World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:14, No:12, 2020

Greenhouse Gasses' Effect on Atmospheric Temperature Increase and the Observable Effects on Ecosystems

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Abstract**—**Radiative forces of greenhouse gases (GHG) increase the temperature of the Earth's surface, more on land, and less in oceans, due to their thermal capacities. Given this inertia, the temperature increase is delayed over time. Air temperature, however, is not delayed as air thermal capacity is much lower. In this study, through analysis and synthesis of multidisciplinary science and data, an estimate of atmospheric temperature increase is made. Then, this estimate is used to shed light on current observations of ice and snow loss, desertification and forest fires, and increased extreme air disturbances. The reason for this inquiry is due to the author's skepticism that current changes cannot be explained by a "~1 °C" global average surface temperature rise within the last 50-60 years. The only other plausible cause to explore for understanding is that of atmospheric temperature rise. The study utilizes an analysis of air temperature rise from three different scientific disciplines: thermodynamics, climate science experiments, and climactic historical studies. The results coming from these diverse disciplines are nearly the same, within ± 1.6%. The direct radiative force of GHGs with a high level of scientific understanding is near 4.7 W/m^2 on average over the Earth's entire surface in 2018, as compared to one in pre-Industrial time in the mid-1700s. The additional radiative force of fast feedbacks coming from various forms of water gives approximately an additional ~15 W/m^2. In 2018, these radiative forces heated the atmosphere by approximately 5.1 °C, which will create a thermal equilibrium average ground surface temperature increase of 4.6 °C to 4.8 °C by the end of this century. After 2018, the temperature will continue to rise without any additional increases in the concentration of the GHGs, primarily of carbon dioxide and methane. These findings of the radiative force of GHGs in 2018 were applied to estimates of effects on major Earth ecosystems. This additional force of nearly 20 W/m^2 causes an increase in ice melting by an additional rate of over 90 cm/year, green leaves temperature increase by nearly 5 °C, and a work energy increase of air by approximately 40 Joules/mole. This explains the observed high rates of ice melting at all altitudes and latitudes, the spread of deserts and increases in forest fires, as well as increased energy of tornadoes, typhoons, hurricanes, and extreme weather, much more plausibly than the 1.5 °C increase in average global surface temperature in the same time interval. Planned mitigation and adaptation measures might prove to be much more effective when directed toward the reduction of existing GHGs in the atmosphere.

Keywords**—**GHG radiative forces, GHG air temperature, GHG thermodynamics, GHG historical, GHG experimental, GHG radiative force on ice, GHG radiative force on plants, GHG radiative force in air.

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This work is voluntary, without any sponsors or financial support.

I. Introduction

GHG are commonly known to increase ground surface temperature. Due to the thermal inertia of oceans and land, this increase is delayed over time. Increase of air temperature, however, is not delayed.

In the following review and combination of known facts, an attempt is made to estimate atmospheric temperature increase, to compare it with known surface temperature increase, and to then apply it to the understanding of changes within Earth's ecosystems. The reason for this inquiry is doubt that current changes can be explained by a "~1 °C" rise of global average surface temperature. Important surprising ecosystem changes consist of ice melting all over the planet, spread of deserts and forest fires, the strength and magnitude of air disturbances, the disappearance of snow, and a large number of "once in a hundred years events" occurring each year. The only other plausible possibility to explore for understanding is that of atmospheric temperature rise. Several methods will apply to this inquiry. Isaac Newton, the father of the modern scientific method, left behind an admonition about the "theory of everything: to explain all nature is too difficult a task for any one man… much better to do a little with certainty…"

The scientific method is not applicable in explaining all of Earth's nature; rather, it can be used for a narrow inquiry "to do a little with certainty". However, another widely used heuristic method gives answers with less certainty, but covers phenomena that are more complex. In this inquiry, both methods are used in order to achieve increased accuracy of answers.

II. Basics of the GHG Effect

In 2012, the American Chemical Society published an informative Climate Science Toolkit (ACS Toolkit) on its website [1]. In the chapter, "Getting Started," there is a good explanation. Planetary temperature is determined by energy balance between absorbed solar radiation and emitted infrared radiation from a planet. When planet's atmosphere contains infrared absorbing gasses, then more infrared radiation from a planet must be emitted to balance solar energy, meaning that planetary temperature must be higher. "This is called the atmospheric greenhouse effect" [1].

In another ACS Toolkit Chapter, "Single Layer Atmospheric Model" [2], we find the following "…model that illustrates the fundamental mechanism for atmospheric warming".

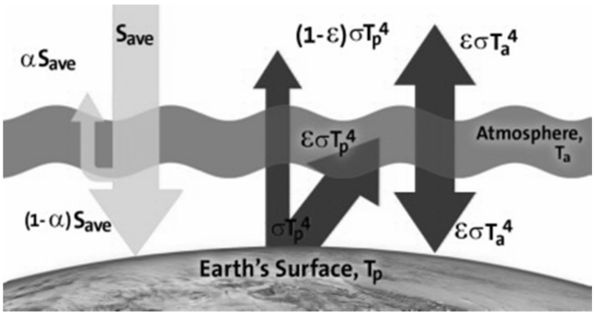

Fig. 1 Single Layer Atmospheric Model

The symbols in Fig. 1 from [2] represent the following:

- "**S_{ave}** is the average incoming solar energy per unit area of the Earth, 342 W/m^2;
- **α** is the Earth's average albedo, 0.3;
- The warmed (planet) surface emits radiation as a black body, at a temperature of $\mathbf{T_p}$;
- The atmosphere is represented by a single homogeneous layer of gases in thermal equilibrium at temperature $\mathbf{T_a}$ acting as a grey body;
- With an emissivity and an absorptivity given by **ε;**
- **σ** is the Stefan-Boltzmann constant, $5.67 \cdot 10^{-8}$ $W/m^2 \cdot K^4$."

This model provides a simple, functional dependence between atmospheric and surface temperatures at equilibrium of energy absorbed and radiated:

$$\mathbf{T_a = (1/2)^{1/4}\, T_p \approx 0.841 \times T_p} \qquad (1)$$

In another ACS Toolkit chapter, "Predicted Planetary Temperatures/Energy Balance" [3], one finds a simple calculation for planetary temperatures.

"Assuming that the planets act like black bodies, the incoming and outgoing energies are balanced by equating the energy flux that is absorbed to the energy flux that the black body would emit, σT_P^4, from the Stefan-Boltzmann law, with T_P equal to average planetary temperature" [3].

$$S_{ave}(1 - \alpha) = \sigma T_P^4$$

$$T_P = (S_{ave}(1 - \alpha)/\sigma)^{1/4}$$

Based on these relations, calculated temperatures of the Earth and nearby planets are presented in Table I [3].

TABLE I
PREDICTED PLANETARY TEMPERATURES BASED ON ENERGY BALANCE

Planet	Mercury	Venus	Earth	Mars
S_{ave}, W/m^2	2290	662	342	145
α	0.10	0,75	0,3	0,25
T_p, K(°C)	437 (163)	232 (-41)	255 (-18)	209 (-64)
Tabs, K(°C)	~440 (167)	735 (462)	288 (15)	215 (-58)

In Table I, symbol $\mathbf{T_{obs}}$ stands for observed temperature. The observed temperature on Earth is 33 °C larger than in the model. In another ACS Toolkit, chapter "Atmospheres and Planetary Temperatures" [4], an explanation for this difference is found.

TABLE II
EFFECT OF ATMOSPHERE COMPOSITION ON THE OBSERVED SURFACE TEMPERATURE

Planet	Mercury	Venus	Earth	Mars
T_p, K(°C)	437 (163)	232 (-41)	255 (-18)	209 (-64)
Tobs, K(°C)	~440 (167)	735 (462)	288 (15)	215 (-58)
Atmosphere:				
Pressure, kPa	none	9300	101	0,64
composition		CO_2 (0.965)	N_2 (0.78)	CO_2 (0.95)
		N_2 (0.035)	O_2 (0.21)	N_2 (0.03)
			Ar (0.009)	Ar (0.02)
trace gases		SO_2, Ar	CO_2, H_2O	O_2,CO

Table II summarizes the data on the planetary temperatures and atmospheric composition of these planets. Venus has an observed temperature near 500 °C with its atmosphere containing mostly CO_2 at high pressure, meaning there is a lot of it. Mars' atmosphere contains a similar proportion of CO_2, but at a very low pressure resulting in a small greenhouse effect and planetary temperature near *minus* 60°C. Neither Venus nor Mars are suitable for life. Our home Earth is a miracle. Without GHG, Earth's temperature would be near *minus* 20 °C, but with relatively small amounts of CO_2 and water vapors, Earth temperature is near *plus* 15 °C. This is necessary condition for life to exist.

ACS Toolkit [4] also provides a comparison between atmospheric greenhouse effect and common agricultural greenhouses. "The analogy of the atmosphere to a greenhouse is misleading".

In the agricultural greenhouse, the Sun's radiative energy penetrates through a transparent enclosure and heats inside surfaces that warm inside air. "The warm air reaches the cool wall and roof, loses its extra energy, and recirculates to the warm surfaces, thus setting up a steady state of trapped warm air in which the surface of the soil and plants and the average air temperature are higher than the temperature outside" [4]. In contrast, atmospheric warming is connected mainly with certain molecules in atmosphere called GHG that absorb infrared radiation coming from Earth surface to balance energy absorbed from Sun. This is a basic idea of atmospheric greenhouse effect.

III. PRE-INDUSTRIAL TIME

The time reference that is generally adopted in climate science is around the year 1750, which is often viewed as a marker for the pre-Industrial time.

The first question is, what was the Earth's equilibrium temperature in 1750? One of the sources to this query presents the following observations: In 1750, it was 13.4 °C (56 °F); assuming that the rise from 1750 to the baseline of 1951-1980 was 0.58 °C. This 0.58 °C for the rise from 1750 to 1951-1980 can be calculated in a number of ways, such as: By using 0.3 °C for the rise from 1750 to 1900, and adding 0.28 °C for the rise 1900 to 1951-1980 Arctic News weblog [5].

In 1750, GHG were composed mainly of carbon dioxide, CO_2, and water vapors. The observed temperature of the surface is believed to have been not 15 °C, but 13.4 °C, or ~286 ^{K}. This was 286-255 ≈ 31 °C larger than without the

GHG, at that time.

The radiative forcing of the Sun was:

$$S_{ave}(1 - \alpha) = 342*(1\text{-}0.3) \approx 240\ W/m^2.$$

This power increased the surface temperature to 255 K without the GHG effect. The GHG effect of water and CO_2 increased surface temperature by additional 31 °C.

The atmosphere temperature is calculated using (1):

$$T_a = 0.841 \times T_p = 0.841 \times 286 \approx 241^oK = -32°C.$$

Carbon dioxide concentration was 275 ppm, NOAA [6].

A. Radiative Direct Forcing of the GHG in 2018

In the IPCC AR5 [7], there is an explanation for the definition of radiative forcing. "RF is defined, as it was in AR4, as the change in net downward radiative flux…"

The main reference data for the GHG are located in NOAA [6] for 2018

NOAA states its inclusion boundaries for the GHG:

> Because we seek an index that is accurate, only direct forcing from these gases has been included. Model-dependent feedbacks, for example, due to water vapor and ozone depletion, are not included. Other spatially heterogeneous, short-lived, climate forcing agents, such as aerosols and tropospheric ozone, have uncertain global magnitudes and also are not included here to maintain accuracy. In contrast to climate model calculations, the results reported here are based mainly on measurements of long-lived, well-mixed gases and have small uncertainties. NOAA [6].

NOAA data for radiative forcing (power density) have an uncertainty of 10%. Carbon dioxide concentration in 2018 was 407 ppm. Carbon dioxide radiative forcing in W/m^2 is:

$$RF_{CO2}=5.35*\ln (407/275) = 2.1\ W/m^2 \quad (2)$$

Methane radiative forcing in 2018 over reference in 1750 is 0.512 W/m^2 - that is, for methane concentration on a basis of a "long-lived" time horizon.

The IPCC AR5 [8] points to an accepted practice of using a 100-year time horizon:

> In this report [8], in Fig. 8.29, we find the GWP (Global Warming Potential) of methane over time. At the time of emission, the GWP is 120, and then decreases over time due to continuing "burning" in the atmosphere and its corresponding reduction in concentration. If concentration remains unchanged because of addition of new emissions (of either manmade or natural origin), then the GWP at time of emission stays the same -120.

NOAA [6] data are for a 100-year time horizon that is near GWP = 30 in Fig. 8.29. Recalculating methane radiative forcing for 2018 concentration gives:

$$0.512 *120/30 \approx 2.05\ W/m^2.$$

The combined radiative forcing of other GHGs in NOAA [6] is ~0.55 W/m^2. The total combined radiative forcing is:

$$RF_{GHG} = 2.1+2.05+0.55 = 4.7\ W/m^2.$$

It is important to note that, while the CO_2 effect attracts most of the attention for the reduction of GHG emissions, it makes up for less than half of the total. There are other sources of radiative forcing that are omitted from NOAA [6] report, for the stated reason of uncertainties. This is corroborated in the IPCC TAR, 2018 [9].

Ozones have a medium level of scientific understanding, and their combined effect adds another 0.2 W/m^2; sulfates have a low level of scientific understanding, and their effect is -0.4 W/m^2. Even going toward 2050, sulfates add -0.04 W/m^2; all other sources of radiative forcing have a very low level of scientific understanding.

For scientific analysis on the basis of the idea of "do little with certainty," the effect of all sources that are not included in the NOAA [6] report is omitted. The secondary reason for this is that estimates of even medium-to-low levels of scientific understanding sources of radiative forcing are well within a 10% uncertainty of the combined effect of a high level of scientific understanding sources in NOAA [6].

B. Fast Feedback GHG Thermodynamic Analysis

So far, we have analyzed the radiative direct forcing of the primary GHG. However, there are other radiative forcings which are caused by feedbacks on forcing by the primary GHG. In the ACS Toolkit chapter, "Climate Sensitivity| How Atmospheric Warming Works" [10], we find large effects of feedbacks: "…relationship between radiative forcing and the counterbalancing temperature change that would be required to return the planet to energy balance is:

$$\Delta T \approx Tp\ \Delta F/[4(1 - \alpha)S_{ave}] \approx [\underline{0.3\ K\cdot(W\cdot m^{-2})^{-1}}]\ \Delta F,$$
$$\text{(for } Tp \approx 288\text{ K)"}$$

The primary analysis in this toolkit is based on the laws of thermodynamics. In the same ACS Toolkit, the following observation is added:

> Our calculated temperature change, that includes only the radiative forcing from increases in GHG concentrations, accounts for 20-25% of this observed temperature increase. This result implies climate sensitivity factor perhaps four to five times greater, ~1.3 $K\cdot(W\cdot m^{-2})^{-1}$, than obtained by simply balancing the radiative forcing of the GHG. The analysis based only on GHG forcing has not accounted for feedbacks in the planetary system triggered by increasing temperature, including changes in the structure of the atmosphere [10].

This observation is also supported by a similar observation found in the IPCC AR5:

> Currently, water vapor has the largest greenhouse effect in the Earth's atmosphere. However, other GHG, primarily CO_2, are necessary to sustain the presence of water vapor in the atmosphere. Indeed, if these other gases were removed from the atmosphere, its temperature

would drop sufficiently to induce a decrease of water vapor, leading to a runaway drop of the greenhouse effect that would plunge the Earth into a frozen state. So, GHG other than water vapor provide the temperature structure that sustains current levels of atmospheric water vapor. Therefore, although CO_2 is the main anthropogenic control knob on climate, water vapor is a strong and fast feedback that amplifies any initial forcing by a typical factor between two and three. Water vapor is not a significant initial forcing, but is nevertheless a fundamental agent of climate change [11].

The fast feedback agents are further explained in [12]: "Climate sensitivity to an imposed external forcing depends solely on fast climate feedbacks due to changes in water vapor, clouds, and sea ice".

Returning back to the ACS' Toolkit observation of climate sensitivity of ~1.3 $K\cdot(W\cdot m^{-2})^{-1}$ for the GHG, one can then calculate that:

a) Additional global radiative forcing in 2018 of 4.7 W/m^2 will result in an eventual global average surface temperature increase, at equilibrium of radiative forces, of 4.7*1.3 ≈ 6.1 °C, on a basis of the primary GHG and fast feedbacks associated with water.
b) Total radiative forcing in 2018, the primary and the feedback GHG, will produce the eventual surface temperature rise of 6.1 °C. The thermodynamic analysis presented within ACS Toolkit as climate sensitivity for both, the primary and the feedback, radiative forcing is 0.3 $K\cdot(W\cdot m^{-2})^{-1}$. Then, the combined radiative forcing is 6.1/0.3 ≈ 20 W/m^2. This includes ~5 W/m^2 of the primary GHG, and ~15 W/m^2 of the feedback GHG radiative forcing.
c) The average global radiative forcing in 1750 can be calculated by dividing the GHG-caused temperature increase of 31 °C by the climate sensitivity for both the primary and the feedback radiative forcing of the same 0.3 $K\cdot(W\cdot m^{-2})^{-1}$, and the result is ~103 W/m^2.

For comparison, radiative forcing of the Sun absorbed by the Earth's surface is ~51% [13] of the incoming radiation of 342 W/m^2. This gives an absorbed radiative forcing or power density of ~174 W/m^2. These values are based on both thermodynamic analysis and experimental findings.

V. Atmospheric Temperature Increase

The next question is, when in time do fast feedbacks amplify the radiative forcing of the primary GHG. We have found a summary of this information, and present it in Fig. 2.

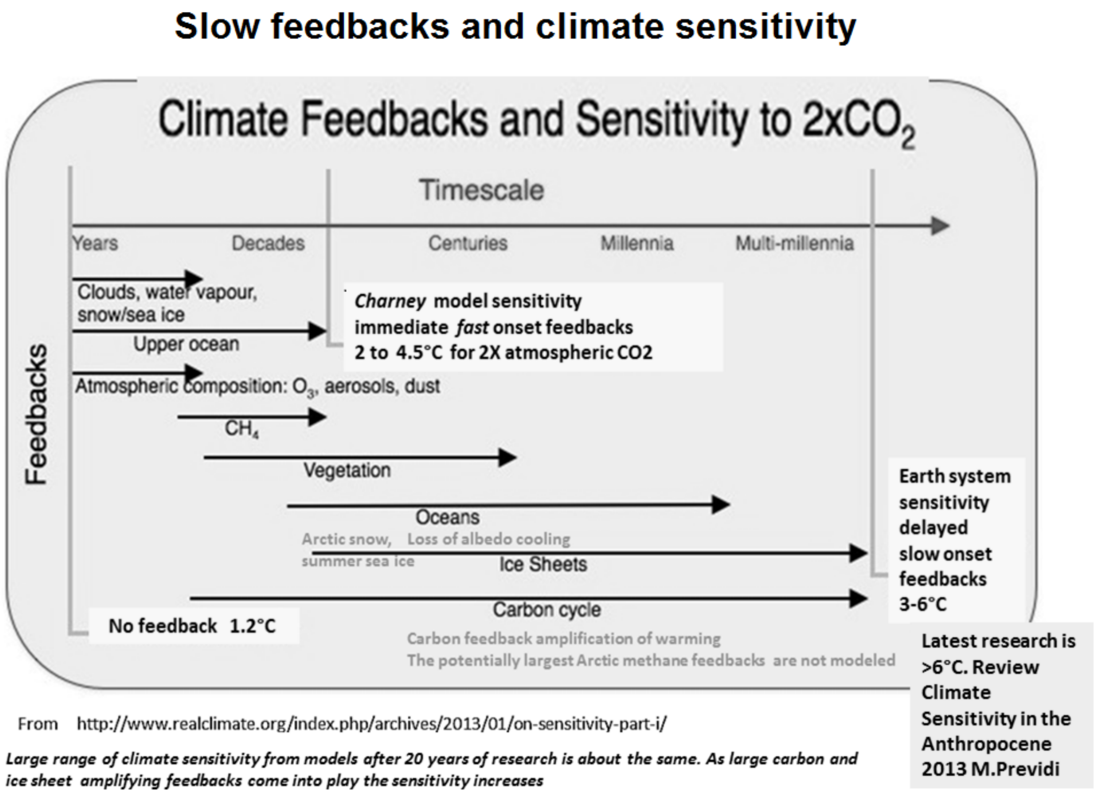

Fig. 2 Timing for various feedbacks on temperature increase by the primary GFG [26]

The fast feedback agents are further explained in [12]. The fast feedback that takes years to react upon heating by the primary GFG are all water-based - water vapor, clouds, snow/ sea ice - with water vapors being the main one, as observed by IPCC [11]. Review of NOAA [6] shows that, between 2008 and 2018, radiative forcing of the primary GFG changed within ± 6%, meaning that the fast feedback of water had enough time to develop. It is rational, then, to accept that in 2018 radiative forcing included both the primary GFG and the water-based fast feedback GFG. This rationale allows us to proceed with further analysis.

1. As the *eventual* average ground surface temperature increase will be 6.1 °C at thermodynamic equilibrium of the Earth energy flow, one can then calculate the single layer model *current* atmospheric temperature increase using (1):

$$\Delta T_a = 0.841 \times \Delta T_p \text{ or } 0.841 \times 6.1 \approx 5.1\ °C$$

2. In 2018, the average global surface temperature increase, in comparison with 1750, was as follows:
- By 1900: plus 0.3 °C,
- From 1900 to 2018, averaged trend over 12 years: ―1.2 °C.

In total, the increase was 1.5 °C, making the average global surface temperature equal to 13.4+1.5 ≈ 15 °C. This is an answer to the original inquiry: since 1750, the global surface temperature increased by 1.5 °C, while atmospheric temperature increased by 5.1 °C.

3. Concentration of the primary GHG in NOAA [6] would not be increasing after 2018, and that,
- There will be no further anthropogenic GHG emissions,
- There will be no changes in global ecosystems producing more of at least CO_2 and methane.
4. In those unlikely circumstances, over time, the average global surface temperature will increase by an additional 6.1 - 1.5 = 4.6 °C after 2018 as a function of the thermal inertia of oceans and land ecosystems.

VI. Radiative Forcing of the GHG in 2018 Historical Method

Due to large uncertainties, IPCC has not included slow feedback amplification in temperature rise. Recently, Hansen found a way to include both fast and slow feedbacks into temperature rise caused by GHGs [14].

We begin this analysis from a historical observation of the change in average global surface temperature as a function of change in CO_2 concentration. Fig. 3 is from [14], (for identification: temperature graph reaches near 300 and CO_2 graph reaches near 400 on the right scale).

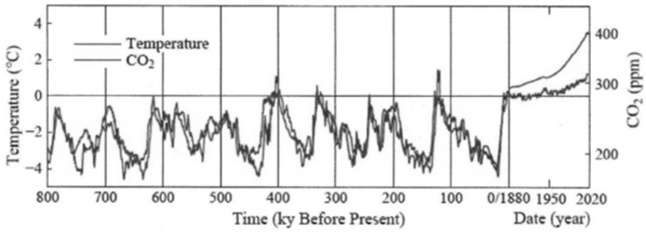

Fig. 3 Atmospheric CO_2 and global surface temperature versus time

Hansen [14] provides sources of data for Fig. 3: "CO_2 amount is from Antarctic ice cores (Jouzel et al., 2007) and paleo global surface temperature change is from ocean core data (Zachos et al., 2008) via approximation to convert oxygen isotopic data to ocean temperature (Hansen et al., 2013)".

CO_2 amount is plotted on a *logarithmic scale,* due to the fact that the CO_2 climate forcing, and thus expected temperature response, is proportional to the logarithm of CO_2 concentration change. This is the historical origin of (2). We will use this equation in reverse, in order to calculate the CO_2 equivalent concentration in 2018 for RF_{GHG} = 4.7 W/m^2 versus the reference year, 1750:

$$4.7 = 5.35 * \ln (CO_2eq/275)$$

Solving for CO_2eq, one finds that it is ~660 ppm.

There is another widely accepted concept of "climate sensitivity", which is expressed in average global surface temperature change for doubling CO_2 concentration, referred to as 2xCO_2. The need for this concept had come to include feedback effects arising from temperature change caused by changing CO_2 concentration.

Hansen [14] made an important comparison (depicted in Fig. 3) which implies that the eventual warming resulting from 400 ppm CO_2 concentration in 2015 will be ~3.5 °C, including the full effect of both *fast and slow* climate feedback processes - in reference to the temperature in the time interval of 1880 to 1920.

The equation that is widely used in climate science connecting temperature change with the change in CO_2 concentration is a modification in the form of (2):

$$\Delta T = K * \log_{10}(C_1/C_0), \quad (3)$$

where: ΔT is a change in temperature caused by CO_2 concentration change, increasing from C_0 to C_1; K is an experimental coefficient.

In the last case, ΔT = 3.5 °C, C_1 = 400 and C_0 = 296 near 1900. Solving for K, one gets ~27.

By using (3) for our case with C_0 = 275 and C_1 = 660 equivalent, with K = 27, one gets ~10.3 °C eventual average global surface temperature rise, incorporating the change in the GHG by 2018, as well as consequent fast and slow feedbacks. The assumption is that, going forward, there will be no change in GHG concentration. This analysis is for a better contemporaneous understanding of the existing ecosystem changes.

There is also another interesting comparison to note. In [15], Hansen presents a timeline of average ground surface temperature increase following an initial increase in climate forcing. In Fig. 14 of his paper, Hansen presents that, within the course of a century, 60% of the equilibrium temperature is reached. Our calculation shows that this temperature is 10.3 °C, and 60% of it, within a century, equals 6.2 °C. This further confirms our prior analysis, based on thermodynamic and experimental data.

VII. Radiative Forcing of the GHG in 2018 Heuristic Method

IPCC reports have voluminous descriptions of climate sensitivity as a function of doubling CO_2 concentration along with fast feedbacks. The IPCC AR5 report [16] describes various methods of estimation of this climate sensitivity. We use the summary of instrumental measurement by various researchers. The results vary widely, thus underlining a problem with this concept of climate sensitivity. Instrumental climate sensitivity varies between 1 °C and 9 °C. We then use the middle value for further analysis: 5 °C.

In this analysis, the CO_2 concentration change between 2018 and 1750 is 660/275 ≈ 2.4. If 5 °C change is due to 2xCO_2, then by taking the logarithmic connection to temperature into account, one gets ~26% larger temperature for 2.4 ratio. Therefore, the resulting temperature increase is 6.3 °C for the GHG and the fast feedback effects. Again, this result is very close to our findings in two prior approaches.

VIII. Summary of Analysis

The summary of our analysis is presented in Table III.

TABLE III
SUMMARY OF THE RESULTS

Temperatures, °C	1750	2018	Radiative forces, RF		
Surface T without GHG heating	-18	-18			
Absolute surface average T in °K without GHG	255	255	RF of the Sun, absorbed by the Earth surface	174	W/m^2
Increase in surface T by GHG heating	31	33	RF GFG in 1750, ACS analysis	103	W/m^2
Increase in atmospheric T by GHG and feedbacks	26	31			
T increases since 1750					
			Increase in RF, using NOAA [6],	~20	W/m^2
Ground surface		1.5	and IPCC data from 1750 to 2018,		
Atmosphere		5.1	and including the fast feedbacks		
Eventual ground surface thermal equilibrium			RF of 40 W rated LED light bulb	4 - 5	W/m^2
with no change in 2018 GHG concentrations					
Based on ACS thermodynamic analysis with experimental data		6.1	RF of the primary GFG	4.7	W/m^2
			RF of the fast feedbacks	~15	W/m^2
Based on heuristic analysis of IPCC average of instrumental reports for fast feedbacks		6.3	CO_2 equivalent concentration	660	ppm
Based on Hansen's climate response function for fast feedbacks within a century		6.2	CO_2 equivalent concentration	660	ppm
Based on Hansen's 800,000 years historical comparison for fast and slow feedbacks		10.3	CO_2 equivalent concentration	660	ppm

IX. Discussion of the Summary

The average ground surface temperature increase in 2018 was 1.5 °C. Temperature will continue to increase without any additional increases in concentration of the GHGs, primarily of CO_2 and methane. This is caused by radiative forces in the atmosphere that has been heated to 5.1 °C. Three different approaches for calculating the approximate average ground surface temperature by the end of this century gave very similar results, between 6.1 °C and 6.3 °C.

Without any changes in the primary GHG concentration after 2018, the average ground surface temperature will increase by an additional 4.6 °C - 4.8 °C, within the course of a century.

The slow feedbacks will further increase this temperature by an additional ~4 °C after this century.

Currently observable changes in ecosystems are more connected with a much larger 5.1 °C atmospheric temperature increase than they are with a 1.5 °C ground surface temperature increase.

Atmospheric temperature increase caused an increase in radiative force by ~20 W/m^2. In comparison, the accumulated GFG by 1750 increased the average ground surface temperature by 31 °C and corresponding radiative forcing by ~100 W/m^2.

For the sake of comparison with everyday human experience, a 20 W rated LED light bulb radiates 4-5 W of light. Today's GFG radiative force accumulated since 1750 is near the effect of using four to five such LED light bulbs, and then directing all that light on one square meter of surface.

X. Observation of the Connection between Changes in Ecosystems with Atmospheric Changes of Temperature and Radiative Forcing

There are three main ecosystems for observation: ice, plants, and air. The changes in each of them are what is well-known as *climate change*. Let us apply the findings to each of them, and then observe primary and secondary changes. Each ecosystem is too complex for scientific analysis, so we will follow Isaac Newton's counsel *"to do a little with certainty"*. Let us look for indications of connections.

A. Ice Melting

The most vivid effects of ice melting can be found in Arctic, in Greenland, and in the Tibetan glaciers.

Ice melts with no change in temperature, and, therefore, does not emit additional infrared radiation. Ice thermal conductivity is low, so the main part of incoming radiation is applied to its melting. Ice is subject to the full radiative force of 20 W/m^2. Part of this radiation is reflected, and the balance will melt ice. The National Snow and Ice Data Center [17] describes the reflective property of ice; it varies, but one can reasonably assume that 50% of radiative power is reflected. This leaves ~10 W/m^2 to melt ice; this is the result of the atmospheric temperature increase by 5.1 °C. By calculating annual energy melting ice, and then dividing it by the specific energy of ice melting 334 kJ/kg, one gets ~940 kg/m^2, or ~ 3 feet thickness of melted ice. This value may be used as a rate of melting, 0.914 m/year (3 ft/year). This rate does not take into account spatial distribution of the atmospheric temperature rise that will make this rate higher or lower as a function of local radiative forcing.

The primary effect is in increasing disappearance of Arctic ice and Tibetan glaciers. There are numerous secondary effects.

The disappearance of Arctic ice, which is known to act as "an air conditioner" for the Northern Hemisphere, became a fast positive feedback. It is well-known that positive feedbacks create unstable systems. We observe this in spatial weather records. As an example, there was no snow in most of Western Russia during the 2019 to 2020 winter season. In that same winter, there was only one day of snowfall in Washington, D.C. However, there were large, record-breaking snowfalls in other areas - such as in parts of Europe and in the US Midwest.

Substantial reduction in size of the Tibetan glaciers has served to reduce the water flow that feeds half of humans. Due to this loss of water, people began moving from Tibet in Nepal to lower altitudes. There is a seemingly never-ending war in Kashmir over the smaller and smaller water flow from reduced glaciers. India is in the process of building dams to reduce water flow to Bangladesh. In China, the Yellow River does not have enough water to flow to the ocean.

Fig. 4 shows a combination of the area’s physical and political geography [18].

Fig. 4 Rivers originating from Tibetan glaciers

B. Plants

Effects on the planetary flora come primarily via temperature change of green leaves.

Green leaves have a small thermal capacity that is not comparable with that of the Earth’s surface. There is no time delay in their temperature increase caused by atmospheric temperature increase. This increase is ~6.1 °C, but the Earth’s surface has been already heated by 1.5 °C, so there is 4.6 °C of imbalance left. If leaves were perfect black bodies in the thermodynamic sense, then their average global leaf temperature increase would have been the same 4.6 °C. But leaves are not perfect black bodies, and their emissivity is less than 1, near 0.98 - not a large difference. One of the numerous references on this subject is Chen [19]. The indication, then, is that the global average of temperature increase in leaves by GHG is ~4.6 °C over whatever the temperature was in 2018.

The secondary effects of increased temperature are numerous. We will point to a few observations. Plants grow because of photosynthesis. This process occurs in the limited temperature range that is well-known in agriculture. The popular reference on this subject is Markings [20]. This range is between 10 °C and 40 °C, with 20 °C being an optimal temperature inside leaves. An increase by ~5 °C moves this range to between 5 °C and 35 °C, meaning toward cooler latitudes. There, insolation is smaller, and gross primary plant productivity is lower. This reduction in plant productivity is one of a few main causes for the spreading of deserts; the other obvious one is the increase in surface temperature that reduces soil moisture, which will continue after 2018.

A less-obvious cause is in plants physiology, a phenomenon described in [21]. The authors described a process through which an increased amount of CO_2 *reduces* evaporation from the plants: "…vegetation-climate feedback causes a significant reduction in global GPP (Gross Primary Productivity) mainly by reducing growing-season precipitation in 60°S–60°N latitude bands".

One of the most visible effects is in the 20-year mega-drought in western United States. Another is the spreading desertification in areas north of existing deserts in Northern

Africa, the Middle East, Southern Europe, Southern Siberia, and Australia. The other visible spread of deserts shows up in forest fires all over the world, from Australia to Siberia, and from California to Canada. Fires start from dry grasses as, due to long channels for water delivery, their stems dry out much faster than tree leaves do.

Our foundational foods are grains grown on grasses, the plant that is the most affected by increased atmospheric temperature.

Not only are deserts spreading away from the Equator, but tropical forests around the Equator are also decaying, due to what has been explained as Gross Primary Productivity based on high atmospheric temperature rise and CO_2 abundance.

One more observation is related to the flora-fauna ecosystem. The fauna food chain starts from microorganisms, and extends all the way up to us. It obtains energy from flora. With the decay of plant productivity, less food is left for us and the rest of fauna, so the fauna moves closer to us who have more food. Wild fauna microbiota and ours are not compatible. We cause large extinctions of fauna species, and fauna does the same to us, via viral, fungal, bacterial, and insect-borne diseases. Mass media reports are too numerous to list.

C. Air

The Ideal Gas Law

General physics/chemistry textbooks explain this law, for example in [22]: The volume (***V***) occupied by *n* moles of any gas has a pressure (*P*) at temperature (*T*) in Kelvin. The relationship for these variables,

$$\mathbf{PV = nRT},$$

where ***R*** is known as the gas constant, is called the ideal gas law, or equation of state. Properties of the gaseous state predicted by the ideal gas law are within 5% for gases under ordinary conditions. In other words, given a set of conditions, we can predict or calculate the properties of a gas to be within 5% by applying the ideal gas law. How to apply such a law for a given set of conditions is the focus of general chemistry. [22]

The gas constant R is ~8.3 J/(mol·°K). One mole of air occupies ~0.24 m^3 (~0.8 ft^3). As atmospheric temperature increased by 5.1 °C, the value of work energy of air increases by 8.3*5.1 ≈ 42 J/mol. Indications of an effect of this additional work energy of air can be glimpsed from a comparison with the strongest land disturbance in air movement - tornadoes.

In the case of a typical tornado, its energy is near 10 MWh. Within the volume of air in such a typical tornado, the addition of 42 J will add more than 4 MWh. This explains why tornadoes today are so much more powerful. Input data are scattered in [23].

Hurricanes are larger and much more visible, but air energy density found inside of them is typically ~6 times smaller than in tornadoes. With the same addition of energy per unit of air volume, 42 J, hurricane strength is therefore very much larger.

Even smaller energy density is present in winds caused by the spatial distribution of Earth and water heating or cooling. This additional 42 J of atmospheric air energy causes the largest changes in wind strength and patterns, and is commonly called "extreme weather". Daily weather maps in localities around the world attest to this [24].

ACKNOWLEDGMENT

The author is thankful to Dr. James Lovelock for his lecture, and for the book "The Revenge of Gaia: Earth's Climate in Crisis and the Fate of Humanity"; New York: Basic Books, 2006, which prompted the author's interest in greenhouse gases; to Dr. Thomas Cochran and Dr. Allen Sessoms for prompting the author to study the subject presented, and to Dr. James Baker for posing questions about initial ideas of this study.

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DOI: 10.5281/zenodo.4387072