CERES Satellite and Climate Sensitivity

by Ken Gregory January 2014

revised February 23, 2014

Abstract

The Transient Climate Response (TCR) to doubling CO_2 was calculated using CERES satellite outgoing longwave radiation data and two versions of the HadCRUT global surface temperature index. The calculation used the change in the greenhouse effect and the greenhouse gas forcing to determine TCR. The method does not require estimates of total forcings or feedbacks acting on the climate system, which are unknown. Using HadCRUT3, TCR = 0.38 °C [0.0 to 0.92 °C] and using HadCRUT4, TCR = 0.74 °C [0.20 to 1.29 °C]; where the range is the 95% confidence interval with zero minimum.

Introduction

The determination of global warming expected from a doubling of atmospheric carbon dioxide (CO_2) is the most important parameter of climate science. The Transient Climate Response (TCR) is the average global warming determined at the time that the CO_2 in the atmosphere doubles. The climate forcing due to CO_2 emissions varies by the logarithm of the CO_2 concentration so each CO_2 doubling results in the same global temperature change. This value is less than the equilibrium climate sensitivity, which is the average global warming resulting from a doubling of CO_2 and allowing time for the oceans to reach temperature equilibrium, which may take many centuries. The TCR is the more policy-relevant parameter because the time period to double CO_2 at the current growth rate (0.535%/year) is only 130 years.

The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) gives no best estimate for equilibrium climate sensitivity "because of a lack of agreement on values across assessed lines of evidence and studies."

Studies published since 2010 indicates that equilibrium climate sensitivity is much less that the 3 °C estimated by the IPCC in its 4th assessment report. A chart here shows that the mean of the best estimates of 14 studies is 2 °C, but all except the lowest estimate implicitly assumes that the only climate forcings are those recognized by the IPCC. They assume the sun affects climate only by changes in the total solar irradiance (TSI). However, the IPCC AR5 Section7.4.6 says,

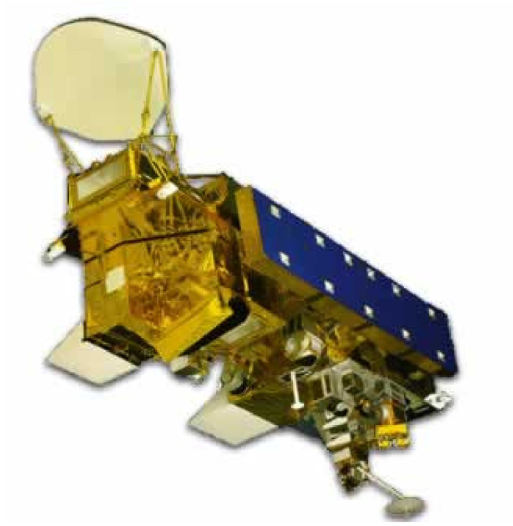
"**Many studies have reported observations that link solar activity to particular aspects of the climate system. Various mechanisms have been proposed that could amplify relatively small variations in total solar irradiance, such as changes in stratospheric and tropospheric circulation induced by changes in the spectral solar irradiance or an effect of the flux of cosmic rays on clouds."**

Many studies have shown that the sun affects climate by some mechanism other than the direct effects of changing TSI, but it is not possible to directly quantify these indirect solar effects. All the studies of climate sensitivity that rely on estimates of climate forcings which exclude indirect solar forcings are invalid.

The IPCC AR5 report estimates the TCR to be *likely* (Box 12.2, Figure 2) in the range of 1.0 to 2.5 °C, with a best estimate of 1.8 °C from climate models using a CO_2 growth of 1.0%/year. These estimates are unrealistic because they assume no natural causes of climate change other than the changes in TSI and assume that forcings and feedbacks used in climate models are correct. Fortunately, we can calculate the transient climate response without an estimate of total forcings or feedbacks by directly measuring the changes to the greenhouse effect (GHE).

Greenhouse Effect

The GHE is the difference in temperature between the earth's surface and the effective radiating temperature of the earth at the top of the atmosphere as seen from space. This temperature difference is generally given as 33 °C, where the top-of-atmosphere global average temperature is about -18 °C and global average surface temperature is about 15 °C. We can estimate climate sensitivity by comparing the changes in the GHE to the changes in greenhouse gas concentrations.



The Clouds and Earth's Radiant Energy System (CERES) experiment started collecting high quality top-of-atmosphere outgoing longwave radiation (OLR) data in March 2000. The last data available is June 2013 as of February 23, 2014. Figure 1 shows a typical CERES satellite.

Figure 1. CERES Satellite

The CERES OLR data presented by latitude versus time is shown in Figure 2.

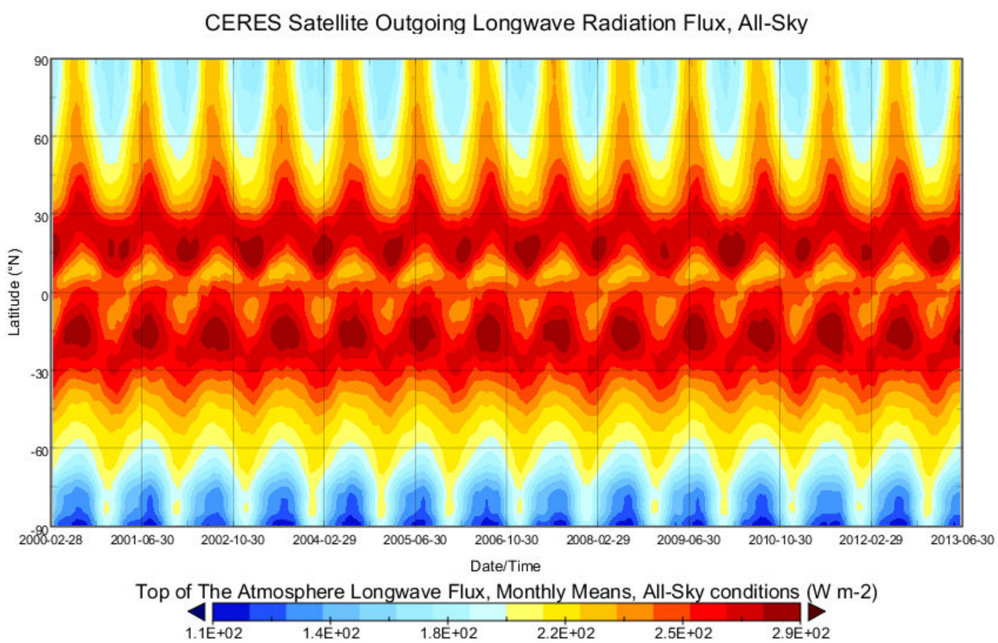


Figure 2. CERES Outgoing Longwave Radiation, latitude versus date.

The global average OLR is shown in Figure 3.

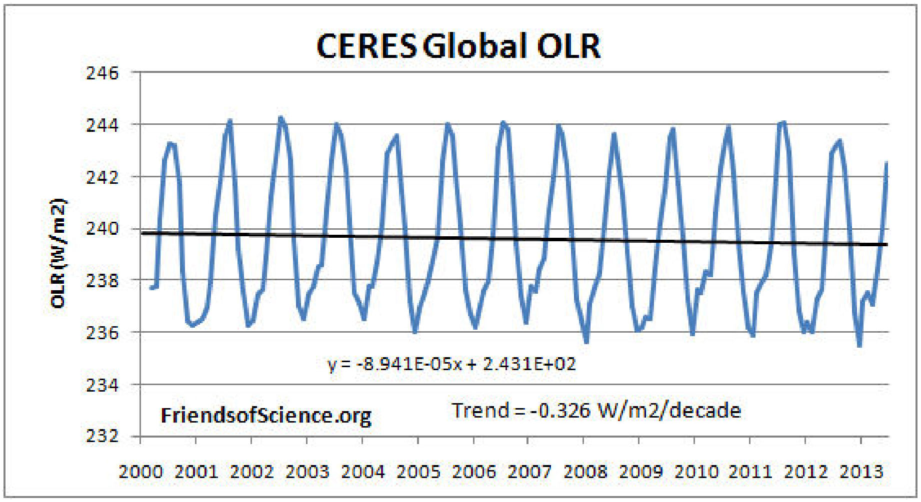


Figure 3. CERES global OLR.

The CERES OLR data is converted to the effective radiating temperature (Te) using the Stefan-Boltzmann equation.

$Te = (OLR/\sigma)^{0.25} - 273.15$. where $\sigma = 5.67$ E-8 W/(m^2K^4), Te is in °C.

The monthly anomalies of the Te were calculated so that the annual cycle would not affect the trend.

We use the HadCRUT temperature anomaly indexes to represent the earth's surface temperature (Ts). The HadCRUT3 temperature index shows a cooling trend of -0.002 °C/decade, and the HadCRUT4 temperature index shows a warming trend of 0.031 °C/decade during the period with CERES data, March 2000 to June 2013. The land measurement likely include a warming bias due to uncorrected urban warming (See Urban heat Island Effect). The hadCRUT4 dataset added more coverage in the far north, where there has been the most warming, but failed to add coverage in the tropics or in the far south, where there has been recent cooling, thereby introducing a warming bias. We present results using both datasets.

The difference between the surface temperatures anomaly and effective radiating temperature anomaly is the GHE anomaly. Figures 4 and 5 show the Greenhouse effect anomaly utilizing the HadCRUT3 and HadCRUT4 temperature indexes, respectively.

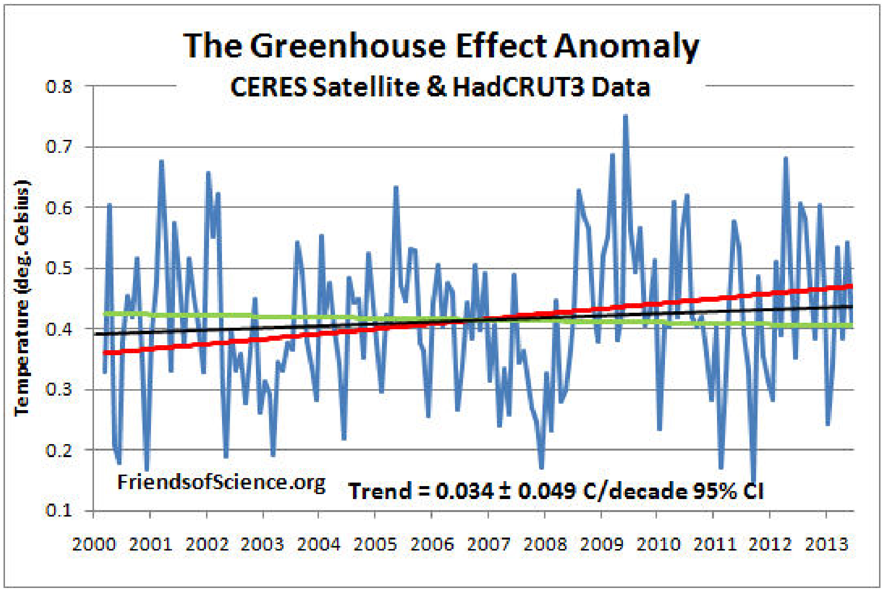


Figure 4. The greenhouse effect anomaly based on CERES OLR and HadCRUT3.

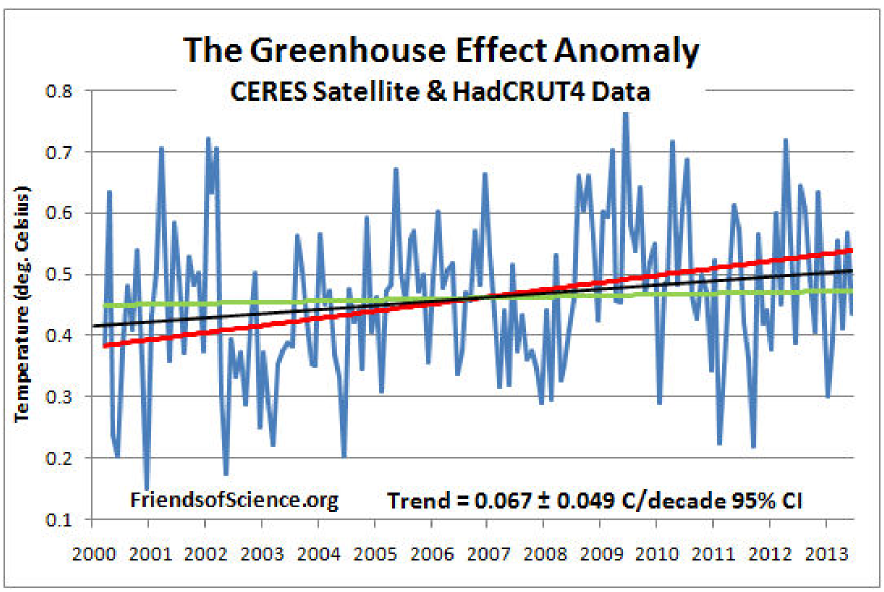


Figure 5. The greenhouse effect anomaly based on CERES OLR and HadCRUT4.

The trends of the GHE are 0.034 ± 0.049 °C/decade based on HadCRUT3, and 0.067 ± 0.049 °C/decade based on HadCRUT4 at 95% confidence. The black lines show the best fit trends and the colored lines indicate the 95% confidence in the trends.

No Feedbacks

In general, the monthly changes in OLR as measured by CERES includes the effects of forcings and feedbacks in unknown quantities. Feedbacks are interactions where a change in global surface temperatures cause a change in the radiation budget, such as by changes in water vapor and clouds, that cause further temperature change. There is no feedback if there is no temperature change. The monthly changes in OLR would include changes from feedbacks, but this analysis uses only the best fit trend during the entire CERES period when the temperature trend was zero. Therefore, over the CERES era, any positive feedbacks were match by negative feedbacks and there were no net feedbacks during the period. The trend in OLR much be entirely due to changes in forcings as there was no trend in temperatures and no net feedback over the period.

Non-greenhouse gas forcings must be equal and opposite to greenhouse gas forcings to result in no temperature change over the CERES era. Both total forcings and total feedbacks were zero over the period.

Greenhouse Gases Only Change the GHE

Changes in non-greenhouse gas forcings such as the sun's TSI, aerosols, ocean circulation changes and urban heating can't change the GHE except by a feedback that might change the water vapor amount. But as previously shown, during the CERES era there was no temperature change, so there was no feedback-induced change in water vapor. Changes in cloudiness could change the GHE, but data from the International Satellite Cloud Climatology Project shows that the average total cloud cover during the period March 2000 to December 2009 changed very little. A change of TSI would change both the surface temperature (Ts) and the effective radiating temperature (Te) equally, so there would be no change in the GHE, which is Ts – Te in the absence of feedbacks. The GHE will change only if the longwave absorption in the atmosphere changes, resulting in a change in the downward longwave radiation. Changes in non-greenhouse gas forcings change Ts and Te equally when there is no feedback-induced change in water vapor.

To further demonstrate this point, the HARTCODE line-by-line radiative code program was used to calculate the change in Te resulting from a change in Ts. The program calculates the surface fluxes, the atmospheric up and down longwave fluxes, the LW window flux, the OLR etc. It includes a realistic water vapor profile and greenhouse gases, which were held constant for this experiment. The results show that a 1 °C increase in surface temperature caused the surface upward flux to increase by 5.30 W/m^2 and the OLR to increase by 3.79 W/m^2, and increased the effective radiating temperature by 0.97 °C. Therefore, non-greenhouse gas forcings without feedbacks have an insignificant effect on the GHE = Ts-Te.

Therefore, we can conclude that the measured change in the GHE during the CERES era is due to only anthropogenic greenhouse gas emissions, which is dominated by CO_2. We want to compare the trends in the GHE to changes in well mixed greenhouse gases to determine the transient climate response.

Greenhouse Gas Forcing

The CO_2 data also has a large annual cycle, so the anomaly is used. Figure 6 shows the monthly CO_2 anomaly calculated from the Mauna Loa data and the best fit straight line.

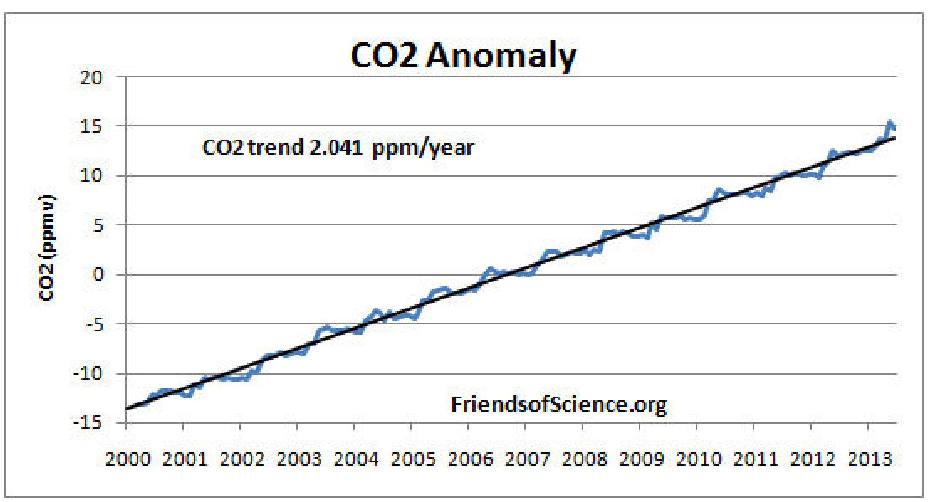


Figure 6. CO2 anomaly.

Table 1 shows the radiative forcing of various greenhouse gases. CO_2 changes in the atmosphere accounts for 84.9% of the total GHG radiative forcing from the year 2000 to 2012. Therefore, the total GHG forcing during the CERES era is the CO_2 forcing divided by 0.849.

Year	CO_2	CH_4	N_20	17-minor	Total
2000	1.513	0.494	0.151	0.322	2.480
2012	1.846	0.507	0.181	0.338	2.872
Change	0.333	0.013	0.030	0.016	0.392
% of total	84.9%	3%	8%	4%	

Table 1. Changes in well-mixed greenhouse gas forcing in W/m^2 relative to 1750, and the change from 2000 to 2012.

The March 2000 CO_2 concentration is assumed to be the 13 month centered average CO_2 concentration at March 2000, and the June 2013 value is that value plus the anomaly change from the fitted linear line. Table 2 below shows the CO_2 concentrations, the CO_2 equivalent of all greenhouse gas changes, the logarithm of the CO_2 equivalent concentrations, and the change in the GHE from March 2000 for both the HadCRUT3 and HadCRUT4 cases. The change in the GHE is proportional to the logarithm CO_2 equivalent concentrations. We assume non-CO_2 greenhouse gases do not change after June 2013.

Transient Climate Sensitivity

					hadCRUT3	hadCRUT4
Date	CO_2	$CO2_{eq}$	Log $CO2_{eq}$	ΔF	ΔGHE	ΔGHE
	ppm	ppm		W/m2	°C	°C
March 2000	368.88	368.88	2.567	0	0	0
June 2013	395.94	400.94	2.603	0.4458	0.046	0.089
January 2100	572.68	577.67	2.762		0.245	0.480
2X CO_2	737.76	737.76	2.868		0.379	0.741

Table 2. Extrapolated changes to the greenhouse effect (GHE) based on two versions of the hadCRUT datasets.

Table 2 shows that the GHE has increased by 0.046 °C from March 2000 to June 2013 based on changes in the CERES OLR data and HadCRUT3 temperature data. Extrapolating to January 2100, the GHE increase to 0.24 °C by January 2100. Using the HadCRUT4 temperature data, the GHE increases by 0.48 °C by January 2100 compared to March 2000.

The last row of Table 2 shows the transient climate response (TCR), which is the temperature response to CO_2 concentration from March 2000 levels to the time when CO_2 concentrations have doubled. TCR is less than the equilibrium climate sensitivity because the oceans have not reached temperature equilibrium at the time of CO_2 doubling.

In this analysis, TCR is calculated by the equation:

TCR = F2x dT/dF ; whereF2x means the forcing due to a doubling of CO_2 concentration, dT means the temperature difference of the GHE, dF means the longwave forcing difference that would cause a change in the GHE, from March 2000 to June 2013.

In the common definition of TCR, dT is the air surface temperature change and dF is the total forcing, including shortwave forcings. However, in this analysis, we compare the change in the GHE to the forcings that cause that change. Only longwave forcings can change the GHE, as shortwave forcings affect Ts and Te equally.

The CO_2 forcing was calculated as 5.35 x ln (CO_2/CO_2i). The change in CO_2 forcing from March 2000 to June 2013 is 0.379 W/m^2. The GHG forcing over the same period was the CO_2 forcing divided by 0.849, equal to 0.446 W/m^2. The forcing for double CO2 (F2x) is 3.708 W/m^2. The TCR is 0.38 ± 0.54 °C using hadCRUT3, and 0.74 ± 0.54 °C using hadCRTU4 data. These values are much less than the multi-model mean estimate of 1.8 °C for TCR given in Table 9.5 of the AR5. The climate model results do not agree with the satellite and surface data and should not be used to set public policies.

Figure 7 shows the results of Table 1 graphically. It also shows the 95% confidence of the calculated temperature changes.

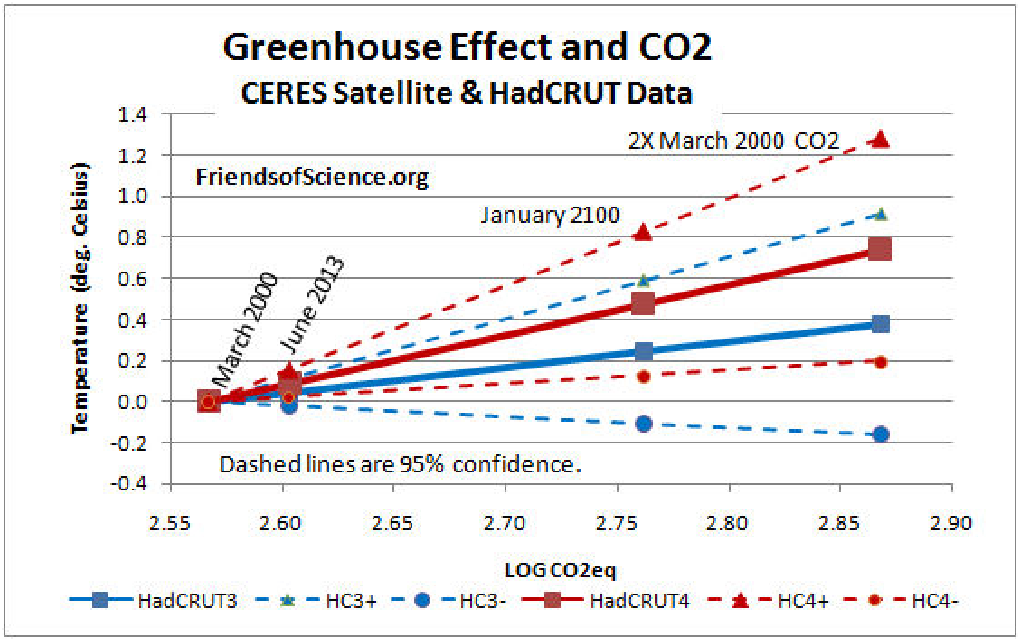


Figure 7. The greenhouse effect and CO_2 extrapolated to January 2100 and double CO_2 bases on CERES and HadCRUT data.

This analysis shows that the temperature change from June 2013 to January 2100 due to increasing CO_2 would be 0.20 ± 0.28 °C using HadCRUT3 or 0.39 ± 0.29 °C using HadCRUT4, assuming the CO_2 continues to increase along the recent linear trend. If the two HadCRUT datasets are considered equally likely to represent global temperatures, and assuming that CO_2 emissions can't cause cooling, the best estimate of CO_2-induced global warming is 0.29 °C with a 95% confidence range of 0.00 to 0.68 °C.

This estimate represents only the expected temperature change due to increasing CO_2 concentrations in the atmosphere. The effects of natural climate change might be much greater than the CO_2 effect. We know that natural climate change caused a negative forcing equal and opposite to the positive greenhouse gas forcing during the CERES era because there was no observed change in surface temperatures.

Data and Calculations

An Excel spreadsheet with the data, calculations and graphs is here.
HadCRUT3 data is here.
HadCRUT4 data is here.
Mauna Loa CO2 data is here.
CERES OLR data is here.
Total cloud cover data is here.
Changes in radiative forcings is here.