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RESEARCH ARTICLE

THE UNCERTAINTIES IN THE MAGNITUDE OF THE GREEN HOUSE EFFECT

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ABSTRACT

An attempt has been made to figure out the magnitude of the Green House Effect. Three different approaches have been tried. First, a purely theoretical approach is presented. Secondly, an estimation based on the observations is given. Finally, an estimate using the Radiative forcing of various Green House Gases has been given. Since the concentration of water vapor is a highly variable quantity and due to the non-availability of concentration data for some gases, the contribution of Carbon dioxide, Methane, Nitrous oxide, Chloro Flouro Carbon – 11 and 12 have been calculated and it amounts to about 75% of the total value. A special attention has been given to study the contribution of Carbon dioxide alone since it is the major man made GHG.

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INTRODUCTION

Global warming is the increase in the average temperature of the earth's near surface air and oceans. This has been prominent during the last few decades (Deepanjan Majumdar, 2001). This global warming is caused by various factors such as the variation in the incoming solar radiation, earth's magnetic field (Bucha, 1991), atmospheric conditions such as cloud formation (Manish Tiwari and Rengaswamy Ramesh, 2007), aerosol content (Nicolas Bellouin *et al.,* 2005), Green House Gas concentration(Robert Sausen *et al*., 2005), etc. In this paper, the effect of the changes in the Green House Gas concentration is studied.

Green House Effect (GHE) is the absorption and reemission of long wave radiation by certain gases present in the atmosphere. These gases are termed as Green House Gases(GHG). Some of the Green House Gases are Carbon di oxide, Methane, Nitrous oxide, Ozone, Water vapour, Chloro Flouro Carbon, etc. Since the middle of the 20th century, the concentration of these gases in the atmosphere has been increasing due to many reasons. Eventually, their contribution to the earth's surface temperature also increases leading to global warming. The present average value of global temperature is around 15°C. This is possible only if we include the Green House Effect. Without including the Green House Effect, the earth's average temperature would be around -17°C. This variation of about 32°C is attributed to the Green House Effect (Goswamy,1996).

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VARIOUS MODELS

2.1. A theoretical model

The mean radioactive equilibrium temperature of earth or earth-atmosphere system can be estimated by a balance between the incoming shortwave solar radiation and outgoing long wave radiation emitted by the earth or the earth-atmosphere system. First considering the earth without the presence of Green House Gases, the radiation balance demands that (Hansen *et al.,* 1981)

$$\pi R^2(1-\alpha)S_0 = 4\pi R^2 \sigma T_e^4 \text{ -----------------------------(1)}$$

(or)

$T_e = [S_o(1-\alpha)/4\sigma]^{1/4}$ --(2)

where R is the radius of the earth; α is the Albedo of the earth; S_o is the solar constant; σ is the Stefan-Boltzmann constant and T_e is the effective radioactive temperature of the earth-atmosphere system. For α=0.3, S_o=1367W/m^2, and σ=5.67X10^{-8}W/m^2-K^4, equation (2) yields

$T_e \approx 255K$ or -18^{o}C

If this were the case, the whole earth would be ice covered and devoid of any life form. The earth's surface temperature would be the sum of this effective radiative temperature and the magnitude of the Green House Effect. Hence, the earth's surface temperature is
$T_S = T_e + GHE$--(3)

where GHE is the magnitude of the GHE.

To compute the magnitude of GHE, now assume that there exists a single layer of GHG above the earth's surface which is quiet transparent to the incoming shortwave solar radiation and absorbs almost all the long wave radiation emitted by the earth. If we apply the principle of radiation balance to the top layer of the atmosphere, we have

$\pi R^2(1-\alpha)S_0 = 4\pi R^2 \sigma T_a^4$ -----------------------------------(4)

where R is the radius of the earth; α is the Albedo of the earth; S_o is the solar constant; σ is the Stefan-Boltzmann constant and T_a is the temperature of the atmospheric GHG layer.

Applying the principle of energy balance to the earth's surface, we have

$\pi R^2(1-\alpha)S_0 + 4\pi R^2 \sigma T_a^4 = 4\pi R^2 \sigma T_s^4$

(OR)

$2x\ 4\pi R^2 \sigma T_a^4 = 4\pi R^2 \sigma T_s^4$ [using equation (4)]

(OR)

$T_s = (2)^{1/4} T_a$ ---(5)

Equation(4) gives the value of the temperature of the atmospheric GHG layer as

$T_a = [S_o(1-\alpha)/4\sigma]^{1/4}$ --(6)

For α=0.3, S_o=1367W/m^2, and σ=5.67X10^{-8}W/m^2-K^4, equation (6) yields

$T_a \approx 255K$ or -18^{o}C

Using the above value in equation(5), we get

$T_s \approx 303K$ or 30^{o}C

This simple single layer model of GHE gives a warmer earth than the actual case leading to an estimate of GHE about 48^{o}C. But the actual surface temperature of the earth is around 15^{o}C. The results obtained from the equations (2) and (5) do not agree with the current observed values. So, it is necessary to introduce some modification in the above said theory.

Actually, the effective Radiative temperature is the physical temperature of the layer at a particular altitude where the emission to the space occurs. In the earth's atmosphere, this emission to space occurs at an altitude of H≈6 Km (Hansen *et al.,* 1984) which lies in the troposphere. Hence to determine the earth's surface temperature, we need to know the temperature gradient of the earth's atmosphere. This temperature gradient is not uniform in all the layers of the atmosphere. It changes from layer to layer due to the changes in the chemical composition of the different layers of the atmosphere. In the troposphere, the temperature decreases as the altitude increases.

The actual magnitude of the Green House Effect is given by(Hansen *et al.,* 1981)

$GHE = \Gamma H$ ---(7)

Where Γ is the mean tropospheric temperature gradient or lapse rate and H is the flux weighted mean altitude of the emission to space. Here, H = 6 Km and the mean tropospheric temperature gradient is Γ ≈5.5^{o}C/Km(Hansen *et al*., 1984). With these values, equation (7) yields a value of **33^{o}C** for the magnitude of the Green House Effect.

2.2. An observational based estimate

The solar constant S_o is treated as a constant for many practical purposes. But, actually it varies by a very small amount due to (i) the orbital parameters of earth-Sun system and (ii) the solar variability due to the Sun Spot Number (Jonna. D. Haigh, 1999). The first factor alters the solar insolation over millennial time-scales and the second factor produces solar variability on century time-scales. Hence the later plays a more vital role in our study. The solar constant is nothing but the solar radiation incident on the outer layer of the earth's atmosphere in unit time on a unit area normal to the direction of propagation of solar radiation when the earth is at its mean distance from the Sun. The World Radiation Center (WRC) has adopted a value of solar constant as 1367 W/m^2 which has been accepted universally (Khan, 2008). The value of the solar constant including the effect of the variation in the Sun Spot Number is given by (William James Burroughs, 1992)

$S = 1366.82 + (0.0071 \times R)$ -------------------------------(8)

where R is the Sun spot Number. Now, the effective Radiative temperature of the earth can be computed from equation (2) with variable solar constant as

$T_e = [S(1-\alpha)/4\sigma]^{1/4}$ ---(9)

Equation (7) gives the average value for the magnitude of the GHE. In reality, the concentration of the GHG keeps changing year by year. So, to study the magnitude of the GHE for every year, the following expression involving the observed surface temperature of every year is used. Now, the magnitude of Green House Effect for each year is given by

$GHE = T_S - T_e$ -- (10)

where T_S is the observed value of the earth's surface temperature.

2.3. An estimate based on the Radiative forcing of the Green House Gases

The Green House warming is due to the presence of certain gases in our atmosphere. If the concentration of these gases increases, then the Green House Warming will also increase. Hence there exists a relationship between the concentration of Green House Gases in the atmosphere and the magnitude of the Green House Effect. The increase in the temperature of the earth's surface due to Green House Effect is given by (Gilbert. M. Masters, 2008)

$GHE = \lambda F$ ---(11)

where λ is the climate sensitivity parameter and F is the radiative forcing due the Green House Gases. Assuming that the earth's Albedo does not change, the expression for the climate sensitivity parameter is (Gilbert. M. Masters, 2008)

$\lambda = (\partial Q_{rad}/\partial T_S)^{-1}$ ---(12)

where Q_{rad} is the quantity of the energy radiated.

There exists a linear relationship between the radiated energy and the earth's surface temperature (Stephen G. Warren and Stephen H. Schneider, 1979) given by

$Q_{rad} = AT_S + B$ --(13)

(or)

$\lambda = (\partial Q_{rad}/\partial T_S)^{-1} = A^{-1}$ ------------------------------------ (14)

where A and B are constants. Many scientists have suggested different values for A and B. One set of values are B=202 W/m^2 and A = 1.45 $W/m^2(^oC)^{-1}$(Budyko, 1969). Hence, equation (14) gives the value of climate sensitivity parameter to be

$\lambda = 0.6897$ --(15)

Table-1 gives the expression for the radioactive forcing of some of the important Green House Gases (IPCC: Climate Change 2001). Knowing the concentration of these gases, we can compute the total radioactive forcing due to these gases using these expressions and then the magnitude of GHE can be computed with the help of the equation (11) and (15).

Table 1. Expression for the Radiative forcing of different GHG

Green House Gases	Radiative forcing	Value of the constants
Carbon-di-oxide	$F=A_1 \ln C$	$A_1 = 5.35$
Methane	$F=A_2(M)^{1/2}$	$A_2 = 0.036$
Nitrous Oxide	$F=A_3(N)^{1/2}$	$A_3 = 0.12$
CFC – 11	$F = A_4(X)$	$A_4 = 0.25$
CFC - 12	$F = A_5(Y)$	$A_5 = 0.32$

4. Data and analysis

The annual average values of Sunspot Number (SSN) are taken for a period of twenty years from 1981 to 2000 (http://solar science.msfc.nasa.gov/green wch/spot_num.txt).

Table 2. Observational based magnitude for GHE:

S.No.	Year	T_e (°C)	T_S (°C)	GHE (°)
1	1980	254.9096	287.27	32.36036
2	1981	254.9045	287.40	32.49546
3	1982	254.8959	287.10	32.20414
4	1983	254.8780	287.34	32.46198
5	1984	254.8705	287.16	32.28945
6	1985	254.8605	287.13	32.26948
7	1986	254.8589	287.19	32.33111
8	1987	254.8646	287.35	32.48542
9	1988	254.8900	287.42	32.52999
10	1989	254.9108	287.28	32.36924
11	1990	254.9052	287.49	32.58480
12	1991	254.9064	287.44	32.53355
13	1992	254.8880	287.16	32.27198
14	1993	254.8737	287.18	32.30626
15	1994	254.8648	287.31	32.44519
16	1995	254.8604	287.47	32.60964
17	1996	254.8572	287.36	32.50283
18	1997	254.8618	287.40	32.53821
19	1998	254.8771	287.71	32.83285
20	1999	254.8876	287.44	32.55244
21	2000	254.8970	287.41	32.51298
22	2001	254.8938	287.56	32.66619

Table 2 gives the computed values of T_e using equation (6), values of the observed temperature T_S and the

Table 3: Radiative forcing of some of the GHG

Year	Radiative forcing of CO_2 (°C)	Radiative forcing of CH_4(°C)	Radiative forcing of N_2O(°C)	Radiative forcing of CFC-11(°C)	Radiative forcing of CFC-12(°C)	Total Radiative forcing(°C)
1987	21.6	1.0476	1.4494	0	0.0927	24.1897
1988	21.63	1.0519	1.4498	0	0.0966	24.2283
1989	21.64	1.0577	1.4513	0	0.1008	24.2498
1990	21.66	1.0582	1.4534	0	0.1045	24.2761
1991	21.67	1.0616	1.4538	0	0.1075	24.2929
1992	21.68	1.0623	1.4553	0	0.1104	24.308
1993	21.69	1.0627	1.4556	0	0.1122	24.3205
1994	21.7	1.0667	1.4583	0	0.1139	24.3389
1995	21.72	1.0671	1.4578	0	0.1153	24.3602
1996	21.74	1.0669	1.4618	0	0.1166	24.3853
1997	21.75	1.0675	1.4629	0	0.1175	24.3979
1998	21.78	1.0712	1.4664	0.0455	0.1181	24.4812
1999	21.8	1.0713	1.4676	0.0453	0.1188	24.503
2000	21.81	1.0706	1.4763	0.0451	0.1204	24.5224
2001	21.82	1.0711	1.4752	0.0448	0.1203	24.5314

magnitude of GHE for the twenty years from 1981 to 2000. It gives the magnitude of GHE obtained by the observational based method. The annual average value of the concentration of Carbon dioxide, Methane, Nitrous oxide, CFC -12 are taken for fifteen years from 1987 to 2001 (http://www.esrl.noaa.gov/gmd/ccl/). The concentration values of CFC -11 are available only for the years from 1998 to 2001. Table – 3 gives the Radiative forcing of all these GHG and their net value.

RESULTS AND DISCUSSION

The pure theoretical model presented in this paper gives a value of about 48°C for the magnitude of the GHE. The observation of the actual surface temperature of the earth sets a value of about 32.5°C for the magnitude of the GHE. From Table-2, it is evident that the observational based magnitude of the GHE does not keep increasing as one expects from the concept of Global warming. It keeps oscillating as it is seen from Table-2. But from the Table-3, it is evident that the Radioactive forcing of the GHG keeps increasing. Hence the increasing trend observed in the average global temperature cannot be thought to be the consequence of the increased Green House Gas concentration alone. So, the other factors influencing the global temperature must also be studied to give a better idea about the climate changes. As seen from the Table-3, the contribution of carbon dioxide alone amounts to about 66% of the total magnitude of GHE while the total contribution of Carbon dioxide, Methane, Nitrous oxide and CFC -11 & 12 amounts to about 75% of the total magnitude of the GHE. Hence the remaining quantity of about 25% can be thought to be arising from water vapor and the surface ozone. This gives an indirect estimate of the contribution of water vapor and ozone.

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