008; Loeb et al., 2009), the OLR flux varies between 233-240 Wm^2 and using Eq. (3) shows that RF value 233 Wm^{-2} gives λ value 0.270, and RF value 240 Wm^{-2} gives λ value 0.265. The variation of λ is relatively small but λ is not invariant. The λ values vary in totality from 0.230 to 0.319 in simulations. If Eq. (3) is applied for OLR changes calculated by the ΔRF 2.16 Wm^{-2} of Spectral Calculator, the ECS is 0.576 °C and λ is 0.267. The same values using the ΔRF=1.834 Wm^{-2} of Modtran, the ECS is 0.49 °C and λ is 0.267. The Modtran calculations' 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 author has also calculated the ECS value utilizing the IR absorption in the clear atmosphere; this value is 0.46 °C. Some other researchers (Miskolczi and Mlynczak, 2004) have calculated almost the same value, namely 0.48 °C. The most reliable results and best estimates are the values calculated by energy balance equations: ECS = 0.576 °C and λ = 0.268 $K/(Wm^{-2})$ with the uncertainty ranges of 0.46–0.6 °C and 0.23–0.32 $K/(Wm^{-2})$.

Some researchers have paid attention to the fact that the temperatures simulated by General Circulation Models (GCM) have departed from the real temperatures since 1998. There are several new research studies, which show lower ECS values than those of IPCC. According to these results, the best estimates and minimum values for ECS are: (Aldrin, 2012) 2.0 °C / 1.1°C; (Bengtson & Schwartz, 2012) 2.0 °C / 1.15 °C; (Otto et al., 2013) 2.0 °C / 1.2 °C and (Lewis, 2012) 1.6 °C / 1.2 °C. Common features of these studies are mathematical methods like Bayes's theorem to analyze the impact of CO_2 based on the measured global data of radiative forcing factors, temperatures and ocean heat content.

These studies' minimum values of ECS are practically same in the range 1.1-1.2 °C. Bengtson & Schwartz (2012) draw a conclusion that this value is the same as the no-feedback Planck sensitivity. An interesting point is that the ECS value of this study without any feedback mechanisms (including the Planck sensitivity calculation which is the same as equation (3)) is in the range 0.559…0.584 °C, and with water feedback the ECS according to the Plank's equation is 1.1 °C. Is this a coincidence? There could be a very simple explanation. All the referred studies use the radiative forcing value of 3.7 Wm^{-2} for CO_2 and they do not mention, whether or not water feedback has been used in their analyses.

The author's conclusion is that the researchers of these studies have applied the RF value of 3.7 Wm^{-2} as in the study of Bengtson & Schwartz (2012). If this RF value has been calculated in the atmosphere, where is constant relative humidity, it would mean that it includes the positive water feedback duplicating the warming values. The author has carried further analyses later on.

The Analysis of IPCC's Warming Calculations

According to IPCC (2013) the water vapor/lapse rate, albedo and cloud feedbacks are the principal determinants of equilibrium radiative forcing and these feedbacks are assessed to be positive. The water provides the largest positive feedback, which doubles the other forcing elements like GH gas effects. According to IPCC the forced component of the global mean surface temperature (GMST) trend responds to the effective radiative forcing (ERF) trend rapidly and almost linearly (medium confidence). Hence, an ERF trend can be approximately converted to a forced-response GMST trend. The air temperature follows the GMST without essential time delays. It should be noticed that ERF and RF values are same up to 2011 (IPCC, 2013).

According to IPCC, the amount of water in the atmosphere is controlled mostly by the air temperature and therefore water does not cause direct radiative forcing but it is classified as a feedback element. The temperature data show a warming of 0.85 °C, over the period 1880 to 2012, and the total radiative forcing is 2.34 Wm^{-2} (IPCC, 2013). Because water amount in the atmosphere follows the air temperature, water feedback acts with short delay in respect to the GH gas impacts. Therefore the GMST increase of 0.85 °C must include the water feedback. Otherwise the concept of water feedback does not follow the mechanism specified by IPCC: RF trend can be converted to GMST trend and water feedback follows the air temperature/surface temperature almost without time delay. Shine et al. (2009) have analyzed the annual cycles of the surface temperature, and the result is a mean time lag of 56 ± 11 days for oceans and 29 ± 6 days for land. The radiative energy budget follows the surface temperatures of land and ocean.

An example about the short time lag of the sea is the situation of the Finnish gulf. In the beginning of May, the surface sea water temperature is about 0 °C and in the end of July it is about 20 °C. This is in line with the time lag defined by Stine and confirms IPCC's statement (IPCC, 2013) that ERF and GMST trends have no time delays thinking the time scales of the climate change.

IPCC has not introduced any other feedback mechanisms other than water feedback in its report AR4 and AR5 causing the observed warming up till the year 2011. Using the warming and radiative forcing values of AR4, the following analysis can be carried out. The warming of 0.76 °C according to IPCC (2007c) happens through the mechanism that a CO_2 increase of 99 ppm (an addition of 35.4% since 1750) warms the climate first by 0.38 °C. The temperature increases another 0.38 °C because of assumed constant relative humidity. The total water amount increases by 2.3%, from 2.6 prcm (precipitated water in centimeters) to 2.66 prcm. This means that the strength of water is 15.4 in comparison to CO_2, which is very close to the value of 15.2 as calculated in the AGA 2005 conditions.

It is useful to compare the results of this study to those reported by IPCC. IPCC (2013) has utilized the logarithmic relationship the 3rd report introduced by Myhre et al. (1998):

$$RF = 5.35 * \ln(C/280), \qquad (9)$$

Where RF is the radiative forcing in Wm^{-2}, C is the CO_2 concentration in ppm. The RF values of CO_2 in AR5 are still based on equation (9). Myhre et al. (1998) informs that "only the direct forcing to a change in WMGG (well mixed greenhouse gases) concentration is considered here" in calculating RF values. There are two other studies referred in AR4 (2007a). The RF values of 560 ppm CO_2 concentrations in these three studies are: Myhre et. al. (1998) 3.71 Wm^{-2}, Hansen et al. (1998) 3.63 Wm^{-2}, and Shi (1992) 3.98 Wm^{-2}. IPCC has regarded these three simplified expressions to be reliable and one can see the RF values are very close to each other. Only Shi specifies that he has used "fixed relative humidity", which means positive water feedback. The other studies do not specify humidity conditions. The author's conclusion is that also Myhre et al. and Hansen et al. have used the constant relative humidity conditions in the atmosphere. Otherwise Shi's RF value for CO_2 should be about twice as much as in the other studies. The exact water content has not been specified in any of these studies.

The RF value according to equation (8) for the CO_2 concentration 560 ppm is 2.16 Wm^{-2} and it is 58.4 % of the RF value of 3.7 Wm^{-2} according to equation (9). The same RF value according to MODTRAN simulations is exactly 50 % smaller. This is another evidence that equation (9) has been calculated in the constant RH conditions, because this RF value of CO_2 is practically 100 % bigger than the value calculated without water increase.

The author has carried out two analyses based on his own calculations and the warming results as published by IPCC. In the first analysis the warming results have been depicted in Fig. 4 according to the different calculation bases. The x-axis is CO_2 concentration or the CO_2 equivalent including all anthropogenic radiative forcing elements in the case of Representative Concentration Pathways (RCP) (IPCC, 2007d). The red graph is the warming calculated according to equation (9) by transforming RF values into temperatures by multiplying by λ=0.5. The actual λ values in AR4 and AR5 would be 0.442 and 0.363 respectively for the years 2005 and 2011. The temperature increases of this study based on the absorption and OLR changes are very close to each other.

The most interesting curve is the one labelled 'modified Myhre et. al' (purple dashed line), which is the original Eq. (9), in which RF has been divided by 2 to eliminate positive water feedback and thereafter multiplied by the newly calculated λ value of 0.268 K/Wm^{-2} to get the temperature. This curve overlaps the two other curves calculated by the author.

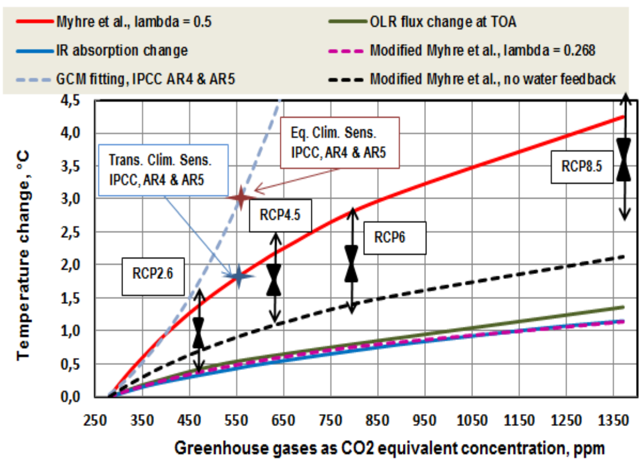

FIG. 4. GLOBAL WARMING INCREASE ACCORDING TO DIFFERENT SIMULATION AND ESTIMATION METHODS.

The latest future projections of IPCC called RCPs are also depicted with symbols of midpoints and whiskers. The numeric value of each RCP indicates radiative forcing in the year 2100, and the equivalent CO_2 concentrations include the effects of GH gases.

The RCP warming values are lower than the warming values caused by CO_2 according to equation (9). The author's conclusion is that equation (9) includes very probably water feedback – i.e. the calculations for finding the relationship have been carried out in the constant relative humidity conditions.

The old ECS value of 3 °C (IPCC, 2007b), which is also the mean value of CS in AR5 (IPCC, 2013), has been depicted in Fig. 3. The curve fitting through three points (280/0, 379/0.76, 560/3.0 values as ppm/°C) produces an exponential curve $T = -0.6 + 0.635 * (C/280)^{2.52}$. It is not possible to achieve such a high value by CO_2 warming and water feedback alone. The studies of Myhre et al. (1998) and equation (8) of this study show that the relationship between RF and CO_2 concentration is very close to a logarithmic form. According to the general laws of IR absorption, the exponential relationship is not possible, and this fact is illustrated in Fig. 3. This kind of exponential relationship would be possible only, if the other feedback effects of the climate change would be positive and highly nonlinear. The ECS value of 3 °C is a combination of several GCM models (IPCC, 2007a). A recent study (von Storch et al., 2013) reveals that 23 common GCMs cannot simulate temperature even at a 2% confidence level since temperature stagnation began in 1998.

The results of the second analysis have been depicted in Fig. 5. The RF values of different RCP scenarios are the same as reported by IPCC (IPCC, 2007d). The graph named as "Linear warming 1750-2011" has been calculated using the linear coefficient of 0.85 °C / 2.34 Wm^{-2}, which is the λ value of 0.363. The RCP values follow closely the same linear relationship as calculated by the warming values of 2011 – only the RCP8.5 warming value is 0.7 °C higher.

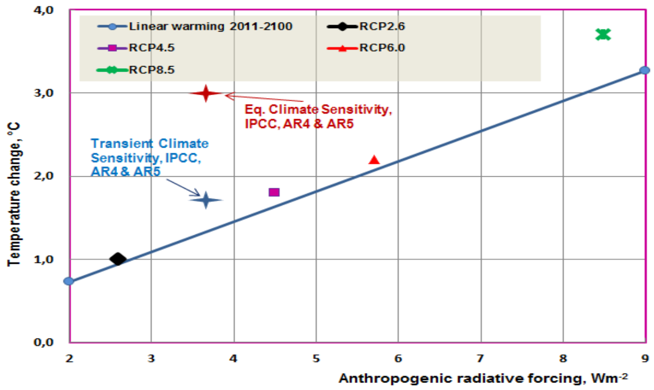

FIG. 5. THE GLOBAL WARMING VALUES ACCORDING TO THE ANTHROPOGENIC RADIATIVE FORCING BY IPCC.

One conclusion is that the RCP warming values include the same feedback mechanisms as the warming value of 2011 and so only water feedback can be considered. The linear straight gives the warming value of 1.4 °C for CS including the anthropogenic warming 0.7 °C and the water feedback 0.7 °C. If the ECS would be 3.0 °C, the other feedback mechanisms would cause 1.6 °C increase. Of course the situation is more complicated considering cross effects but this is a rough estimate about the magnitudes of different warming mechanisms.

The transient climate sensitivity is 1.75 °C (1.0 to 2.5 °C) according to IPCC (IPCC, 2013) and it is depicted in Fig. 4 and Fig. 5. This value can be calculated using equation (9) of Myhre et al. (1998) and the climate sensitivity parameter 0.5 $k(Wm^{-2})$ of the IPCC's report AR4 (IPCC, 2007a).

Conclusions

Pierrehumbert (2011) has come to a conclusion that CO_2 is not near to saturation. The total saturation has not yet been reached, but the warming effects are much smaller than generally believed. The reason is that the equation of Myhre et al. includes water feedback effect making the radiative forcing of CO_2 about 100 % higher than it should be. This applies to other GH gases as well. The evidence is based on the almost similar results of Shi (1992) and Myhre et al. (1998) and two analyses of this study, which are based on the spectral analyses.

The final conclusion is that climate sensitivity and future warming projections depend totally on the behaviors of water in the atmosphere. If the water content is kept constant, ECS is in the range 0.46 to 0.58 °C. If positive water feedback is applied, ECS is about 1.1 °C, and negative water feedback can force warming to 0 °C. The actual relative humidity (RH) measurements since 1948 show negative trends (NOAA, 2012) indicating strongly a negative feedback mechanism in the climate system, Fig.6. Also studies of tropospheric humidity have revealed descending trends (Hoinka, 1999; Paltridge et al., 2009).

These real RH measurements show that there is no basis for using positive water feedback in calculating global warming.

The CS value calculations of this study can be criticized in that they do not cover all feedback mechanisms. On the other hand IPCC calculations can be criticized in that there is no information about the contributions of feedback mechanisms to the CS value of 3.0 °C. The role of the clouds in the climate change according to IPCC (IPCC, 2013) is likely positive but confidence is still low. Today the CO_2 concentration change from 280 ppm to 560 ppm has passed the point of 40%. Regardless of this big change, feedback mechanisms other than water feedback cannot be quantified. Water feedback mechanism is likely negative as proposed by Miskolczi (2010) and not positive as assumed by IPCC.

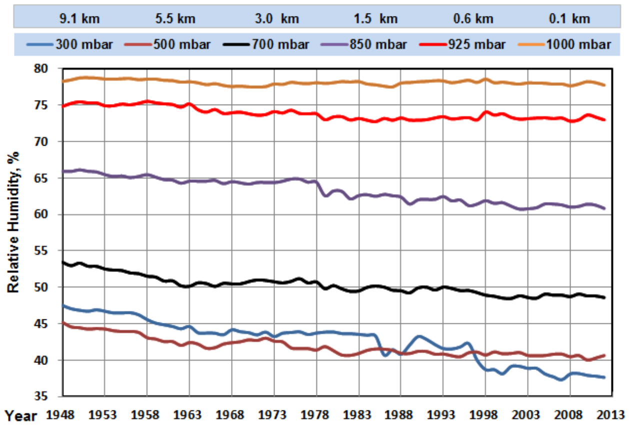

FIG. 6. RELATIVE HUMIDITY TRENDS ACCORDING TO NOAA AT DIFFERENT ALTITUDES IN THE TROPOSPHERE.

The recent CS calculations as referred to in this study (Aldrin, 2012; Bengtson & Schwartz, 2012; Otto et al., 2013; Lewis, 2012) use the mathematical analyses and the real data but they do not test the possibility of theories like "The Sun theory". The author has carried out a study (Ollila, 2012b) showing that the global temperature in the period 1871-2002 has a r_2 = 0.936 correlation to the sun activity changes and a r_2=0.860 correlation to the CO_2 concentration changes. The mathematical analyses alone do not provide enough evidence to conclude, if there are several potential mechanisms available.

One conclusion is that the original Eq. (9) of Myhre et al. (1998) is in line with the calculations of this paper if the RF value is reduced by 41.6 % i.e. positive water feedback is eliminated. Confusion and different results of climate sensitivity are based on positive water feedback used in Eq. (9) and unrealistic high impacts of other feedback mechanisms.

The competing theory of the anthropogenic warming theory is the so called "Sun theory". The majority of clouds forcing studies show that the clouds have played an important role in fortifying the insolation changes of the Sun. The change in cloudiness in the range from 60% to 70% causes a temperature change of 1.5 °C according to energy balance analysis as depicted in Fig. 3. The dynamic analysis (Ollila 2014) gives the value of -0.1 °C/cloudiness-% for cloudiness sensitivity. Applying this value, the temperature increase of 0.76 °C could be attributed to a decrease in the total cloudiness of 7.6%. Even though clouds remain a subject of confusion in climatology, it is clear that climate is very sensitive to albedo changes, and the cloudiness changes are the biggest contributors to albedo changes.

According to IPCC (2013) the total anthropogenic forcing increase during the last 15 years has been about 0.3 Wm^{-2}. Because there has been no temperature increase, it means that the counterforce of the same size has been affecting in the global climate. The global cloudiness increase of 0.54% could cause this kind of effect (Ollila, 2014) together with decreasing sun activity. There is a sound physical mechanism available to explain the cooling in period 1945-1980 as well as the stagnation of the temperature since 1998.

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