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Autonomous Changes in the Concentration of Water Vapor Drive Climate Change

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Abstract

When compared to the average annual global temperature record from 1880, no published climate model posited on the assumption that the increasing concentration of atmospheric carbon dioxide is the driver of climate change can accurately replicate the significant variability in the annual temperature record. Therefore, new principles of atmospheric physics are developed for determining changes in the average annual global temperature based on changes in the average atmospheric concentration of water vapor. These new principles prove that: 1) Changes in average global temperature are not driven by changes in the concentration of carbon dioxide; 2) Instead, autonomous changes in the concentration of water vapor, ΔTPW, drive changes in water vapor heating, thus, the average global temperature, ΔT_{Avg}, in accordance with this principle, $\Delta T_{\text{Avg}} = 0.4\Delta\text{TPW}$ the average accuracy of which is ±0.14%, when compared to the variable annual, 1880-2019, temperature record; 3) Changes in the concentration of water vapor and changes in water vapor heating are not a feedback response to changes in the concentration of CO_2; 4) Rather, increases in water vapor heating and increases in the concentration of water vapor drive each other in an autonomous positive feedback loop; 5) This feedback loop can be brought to a halt if the average global rate of precipitation can be brought into balance with the average global rate of evaporation and maintained there; and, 6) The recent increases in average global temperature can be reversed, if average global precipitation can be increased sufficiently to slightly exceed the average rate of evaporation.

Keywords

Carbon Dioxide, Climate Change, Water Vapor, Global Warming, Driver, Average Global Temperature, Change in Concentration Water Vapor, Water Vapor Heating

1. Introduction

Objectives

- Develop wholly new principles of atmospheric physics;
- Identify and prove the cause of climate change;
- In so doing, assess the role, if any, changes the increasing concentration of CO_2 may play;
- Posit a possible solution to the existential problem that is global warming.

Global Warming

Since 1976, the average global temperature has been increasing at the rate of ~0.2°C/decade. This is a very serious problem, becoming increasingly so and likely to become an existential threat to certain of those living on the margin around the globe.

Like any problem, to find a solution, the cause must be understood.

The increasing concentration of atmospheric carbon dioxide is NOT the cause of climate change. Therefore, limiting the increase of or reducing carbon emissions is irrelevant.

The cause is the continuing increase in the concentration of water vapor, the primary greenhouse gas (GHG) with an average heating power significantly greater than CO_2. As the annual average water vapor concentration changes, the average annual greenhouse heating from water vapor, varies year to year.

As shown below, the changes in the concentration of water vapor are driven in an autonomous positive feedback loop between evaporation variability as a result of changes in water vapor surface heating, WV, driving changes in the average global atmospheric concentration of water vapor and therefore, water vapor surface heating.

Until that is understood, appropriate solutions found and implemented, this is an ever increasing threat to humankind. The good news is that this problem, including the reduction of past increases, at least theoretically, lends itself to solutions.

Figure 1 sets out the average global temperature record [1] [2] [3]. The variability is significant, real and not "noise" in the data. (The data underlying **Figure 1** is set out in **Table S1**, which like all of the charts in this paper is set out in the referenced Tables in **Appendix 2**, Supplementary Materials).

Background—The Physics of Climate Change

As illustrated in **Figure 2**, Earth's surface is warmed by the Sun and the greenhouse gases (GHG) and cooled by surface radiation, evaporation and thermal convection. As shown, at steady state, the total heating of 494 Wm^{-2} was equal to the power of and in balance with the surface radiation, evaporation, thermal convection and the sub-surface heating of the sea of 493.9 Wm^{-2}.

Between 1880 and 2019, the energy of Earth's land surface increased by 0.7%, an average increase of 0.005% per year, which is greater than the increase in the surface energy of the seas. No appreciable fraction of the radiant energy heating the surface is stored in the land. Therefore, determining the average annual

change in average global temperature from a change in average total heating is a straightforward exercise in thermodynamics. Deduct the percentage of total heating that drives evaporation and thermal convection and, given that the average surface radiation, Rad_U, cannot exceed the remaining net heating, NaH, for small changes in net heating, the change in the average surface temperature from temperature T_o is,

$$\Delta T = \mathrm{NaH}\big/\left(4\sigma T_o^3\right) \,^\circ\mathrm{C}$$

Climate Models

Various models of surface heating, based upon the supposition that changes in the concentration of CO_2 drive global warming, have been developed. These can be compared to the average global temperature record.
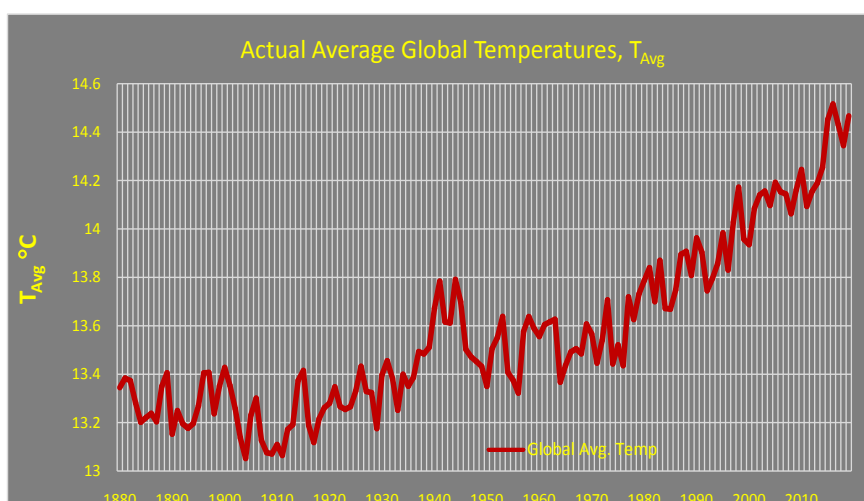
Figure 1. Average global temperature record [1] [2] [3] (**Table S1**).
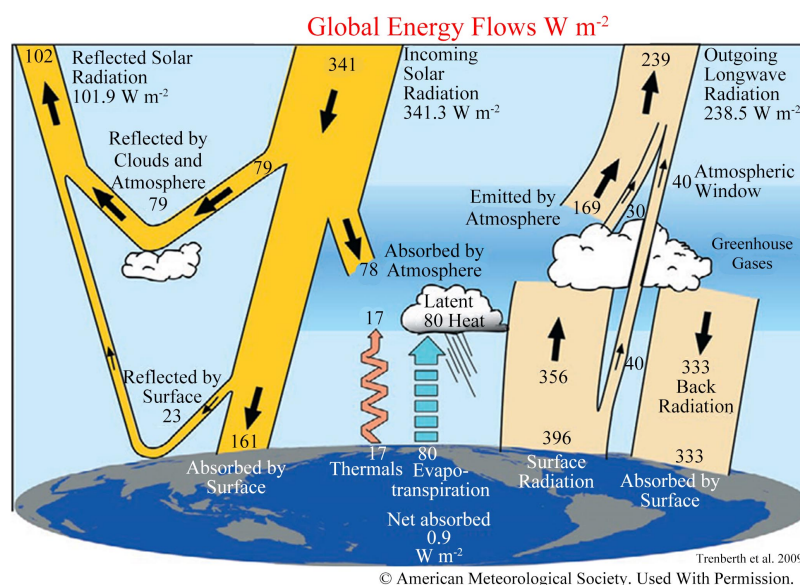
Figure 2. Global energy budget between Mar. 2000 and May 2004 $\mathrm{Wm^{-2}}$ [4]. (When referred to in this paper, it is assumed that this budget represents the year 2002).

Many of these models attempt to calculate the changes in heating from water vapor as a feedback response to changes in the theoretical heating from CO_2, when, since 1880, except for the period 1900-1903, the concentration of CO_2 [5] [6], thus the theoretical heating, increased year over year, while out of the 139 changes in temperature, there were 64 reductions in total heating. A year over year increase in heating from CO_2 cannot cause a reduction in heating as a feedback effect one year and an increase in another.

Referring to **Figure 3**, that some of these CO_2 models are wrong is clear from the fact that they calculate temperatures measurably greater than actual. For each year, the average global surface temperature is at the temperature the average net absorbed heating, NaH (total heating less the power driving evaporation and thermal convection) can drive. For the modeled surface temperature to exceed the actual surface temperature would require the IR radiation emitted by the surface, which is directly proportional to the surface temperature raised to the fourth power, to exceed the actual net absorbed heating, a violation of Kirchhoff's law of thermal radiation and the first law of thermodynamics. The physics underlying models that return such results and these models are facially incorrect.

Many individual models show:

1) year to year variances greater than 20% of the actual year to year temperature increase between 1880 and 2018;

2) increases in temperature when the average temperature declined.

In addition, no published model tracks even the 10 largest year to year variations in average global temperature.

These hindsight comparisons illustrate the failings of many of these models.
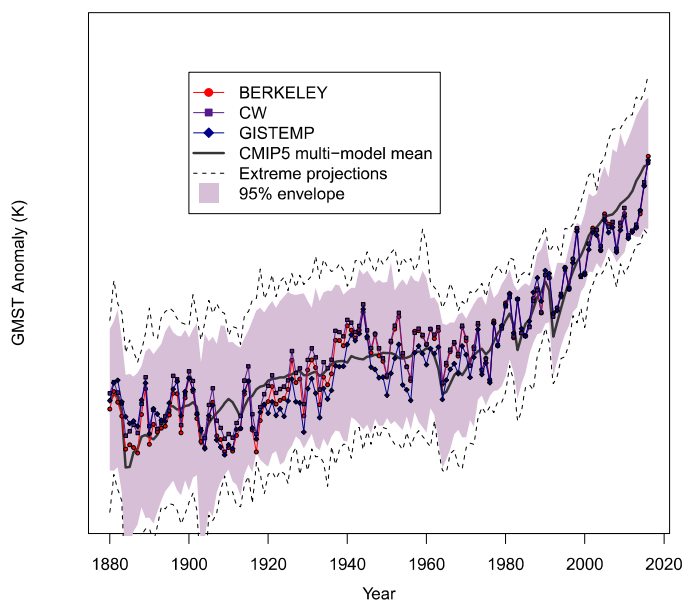
Figure 3. Typical results of computer models of changes in average global temperature [7] (p. 10, Figure 3(a)).

The reason that the calculated changes in heating, ΔTH_{CO2}, from changes in the concentration of CO_2, C, applying this expression,

$$\Delta TH_{CO2} = 5.35 \ln\left(C/C_o\right) \quad [8]$$

are referred to as theoretical, is that the results of this study demonstrate that, in actuality, changes in the concentration of CO_2 have no measurable effect on changes in average global temperature, therefore this expression significantly overstates the changes in heating that changes in CO_2 can drive.

New Principles

Therefore, new Principles to first determine changes in the average concentration of water vapor and then the changes in heating and surface temperature these changes drive, are set out. (The derivation of all of these principles is set out in **Appendix 1**).

Like CO_2 and all greenhouse gases, the heating impact of water vapor is a function of its atmospheric concentration, but there are no methods set out in the literature to correctly determine changes in the average concentration of water vapor.

Therefore, wholly new Principles of climate physics for calculating changes in the concentration of water vapor and water vapor heating and resulting changes in average global temperature have been developed. The results of the application of these principles prove that:

1) The determination of changes in the concentration of water vapor match and are consistent with published data;

2) Changes in average global temperature are driven by and are directly proportional to changes in the concentration of water vapor matching the historic record from 1880-2019 with ±0.14% accuracy;

3) Climate change is not driven by changes in the concentration of carbon dioxide, nor are changes in water vapor heating a feedback response to, related to or a function of, changes in heating from CO_2;

4) Instead, evaporation in excess of precipitation and water vapor heating have been in an autonomous positive feedback loop driving a 14% increase in the concentration of water vapor and a 3% increase in water vapor heating since 1976 which accounts for the increase in average global temperature since then;

5) While affected by sea surface temperature, since 1976, evaporation has been primarily a function of the changes in total heating, absorbing, on average, 64% of the changes in heating of the seas.

Changes in the Concentration of Water Vapor

Changes in the concentration of water vapor, total precipitable water, ΔTPW, are determined from the NOAA data [1] [2] set out in **Table S1** as,

$$\Delta TPW = 0.157\Delta TH + 17.53\left\{ e^{\left[0.0686(SSTo+\Delta SST-288)\right]} - e^{\left[0.0686(SSTo-288)\right]} \right\} \text{ kg} \cdot \text{m}^{-2} \quad (1)$$

where TH is the average total solar and greenhouse gas (GHG) heating, Wm^{-2} And SST is the global average sea surface temperature, K.

A comparison of the percentage changes in average global temperature and the concentration of water vapor plotted on a 53% relatively reduced scale is set out in **Figure 4**. The scaled changes in the concentration of water vapor, ΔTPW, closely match each and every one of the 139 annual percentage changes in average global temperature, ΔT_{Avg}. The correlation coefficient is 0.997.

This is climate change explained.

Computed Change in Concentration of Water Vapor

That Equation (1) is correct can also be seen from **Figure 5** showing the average global concentration of water vapor and the computed concentration of water vapor, TPW_{Tot}, calculated in accordance with Equation (1) for the years 1996-2007, set out in **Table 1** and shown as green dots, along with their trendline (dashed red line).

Further confirmation of the computed changes in the concentration of water vapor follows:

1) "In the SSM/I data, (W_o) increases over the period 1988-2006 by 0.41 kg/m^2 per decade, with a 95% confidence interval of ±0.21 kg/m^2 per decade" [9].

2) The concentration of water vapor from Equation (1) between 1988 and 2012 is shown in **Figure 6**.

The trendline for the computed results for, TPW_{Tot}, from Equation (1) for the period 1988 to 2006 as set out in **Table S2** and shown in **Figure 6**, is 0.533 kg·m^{-2} per decade, well within the confidence interval of ±0.21 kg/m^2 per decade around 0.41 kg/m^2.

3) On July 1, 2010, "The precipitable water ranged from 0.1 to 78.1 mm with a global average of 21.6 mm" [10]. From Equation (1), in 2010 the global average concentration was 20.8 mm.

4) Evaporation and Precipitation—See discussion of **Figure S1** & **Figure S2** in **Appendix 2**, Supplementary Materials, which shows that there is no significant disagreement between the computed results for changes in evaporation, ΔEV, relative to precipitation, ΔPR, for the period 1901-2015, where

$$\Delta EV = \Delta TPW + \Delta PR .$$
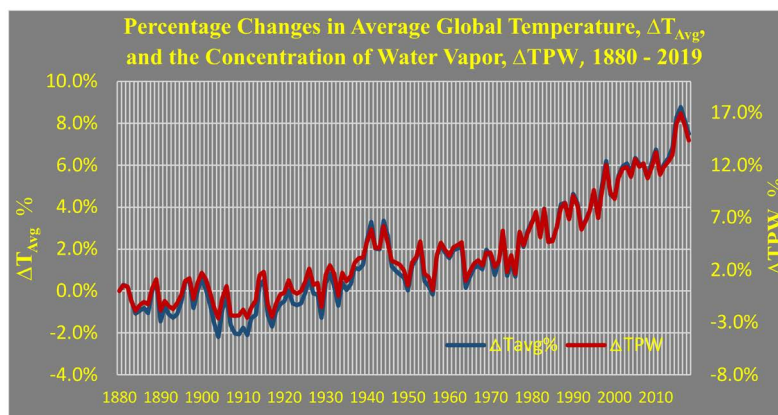
Figure 4. Percentage changes in average global temperature and the concentration of water vapor, ΔTPW [1] [2] [3] (**Table S2**).
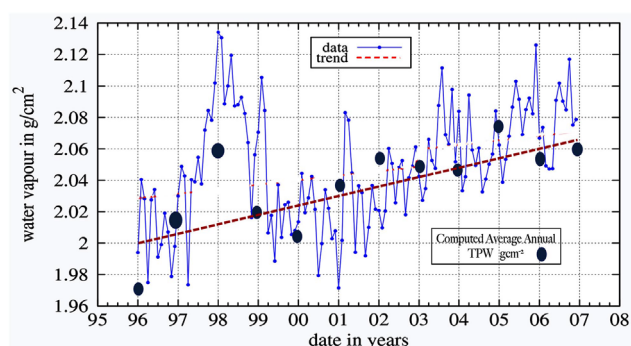
Figure 5. Results of the Application of Equation (1) are set out in **Table 1** in gm·cm⁻² and shown as Green Dots for the period 1996-2007 [11] (p. 498, **Figure 8** with original trendline regarding autocorrelations removed).
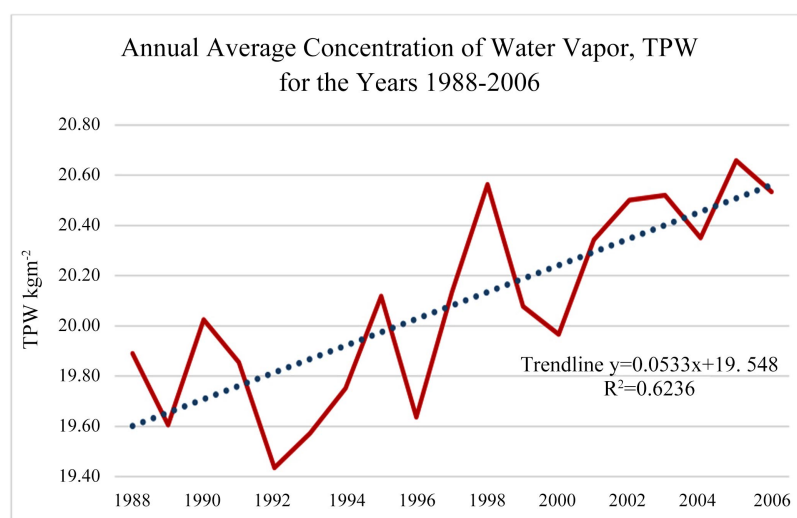
Figure 6. Concentration of Water Vapor for the Period 1988-2006 (**Table S2**).

Table 1. Concentration of water vapor.

Year	gm·cm⁻²
1996	1.96
1997	2.01
1998	2.06
1999	2.01
2000	2.00
2001	2.03
2002	2.05
2003	2.05
2004	2.04
2005	2.07
2006	2.05
2007	2.06

5) The match in changes in the average global temperature from Equation (5) based on the calculated changes in the concentration of water vapor from Equation (1).

In sum, this proves that Equation (1) for calculating the concentration of water vapor is correct.

Changes in Water Vapor Heating

The new principle for determining changes in average global water vapor heating is:

$$\Delta WV = 73.3 \ln\left(1 + \Delta TPW/TPW_o\right) W \cdot m^{-2} \tag{2}$$

If changes in water vapor heating were a feedback response to increases in heating from CO_2, ΔTH_{CO2}, as some assert, a plot of changes in water vapor heating, ΔWV, should show a growing increase as ΔTH_{CO2} increases. The calculated relationship between the two is shown in Figure 7.

Changes in Temperature and Water Vapor Heating are Unrelated to Changes in Heating from CO_2

Referring to Figure 7, while attention is typically focused on and comparisons are made to long term trends in the average global temperature record, the actual variable changes in temperature are significant.

For example, in just one year, 1913-1914, the average global temperature increased by 0.16°C, 14% of the 1.1°C change over the 139 year period between 1880 and 2019, a rate of change 22 times as great as the average long-term rate of change. This 0.16°C rise required an increase in total heating of 1.7 Wm^{-2}, to which the change in radiative heating from CO_2, ΔTH_{CO2}, theoretically contributed no more than 0.004 Wm^{-2}, 0.24%. Further, over a period of 35 years, there was an increase of 0.77°C between 1909 and 1944, 97% of the 0.8°C change over the period between 1880 and 2019 and a rate of change nearly three times as great as the long-term rate of change. This 0.77°C increase required an increase in total heating of 4.2 Wm^{-2}, to which ΔTH_{CO2} theoretically contributed no more than 0.16 Wm^{-2}, 4%. This variability is clearly significant.
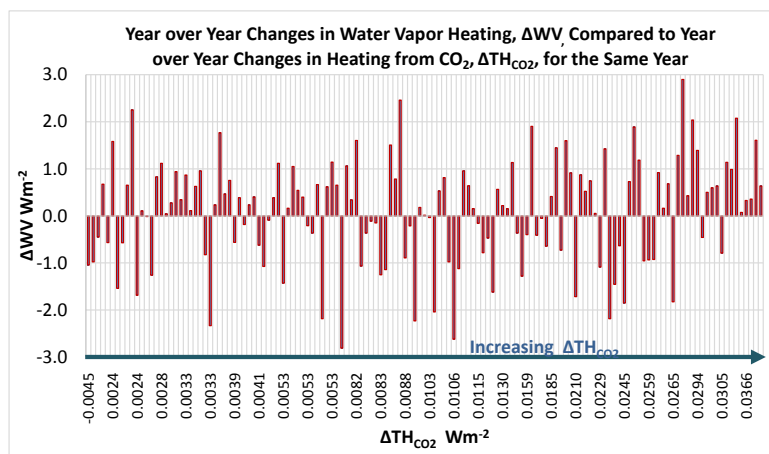
Figure 7. Year over year changes in water vapor heating, ΔWV, compared to year over year changes in heating from CO_2, ΔTH_{CO2}, for the same year (Table S3).

The assertion is made that water vapor heating is a feedback response to changes in heating from CO_2 and provides the change in heating necessary to drive such feedback responses and resulting changes in temperature.

A not atypical observation when it comes to global warming is:

"*Taken on its own, water vapour feedback roughly doubles the amount of CO_2 warming*" [12].

Doubling would hardly compensate for the need to increase CO_2 heating by a multiple of 25 in one case or by a multiple of 425 in another, as required in the examples discussed above.

Given that changes in TH_{CO_2}, alone, can theoretically account for no more than 15% of global warming between 1976 and 2019, the claim is made that the difference is made up by water vapor heating as a feedback response to changes in ΔTH_{CO_2}.

Common misperceptions:

- Increases in CO_2 increase heating increase water vapor, a greenhouse gas which amplifies warming.

- Without an independent increase in heating, the concentration of water vapor cannot increase.

- And after comments such as "… *rising average temperature increases evaporation rates and atmospheric water vapor concentrations*," a common follow on is something to the effect that, since, "*Water vapor cannot itself catalyze temperature increases in the short time* (*estimated at around* 10 *days*) *that a discrete water vapor influx would remain before precipitating out. A sustained increase in tropospheric water vapor requires a strong external forcing to provide the initial temperature increase* [13]."

This ignores the fact, that, when the average precipitative rate is less than the average evaporative rate, the concentration of water vapor, TPW, is increased and, therefore, water vapor heating, WV.

This does not require any increase in heating from ΔTH_{CO_2}, much less "a strong external forcing". (See discussion with respect to **Figure 15**).

These comments may stem from the belief that an increase in TPW requires a corresponding increase in evaporation.

That is not correct.

After 1976, the average annual increase of TPW over the 1976 concentration of water vapor of 18.67 kg·m⁻² was 0.05 kg·m⁻²/yr. or 0.29%. From Equation (5), the resulting annual increase in average global temperature,

$$\Delta T_{\text{Avg}} = 0.4 \Delta \text{TPW} \, ^\circ\text{C}$$

$$\Delta T_{\text{Avg}} = 0.4 \times 0.05 = 0.02 \, ^\circ\text{C}/\text{yr}.$$

over 43 years for a total of:

$$\Delta T_{\text{AvgToT}} = 43 \times 0.02 = 0.86 \, ^\circ\text{C} = \text{the actual average change of } 0.86 \, ^\circ\text{C}$$

Further proof of the validity of these water vapor concentration and water vapor heating calculations and the impact on climate change.

After 1976, there was a continuing slight imbalance between average precipitation and evaporation, with annual precipitation of 0.06 mm·m^{-2}/yr. < evaporation. For an annual average precipitation of 949 mm·m^{-2}, this is 0.007% of average annual precipitation. If this were all due to an increase in cumulative evaporation, this would at most require a 0.007% increase in annual evaporation over precipitation.

However, if it were thought that in order to achieve the average annual increase of TPW over the 1976 concentration of water of 0.33% it would require evaporation to increase by 0.33%/yr., that would be

$$0.0033 \times 949 = 3.13 \text{ mm} \cdot \text{m}^{-2} \text{ or kg} \cdot \text{m}^{-2}$$

Then the resulting increase in temperature would be an annual increase of 1.15°C

$$\Delta T_{Avg} = 0.4 \times 3.13 = 1.25°C$$

compared to actual annual increase of 0.021°C/yr., as determined above, or

$$1.25/0.021 = 60$$

60 times greater or over the entire 43 year period, this would be an increase of 47°C. Clearly any such assumption would be incorrect.

This author appears to seek to downplay the role of water vapor with statements like, "*the amount held in the atmosphere as water vapour varies greatly in just hours and days as result of the prevailing weather in any location. So even though water vapour is the greatest greenhouse gas, it is relatively short-lived*" [12]. This ignores the fact that, just since 1988, "*Satellites have observed an increase in atmospheric water vapour by about* 0.41 *kg/m^2 per decade since* 1988" [14].

The fact that there is a changeover is irrelevant. It is the average global concentration of water vapor that is important and that changes gradually. The global TPW average in 2019 was 21.4 kg·m^{-2} (**Table S2**).

Further, if changes in water vapor heating were a function of changes in TH_{CO2}, a change in radiative heating from CO_2 should cause a predictable change in water vapor heating and therefore temperature change, such as,

$$\Delta T_{Avg} = \lambda \Delta TH_{CO2}$$

where λ is a constant.

In the above case, for 1913-1914 and 1909 and 1944, would require that $\lambda = 425$ in one case and 25 in another. This formulation is clearly incorrect.

Water Vapor Heating is Unaffected by the Theoretical Changes in Heating from CO$_2$

To test just this basic concept, for the same year, the year over year theoretical changes in ΔTH_{CO2} and changes in total water vapor heating, ΔWV, determined by Equation (2) are compared in **Figure 7**, with increasing ΔTH_{CO2} plotted from left to right on the horizontal axis. This is set out in **Table S3**.

If year over year changes in water vapor heating, ΔWV were a feedback re-

sponse to year over year increases in ΔTH_{CO2}, the plot should show a growing increase in year over year changes in water vapor heating, ΔWV, as ΔTH_{CO2} increases.

There is no such correlation. For virtually the same year over year change in CO_2 heating, the change in water vapor heating can be quite different. For example, for a theoretical YoY change from 0.002402 to 0.002405 Wm^{-2} (both 0.002 Wm^{-2}) in CO_2 heating, the YoY change in water vapor heating, ΔWV, varied from a reduction of -1.54 Wm^{-2} to an increase of 2.25 Wm^{-2} and for a theoretical YoY change from 0.00879 to 00.00883 Wm^{-2} YoY in CO_2 heating, (both 0.009 Wm^{-2}) the YoY change in water vapor heating, ΔWV, varied from an increase of 2.46 to a reduction of -2.23 Wm^{-2}.

While, except for the period 1900-2003, the theoretical heating from CO_2 increased year over year, year over year water vapor heating declined, 40% of the time. This is set out in Table S3.

A superficial examination of these changes clearly shows that there is no correlation between the theoretical changes in heating from CO_2 and changes in water vapor heating. This is random. The same is true if percentage changes in year over year average global temperatures, ΔT_{Avg} are plotted against year over year percentage changes in the concentration of CO_2 for the same year. See Table S3. These changes and changes in ΔWV, are not driven, triggered or caused by, or a feedback response to, changes in ΔTH_{CO2}. They are autonomous, wholly unrelated.

This also means that if the formula,

$$\Delta T_{Avg} = \lambda \Delta TH_{CO2}$$

were correct, ΔT_{Avg} could be negative only during years 1900-1903, when the concentration of CO_2 declined slightly. That is not the case. Except for years 1900-1903, for the other 53 reductions in water vapor heating, there are no reductions in heating from CO_2.

The changes in the concentration of water vapor and water vapor heating determined by these new principles are shown to be wholly independent of and not feedback to changes in CO_2 heating.

Changes in Average Global Temperature

As noted above, the theoretical direct heating effect, ΔTH_{CO2}, from changes in the concentration, C, of CO_2, alone, is [8],

$$\Delta TH_{CO2} = 5.35 \ln \left(C/C_o \right)$$

Including this factor along with the contributions from water vapor heating, the expression for determining changes in the average global temperature ΔT_{Avg}, would be,

$$\Delta T_{Avg} = 0.096 \left(5.35 \ln \left(C/C_o \right) + \Delta WV_{Tot} \right) \, ^\circ C \tag{3}$$

where C is the concentration of CO_2.

From NOAA data [1] [2], the results of the application of Equation (3) are shown in Figure 8.
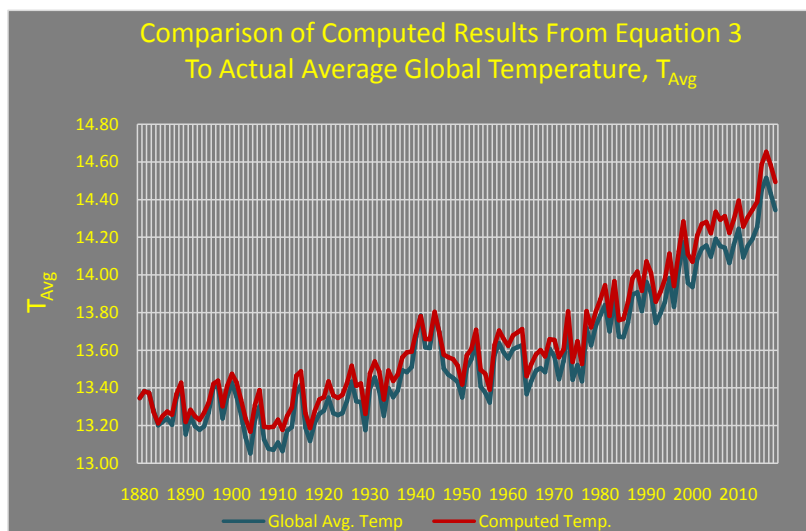
Figure 8. Comparison between calculated changes in the average global temperature applying Equation (3) and the record [1] [2] [3] (**Table S4**).

Between 1880 and 2019, the theoretical increase in heating from the increase in CO_2 was 1.8 Wm^{-2}; from Equation (2) for water vapor, it was 11.3 Wm^{-2}.

Compared to the record, the results set out in **Figure 8** are, on average, far more accurate than published models, within 0.64%.

Percentage temperature accuracy is measured as the absolute value of the actual average global temperature less the computed average global temperature, which result is divided by the Actual Average Global Temperature measured in Celsius.

$$\left|\left(T_{\text{Avg}} - T_{\text{AvgComp}}\right)\right|\Big/T_{\text{Avg}}$$

Average temperature accuracy is the average of the values for each determination.

While, with 0.64% accuracy, this is far more accurate than any published models and clearly illustrates the impact of changes in the concentration of water vapor, the calculated temperatures exceed actual 97% of the time and by as much a 0.16°C, 14% of the total increase between 1880 and 2019. Therefore, this formulation does not comply with Kirchhoff's law of thermal radiation and the First Law of Thermodynamics, thus, Equation (3) is incorrect.

Water Vapor Heating

While the CO_2 heating component of Equation (3)

$$\Delta \text{TH}_{\text{CO2}} = 5.35 \ln\left(C/C_o\right)$$

is consistent with the literature, it is based on the assumption that the absorption of the IR radiation from Earth's surface by CO_2 occurs without significant interference from the other GHG.

Analyzing the results of the application of Equation (3), it becomes apparent that the increase over actual primarily results from the inclusion of CO_2 heating.

When the CO_2 dependent function is removed from Equation (3), it becomes,

$$\Delta T_{\text{Avg}} = 0.096 \times 73.3 \ln \left(1 + \Delta \text{TPW}_{\text{Tot}} / \text{TPW}_{\text{Toto}} \right) \,^\circ\text{C} \qquad (4)$$

The results are set out in Figure 9.

Excluding CO_2, the results from the application of Equation (4) are mathematically more accurate, within 0.27% on average. This clearly shows the calculated effect from water vapor heating, alone.

However, while excluding the effects of CO_2, Equation (4) still overstates the temperature increase in violation of Kirchoff's law and the first law of thermodynamics. 114 out of 139 or 82% are higher than actual, some as great as 0.1°C,. Therefore, Equation (4) is also not advanced as correct.

Why?

The Effects of Relative Emissivity and Overlapping Absorption Bands

The theoretical GHG back radiation in 2002 was 333 Wm^{-2} with 301 Wm^{-2} and 32 Wm^{-2}, from H_2O and CO_2, respectively, a difference of a factor of 10 and between 2002 and 2019, the theoretical heating from CO_2 increased by 0.5 Wm^{-2} and water vapor by 3.4 Wm^{-2}, the latter the equal to the total increase in back radiation. See Table S3.

Figure 10 shows that there is significant absorption band overlap between the absorption wave lengths for CO_2 and water vapor.

The overlapping wave lengths at which water vapor and CO_2 absorb surface radiation are dominated by water vapor. This suggests that water vapor can interfere with IR absorption by CO_2.

This is consistent with a finding by Evans [15] comparing three summer measurement of GHG heating to winter measurements in Peterborough, Ontario: "The H_2O flux has increased from about 100 W/m^2 to 200 W/m^2. CO_2 is reduced from 33 W/m^2 to 11 W/m^2" p. 4 and Soares [16] who found no correlation between current changes in the concentration of CO_2 and changes in surface temperature, but a correlation of 0.5 with changes in specific humidity. Reviewing various data for periods prior to 2010, the author states:

"*The main conclusion one arrives at the analysis is that CO_2 has not a causal relation with global warming and it is not powerful enough to cause the historical changes in temperature that were observed … The greenhouse effect of the CO_2 is very small compared to the water vapor because the absorbing effect is already realized with its historical values. So, the reduction of the outcoming long wave radiation window is not a consequence of current [CO_2] enrichment …*" [16] (p. 111).

Possible explanations:

- In 2009 CO_2 was at a concentration of 387 ppm and water vapor, on average, 2662 ppmv, which is consistent with the total precipitable water for 2009 of 20.56 kg·m^{-2} ~ 7 times greater than CO_2. (The authors [17] use 10,200 ppm—water vapor at an average of 1%. If this were correct, these results would be increased by a factor of 3.8).
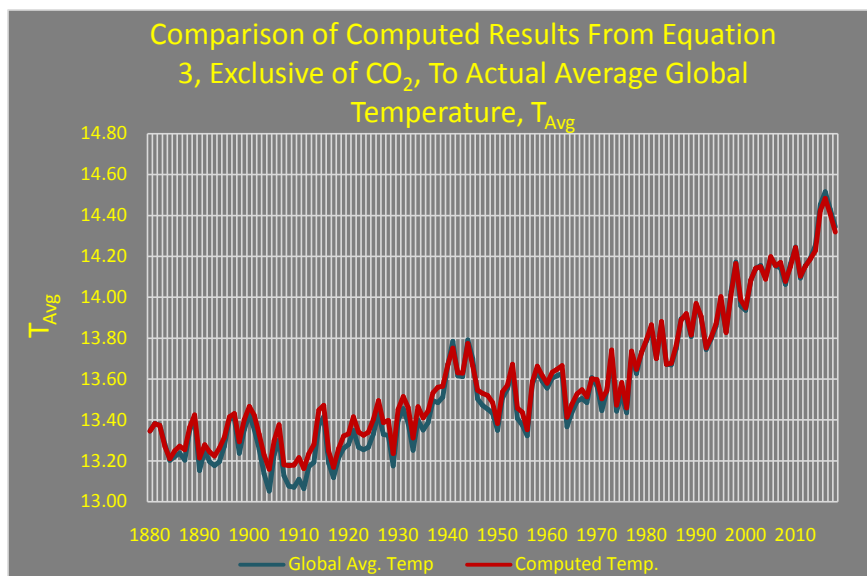
Figure 9. Results of the application of Equation (3) eliminating changes in heating from CO_2, as a factor [1] [2] [3] (**Table S4**).
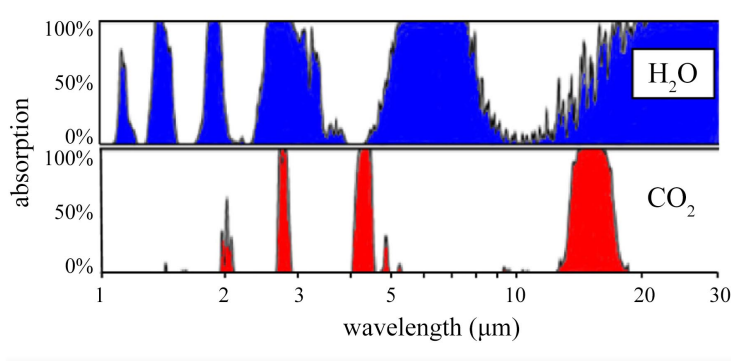
Figure 10. Atmospheric absorption spectra for water vapor and CO_2 [18] (**Figure 3**).

- Imagine a stream of photons emitted from Earth's surface at an absorption wavelength common to both CO_2 and H_2O approaching an atmosphere containing 2662 ppmv water molecules and 387 ppmv molecules of CO_2, all on the same plane. It would appear that the odds of that photon interacting with a molecule of CO_2 would be 387/2662 or 14%.

- However, with each water vapor molecule 43 times more efficient in absorbing and emitting energy, the odds would be reduced to 14%/43 or 0.3%. See [17] (p. 351, **Figure 4**), where the authors state: "Another important point is how fast reradiation occurs. The faster the gas molecule emits the stored energy, the sooner it is ready to accept a new portion of electromagnetic radiation, and so the more effective this greenhouse gas is. Thus, in determining the effectiveness of a greenhouse gas, it is important to know not only the absorbed energy but also the rate of transfer of electromagnetic radiation", which the authors gauge as its "efficiency".

- See [17] (p. 351, Figure 3(a)). This shows that the emissivity (therefore the absorptivity) of an H_2O molecule is 60 times greater than a CO_2 molecule, on a molecule to molecule comparison. Thus, the odds of a water molecule interacting with a photon are 60 times greater than an interaction with a molecule of CO_2.

- Finally note that, "The average frequency of emission for CO_2 is 1.6 times lower than that of the other considered gases. Therefore, the energy efficiency of the resulting CO_2 emission, proportional to ω, is almost five times lower than that of the other gases." See [17] (p. 349, Figure 2).

- Thus, assuming no effects of altitude, the relative likelihood that effects of changes in the concentration of CO_2 would be felt at the surface would be reduced to less than 0.01%, well within the error band of Equation (5). Hence, in 2009, in accordance with the Equation (5), the heating effect of changes in the concentration of water vapor should have effectively accounted for the average changes in heating.

Regardless of whether these explanations are correct or account for the entire difference between water vapor and CO_2 heating, what is clear from Equation (5), changes in the concentration of water vapor, alone, control global warming.

There Is a Strong Correlation between Changes in ΔT_{Avg} and Changes in Concentration of Water Vapor, ΔTPW

While there is no correlation between changes in the concentration of CO_2 and the actual changes in the average global temperature or in changes in TH_{CO2} and changes in water vapor heating, as shown in Figure 4, there is a clear correlation between changes in the average global temperature from temperature records commencing in 1880 [3] and calculated changes in the concentration of water vapor from Equation (1). See Figure 11.
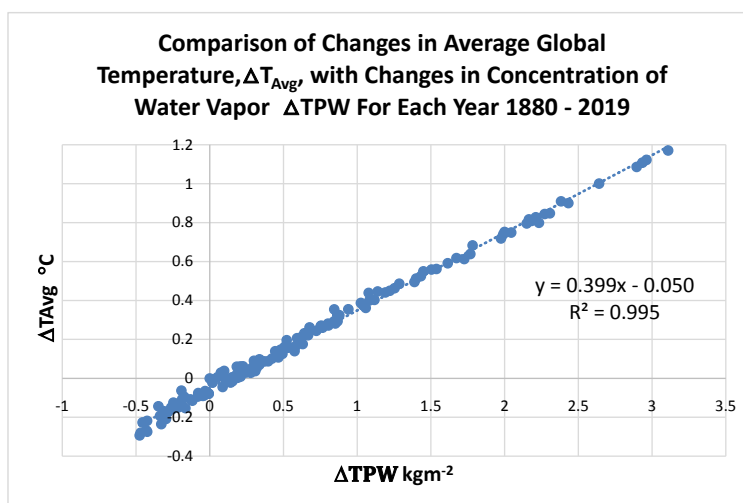
Figure 11. Correlation of changes in average global temperature with changes in concentration of water vapor [1] [2] [3] (Table S2 Appendix 2, Supplementary Materials).

This relationship is:

$$\Delta T_{Avg} = 0.4\Delta TPW - 0.05\,^{\circ}C \tag{5}$$

with an R^2 of 0.9953.

This correlation is exclusive of heating from CO_2.

The results of employing this relationship to determine the average global temperature is shown in Figure 12.

While the theoretical heating by CO_2 is also removed in Equation (4), Equation (5) is based upon a comparison to the actual temperature record.

The results from the application of Equation (5) have a correlation coefficient of 0.9976, exceeding the average global temperature 68% of the time, but never by more by more than 0.05°C, which is itself well within the error band of average global temperature estimates for the period in which this occurred, 1904-1910 [19].

Equation (5) captures the relationship between changes in the concentration of water vapor and the average global temperature—demonstrating the mechanism driving climate change and at an average accuracy of ±0.14%, validating the physics set out herein. It is, therefore, is advanced as The Principle of Climate Physics accounting for climate change, which along with the foregoing, demonstrates that:

1) Changes in the concentration of water vapor, not CO_2, drive climate change;

2) Equation (1) is a valid principle of climate physics;

3) Changes in the concentration of water vapor are sufficient, in and of themselves, to drive all of the changes in heating;
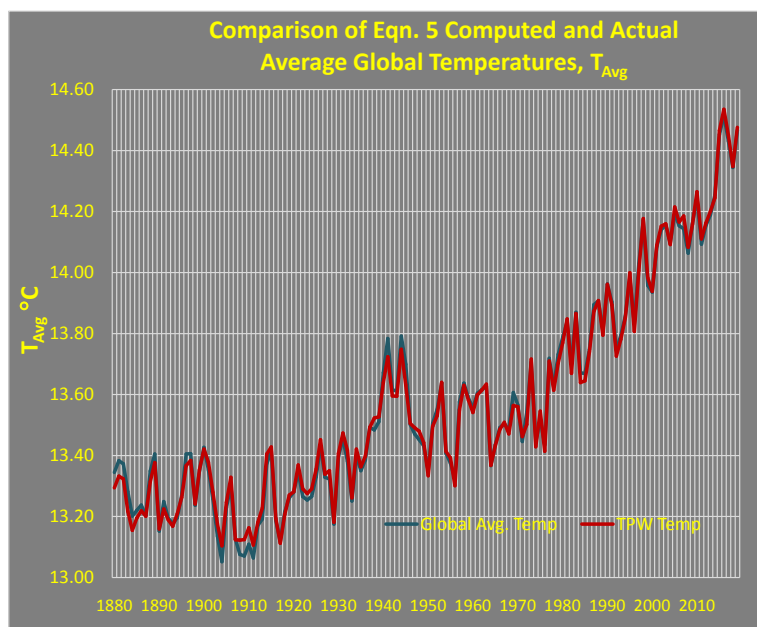
Figure 12. Comparison of the results of the application of the new principles, Equations (1) & (5), in red, to the average global temperature record, in blue, for the period 1880-2019 [1] [2] [3] (**Table S4**).

4) These changes in water vapor heating and concentration, together with changes in the relative rates of evaporation and precipitation, are sufficient to autonomously and independently drive climate change independently of any other climate factors, in a positive feedback loop, as discussed below.

This is Why I Care

Water Vapor is The Key Factor

In 1977 was the year of the largest single year increase in the concentration of water vapor since 1880, 0.76 kg·m^{-2} or 4%, which was the start of a major and continuing increase. Before that, the concentration of water vapor increased at a rate of 0.002 kg·m^{-2} per year and after 1977 at a rate of 0.06 kg·m^{-2} per year, corresponding to an increase of 3.3% per decade.

The average global temperature increased at a rate ~ 25 times greater than the prior 96 year period.

While there is variation and the rate of precipitation for some years exceeded the evaporative rate, since 1977, on average, the increase in the rate of precipitation was less than the average increase in the rate of evaporation. Thus, the precipitation/evaporation imbalance that arose in 1977 was, on average, maintained as global warming commenced in earnest.

A simple linear regression:

$$\Delta T_{\text{Avg}}/\text{decade} = 0.2°\text{C}/\text{decade}$$

matches these results with an R^2 of 0.85. This rate of increase is 4.3 times greater than the rate of increase for the period 1880-1975.

Set out in Figure 13 is a chart of year over year percentage changes in global average temperature, ΔT_{Avg}, since 1976, shown in blue. Shown in red is a curve fit to this data:

$$\Delta T_{\text{AvgN}} = \left\{0.245 + 0.02(\text{Yr} - 1976) + 0.11\sin\left[1.8(\text{Yr} - 1976)\right]\right\}\Big/ T_{\text{Avg1976}} \atop - 0.0257 - \Delta T_{\text{AvgN}-1} \tag{22}$$
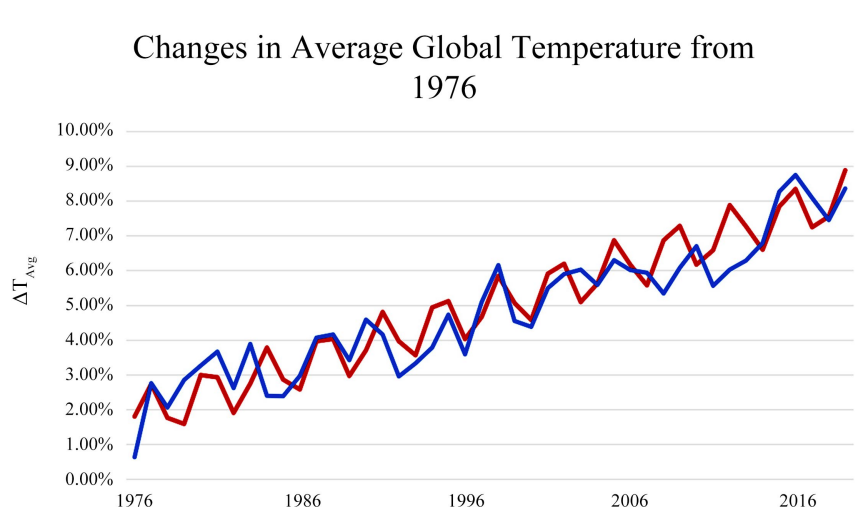
Figure 13. Change in average global temperature 1976-2019 [1] [2] [3] (Table S1).

This expression has a correlation coefficient of 0.925. This would predict an increase of an additional 1.4°C, by the end of the century, 0.2°C less than the linear regression set out in **Figure 14**.

From **Figure 4**, **Figure 11**, **Figure 14**, this chart and this expression, it is evident that this increase in average global temperature ΔT_{Avg} is ongoing and the result of the change in average global water vapor concentration, in a roughly 3.5 year, autonomous, positive feedback cycle with changes in the concentration of water vapor, ΔTPW.

As shown in **Figure 15**, evaporation and water vapor heating are in an autonomous, positive feedback loop. As the concentration of water vapor increases, water vapor heating and evaporation increase.

"The trends of TPW in our data set, which are heavily biased toward middle latitudes … are higher than previous global estimates over earlier time periods by about a factor of 4 to 6. As also shown by the regional distribution of TPW trends …, the large positive trends in these latitudes, … are a strong confirmation of the water vapor-temperature feedback in a warming global atmosphere …" [20].
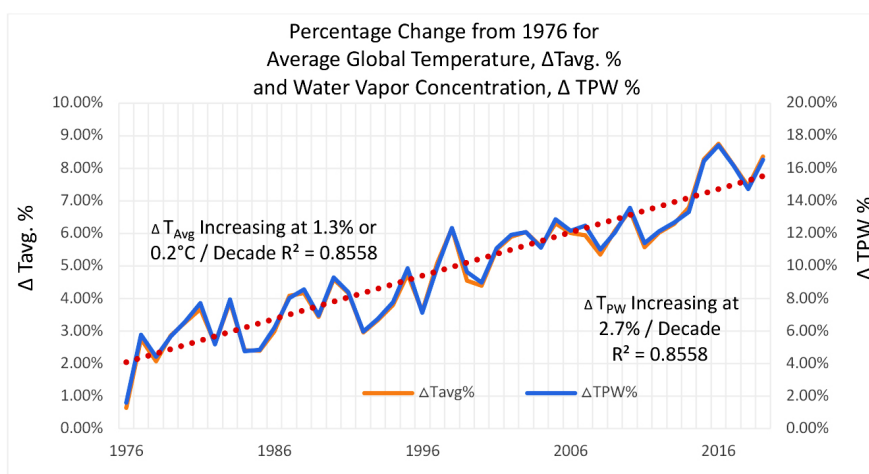
Figure 14. Changes in average global temperature and the concentration of water vapor between 1976 and 2019 [1] [2] [3] (**Table S2**).
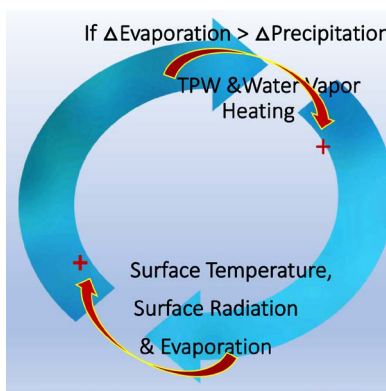
Figure 15. Self-sustaining increase in heating.

If the rate of evaporation exceeds precipitation, the concentration of water vapor increases; on and on. The heating from water vapor drives a rate of evaporation sufficient to maintain this totally autonomous cycle.

A characteristic of positive feedback loops is that, absent external intervention, they continue. Therefore, to the extent evaporation exceeds precipitation, this continues. The result—every 50 years there will be a 1°C increase driven by changes in the concentration of water vapor.

Limiting or reducing carbon emissions can have no effect.

2. Discussion

Temperature Responses of Land and Seas

In addition to determining changes in the concentration of water vapor without regard to changes in the concentration of CO_2, these new principles take into consideration the significant differences in the temperature response of the seas compared to land for the same changes in total heating resulting from their differences in evaporative responses.

See **Figure 16** and **Table 2** & **Table 3**, which show that the average global temperature of land and ocean change at different rates in response to the same changes in total heating.

A major factor driving this difference is the response of the seas to changes in total heating, with 64% of the change in total heating of the seas driving evaporation, while for land 8% is lost to evaporation and 18% to thermal convection in the response to changes in total heating. See **Table 2** and **Table S3**. This explains the comparative lag that is evident in **Figure 16**. Therefore, when determining changes in water vapor concentration, the effect of changes in total heating on evaporation, in addition to changes in sea surface temperature, SST, must be taken into account.
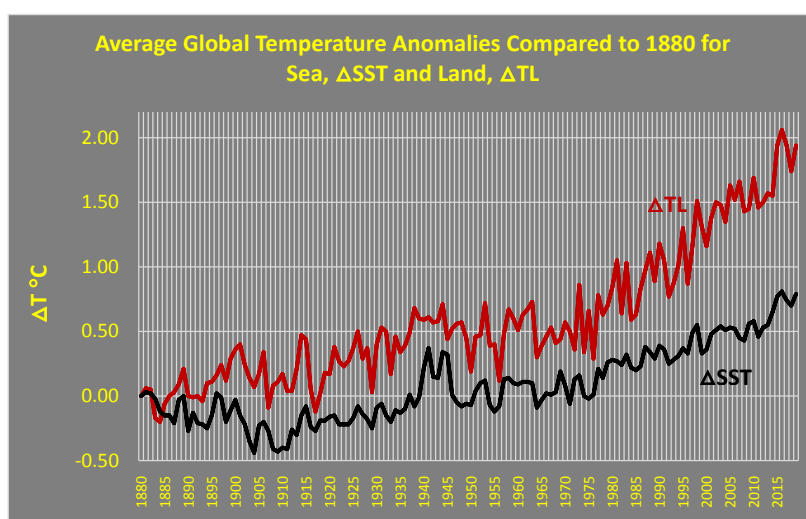
Figure 16. Global surface annual mean temperature anomalies 1880-2019 [1] [2] [3] (**Table S1**).

As shown in Figure 2, on average and at steady state temperatures, evaporation and convection together reduce the total heating, TH, of 494 Wm^{-2} by 97 Wm^{-2} or 20%, a significant fraction. The average net absorbed heating fraction, NaH, that drives the surface heating, is, therefore, 80% of TH, which for steady state temperature is denominated as the average steady state heating efficiency, Eff_{STAv}. If this were also true, not only for steady state, but for changes in total heating, the change in total heating between 1880 and 2019 required to drive the change in average global temperature could be gauged solely on the basis of the change in average global temperature. This would mean that the change in total heating required to drive the 1°C increase in average global temperature between 1880 and 2019, would be:

Table 2. Global average land, ocean and average steady state heating budgets for 1880, 1976 and 2002 (Wm^{-2}).

Year	1880	1976	2002
Total Heating (TH)	485	486	494
Radiant Emittance Rad_{UL}	389	390	396
Solar Radiation (Sol)	161	161	161
Back-Radiation (BR)	324	325	333
Evaporative Power ($Evap_{Avg}$)	78	78	80
Thermal Convection ($Conv_{Avg}$)	18	18	18
Eff_{Avg} Steady State	0.80	0.80	0.80
Land Heating Budget			
Year	1880	1976	2002
Total Heating (TH)	485	486	494
Radiant Emittance Rad_{UL}	354	356	362
Solar Radiation (Sol)	161	161	161
Back-Radiation (BR)	324	325	333
Evaporative Power ($Evap_L$)	41	41	42
Thermal Convection ($Conv_L$)	89	89	91
Eff_L Steady State	0.73	0.73	0.73
Ocean Heating Budget			
Year	1880	1976	2002
Total Heating (TH)	485	486	494
Radiant Emittance Rad_{UO}	394	394	397
Solar Radiation (Sol)	161	161	161
Back-Radiation (BR)	324	325	333
Evaporative Power ($Evap_O$)	89	91	96
Thermal Convection ($Conv_O$)	2	2	2
Eff_O Steady State	0.81	0.81	0.80

Table 3. Breakdown of the increase in the heating (Wm^{-2}) required for an increase in the global average land and global average ocean temperature between 1880-2002 and 1976-2002.

Global Average	1976-2002	1880-2002
Increase in the average global temperature (˚C)	0.7	0.8
Increase in total heating, ΔTH required for this increase in temperature Wm^{-2}	7.7	9.4
Increase in radiant emittance (ΔRad$_{UAvg}$) Wm^{-2}	5.6	7.2
Change in solar radiation (ΔSol) Wm^{-2}	0.0	0.0
Increase in back radiation (ΔBR) Wm^{-2}	7.7	9.4
Increase in evaporative power (ΔEvap$_{Avg}$) Wm^{-2}	1.8	1.6
Change in thermal convective power (ΔConv$_{Avg}$) Wm^{-2}	0.4	0.5
Eff $_{ΔTHTotAv}$	0.73	0.77
Land	1976-2002	1880-2002
Increase in the average global land temperature (˚C)	1.2	1.5
Increase in total heating, ΔTH required for this increase in land temperature Wm^{-2}	7.7	9.40
Increase in radiant emittance (ΔRad$_{UL}$) Wm^{-2}	6.2	7.5
Change in solar radiation (ΔSol) Wm^{-2}	0.0	0.0
Increase in back radiation (ΔBR) Wm^{-2}	7.7	9.4
Increase in evaporative power (ΔEvap$_{L}$) Wm^{-2}	0.0	0.0
Change in thermal convective power (ΔConv$_{L}$) Wm^{-2}	1.5	1.9
Eff$_{ΔTHTotL}$	0.80	0.80
Ocean	1976-2002	1880-2002
Increase in the average global ocean temperature (˚C)	0.5	0.5
Increase in total heating, ΔTH required for this increase in ocean temperature Wm^{-2}	7.7	9.4
Increase in radiant emittance (ΔRad$_{UO}$) Wm^{-2}	2.7	2.8
Change in solar radiation (ΔSol) Wm^{-2}	0.5	0.0
Increase in back radiation (ΔBR) Wm^{-2}	7.7	9.4
Increase in evaporative power (ΔEvap$_{O}$) Wm^{-2}	5.0	6.6
Change in thermal convective power (ΔConv$_{O}$) Wm^{-2}	0.0	0.0
Eff$_{ΔTHTotO}$	0.36	0.30

$$\Delta\text{TH} = \sigma\left(T_{\text{Avg2019}}^{4} - T_{\text{Avg1880}}^{4}\right)\Big/\text{Eff}_{\text{STAv}} = 5.67\times10^{-8}\left(289.46^{4} - 286.67^{4}\right)\Big/0.8$$

$$\Delta\text{TH} = 5.4 \text{ W}\cdot\text{m}^{-2}$$

where, *T* is the global average absolute temperature, K.

However, over the same time period, the increase in average global land tem-

perature was 1.94˚C. Referring to Table 2 & Table 3, the percentage reduction in heating for evaporation and thermal convection losses for land in response to changes in heating is 20%. Thus,

$$\Delta TH = \sigma \left(T_{L2019}^4 - T_{L1880}^4 \right) \Big/ Eff_{S\Delta THL} = 5.67 \times 10^{-8} \left(283.08^4 - 281.14^4 \right) \Big/ 0.8$$

$$\Delta TH = 12.35 \ W \cdot m^{-2}$$

Therefore, the total heating required to drive the 1.1˚C increase in average global temperature change is 12.35 Wm^{-2}, not 5.4 Wm^{-2}.

If there were no change in heating efficiency in response to changes in total heating, for the seas, using solely the change in ocean temperature, the required change in total heating to drive the 0.7˚C increase over this period, would be calculated as 4.3 Wm^{-2}, but the average total heating is the same, 12.35 Wm^{-2}.

Since 1976, changes in total heating, ΔTH, have been the primary driver of evaporation. The resulting increase in water vapor, $\Delta TPW_{\Delta TH}$ and water vapor heating, $\Delta WV_{\Delta TH}$, is the most significant change in heating, responsible, on average, for ~ 60% of water vapor heating.

Global Efficiency Budgets

Estimates of Earth's global average energy budget broken out for the seas and land for 1880, 1976 and 2002 are set out in Table 2. 1976 is chosen because this was the inflection point in global warming.

This is based on changes in average global temperature and average global land and sea temperatures from Table S1 and the data set out in Figure 2, for the global annual mean Earth's energy budget for the March 2000 to May 2004 period, setting 2002 as the year to which this is applied.

These are the Bases for the construction of Table 1 and Table 2.

1) Radiant Emittance, Rad$_{UL}$: For 2002, and land temperature of 282.6 K, the radiant emittance or surface radiation of land, Rad$_{UL}$, was,

$$Rad_{UL2002} = \sigma T_{L2002}^4 = \sigma 282.6^4 = 362 \ W \cdot m^{-2}$$

Similarly, for 2002, and ocean temperature of 289.2 K, the global average radiant emittance of the seas, Rad$_{UO}$, was

$$Rad_{UO2002} = \sigma T_{O2002}^4 = \sigma 289.2^4 = 397 \ W \cdot m^{-2}$$

The radiant emittance for 1880 and 1976 for each surface is the radiant emittance so determined for 2002 multiplied by the ratio of the respective surface temperatures raised for each year raised to the fourth power. Thus, for land,

$$Rad_{ULN} = Rad_{2002L} \left(T_{LN} / T_{L2002} \right)^4$$

2) Steady State Efficiency Factor, Eff: The steady state efficiency factor, Eff$_{LSst}$ for land for 2002 can then be determined as:

$$Eff_{LSst2002} = Rad_{UL2002} / TH_{2002}$$

$$Eff_{LSst2002} = 362/494 = 0.73$$

For the seas:

$$Eff_{OSst2002} = Rad_{UO2002} / TH_{2002}$$
$$Eff_{OSst2002} = 397/494 = 0.8$$

3) **Evaporation:** For 2002, 85% of global evaporation is assumed to come from the seas, $Evap_O$ [21] and land is assumed to generate 15% of total global evaporation. For the other years for land this is held constant and for the seas, it is calculated as,

$$Evap_O = TH_O - Rad_O - Conv_O$$

4) **Convection:** For 2002,

$$Conv_{2002} = TH_{2002} - Rad_{U2002} - Evap_{2002}$$

for the other years,

$$Conv_N = Conv_{2002} Rad_{UN} / Rad_{U2002}$$

5) **Total Heating, TH:** The total heating in 2002 was 494 Wm^{-2}. For and for each year it is calculated as,

$$TH = Rad_{UL} + Evap_L + Conv_L$$

6) **Back Radiation:** Solar heating is assumed to be effectively constant, therefore, the change in back radiation is equal to the change in total heating.

7) **Efficiency Factor for the change in Total Heating Land:** The efficiency factor for the change in total heating, $Eff_{\Delta THL}$ from **Table 3** is then, the change in radiant emittance, ΔRad_U divided by the change in total heating, ΔTH. So,

Between 2002 and 1976, for land

$$Eff_{\Delta THL} = \Delta Rad_{UL} / \Delta TH = 6.2/7.7 = 0.8$$

Between 2002 and 1880,

$$Eff_{\Delta THL} = \Delta Rad_{UL} / \Delta TH = 7.5/9.4 = 0.8$$

8) **Efficiency Factor for the change in Total Heating Seas:** Averaging the annual changes in the efficiency factor for changes in heating for the sea, $Eff_{\Delta THO}$,

$$\Delta Rad_{UO} / \Delta TH$$

for the period 1880-2019, as shown in **Table 3**,

$$Eff_{\Delta THL} = 0.36$$

See discussion of **Figure 16** which shows that the temperatures of land and sea increase at different rates while subjected to the same changes in heating. In terms of increasing surface temperature, this is far less efficient for the sea, because

"*The specific heat of dry land is roughly a factor of four-and-a-half less than that of sea water (for moist land the factor is probably closer to two). Moreover, heat penetration into land is limited and only the top 2 metres or so typically play an active role (as a depth for most of the variations on annual time-scales, say). Accordingly, land plays a much smaller role in the storage of heat ...*" [22] (p. 2688).

Moreover, taking into account the depth of sea water playing a role, for short

wave solar heating, it is necessary to raise the temperature of a greater mass, all of which means that for the same temperature increase as land, the seas require more heat energy and more heat energy is lost to evaporative phase change than would result from simply maintaining the same surface temperature.

Further, heating water by long wave IR radiation is inherently inefficient. While shortwave radiation can transfer energy meters under the surface of the seas, longwave radiation penetrates less than a millimeter [23] and from 1976, essentially the entire increase in heating came from longwave radiation. Evaporation from this thin layer increases in response to an increase in heating. The increase in evaporation reduces surface temperature below what it would otherwise be and results in an increase in the rate of subsurface waters coming to the surface than, at steady state, which takes time to heat, as evaporation continues. These combine to require greater heating power to raise surface temperatures than land.

3. Results

This methodology:

1) Proves that:

a) It is an imbalance between average evaporation and precipitation rates in which evaporation exceeds precipitation that drives increases in the concentration of water vapor, water vapor heating, evaporation and on and on as long as this average imbalance continues;

b) Changes in heating driven by changes in the concentration of water vapor are wholly independent of, and not a feedback response to, the changes in heating from CO_2.

2) Takes into account changes in heating from changes in the concentration of water vapor, driven by:

a) Sea surface temperature, SST;

b) The evaporative response of the seas to changes in heating.

3) Demonstrates that the recent upsurge in average global temperature was driven by increases in the concentration of water vapor.

4) Demonstrates, that compared to steady state, increases in total heating are the primary drivers of evaporation.

5) Shows that, after 1976, the increase in average global temperature was and is driven in a positive feedback loop and so, will likely, continue.

6) Is validated by the determinations of average global temperatures, going back to 1880, which, from the application of Equations (1) & (4) are shown to be a function of changes in the concentration of water vapor,

$$\Delta T_{Avg} = 0.4 \Delta TPW - 0.045 \,^{\circ}\text{C}$$

with a R^2 of 0.9959 (See **Figure 11**) and an average accuracy of ±0.14%.

The Future

Since 1976, there has been a marked rate of increase in global temperature. A simple linear regression:

$$\Delta T_{\text{Avg}}/\text{decade} = 0.2°C/\text{decade}$$

matches these results with an R^2 of 0.85. This rate of increase is 4.3 times greater than the rate of increase for the period 1880-1975.

As noted, this is not driven by the buildup of CO_2 or from a resultant water feedback effect.

Relative Changes in Precipitation

In 1977 there was the largest single year increase in the concentration of water vapor since 1880, 1.09 kg·m⁻² or 5.7%, which was the start of a major and continuing increase. Before that, the concentration of water vapor increased at a rate of 0.002 kg·m⁻² per year and after 1977 at a rate of 0.05 kg·m⁻² per year, which corresponded to an increase of 4% per decade.

While there is variation and the rate of precipitation for some years exceeded the evaporative rate, since 1977, on average, the increase in the rate of precipitation was less than the average increase in the rate of evaporation. Thus, the precipitation/evaporation imbalance that arose in 1977 was, on average, maintained as global warming commenced in earnest. The average global temperature increased at a rate ~25 times greater than the prior 96 year period. The result is illustrated in Figure 1.

Referring to Equations (3) & (5) and Figure 4, there can be no doubt that changes in the concentration of water vapor drive changes in water vapor heating and therefore, in average global temperature. The correlation coefficient between changes in water vapor concentration and average global temperature is 0.993. Changes in water vapor heating drive changes in evaporation. To the extent that the average evaporative rate exceeds the average rate of precipitation, the concentration of water vapor will increase. There is no drag on the system. This a classic positive feedback loop, which means that, absent some external intervention, as long as this imbalance continues, global warming will increase. See Figure 15.

As noted above, after 1976, there was a continuing slight imbalance between average precipitation and evaporation, with average annual evaporation exceeding annual precipitation of 0.06 mm·m⁻²/yr. This slight imbalance is the forcing function driving the post 1976 increase in average global temperature stemming from the average rate of evaporation exceeding the average rate of precipitation and, possibly, a periodic insufficiency in the atmospheric density of cloud condensing nuclei, CCN, over certain parts of the globe as air pollution was reduced and precipitation increased, precipitating out more CCN.

4. Conclusions

In Sum

Climate change is a function of changes in the concentration of water vapor. The results from the application of Equation (1) to determine changes in the concentration of water vapor closely tracks the recent record of changes in in the concentration of water vapor and Equations (5) & (7) to determine changes in

the average global temperature, track, almost exactly, changes in the average global temperature.

The climate reached a tipping point in 1977 when the concentration of water vapor jumped by 4%, the greatest short-term increase. Thereafter, the rate of increase in evaporation on average, continued to exceed the rate of increase in precipitation.

Unfortunately, as noted above, the physics are self-perpetuating. Until such time as there is an increase in cloud condensing nuclei sufficient in critical regions to ensure that average precipitation continually equals or exceeds evaporation, the buildup in atmospheric water vapor will continue, increasing atmospheric heating, which increases evaporation and so on. As noted above, this is a positive feedback loop.

The good news is that the solution is at least mathematically simple. If average annual global precipitation can be increased by 3 mm·m^{-2} (0.3% of average annual precipitation of 949 mm/yr.) over evaporation and thereafter maintained in equivalence with the evaporative rate, global warming can be halted and if precipitation can be increased further relative to evaporation, reversed. (A similar 5.5% water vapor driven increase in average global temperature which commenced in 1904 and concluded 41 years later in 1945 after a 9.24% increase in the concentration of water vapor was followed by 6 years of decline in the concentration of water vapor and average global temperature. This occurred without anthropogenic intervention).

Meanwhile there is a real urgency in coming to understand this problem and developing and implementing efficient and environmentally sound means of increasing precipitation, because, until then, the problem will only get worse.

As long as the ratio of average annual precipitation/evaporation < 1, for the reasons set out above, this is likely to continue. Thus, by 2100, the increase could be another 1.5°C, which would be a very serious and ongoing concern to our grandchildren.

There is also the possibility that the rate of evaporation compared to precipitation will increase further which would make the problem even worse.

There is no certainty, this must be viewed as an existential threat to those populations most at risk to rising sea levels.

However, if the atmospheric density of CCN can be increased to the point that average annual precipitation can again equal or exceed average annual evaporation, global warming can not only be halted, it can be reversed. There can, at least in theory, be an immediate resolution.

Therefore, the goal should be a permanent 13% or 2.7 kg·m^{-2}, 2.7 mm·m^{-2}, or 0.3% of average annual precipitation of 949 mm/yr., global reduction in TPW, which means reducing TPW slightly below the concentration level in 1976, before global warming accelerated, which should be achieved gradually.

If maintained, this would bring the increase in average global total heating since 1880, ΔTH, to ~2.41 Wm^{-2}, the increase in average global total heating by 1975, and bring the average global temperature to the average global tempera-

ture for that year, 14˚C.

It is important to recognize that and these numbers are averages. In terms of a solution to the effects of average increases in the concentration of water vapor, increased precipitation; the design, therefore, should not only be environmentally sound, efficient and minimize the risk of flooding, but comprise varied solutions, tailored to seasonal changes and the areas most affected by climate change, because, unlike other constituents of the atmosphere, water vapor is not well mixed. It is concentrated in the tropics, decreases with distance from the equator, differs between the seas and land and is affected by changes in topography and seasons. For this reason, changes in heating from changes in the concentration of water vapor are geographically and seasonally, quite disparate. It would not be surprising to find areas in which the evaporation/precipitation differences are orders of magnitude higher. Therefore, a total global response may not be required. However, it will take time to develop and implement practical and sensible solutions.

An immediate and intense focus on finding environmentally safe, effective and efficient mechanisms of increasing CCN sufficient to increase precipitation and reduce TPW could pay massive benefits and efforts to effect this are required. While changes in the concentration of CO_2 have no effect on the changes in the concentration of water vapor, even if one incorrectly believed CO_2 somehow affected the changes in the concentration of water vapor, increasing precipitation would nonetheless reduce TPW and therefore, heating.

That water vapor is the driver is totally at odds with the current "wisdom" so there is no focus on this as an issue. It is an understatement to say that these physics and conclusions will be controversial. However, the resolution of this problem cannot await a consensus that the solutions currently posited have failed, which given the vested interests and strongly held beliefs, is very, very unlikely in the near term and will take years to realize.

There is no need for a consensus. These physics comply with the laws of thermodynamics and are not assumption or probability based. They are straightforward mathematical formulations shown to be accurate calculations of annual global averages. There is no downside to finding efficient and environmentally friendly means of effecting and experimenting with increasing precipitation in those regions most at risk and no conflict with efforts aimed at reducing CO_2, levels, at the same time.

To minimize delay what is required is leadership from academics from top-flight institutions with the requisite expertise to affirm what is set out herein. When this is accepted, it will take time to design and implement solutions as the average global temperature continues to increase.

Meanwhile, the existential threat of continuing global warming is not being addressed and will likely continue to grow at the rate of 0.2˚C per decade until effective intervention is undertaken. Time is truly of the essence. This is why I care.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] NOAA National Centers for Environmental Information: Land Data, Climate at a Glance: Global Time Series. https://www.ncdc.noaa.gov/cag/time-series

[2] NOAA National Centers for Environmental Information: Ocean Data, Climate at a Glance: Global Time Series. https://www.ncdc.noaa.gov/cag/time-series

[3] GISTEMP Team (2019) GISS Surface Temperature Analysis (GISTEMP), Version 4. NASA Goddard Institute for Space Studies. https://data.giss.nasa.gov/gistemp

[4] Trenberth, K.E., Fasullo, J.T. and Kiehl, J. (2009) Earth's Global Energy Budget. *Bulletin of the American Meteorological Society*, **90**, 311-324. https://doi.org/10.1175/2008BAMS2634.1

[5] 2018 Trends in Atmospheric Carbon Dioxide National Oceanic and Atmospheric Administration Earth System Research Laboratory Global Monitoring Division. https://www.esrl.noaa.gov/gmd/ccgg/trends/

[6] Earth Policy Institute. Climate, Energy, and Transportation: Atmospheric Carbon Dioxide Concentration 1000-2014. http://www.earth-policy.org/data_center/C23

[7] Lewandowsky, S., Cowtan, K., Risbey, J.S., Mann, M.E., Steinman, B.A., Oreskes, N. and Rahmstorf, S. (2018) The "Pause" in Global Warming in Historical Context: (II). Comparing Models to Observations. *Environmental Research Letters*, **13**, Article ID: 123007. https://doi.org/10.1088/1748-9326/aaf372

[8] Myhre, G., Highwood, E.J., Shine, K.P. and Stordal, F. (1998) New Estimates of Radiative Forcing Due to Well Mixed Greenhouse Gases. *Geophysical Research Letters*, **25**, 2715-2718. https://doi.org/10.1029/98GL01908

[9] Santer, B.D., *et al*. (2007) Identification of Human-Induced Changes in Atmospheric Moisture Content. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 15248-15253. https://doi.org/10.1073/pnas.0702872104

[10] Liang, J. (2013) Climate Change. In: *Chemical Modeling for Air Resources: Fundamentals*, *Applications*, *and Corroborative Analysis*, Academic Press, Cambridge, 143-161. https://doi.org/10.1016/B978-0-12-408135-2.00007-0

[11] Mieruch, S., Noel, S., Bovensmann, H. and Burrows, J.P. (2008) Analysis of Global Water Vapour Trends from Satellite Measurements in the Visible Spectral Range. *Atmospheric Chemistry and Physics*, **8**, 491-504. https://doi.org/10.5194/acp-8-491-2008

[12] Frank, J. (2015) Explaining How the Water Vapor Greenhouse Effect Works. Skeptical Science. https://skepticalscience.com/water-vapor-greenhouse-gas-intermediate.htm

[13] Hausfather, Z. (2008) The Water Vapor Feedback. Analysis, Yale Climate Connections. https://www.yaleclimateconnections.org/2008/02/common-climate-misconceptions-the-water-vapor-feedback-2

[14] Cook, J. (2015) Explaining How the Water Vapor Greenhouse Effect Works Skeptical Science. https://skepticalscience.com/print.php?r=44

[15] Evans, W.F. and Puckrin, E. (2006) Measurements of the Radiative Surface Forcing of Climate. 18*th Conference on Climate Variability and Change*, 30 January 2006.

[16] Soares, P.C. (2010) Warming Power of CO_2 and H_2O: Correlations with Temperature Changes. *International Journal of Geosciences*, **1**, 102-112. https://doi.org/10.4236/ijg.2010.13014

[17] Galashev, A.E. and Rakhmanova, O.R. (2013) Emissivity of the Main Greenhouse Gases. *Russian Journal of Physical Chemistry B*, **7**, 346-353. https://doi.org/10.1134/S1990793113030020

[18] Anderson, T.R., Hawkins, E. and Jones, P.D. (2016) CO_2, the Greenhouse Effect and Global Warming: from the Pioneering Work of Arrhenius and Callendar to Today's Earth System Models. *Endeavour*, **40**, 178-187. https://doi.org/10.1016/j.endeavour.2016.07.002

[19] Cowtan, K., Jacobs, P., Thorne, P. and Wilkinson, R. (2018) Statistical Analysis of Coverage Error in Simple Global Temperature Estimators. *Dynamics and Statistics of the Climate System*, **3**, dzy003. https://doi.org/10.1093/climsys/dzy003

[20] Ho, S., *et al.* (2018) Comparison of Global Observations and Trends of Total Precipitable Water Derived from Microwave Radiometers and COSMIC Radio Occultation from 2006 to 2013. *Atmospheric Chemistry and Physics*, **18**, 259-274. https://doi.org/10.5194/acp-18-259-2018

[21] Ocean in the Global Water Cycle. https://www.ametsoc.org/ams/index.cfm/education-careers/education-program/undergraduate-faculty/ocean-studies/course-components/investigations-manual/ocean-manual-01b

[22] Trenberth, K.E. and Stepaniak, D.P. (2004) The Flow of Energy through the Earth's Climate System. *Quarterly Journal of the Royal Meteorological Society*, **130**, 2677-2701. https://doi.org/10.1256/qj.04.83

[23] Wong, E.W. and Minnett, P.J. (2018) The Response of the Ocean Thermal Skin Layer to Variations in Incident Infrared Radiation. *Journal of Geophysical Research: Oceans*, **123**, 2475-2493. https://doi.org/10.1002/2017JC013351

[24] Luciuk, M. (2013) Temperature and Radiation. http://www.asterism.org/tutorials/tut40RadiationTutorial.pdf

[25] Smith, T.M. and Arkin, P.A. (2015) Improved Historical Analysis of Oceanic Total Precipitable Water. *Journal of Climate*, **28**, 3099-3121. https://doi.org/10.1175/JCLI-D-14-00601.1

[26] Finlayson-Pitts, B.J. and Pitts Jr., J.N. (2000) Global Tropospheric Chemistry and Climate Change. In: *Chemistry of the Upper and Lower Atmosphere*, Elsevier, Amsterdam, 762-843. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/infrared-absorption/pdf

[27] ACCRI Theme 7: Metrics for Comparison of Climate Impacts from Well Mixed Greenhouse Gases and Inhomogeneous Forcing Such as Those from UT/LS Ozone, Contrails and Contrail-Cirrus. https://www.faa.gov/about/office_org/headquarters_offices/apl/research/science_integrated_modeling/accri/media/ACCRI_SSWP_VII_Forster.pdf

[28] Schmidt, G.A. Observed Land Surface Precipitation Data: 1901-2000 (CRU TS 2.0). Goddard Institute for Space Studies, New York. https://data.giss.nasa.gov/precip_cru

[29] Babkin, V.I. (2002) Hydrological Cycle Vol. II, Evaporation from the Surface of the Globe. In: *Encyclopedia of Life Support Systems*, State Hydrological Institute, St. Petersburg. http://www.eolss.net/sample-chapters/c07/e2-02-03-02.pdf

[30] Blunden, J. and Arndt, D.S. (2016) Precipitation Worldwide, 1901-2015. EPA's Climate Change Indicators in the United States.
http://www.epa.gov/climate-indicators

Appendix 1: Derivation of Formulations and Definition of Terms

Nomenclature

Conv—heating flux that drives thermal convection, Wm^{-2}.

ΔT—change in temperature, ˚C.

Eff—heating efficiency—the fraction of total heating remaining after the deduction of evaporative and convective losses,

$$Eff = 1 - (Evap + Conv)/TH .$$

Evap—heating flux absorbed by evaporation, Wm^{-2}.

GHG—Green House Gases.

IR—Infrared Radiation.

NaH—net absorbed heating flux, that fraction of total radiative heating remaining, after deducting the power driving evaporation and convection, Wm^{-2}

$$NaH = TH - Evap - Conv = Eff \cdot TH .$$

OLR—Outgoing Longwave Radiation.

Power—heating flux per square meter, Wm^{-2}.

ppmv—parts per million, volume.

Rad_U—Radiant Emittance, Wm^{-2}.

ΔTH_{CO2}—Back-radiation flux solely from CO_2, Wm^{-2}.

σ—Stefan-Boltzmann constant, 5.67×10^{-8} $Wm^{-2} \cdot K^{-4}$.

Sol—Heating flux from solar radiation, Wm^{-2}.

SST—Sea Surface Temperature.

T—absolute temperature, K.

TH—total radiative heating flux, including WV, Wm^{-2}.

WV—total heating flux from water vapor feedback effect, Wm^{-2}.

Subscripts

Avg—global average.

CO_2—indicates a factor driven solely by CO_2.

L—land.

N—new.

o—original or initial.

O—ocean.

Tot—total.

U—up.

WV—water vapor.

Derivations

Total Heating

1) Changes in Total Heating

Total heating, TH, is the sum of solar and back radiation absorbed by the surface.

2) The net absorbed heating for land, NaH_L is total heating less the heating driving evaporation and thermal convection, $Evap_L$ and $Conv_L$.

$$\mathrm{NaH_L = TH - Evap_L - Conv_L} \tag{6}$$

The heating efficiency of the land surface, $\mathrm{Eff_L}$, is the ratio of the net absorbed heating $\mathrm{NaH_L}$ to total heating, TH,

$$\mathrm{Eff_L = NaH_L/TH}$$

Thus,

$$\mathrm{NaH_L = Eff_L\,TH}$$

As discussed above and shown in **Table 2**, the efficiency factor for land at steady state, $\mathrm{Eff_{LSS}}$,

$$\mathrm{Eff_{LSS} = 0.73}$$

Since in accordance with Kirchhoff's law of thermal radiation and the First Law of Thermodynamics, the surface radiation, $\mathrm{Rad_U}$ from the surface cannot exceed the net heating absorbed by the surface,

$$\mathrm{\Delta Rad_{UL} \ngtr \Delta NaH_{UL}}$$

it is assumed that the surface temperature is at equilibrium, the maximum surface temperature, therefore:

$$\mathrm{\Delta Rad_{UL} = \Delta NaH_{UL}} \tag{7}$$

The efficiency of a change in heating for land, $\mathrm{Eff_{\Delta THL}}$, is

$$\mathrm{Eff_{\Delta THL} = \Delta Rad_{UL}/\Delta TH}$$

thus, changes in total heating, ΔTH, can be gauged from changes in surface radiation

$$\mathrm{\Delta TH = \left(Rad_{ULN} - Rad_{ULo}\right)/Eff_{\Delta THL}}$$

Since the change for surface radiation, $\mathrm{\Delta Rad_{UL}}$, as a function of changes in land temperature, is,

$$\mathrm{\Delta Rad_{UL} = \sigma\left(T_{LN}^4 - T_{Lo}^4\right)}$$

Therefore, changes in total heating can be gauged from changes in the surface temperature of land,

$$\mathrm{\Delta TH = \sigma\left(T_{LN}^4 - T_{Lo}^4\right)\Big/Eff_{\Delta THL}}$$

As discussed above and shown in **Table 3**, the efficiency of a change in heating for land, $\mathrm{Eff_{\Delta THL}}$,

$$\mathrm{Eff_{\Delta THL} = 0.8}$$

Thus,

$$\mathrm{\Delta TH = \sigma\left(T_{LN}^4 - T_{Lo}^4\right)\Big/0.8}$$

This is different for the seas. At steady state, from **Table 2**,

$$\mathrm{Eff_{OSS} = 0.8}$$

However, in response to changes in heating, taking the average of the efficiency factor for change of heating for the seas over the 1880-2019 period $\mathrm{Eff_{\Delta THO}}$ is 0.36. See **Table S3**.

3) Land Heating

The determination of the maximum temperature response (which is the temperature calculated throughout) of the land surface to changes in heating is determined as the temperature at which the average surface radiation matches the average total heating less the power absorbed by evaporation and thermal convection, as shown in Figure 1. This is defined as the surface temperature limit or STL and the temperature utilized in these calculations.

The surface radiation from land, Rad_{UL}, is [24]

$$\text{Rad}_{\text{UL}} = \sigma T_{\text{L}}^4 \tag{8}$$

with

$$\sigma = 5.67 \times 10^{-8} \ \text{W}^{-1} \cdot \text{m}^2 \cdot \text{K}^{-4}$$

Since

$$T_{\text{LN}} = T_{\text{Lo}} + \Delta T_{\text{L}}$$

then,

$$\Delta \text{Rad}_{\text{UL}} = \sigma \left[\left(T_{\text{Lo}} + \Delta T_{\text{L}} \right)^4 - T_{\text{Lo}}^4 \right] \text{W} \cdot \text{m}^{-2} \tag{9}$$

where: T_{Lo} is the initial average global land temperature, and,

ΔT_{L} is the change in average global land temperature,

Solving for ΔT_{L}

Therefore, the increase in surface temperature, ΔT_{L}, cannot exceed, and the average surface temperature limit increase for land (STL), is:

$$\Delta T_{\text{STLL}} = \left(T_{\text{Lo}}^4 + \Delta \text{NaH}_{\text{L}} / \sigma \right)^{1/4} - T_{\text{Lo}} \ ^\circ \text{C}$$

For land temperature in 1880 of 281.2 K, the change in surface temperature limit, ΔT_{STLL} for land is:

$$\Delta T_{\text{STLL}} = \left(T_{\text{Lo}}^4 + \Delta \text{NaH}_{\text{L}} / \sigma \right)^{1/4} - T_{\text{Lo}}$$

$$\Delta T_{\text{STLL}} = \left(281.2^4 + \Delta \text{NaH}_{\text{L}} / 5.67 \times 10^{-8} \right)^{1/4} - 281.2$$

$$\Delta T_{\text{STLL}} = \left(6.34 \times 10^9 + \Delta \text{NaH}_{\text{L}} / 5.67 \times 10^{-8} \right)^{1/4} - 281.2$$

Since, the efficiency factor for land with respect to changes in total heating, $\text{Eff}_{\Delta \text{THL}}$ from Table 3, is 0.8, then

$$\Delta \text{NaH}_{\text{L}} = \text{Eff}_{\Delta \text{THL}} \Delta \text{TH} = 0.8 \Delta \text{TH}$$

$$\Delta T_{\text{STLL}} = \left(6.34 \times 10^9 + 0.73 \Delta \text{TH} / 5.67 \times 10^{-8} \right)^{1/4} - 281.2$$

Another approach—taking the first derivative, the change for surface radiation, $\Delta \text{Rad}_{\text{UL}}$, as a function of changes in land temperature, is,

$$\frac{\text{d}}{\text{d}T_{\text{L}}} \text{Rad}_{\text{UL}} = 4 \sigma T_{\text{L}}^3$$

Thus, for small changes in average land temperature,

$$\Delta \mathrm{Rad}_{\mathrm{UL}} = 4\sigma T_{\mathrm{Lo}}^{3} \Delta T_{\mathrm{L}}$$

Therefore, a good approximation for the surface temperature limit (STL), for small changes in temperature, is

$$\Delta T_{\mathrm{STLL}} = \Delta \mathrm{NaH}_{\mathrm{L}} \Big/ \left(4\sigma T_{\mathrm{Lo}}^{3}\right) {}^{\circ}\mathrm{C}$$

And for land temperature in 1880 of 281.2 K

$$4\sigma T_{\mathrm{Lo}}^{3} = 4 \times 5.67 \times 10^{-8} \times 281.23 = 5.04$$

$$\therefore \Delta T_{\mathrm{STLL}} = 0.198 \Delta \mathrm{NaH}_{\mathrm{L}}$$

with

$$\Delta \mathrm{NaH}_{\mathrm{L}} = \mathrm{Eff}_{\Delta \mathrm{THL}} \Delta \mathrm{TH}$$

In terms of changes in total heating, $\Delta \mathrm{TH}$,

$$\mathrm{NaH}_{\mathrm{LN}} = \mathrm{NaH}_{\mathrm{Lo}} + \Delta \mathrm{NaH}_{\mathrm{L}}$$

$$\mathrm{NaH}_{\mathrm{Lo}} = \mathrm{Eff}_{\mathrm{SSL}} \mathrm{TH}_{\mathrm{Lo}}$$

$$\mathrm{NaH}_{\mathrm{LN}} = \mathrm{Eff}_{\mathrm{SSL}} \mathrm{TH}_{\mathrm{Lo}} + \mathrm{Eff}_{\Delta \mathrm{THL}} \Delta \mathrm{TH}$$

From Table 2 & Table 3

$$\mathrm{Eff}_{\mathrm{SSL}} = 0.73$$

$$\mathrm{Eff}_{\Delta \mathrm{THL}} = 0.8$$

$$\mathrm{NaH}_{\mathrm{LN}} = 0.73 \mathrm{TH}_{\mathrm{Lo}} + 0.73 \Delta \mathrm{TH}$$

$$\mathrm{NaH}_{\mathrm{LN}} = \mathrm{NaH}_{\mathrm{Lo}} + \Delta \mathrm{NaH}_{\mathrm{L}}$$

$$\Delta \mathrm{NaH}_{\mathrm{L}} = \mathrm{NaH}_{\mathrm{LN}} - \mathrm{NaH}_{\mathrm{Lo}} = \mathrm{Eff}_{\mathrm{SSL}} \mathrm{TH}_{\mathrm{Lo}} + \mathrm{Eff}_{\Delta \mathrm{THL}} \Delta \mathrm{TH} - \mathrm{Eff}_{\mathrm{SSL}} \mathrm{TH}_{\mathrm{Lo}}$$

$$\Delta \mathrm{NaH}_{\mathrm{L}} = \mathrm{Eff}_{\Delta \mathrm{THL}} \Delta \mathrm{TH}$$

$$\Delta T_{\mathrm{STLL}} = 0.198 \Delta \mathrm{NaH}_{\mathrm{L}} = 0.198 \mathrm{Eff}_{\Delta \mathrm{THL}} \Delta \mathrm{TH} = 0.198 \times 0.8 \Delta \mathrm{TH}$$

$$\Delta T_{\mathrm{STLL}} = 0.158 \Delta \mathrm{TH}\ {}^{\circ}\mathrm{C} \tag{10}$$

4) Change in ocean temperature from changes in total heating, ΔT_{ATHO}).
Following the same analysis as for land:
For Ocean temperature in 1880 of 288.67 K
The surface temperature limit for the seas is,

$$\Delta T_{\mathrm{STLO}} = \left(6.94 \times 10^{9} + \mathrm{Eff}_{\Delta \mathrm{THO}} \Delta \mathrm{TH}/5.67 \times 10^{-8}\right)^{1/4} - 288.67$$

From Table 3,

$$\mathrm{Eff}_{\Delta \mathrm{THO}} = 0.36$$

$$\Delta T_{\mathrm{STLO}} = \left(6.94 \times 10^{9} + 6.35 \times 10^{6} \Delta \mathrm{TH}\right)^{1/4} - 288.67$$

For small changes, ΔT_{STLO} is,

$$\Delta T_{\mathrm{STLO}} = \Delta \mathrm{NaH}_{\mathrm{O}} \Big/ \left(4\sigma T_{\mathrm{Oo}}^{3}\right) {}^{\circ}\mathrm{C}$$

Therefore, the average ocean surface temperature limit (STL) for changes in total heating, is:

$$\Delta T_{\mathrm{STLO}} = \Delta \mathrm{NaH}_{\mathrm{O}} \Big/ \left(4\sigma T_{\mathrm{Oo}}^{3}\right)$$

with

$$\sigma = 5.67 \times 10^{-8} \ \text{W}^{-1} \cdot \text{m}^2 \cdot \text{K}^{-4}$$

And for Ocean temperature in 1880 of 288.67 K

$$4\sigma T_{\text{Oo}}^3 = 4 \times 5.67 \times 10^{-8} \times 288.67^3 = 5.46$$

$$\Delta T_{\text{STLO}} = \Delta \text{Rad}_{\text{UO}} \Big/ \left(4\sigma T_{\text{Oo}}^3\right) = 0.183 \Delta \text{Rad}_{\text{UO}}$$

For $\text{Eff}_{\Delta \text{THO}} = 0.36$

$$\Delta \text{Rad}_{\text{UO80-19}} = 0.36 \Delta \text{TH}$$

$$\Delta T_{\text{STLO}} = 0.183 \times 0.36 \Delta \text{TH}$$

$$\Delta T_{\text{STLO}} = 0.07 \Delta \text{TH} \ ^{\circ}\text{C} \tag{11}$$

5) Changes in the Concentration of Water Vapor

The total concentration of water vapor, total precipitable water (TPW_{Tot}), is the sum of the concentration of water vapor from steady state evaporation as a function of sea surface temperature, TPW_{SST} and changes in concentration in response to changes in total heating, $\Delta \text{TPW}_{\Delta \text{TH}}$.

$$\text{TPW}_{\text{ToT}} = \text{TPW}_{\text{SST}} + \Delta \text{TPW}_{\Delta \text{TH}} \ \text{kg} \cdot \text{m}^{-2}$$

6) Changes in concentration of Water Vapor from changes in steady state Sea Surface Temperature, SST.

The total precipitable water ($\text{kg} \cdot \text{m}^{-2}$) from evaporation based solely on steady state sea surface temperature, SST, is determined as follows: [25]

$$\text{TPW}_{\text{SST}} = 10 \times 10.82 \left[r/(1+\mu) \right] e^{\left[a(\text{SST}-288) \right]} \ \text{kg} \cdot \text{m}^{-2} \tag{12}$$

The constants, a and $r/(1+\mu)$ were estimated by the authors, as

$$a = 0.0686 \quad \text{and} \quad r/(1+\mu) = 0.162 \ ,$$

thus,

$$\text{TPW}_{\text{SST}} = 10 \times 10.82(0.162) e^{\left[0.0686(\text{SST}-288) \right]} = 17.53 e^{\left[0.0686(\text{SST}-288) \right]}$$

Therefore, the difference in steady state water vapor concentration at two different surface temperatures is,

$$\Delta \text{TPW}_{\text{SST}} = 17.53 \left(e^{\left[0.0686(\text{SSTo}+\Delta \text{SST}-288) \right]} - e^{\left[0.0686(\text{SSTo}-288) \right]} \right) \text{kg} \cdot \text{m}^{-2} \tag{13}$$

The results from Equation (13), for sea surface temperatures for 1880 and 2019, temperatures of 288.67 and 289.37 K, are a 5% increase in water vapor concentration in 2019 over 1880.

$$\Delta \text{TPW}_{\text{SST}} = 17.53 \left(e^{\left[0.0686(289.37-288) \right]} - e^{\left[0.0686(288.67-288) \right]} \right) = 0.9$$

In 1880, the initial water vapor concentration, TPW_{1880}, calculated in accordance with Equation (12), for SST = 288.67 K, was 18.35 $\text{kg} \cdot \text{m}^{-2}$.

Then, this increase was,

$$0.9/18.35 = 0.05 = 5\%$$

7) Changes in Water Vapor Concentration Driven by Changes in Total Heat-

ing

Referring to Table S1 and Figure 16, over the same period of time, the global average temperature change of the seas in response to the same changes in total heating was ~40% of the global average temperature change for land, demonstrating that greater heating of the oceans is required to effect the same change in temperature as land.

While a change in surface temperature changes evaporation, Equation (13), that there is an additional change in evaporation from the seas in response to a change in total heating, ΔTH (which of course includes changes in water vapor heating, ΔWV) is a new principle of climate physics. This is set out as Equation (14) which underlies all that follows.

From Table 3 and Table S2, the average heating efficiency of the seas since 1976 in response to an increase in total heating is 0.36, $\text{Eff}_{\Delta\text{THTotO}}$, from Table 3, which reflects the net absorbed heating that actually increases the surface temperature of the seas. The other 64% of change in total heating of the seas is allocated to the change in evaporative power.

Changes in water vapor concentration require an imbalance between average precipitation per year, PR, and evaporation per year, EV. The change in water vapor concentration over a one year period can be determined from this expression:

$$\text{TPW} = \text{EV} - \text{PR} \quad \text{kg·m}^{-2}$$

Set

$$\text{PR} = \beta \text{EV}$$

Then,

$$\text{TPW} = \text{EV}(1-\beta)$$

Using average rates and changes therefrom for the year in question, this is changed to:

$$\Delta\text{TPW} = \text{EV}_{\text{Avg}} + \Delta\text{EV} - \text{PR}_{\text{Avg}} - \Delta\text{PR}$$

where, EV_{Avg} is the average annual global evaporation, mm·m^{-2}/yr.

PR_{Avg} is the average annual global precipitation, mm·m^{-2}/yr.

ΔEV is the change in annual evaporation from average mm·m^{-2}

ΔPR is the change in annual precipitation from average mm·m^{-2}

Set,

$$\text{EV}_{\text{Avg}} = \text{PR}_{\text{Avg}}$$

Then,

$$\Delta\text{TPW} = \Delta\text{EV} - \Delta\text{PR}$$

Since for each year, precipitation is proportional to evaporation, then,

$$\Delta\text{PR} = \beta\Delta\text{EV}$$

Then, for that year,

$$\Delta\text{TPW} = \Delta\text{EV}(1-\beta)$$

Assume, the rate of evaporation is proportional to the fraction of heating flux driving evaporation from the seas, Evap_O.

$$EV \propto \text{Evap}_O$$

And changes in the concentration of water vapor are proportional to changes in the heating that drives evaporation.

$$\therefore \Delta TPW \propto \Delta \text{Evap}_O$$

with changes in water vapor concentration, ΔTPW, proportional to changes in evaporative power, this means that:

$$\Delta TPW_o = \Gamma \Delta \text{Evap}_o$$

where Γ is a constant.

The steady state power driving evaporation for the seas in 1880, Evap_O, from **Table 2**, was 89 Wm^{-2}. In 1880, when the change in average global temperature and therefore, total heating, was minor, ignoring changes in total heating for that year, the initial water vapor concentration, TPW_{1880}, calculated in accordance with Equation (12) for SST = 288.67 K, was 18.35 kg·m^{-2}. So,

$$TPW_{1880} = \Gamma \text{Evap}_{1880}$$

$$18.35 \text{ kg} \cdot \text{m}^{-2} = \Gamma 89 \text{ W} \cdot \text{m}^{-2}$$

Since changes in evaporative power are proportional to changes in total heating, And, for changes in the evaporative power, therefore changes in total heating, ΔTH, the change in water vapor concentration driven by changes in total heating, $\Delta TPW_{\Delta THO}$ is

$$\Delta TPW_{\Delta THO} = \Gamma \Delta \text{Evapo}$$

From **Table 2**, the steady state power driving evaporation for the seas in 1880, Evap_O, was 89 Wm^{-2} and for land, Evap_L, 42 Wm^{-2}. The total evaporative power is the area weighted average of the two,

$$\text{Evap}_{1880Tot} = \% \text{ Area Ocean} \times \text{Evap}_{1880O} + \% \text{ Area Land} \times \text{Evap}_{1880L}$$

$$\text{Evap}_{1880Tot} = 71.11\% \times 89 + 29.89\% \times 42 = 75.3 \text{ W} \cdot \text{m}^{-2}$$

For the seas, ignoring changes in thermal convection, the change in evaporative power, ΔEvap_O, in response to changes in total heating, ΔTH, is the fraction of the change in total heating, ΔTH, that does not drive an increase in temperature, $(1 - \text{Eff}_{\Delta THO}) \Delta TH$, then

$$\Delta \text{Evapo} = (1 - \text{Eff}_{\Delta THO}) \Delta TH,$$

$$\therefore TPW_{\Delta THO} = \Gamma \Delta \text{Evapo} = \Gamma (1 - \text{Eff}_{\Delta THO}) \Delta TH,$$

Then, since

$$\Gamma = \Delta TPW_{\Delta THO} \big/ \left((1 - \text{Eff}_{\Delta THO}) \Delta TH \right),$$

Therefore,

$$\Delta TPW_{\Delta THO} = (1 - \text{Eff}_{\Delta THO}) \Delta TH \, TPW_{1880} \big/ \text{Evap}_{Tot1880}$$

$$\Delta \text{TPW}_{\Delta \text{THO}} = 18.35(1 - 0.36)\Delta \text{TH}/75.3$$

$$\Delta \text{TPW}_{\Delta \text{THTot}} = 0.157\Delta \text{TH} \tag{14}$$

8) Total Change in the Concentration of Water Vapor

Taking into account changes in evaporation from changes in total heating, ΔTH and sea surface temperature, ΔSST, the total change in the concentration of water vapor is therefore,

$$\Delta \text{TPW}_{\text{Tot}} = \Delta \text{TPW}_{\Delta \text{THTot}} + \Delta \text{TPW}_{\text{SST}}$$

$$\Delta \text{TPW}_{\text{Tot}} = 0.157\Delta \text{TH} + 17.53\left\{ e^{\left[0.0686(\text{SSTo} + \Delta \text{SST} - 288)\right]} - e^{\left[0.0686(\text{SSTo} - 288)\right]} \right\} \text{kg} \cdot \text{m}^{-2} \tag{1}$$

9) Changes in Water Vapor Heating from Changes in Concentration of Water Vapor

The intensity of back radiation from water vapor depends on the extent to which surface radiation is absorbed by the water vapor, which is a function of the concentration, TPW [26].

Ignoring convection cooling and focusing on changes in temperature, the heating required to maintain sea surface temperature, is

$$\text{TH}_{\text{SST}} = \text{NaH}_{\text{OSST}}/\text{Eff}_{\text{SSTO}}$$

And, since

$$\text{Rad}_{\text{UOSST}} = \text{NaH}_{\text{OSST}}$$

$$\text{TH}_{\text{SST}} = \text{Rad}_{\text{UOSST}}/\text{Eff}_{\text{SSTO}}$$

thus,

$$\text{Rad}_{\text{UOSST}} = \text{Eff}_{\text{SSTO}}\text{TH}_{\text{SST}}$$

The change in total heating from changes in water vapor heating, ΔWV, is,

$$\Delta \text{TH}_{\text{WV}} = \Delta \text{WV} \text{, then,}$$

$$\Delta \text{Rad}_{\Delta \text{WVO}} = \text{Eff}_{\Delta \text{THO}}\Delta \text{WV}$$

and, the water vapor heating power required to effect this change in up-radiation is,

$$\Delta \text{WV} = \Delta \text{Rad}_{\text{WVO}}/\text{Eff}_{\Delta \text{THO}}$$

And, the surface temperature limit for the sea from this heating is,

$$\Delta T_{\text{SSTL}\Delta \text{WV}} = \Delta \text{Rad}_{\Delta \text{WVO}}/4\sigma \text{SST}_{\text{Oo}}^3$$

With SST_o in 1880 = 288.67

$$\Delta T_{\text{SSTL}\Delta \text{WV}} = \frac{\Delta \text{Rad}_{\Delta \text{WVO}}}{4\sigma \text{SST}_{\text{Oo}}^3} = 0.183\Delta \text{Rad}_{\Delta \text{WvO}}$$

and the net absorbed heating required to drive this change in the sea surface temperature,

$$\text{NaH}_{\Delta \text{WVO}} = \text{Rad}_{\Delta \text{WVO}}$$

To determine the change in water vapor heating:

From Table 2

BR_{1880}	BR_{2002}
323.60	333

Assume back radiation from the GHG, other than Water Vapor and CO_2, and effects from cloud cover and other atmospheric factors net to zero [27] (p. 11, Table 2) and heating from CO_2 in 1880 was,

$$TH_{CO21880} = 5.35 \ln\left(Conc_{CO21880}\right) = 5.35 \ln\left(290.74\right) = 30.35 \text{ W} \cdot \text{m}^{-2}$$

Then to determine the change in water vapor heating, $\Delta WV_{1880\text{-}2002}$, from Table 2 and om Table S1,

$$WV_{Tot1880} = BR_{1880} - TH_{CO21880} = 322.73 - 30.35 = 292.38 \text{ W} \cdot \text{m}^{-2}$$

$$WV_{2002} = BR_{2002} - TH_{CO22002} = BR_{2002} - \left(TH_{CO21880} + TH_{CO21880\text{-}2002}\right)$$

$$WV_{2002} = 333 - \left[30.35 + 5.35 \ln\left(373.22/290.74\right)\right] = 301.31$$

$$\Delta BR_{1880\text{-}2002} = BR_{2002} - BR_{1880} = 333 - 323.6 = 9.4$$

$$\Delta TH_{CO21880\text{-}2002} = 5.35 \ln\left(373.22/290.74\right) = 1.34$$

$$\Delta WV_{1880\text{-}2002} = \Delta BR_{1880\text{-}2002} - \Delta TH_{CO21880\text{-}2002} = 9.4 - 1.34 = 8.06$$

To calculate the change in water vapor heating, ΔWV, from a change in the concentration of water vapor, assume that, the absorption of surface radiation changes logarithmically with changes in the concentration of water vapor, TPW. ("For very strongly absorbing peaks such as those due to CO_2 and H_2O, absorption only occurs at the fringes of the band and the net absorption varies with the logarithm of the absorber concentration" [26]).

$$WV = f\left[\ln\left(TPW\right)\right]$$

then,

$$\Delta WV_{1880\text{-}2002} = X\left[\ln\left(TPW_{2002}\right) - \ln\left(TPW_{1880}\right)\right]$$

Since,

$$TPW_{2002} = TPW_{1880} + \Delta TPW_{1880\text{-}2002}$$

then,

$$\Delta WV_{1880\text{-}2002} = X\left[\ln\left(\Delta TPW_{1880\text{-}2002} + TPW_{1880}\right) - \ln\left(TPW_{1880}\right)\right]$$

$$\Delta WV_{1880-2002} = X\left[\ln\left(1 + \Delta TPW_{1880\text{-}2002}/TPW_{1880}\right)\right]$$

solving for X,

$$X = \Delta WV_{1880\text{-}2002}\big/\ln\left(1 + \Delta TPW_{1880\text{-}2002}/TPW_{1880}\right)$$

as shown above,

$$\Delta WV_{1880\text{-}2002} = 8.06$$

$$X = 8.06\big/\ln\left(1 + \Delta TPW_{1880\text{-}2002}/TPW_{1880}\right)$$

$$\Delta TPW_{1880\text{-}2002} = \Delta TPW_{\Delta THW_{1880\text{-}2002}} + \Delta TPW_{SSTW_{1880\text{-}2002}}$$

From Equation (13)

$$\Delta \mathrm{TPW}_{\mathrm{SST}} = 17.53 \left(e^{\left[0.0686 \left(\mathrm{SSTo} + \Delta \mathrm{SST} - 288 \right) \right]} - e^{\left[0.0686 \left(\mathrm{SSTo} - 288 \right) \right]} \right)$$

And from Equation (14)

$$\Delta \mathrm{TPW}_{\Delta \mathrm{TH}} = 0.157 \Delta \mathrm{TH}$$

From **Table 1**

$$\Delta \mathrm{TH}_{1880\text{-}2002} = 9.4$$

Thus,

$$\Delta \mathrm{TPW}_{\Delta \mathrm{TH}1880\text{-}2002} = 0.157 \Delta \mathrm{TH} = 0.157 \times 9.4 = 1.48$$

$$\Delta \mathrm{TPW}_{\mathrm{SST}} = 17.53 \left(e^{\left[00.0686 \left(\mathrm{SSTo} + \Delta \mathrm{SST} - 288 \right) \right]} - e^{\left[00.0686 \left(\mathrm{SSTo} - 288 \right) \right]} \right)$$

With $\mathrm{SST}_{1880} = 288.67, \mathrm{SST}_{2002} = 289.18, \Delta \mathrm{SST} = 0.51^{\circ}\mathrm{C}$

$$\Delta \mathrm{TPW}_{\mathrm{SST}1880\text{-}2002} = 17.53 \left(e^{\left[0.0686 \left(\mathrm{SSTo} + \Delta \mathrm{SST} - 288 \right) \right]} - e^{\left[0.0686 \left(\mathrm{SSTo} - 288 \right) \right]} \right)$$

with

$$0.0686 \left(\mathrm{SST}_{\mathrm{o}} + \Delta \mathrm{SST} - 288 \right) = 0.0686 \left(288.67 + 0.51 - 288 \right) = 0.081$$

$$0.0686 \left(\mathrm{SST}_{\mathrm{o}} - 288 \right) = 0.0686 \left(288.67 - 288 \right) = 0.0686 \times 0.67 = 0.046$$

Thus,

$$\Delta \mathrm{TPW}_{\mathrm{SST}1880\text{-}2002} = 17.53 \left(e^{0.081} - e^{0.046} \right)$$

$$\Delta \mathrm{TPW}_{\mathrm{SST}1880\text{-}2002} = 17.53 \left(e^{0.081} - e^{0.046} \right) = 0.654$$

$$\Delta \mathrm{TPW}_{\mathrm{TotSST}1880\text{-}2002} = \Delta \mathrm{TPW}_{\Delta \mathrm{THW}1880\text{-}2002} + \Delta \mathrm{TPW}_{\mathrm{SSTW}1880\text{-}2002}$$

$$\Delta \mathrm{TPW}_{\mathrm{TotSST}1880\text{-}2002} = 1.48 + 0.654 = 2.134$$

Then to determine the water vapor heating in 1880, set,

$$\mathrm{WV}_{1880} = X \ln \left(\mathrm{TPW}_{1880} \right) + Z$$

From above,

$$\mathrm{WV}_{1880} = 292.38 \ \mathrm{W} \cdot \mathrm{m}^{-2}$$

$$\therefore 292.38 = X \ln \left(\mathrm{TPW}_{1880} \right) + Z$$

and, the change in water vapor heating, is,

$$\Delta \mathrm{WV} = X \ln \left(1 + \Delta \mathrm{TPW} / \mathrm{TPW}_{1880} \right)$$

Solving for X,

$$X = \Delta \mathrm{WV} / \ln \left(1 + \Delta \mathrm{TPW} / \mathrm{TPW}_{1880} \right)$$

And, with

$$\Delta \mathrm{WV}_{1880\text{-}2002} = 8.06$$

$$X = 8.06 / \ln \left(1 + \Delta \mathrm{TPW}_{1880\text{-}2002} / \mathrm{TPW}_{1880} \right)$$

$$X = 8.06 / \ln \left(1 + 2.134 / 18.35 \right) = 73.3$$

Therefore,

$$Z = 292.38 - X \ln\left(\mathrm{TPW_{1880}}\right) = 292.38 - 73.3 \ln\left(18.35\right) = 79.1$$

Thus,

$$\mathrm{WV} = 73.3 \ln\left(\mathrm{TPW}\right) + 79.1$$

10) Changes in Water Vapor Heating from Changes in Total Heating

The change in water vapor heating from changes in total heating, $\Delta\mathrm{TH}$, is then calculated as:

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left[\left(\mathrm{TPW_{1880}} + \Delta\mathrm{TPW_{\Delta TH}}\right)\middle/\mathrm{TPW_{1880}}\right]$$

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left(1 + \Delta\mathrm{TPW_{\Delta TH}}\middle/\mathrm{TPW_{1880}}\right)$$

Substituting $\mathrm{TPW_{1880}} = 18.35\ \mathrm{kg\cdot m^{-2}}$ and from Equation (14),

$$\Delta\mathrm{TPW_{\Delta TH}} = 0.157\Delta\mathrm{TH}\ \mathrm{kg\cdot m^{-2}}$$

Therefore, the change in water vapor heating compared to 1880 as a result of the change in the concentration of water vapor, is calculated as:

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left(18.35 + \Delta\mathrm{TPW_{\Delta TH}}\middle/\mathrm{TPW_{1880}}\right)$$

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left[\left(18.35 + \Delta\mathrm{TPW_{\Delta TH}}\right)\middle/\mathrm{TPW_{1880}}\right]$$

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left(1 + 0.157\,\Delta\mathrm{TH}/18.35\right)$$

$$\Delta\mathrm{WV_{\Delta TH}} = 73.3 \ln\left(1 + 0.0082\Delta\mathrm{TH}\right)\ \mathrm{W\cdot m^{-2}} \tag{15}$$

11) Changes in Water Vapor Heating from Steady State Temperature Driven Evaporation

The change in water vapor heating compared to 1880 as a result of changes in sea surface temperature, $\Delta\mathrm{SST}$, is:

$$\Delta\mathrm{WV_{SST}} = 73.3 \ln\left(\Delta\mathrm{TPW_{SST}}\right)$$

The change in concentration of water vapor solely in response to a change in surface temperature, is:

$$\Delta\mathrm{TPW_{SST}} = 17.53\left(\mathrm{e}^{\left[0.0686(\mathrm{SSTo}+\Delta\mathrm{SST}-288)\right]} - \mathrm{e}^{\left[0.0686(\mathrm{SSTo}-288)\right]}\right)$$

Then,

$$\Delta\mathrm{WV_{SST}} = 73.3 \ln\left[17.53\left(\mathrm{e}^{\left[0.0686(\mathrm{SSTo}+\Delta\mathrm{SST}-288)\right]} - \mathrm{e}^{\left[0.0686(\mathrm{SSTo}-288)\right]}\right)\right]$$

$$\Delta\mathrm{WV_{SST}} = 73.3 \ln\left[17.53\mathrm{e}^{\left[0.0686(\mathrm{SSTo}+\Delta\mathrm{SST}-288)\right]}\middle/17.53\mathrm{e}^{\left[0.0686(\mathrm{SSTo}-288)\right]}\right]$$

Simplifying,

$$\Delta\mathrm{WV_{SST}} = 73.3 \ln\left[\mathrm{e}^{\left[0.0686(\mathrm{SSTo}+\Delta\mathrm{SST}-288)\right]}\middle/\mathrm{e}^{\left[0.0686(\mathrm{SSTo}-288)\right]}\right]$$

$$\Delta\mathrm{WV_{SST}} = 73.3\left[0.0686\left(\mathrm{SSTo}+\mathrm{SST}-288\right) - 0.0686\left(\mathrm{SSTo}-288\right)\right]$$

$$\Delta\mathrm{WV_{SST}} = 73.3 \times 0.0686\Delta\mathrm{SST} = 5.17\Delta\mathrm{SST}\ \mathrm{W\cdot m^{-2}} \tag{16}$$

12) The Change in Water Vapor Heating compared to 1880 as a Result of Both Evaporative Responses

Thus, the increase in water vapor heating compared to 1880 as a result of both evaporative responses, is calculated as:

$$\Delta WV_{Tot} = WV_{\Delta TH} + WV_{\Delta SST}$$

$$\Delta WV_{Tot} = 73.3\ln(1 + 0.0082\Delta TH) + 5.17\Delta SST \text{ W}\cdot\text{m}^{-2} \qquad (17)$$

13) Change in Average Global Temperature, ΔT_{Avg}

The change in average global temperature is the area weighted average of changes in land, T_L, and ocean temperature. Therefore, with the seas covering 71.11% of the surface and land 28.89%, the change in average global temperature is,

$$\Delta T_{Avg} = 0.29\Delta T_L + 0.71\Delta T_O$$

From Equation (10),

$$\Delta T_L = 0.158\Delta TH \text{ °C}$$

From Equation (12), for the maximum increase, the surface temperature limit, ΔT_{STLO} for the seas,

$$\Delta T_{STLO} = 0.07\Delta TH \text{ °C}$$

Since $\Delta TH = \Delta T_L / 0.158$

$$\Delta T_{STLO} = 0.07 \times \Delta T_L / 0.158$$

$$\therefore \Delta T_{Avg} = 0.29\Delta T_L + 0.71 \times 0.07/0.158\Delta T_L$$

thus,

$$\Delta T_{Avg} = \Delta T_L(0.29 + 0.315) = 0.605\Delta T_L$$

Since

$$\Delta T_L = 0.158\Delta TH$$

$$\Delta T_{Avg} = 0.605 \times 0.158\Delta TH = 0.096\Delta TH$$

Thus, the Temperature Response Factor, k_T, to changes in total heating, ΔTH, is,

$$k_T = 0.096 \text{ K}\cdot\text{m}^2\cdot\text{W}^{-1}$$

14) Changes in Heating Driven by Changes in the Concentration of CO_2

The theoretical change in heating driven by changes in the concentration, C, of CO_2, ΔTH_{CO2}, is

$$\Delta TH_{CO2} = 5.35\ln(C/C_o) \text{ W}\cdot\text{m}^{-2} \qquad (18)$$

15) Change in Total Heating

If in the change in total heating, ΔTH_{Tot}, CO_2 were a factor, then the total change in heating would be,

$$\Delta TH_{Tot} = 5.35\ln(C/C_o) + \Delta WV_{Tot} \qquad (19)$$

16) Change in Average Global Temperature

The total increase in average global temperature, ΔT_{Avg}, in response to the total change in heating, ΔTH_{Tot} is, therefore,

$$\Delta T_{\text{Avg}} = k_T \Delta \text{TH}_{\text{Tot}}$$

Thus, from Equation (19), the increase in average global temperature, ΔT_{Avg} from water vapor and heating from CO_2 would be,

$$\Delta T_{\text{Avg}} = 0.096 \left(5.35 \ln \left(C/C_o \right) + \Delta \text{WV}_{\text{Tot}} \right) \text{ °C} \tag{3}$$

However, Equations 4 & 5 show that CO_2 is not a factor and the correct expression is,

$$\Delta T_{\text{Avg}} = 0.4 \Delta \text{TPW} - 0.05 \text{ °C} \tag{5}$$

Appendix 2: Supplementary Materials

Background

Evaporation and Precipitation

The data for changes from average in global land precipitation, ΔPR_L, evaporation and concentration of water vapor are set out in **Figure S1** and **Table S5**.

The relationship between annual changes in the concentration of water vapor, ΔTPW, and changes in the annual rates of evaporation, ΔEV and global land precipitation, ΔPR_L, which is 15% of global precipitation [28], is

$$\Delta \text{EV} = \Delta \text{PR}_L + 0.15 \Delta \text{TPW} \tag{S1}$$

Year over year changes in annual precipitation, evaporation and concentration of water vapor, as a percentage of average global precipitation, 949 mm·m^{-2} are set out in **Table S5**. The annual year over year percentage changes in evaporation, determined from the precipitation change data set out in **Figure S2**, calculated changes in the concentration of water vapor, ΔTPW, using NOAA data [2] [3] which is set out in **Table S5** and determined from the application of Equations 1 and S1 are shown in red in **Figure S2**, year over year changes in annual precipitation are set out in blue.
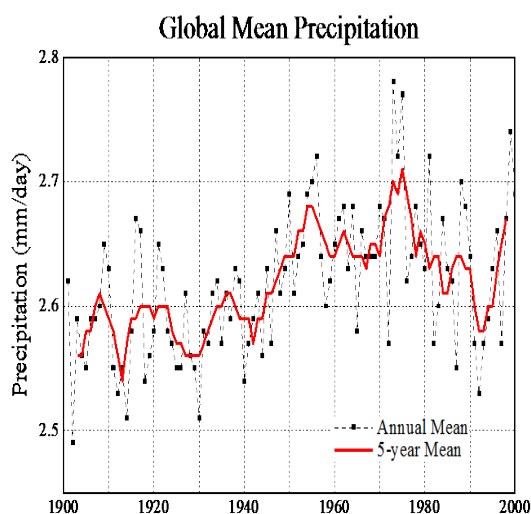
Figure S1. Global annual and five-year running mean precipitation [26] (**Figure 3**).
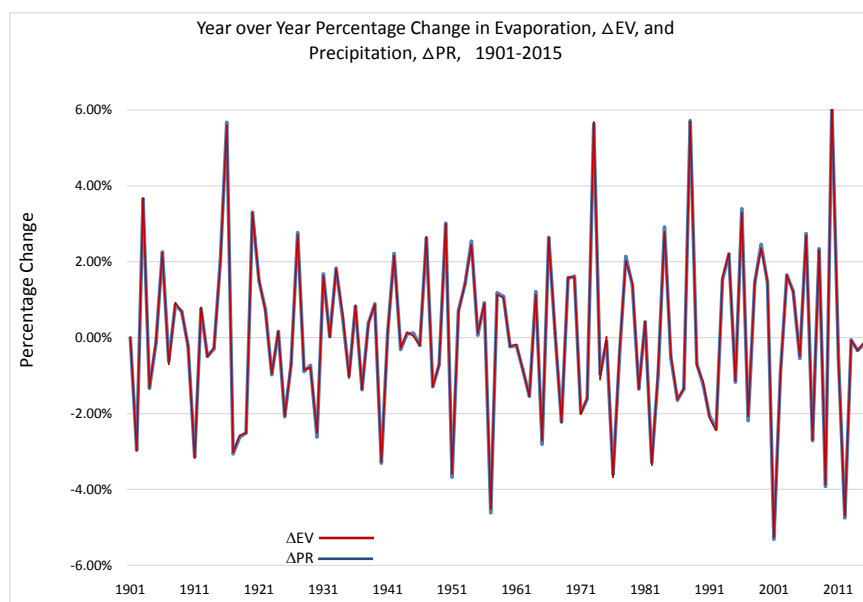
Figure S2. Comparison between year over year percentage changes in land precipitation and evaporation rates from 1901.

The precipitation (blue) and evaporation (red) lines are congruent. Thus, they merge into purple, which is the expectation [29]. If the calculated changes in the concentration of water vapor concentration were significantly incorrect, there would not be this match. For example, if, ΔPR_{LN}-ΔPR_{Lo} were 1% and 0.15% (ΔTPW_N-ΔTPW_o) were to be calculated as -1%, then,

$$\Delta EV_N - \Delta EV_o = \Delta PR_{LN} - \Delta PR_{LO} + 0.15\left(\Delta TPW_N - \Delta TPW_o\right)$$

$$\Delta PR_{LN} - \Delta PR_{LO} = 1\%$$

$$\Delta EV_N - \Delta EV_o = \Delta PR_{LN} - \Delta PR_{LO} + 0.15\left(\Delta TPW_N - \Delta TPW_o\right) = 1\% - 1\% = 0$$

Thus, in this case,

$$\Delta EV_N - \Delta EV_o = -1\%$$

$$\Delta PR_{LN} - \Delta PR_{LO} = 1\%$$

no match.

Referring to **Table S5** and **Figure S2**, such differences do not occur. There is no significant disagreement between the computed results for ΔEV relative to precipitation for the period 1901-2015. Thus, no significant errors in the application of Equation (1) and the 114 calculations of ΔTPW.

Accuracy of Results

That the water vapor concentration methodology set out in this paper is correct is proven by the almost exact match to the historic temperature record from the application of Equation (5) based on the calculated changes in the concentration of water vapor, ΔTPW from Equation (1).

The results of the application of Equation (5) of this methodology based on the NOAA data [2] [3] set out in **Table S1** for the period 1880-2018, are shown

in Table S4 and compared to the average global temperature record in Figure 12. The results have an average accuracy of ±0.14% compared to the actual change in average global temperature measured in degrees Celsius.

Referring to Figure 4, which shows percentage changes in TPW, from 1880 to 1976, the average global concentration of water vapor increased by 1.7% or 0.018% per year. Therefore, while there were short term variations, over this period, the average rate of precipitation was roughly equal to the average rate of evaporation, which is normal [29]. After 1976 the concentration of water vapor increased by 14% or 0.3% per year; a rate 18 times greater, which, as shown in Figure 4 & Figure 11, drove recent global warming.

Moreover, referring to Table S5, the year over year changes in the concentration of water vapor is slight, <0.2 mm·m^{-2}. It is these slight changes that are responsible for changes in the average global temperature.

Positive Feedback Loop

In an audio system with a microphone connected to an amplifier which is, in turn, connected to a speaker, a signal from the speaker, if received by the microphone, passes to the amplifier, is amplified and emitted from the loudspeaker, at a greater volume. Each time sound from the loudspeaker is received by the microphone, it is louder, passed to the amplifier at increased volume and then further amplified and passed out through the loudspeaker at ever increasing volume, again and again. The increase in amplification comes from the increase in acoustic power supplied by the electrically powered amplifier. As long as it remains plugged in and the microphone remains in the same position, the volume of the sound will be increasing to or maintained at the maximum volume for the system. This is a positive feedback loop.

In the climate change loop, an increase in the concentration of water vapor increases water vapor heating, surface temperature and evaporation. To the extent the most recent increase in evaporation is not matched by an increase in precipitation, there is an increase in the concentration of water vapor, water vapor heating, surface temperature and evaporation, on and on. The evaporation > precipitation imbalance is the amplifier. This imbalance does not require any energy in addition to the energy driving evaporation occurring as a direct result of the increase in heating and surface temperature. Thus, as long the rate of evaporation exceeds the rate of precipitation, this imbalance and the positive feedback illustrated in Figure 15 will continue.

The physics are reinforcing. With the rate of change in concentration increasing, this has clearly been a positive feedback loop driven by water vapor heating resulting from the increasing concentration in water vapor shown in Figure 4, increasing water vapor heating, evaporation and in turn water vapor concentration and so on.

This feedback is driven by the average annual small excess in evaporation compared to precipitation.

Until such time as there is an increase in cloud condensing nuclei sufficient

and/or some other factor(s), necessary to compensate for this slight difference and ensure that average precipitation again, continually equals or exceeds average evaporation, the buildup in atmospheric water vapor will continue increasing atmospheric heating, increasing evaporation, and so on, with a continuing increase in average global temperature of 0.2˚C/decade, until limited by the average relative humidity building to a point that sufficiently retards the rate of evaporation. But, by this time, it is possible that the average global temperature will have increased to the point that the areas of habitable and food producing land has shrunk to the point that the very existence of much of humanity is in doubt. Thus, this relative decline in precipitation should be viewed as a threat to humankind.

As noted above, after 1976, there was a continuing slight imbalance between average precipitation and evaporation, with average annual evaporation exceeding annual precipitation of 0.06 mm·m^{-2}/yr.

This slight imbalance is the forcing function driving > 60% of the post 1976 increase in average global temperature stemming from the average rate of evaporation exceeding the average rate of precipitation and, possibly, a periodic insufficiency in the atmospheric density of cloud condensing nuclei, CCN, over certain parts of the globe as air pollution was reduced and precipitation increased, precipitating out more CCN.

The good news is that the solution is mathematically simple. If annual global precipitation can be increased by 3 mm·m^{-2} (0.3% of average annual precipitation of 949 mm/yr.) in excess of evaporation and thereafter maintained in equivalence with the evaporative rate, this is completely reversible and can be controlled.

Meanwhile there is a real urgency in coming to understand this problem and developing and implementing efficient and environmentally sound means of increasing precipitation, because, until then, the problem will only get worse.

As long as the average ratio of annual precipitation/evaporation < 1, for the reasons set out above, this is likely to continue. Thus, by 2100, the increase could be another 1.5˚C, which would be of very serious and ongoing concern to our grandchildren.

Table S1. Input data [1] [2] [3] [5], global average land, ocean and land/ocean temperature data and concentration of CO_2, Figure 1, Figure 8, Figure 9, Figure 13, Figure 14, Figure 16.

Year	Avg. Global Temp. K	Avg. Global Land Temp. K	NOAA Global Land Anomaly ˚C to 20th Century Avg.	Avg. Global Ocean Temp. K	NOAA Global Ocean Anomaly ˚C to 20th Century	Conc. CO_2 ppmv
1880	286.49	281.14	−0.52	288.67	−0.02	290.74
1881	286.53	281.2	−0.46	288.7	0.01	290.97
1882	286.52	281.19	−0.47	288.69	0	291.19

Continued

1883	286.43	280.97	−0.69	288.65	−0.04	291.41
1884	286.35	280.94	−0.72	288.55	−0.14	291.63
1885	286.37	281.08	−0.58	288.52	−0.17	291.86
1886	286.39	281.14	−0.52	288.52	−0.17	292.08
1887	286.35	281.17	−0.49	288.46	−0.23	292.30
1888	286.50	281.23	−0.43	288.64	−0.05	292.59
1889	286.56	281.35	−0.31	288.67	−0.03	292.88
1890	286.30	281.14	−0.52	288.4	−0.29	293.18
1891	286.40	281.13	−0.53	288.54	−0.15	293.47
1892	286.35	281.14	−0.52	288.46	−0.23	293.76
1893	286.33	281.1	−0.56	288.45	−0.24	294.05
1894	286.35	281.24	−0.42	288.42	−0.27	294.34
1895	286.42	281.25	−0.41	288.52	−0.17	294.63
1896	286.56	281.3	−0.36	288.69	0	294.93
1897	286.56	281.38	−0.28	288.66	−0.03	295.22
1898	286.39	281.26	−0.4	288.47	−0.22	295.51
1899	286.50	281.43	−0.23	288.56	−0.13	295.80
1900	286.58	281.5	−0.16	288.64	−0.05	295.55
1901	286.50	281.54	−0.12	288.52	−0.17	295.30
1902	286.41	281.38	−0.28	288.45	−0.24	295.05
1903	286.29	281.28	−0.38	288.32	−0.37	294.80
1904	286.20	281.21	−0.45	288.23	−0.46	295.85
1905	286.38	281.31	−0.35	288.44	−0.25	296.90
1906	286.45	281.48	−0.18	288.47	−0.22	297.48
1907	286.28	281.05	−0.61	288.4	−0.29	298.05
1908	286.23	281.22	−0.44	288.26	−0.43	298.63
1909	286.22	281.25	−0.41	288.24	−0.45	299.20
1910	286.26	281.31	−0.35	288.27	−0.42	299.42
1911	286.21	281.18	−0.48	288.26	−0.43	299.63
1912	286.32	281.18	−0.48	288.41	−0.28	299.85
1913	286.34	281.35	−0.31	288.37	−0.32	300.07
1914	286.52	281.61	−0.05	288.52	−0.17	300.28
1915	286.56	281.58	−0.08	288.59	−0.1	300.50
1916	286.34	281.19	−0.47	288.43	−0.26	300.68
1917	286.27	281.02	−0.64	288.4	−0.29	300.87

Continued

1918	286.37	281.16	−0.5	288.48	−0.21	301.05
1919	286.41	281.32	−0.34	288.48	−0.21	301.23
1920	286.43	281.31	−0.35	288.51	−0.18	301.42
1921	286.50	281.52	−0.14	288.52	−0.17	301.60
1922	286.42	281.41	−0.25	288.45	−0.24	302.25
1923	286.40	281.37	−0.29	288.45	−0.24	302.90
1924	286.42	281.41	−0.25	288.45	−0.24	303.55
1925	286.48	281.51	−0.15	288.5	−0.19	304.20
1926	286.58	281.64	−0.02	288.59	−0.1	304.85
1927	286.48	281.43	−0.23	288.53	−0.16	305.50
1928	286.47	281.51	−0.15	288.49	−0.2	305.64
1929	286.33	281.17	−0.49	288.42	−0.27	305.76
1930	286.55	281.54	−0.12	288.58	−0.11	305.91
1931	286.61	281.67	−0.01	288.61	−0.08	306.05
1932	286.53	281.64	−0.02	288.52	−0.17	306.19
1933	286.40	281.31	−0.35	288.47	−0.22	306.33
1934	286.55	281.6	−0.06	288.56	−0.13	306.46
1935	286.50	281.48	−0.18	288.54	−0.15	306.60
1936	286.54	281.53	−0.13	288.57	−0.12	306.76
1937	286.64	281.63	−0.03	288.68	−0.01	306.93
1938	286.63	281.82	0.16	288.59	−0.1	307.09
1939	286.66	281.74	0.08	288.66	−0.03	307.25
1940	286.82	281.73	0.07	288.89	0.2	307.41
1941	286.93	281.75	0.09	289.04	0.35	307.58
1942	286.77	281.71	0.05	288.82	0.13	307.74
1943	286.76	281.72	0.06	288.81	0.12	307.90
1944	286.94	281.85	0.19	289.01	0.32	308.38
1945	286.85	281.58	−0.08	288.99	0.3	308.86
1946	286.65	281.66	−0.01	288.68	−0.01	309.34
1947	286.62	281.7	0.04	288.62	−0.07	309.82
1948	286.60	281.71	0.05	288.59	−0.1	310.30
1949	286.58	281.59	−0.07	288.61	−0.08	310.76
1950	286.50	281.33	−0.33	288.6	−0.09	311.26
1951	286.66	281.6	−0.06	288.71	0.02	311.74

Continued

1952	286.70	281.61	−0.05	288.77	0.08	312.22
1953	286.79	281.86	0.2	288.79	0.1	312.70
1954	286.56	281.53	−0.13	288.6	−0.09	313.22
1955	286.52	281.54	−0.12	288.55	−0.14	313.73
1956	286.47	281.26	−0.4	288.59	−0.1	314.25
1957	286.73	281.62	−0.04	288.8	0.11	314.77
1958	286.79	281.81	0.15	288.81	0.12	315.28
1959	286.74	281.74	0.08	288.77	0.08	315.97
1960	286.71	281.65	−0.01	288.76	0.07	316.91
1961	286.75	281.77	0.11	288.78	0.09	317.64
1962	286.77	281.81	0.15	288.78	0.09	318.45
1963	286.78	281.87	0.21	288.77	0.08	318.99
1964	286.52	281.44	−0.22	288.58	−0.11	319.62
1965	286.59	281.53	−0.13	288.64	−0.05	320.04
1966	286.64	281.6	−0.06	288.69	0	321.38
1967	286.65	281.67	0.01	288.68	−0.01	322.16
1968	286.63	281.55	−0.11	288.7	0.01	323.04
1969	286.76	281.58	−0.08	288.86	0.17	324.62
1970	286.72	281.71	0.05	288.75	0.06	325.68
1971	286.60	281.64	−0.02	288.61	−0.08	326.32
1972	286.69	281.5	−0.16	288.8	0.11	327.45
1973	286.86	282	0.34	288.83	0.14	329.68
1974	286.59	281.48	−0.18	288.67	−0.02	330.18
1975	286.67	281.8	0.14	288.65	−0.04	331.08
1976	286.59	281.43	−0.23	288.68	−0.01	332.05
1977	286.87	281.92	0.26	288.88	0.19	333.76
1976	286.78	281.77	0.11	288.81	0.12	335.41
1979	286.88	281.84	0.18	288.93	0.24	336.76
1980	286.94	281.98	0.32	288.95	0.26	338.68
1981	286.99	282.19	0.53	288.94	0.25	340.10
1982	286.85	281.78	0.12	288.91	0.22	341.44
1983	287.02	282.17	0.51	288.99	0.3	343.03
1984	286.82	281.73	0.07	288.89	0.2	344.58
1985	286.82	281.77	0.11	288.87	0.18	346.04

Continued

1986	286.90	281.97	0.31	288.9	0.21	347.39
1987	287.05	282.11	0.45	289.05	0.36	349.16
1988	287.06	282.25	0.59	289.01	0.32	351.56
1989	286.96	282.03	0.37	288.96	0.27	353.07
1990	287.11	282.32	0.66	289.06	0.37	354.35
1991	287.05	282.19	0.53	289.03	0.34	355.57
1992	286.89	281.91	0.25	288.92	0.23	356.38
1993	286.95	282.01	0.35	288.95	0.25	357.07
1994	287.01	282.15	0.49	288.98	0.29	358.82
1995	287.13	282.44	0.78	289.04	0.35	360.80
1996	286.98	282.01	0.35	289	0.31	362.59
1997	287.18	282.3	0.64	289.16	0.47	363.71
1998	287.32	282.65	0.99	289.22	0.52	366.65
1999	287.11	282.45	0.79	289	0.31	368.33
2000	287.09	282.3	0.64	289.03	0.34	369.52
2001	287.23	282.52	0.86	289.15	0.46	371.13
2002	287.29	282.64	0.98	289.18	0.49	373.22
2003	287.31	282.62	0.96	289.21	0.52	375.77
2004	287.25	282.49	0.83	289.18	0.49	377.49
2005	287.34	282.77	1.11	289.2	0.5	379.80
2006	287.30	282.66	1	289.19	0.5	381.90
2007	287.29	282.8	1.14	289.12	0.43	383.77
2008	287.21	282.57	0.91	289.1	0.41	385.59
2009	287.31	282.59	0.93	289.23	0.54	387.37
2010	287.40	282.83	1.17	289.25	0.56	389.85
2011	287.24	282.6	0.94	289.13	0.44	391.62
2012	287.30	282.64	0.98	289.2	0.51	393.81
2013	287.34	282.71	1.05	289.22	0.53	396.52
2014	287.40	282.69	1.03	289.32	0.63	398.65
2015	287.60	283.08	1.42	289.44	0.75	400.83
2016	287.67	283.2	1.54	289.48	0.79	404.24
2017	287.58	283.08	1.42	289.41	0.72	406.55
2018	287.50	282.88	1.22	289.37	0.68	408.52
2019	287.62	283.08	1.42	289.46	0.77	410.44

Table S2. Changes in concentration of water vapor, average global temperature, back radiation from water vapor and theoretical CO_2 heating, Figure 4, Figure 6, Figure 11 & Figure 14.

Year	ΔTPW% from 1880	ΔT$_{Avg}$% from 1880	TPW kgm^{-2}	ΔTPW from 1880 kgm^{-2}	ΔTavg from 1880 Deg. C	ΔWV from 1880 Wm^{-2}	TH$_{CO2}$ Wm^{-2}
1880	0.00%	0.00%	18.35	0.00	0.00	0.00	0
1881	0.53%	0.29%	18.45	0.10	0.04	0.39	0.00
1882	0.41%	0.21%	18.43	0.07	0.03	0.30	0.01
1883	−1.05%	−0.47%	18.16	−0.19	−0.06	−0.77	0.01
1884	−1.90%	−1.07%	18.00	−0.35	−0.14	−1.40	0.02
1885	−1.35%	−0.93%	18.11	−0.25	−0.12	−0.99	0.02
1886	−1.02%	−0.80%	18.16	−0.19	−0.11	−0.75	0.02
1887	−1.27%	−1.05%	18.12	−0.23	−0.14	−0.94	0.03
1888	0.28%	0.03%	18.40	0.05	0.00	0.20	0.03
1889	1.13%	0.45%	18.56	0.21	0.06	0.83	0.04
1890	−1.84%	−1.44%	18.02	−0.34	−0.19	−1.36	0.04
1891	−0.94%	−0.71%	18.18	−0.17	−0.10	−0.69	0.05
1892	−1.43%	−1.12%	18.09	−0.26	−0.15	−1.06	0.06
1893	−1.71%	−1.26%	18.04	−0.31	−0.17	−1.26	0.06
1894	−1.16%	−1.12%	18.14	−0.21	−0.15	−0.86	0.07
1895	−0.43%	−0.56%	18.27	−0.08	−0.07	−0.32	0.07
1896	1.00%	0.45%	18.54	0.18	0.06	0.73	0.08
1897	1.23%	0.47%	18.58	0.23	0.06	0.89	0.08
1898	−0.72%	−0.81%	18.22	−0.13	−0.11	−0.53	0.09
1899	0.81%	0.04%	18.50	0.15	0.01	0.59	0.09
1900	1.74%	0.62%	18.67	0.32	0.08	1.26	0.09
1901	1.14%	0.07%	18.56	0.21	0.01	0.81	0.08
1902	−0.20%	−0.65%	18.32	−0.04	−0.09	−0.16	0.08
1903	−1.62%	−1.56%	18.06	−0.30	−0.21	−1.21	0.07
1904	−2.60%	−2.19%	17.88	−0.48	−0.29	−1.94	0.09
1905	−0.65%	−0.86%	18.23	−0.12	−0.11	−0.49	0.11
1906	0.47%	−0.33%	18.44	0.09	−0.04	0.33	0.12
1907	−2.32%	−1.63%	17.93	−0.43	−0.22	−1.71	0.13
1908	−2.34%	−2.01%	17.92	−0.43	−0.27	−1.75	0.14
1909	−2.31%	−2.05%	17.93	−0.42	−0.27	−1.73	0.15
1910	−1.79%	−1.76%	18.02	−0.33	−0.24	−1.34	0.16
1911	−2.56%	−2.10%	17.88	−0.47	−0.28	−1.90	0.16
1912	−1.55%	−1.30%	18.07	−0.28	−0.17	−1.15	0.16
1913	−0.90%	−1.14%	18.19	−0.17	−0.15	−0.68	0.17

Continued

1914	1.52%	0.22%	18.63	0.28	0.03	1.08	0.17
1915	1.83%	0.53%	18.69	0.34	0.07	1.32	0.18
1916	−1.36%	−1.17%	18.10	−0.25	−0.16	−1.01	0.18
1917	−2.48%	−1.70%	17.90	−0.46	−0.23	−1.83	0.18
1918	−1.19%	−0.97%	18.13	−0.22	−0.13	−0.88	0.19
1919	−0.32%	−0.62%	18.29	−0.06	−0.08	−0.25	0.19
1920	−0.17%	−0.48%	18.32	−0.03	−0.06	−0.14	0.19
1921	1.03%	0.02%	18.54	0.19	0.00	0.73	0.20
1922	−0.04%	−0.59%	18.35	−0.01	−0.08	−0.05	0.21
1923	−0.26%	−0.67%	18.31	−0.05	−0.09	−0.20	0.22
1924	−0.04%	−0.59%	18.35	−0.01	−0.08	−0.05	0.23
1925	0.84%	−0.10%	18.51	0.15	−0.01	0.60	0.24
1926	2.15%	0.66%	18.75	0.40	0.09	1.55	0.25
1927	0.61%	−0.12%	18.46	0.11	−0.02	0.43	0.26
1928	0.77%	−0.16%	18.49	0.14	−0.02	0.54	0.27
1929	−1.54%	−1.27%	18.07	−0.28	−0.17	−1.14	0.27
1930	1.54%	0.39%	18.64	0.28	0.05	1.11	0.27
1931	2.45%	0.83%	18.80	0.45	0.11	1.77	0.27
1932	1.68%	0.28%	18.66	0.31	0.04	1.20	0.28
1933	−0.45%	−0.70%	18.27	−0.08	−0.09	−0.34	0.28
1934	1.73%	0.41%	18.67	0.32	0.05	1.25	0.28
1935	0.95%	0.04%	18.53	0.17	0.01	0.68	0.28
1936	1.42%	0.31%	18.61	0.26	0.04	1.02	0.29
1937	2.72%	1.11%	18.85	0.50	0.15	1.97	0.29
1938	3.13%	1.05%	18.93	0.57	0.14	2.25	0.29
1939	3.18%	1.25%	18.94	0.58	0.17	2.29	0.30
1940	4.71%	2.45%	19.22	0.86	0.33	3.41	0.30
1941	5.87%	3.29%	19.43	1.08	0.44	4.24	0.30
1942	4.12%	2.03%	19.11	0.76	0.27	2.98	0.30
1943	4.10%	2.00%	19.11	0.75	0.27	2.97	0.31
1944	6.20%	3.35%	19.49	1.14	0.45	4.47	0.32
1945	4.60%	2.66%	19.20	0.84	0.35	3.33	0.32
1946	2.88%	1.18%	18.88	0.53	0.16	2.08	0.33
1947	2.68%	0.95%	18.85	0.49	0.13	1.93	0.34
1948	2.53%	0.81%	18.82	0.47	0.11	1.82	0.35
1949	2.02%	0.65%	18.72	0.37	0.09	1.46	0.36

Continued

1950	0.55%	0.04%	18.45	0.10	0.01	0.40	0.36
1951	2.76%	1.21%	18.86	0.51	0.16	2.00	0.37
1952	3.23%	1.55%	18.95	0.59	0.21	2.34	0.38
1953	4.72%	2.20%	19.22	0.87	0.29	3.40	0.39
1954	1.63%	0.47%	18.65	0.30	0.06	1.18	0.40
1955	1.34%	0.23%	18.60	0.25	0.03	0.96	0.41
1956	0.10%	−0.17%	18.37	0.02	−0.02	0.07	0.42
1957	3.49%	1.73%	18.99	0.64	0.23	2.53	0.42
1958	4.59%	2.20%	19.19	0.84	0.29	3.31	0.43
1959	3.93%	1.83%	19.07	0.72	0.24	2.84	0.45
1960	3.38%	1.58%	18.97	0.62	0.21	2.45	0.46
1961	4.16%	1.95%	19.12	0.76	0.26	3.01	0.47
1962	4.38%	2.04%	19.16	0.80	0.27	3.16	0.49
1963	4.64%	2.11%	19.20	0.85	0.28	3.34	0.50
1964	1.00%	0.17%	18.54	0.18	0.02	0.72	0.51
1965	1.90%	0.68%	18.70	0.35	0.09	1.38	0.51
1966	2.62%	1.10%	18.83	0.48	0.15	1.90	0.54
1967	2.93%	1.20%	18.89	0.54	0.16	2.12	0.55
1968	2.42%	1.05%	18.80	0.44	0.14	1.76	0.56
1969	3.69%	1.97%	19.03	0.68	0.26	2.68	0.59
1970	3.63%	1.66%	19.02	0.67	0.22	2.63	0.61
1971	2.29%	0.76%	18.77	0.42	0.10	1.65	0.62
1972	2.84%	1.47%	18.87	0.52	0.20	2.06	0.64
1973	5.76%	2.71%	19.41	1.06	0.36	4.14	0.67
1974	1.84%	0.74%	18.69	0.34	0.10	1.33	0.68
1975	3.43%	1.32%	18.98	0.63	0.18	2.47	0.70
1976	1.63%	0.68%	18.65	0.30	0.09	1.19	0.71
1977	5.67%	2.81%	19.39	1.04	0.37	4.09	0.74
1976	4.37%	2.11%	19.16	0.80	0.28	3.16	0.76
1979	5.59%	2.90%	19.38	1.03	0.39	4.03	0.79
1980	6.49%	3.31%	19.54	1.19	0.44	4.67	0.82
1981	7.56%	3.71%	19.74	1.39	0.50	5.41	0.84
1982	5.12%	2.66%	19.29	0.94	0.36	3.70	0.86
1983	7.80%	3.94%	19.78	1.43	0.53	5.59	0.88
1984	4.71%	2.45%	19.22	0.86	0.33	3.41	0.91

Continued

1985	4.79%	2.43%	19.23	0.88	0.32	3.46	0.93
1986	6.08%	3.02%	19.47	1.12	0.40	4.38	0.95
1987	7.90%	4.12%	19.80	1.45	0.55	5.66	0.98
1988	8.38%	4.21%	19.89	1.54	0.56	5.99	1.02
1989	6.83%	3.47%	19.61	1.25	0.46	4.91	1.04
1990	9.11%	4.63%	20.02	1.67	0.62	6.51	1.06
1991	8.19%	4.19%	19.86	1.50	0.56	5.87	1.08
1992	5.90%	3.00%	19.44	1.08	0.40	4.25	1.09
1993	6.65%	3.38%	19.57	1.22	0.45	4.78	1.10
1994	7.62%	3.84%	19.75	1.40	0.51	5.46	1.13
1995	9.63%	4.79%	20.12	1.77	0.64	6.86	1.15
1996	7.00%	3.64%	19.64	1.28	0.49	5.03	1.18
1997	9.71%	5.12%	20.13	1.78	0.68	6.94	1.20
1998	12.05%	6.20%	20.56	2.21	0.83	8.54	1.24
1999	9.40%	4.59%	20.08	1.72	0.61	6.69	1.27
2000	8.79%	4.43%	19.97	1.61	0.59	6.28	1.28
2001	10.84%	5.55%	20.34	1.99	0.74	7.71	1.31
2002	11.71%	5.97%	20.50	2.15	0.80	8.31	1.34
2003	11.81%	6.08%	20.52	2.17	0.81	8.38	1.37
2004	10.89%	5.64%	20.35	2.00	0.75	7.75	1.40
2005	12.56%	6.35%	20.66	2.31	0.85	8.89	1.43
2006	11.89%	6.06%	20.53	2.18	0.81	8.43	1.46
2007	12.16%	5.99%	20.58	2.23	0.80	8.60	1.49
2008	10.76%	5.39%	20.33	1.97	0.72	7.64	1.51
2009	11.79%	6.12%	20.52	2.16	0.82	8.37	1.54
2010	13.25%	6.75%	20.78	2.43	0.90	9.36	1.57
2011	11.14%	5.61%	20.40	2.04	0.75	7.91	1.59
2012	11.85%	6.07%	20.53	2.18	0.81	8.41	1.62
2013	12.38%	6.33%	20.62	2.27	0.84	8.77	1.66
2014	12.98%	6.82%	20.74	2.38	0.91	9.20	1.69
2015	15.99%	8.30%	21.29	2.93	1.11	11.23	1.72
2016	16.94%	8.78%	21.46	3.11	1.17	11.87	1.76
2017	15.77%	8.14%	21.25	2.89	1.09	11.08	1.79
2018	14.38%	7.50%	20.99	2.64	1.00	10.15	1.82
2019	16.13%	8.41%	21.31	2.96	1.12	11.33	1.84

Table S3. Year over year changes in water vapor heating, ΔWV, compared to changes in heating from CO_2, ΔTH_{CO_2}, for the same year and changes in efficiency of ocean heating, $Eff_{\Delta THO}$, **Figure 7**.

YoY ΔTH_{CO_2}	YoY ΔWV
Wm^{-2}	Wm^{-2}
−0.005	−1.05
−0.005	−0.98
−0.005	−0.45
−0.005	0.67
0.002	−0.57
0.002	1.58
0.002	−1.54
0.002	−0.57
0.002	0.65
0.002	2.25
0.002	−1.68
0.002	0.11
0.003	−0.01
0.003	−1.26
0.003	0.83
0.003	1.12
0.003	0.04
0.003	0.28
0.003	0.94
0.003	0.35
0.003	0.87
0.003	0.11
0.003	0.63
0.003	0.96
0.003	−0.82
0.003	−2.33
0.004	0.24
0.004	1.77
0.004	0.47
0.004	0.75
0.004	−0.56
0.004	0.39

Continued

0.004	−0.18
0.004	0.24
0.004	0.41
0.004	−0.62
0.004	−1.07
0.004	−0.09
0.004	0.39
0.005	1.12
0.005	−1.43
0.005	0.16
0.005	1.05
0.005	0.54
0.005	0.40
0.005	−0.21
0.005	−0.36
0.005	0.66
0.005	−2.18
0.005	0.62
0.005	1.14
0.007	0.65
0.008	−2.81
0.008	1.06
0.008	0.34
0.008	1.60
0.008	−1.06
0.008	−0.36
0.008	−0.11
0.008	−0.15
0.008	−1.25
0.008	−1.14
0.008	1.51
0.009	0.78
0.009	2.46
0.009	−0.89
0.009	−0.21
0.009	−2.23

Continued

0.009	0.18
0.010	0.02
0.010	−0.03
0.010	−2.04
0.010	0.53
0.010	0.82
0.011	−0.97
0.011	−2.62
0.011	−1.12
0.011	0.96
0.011	0.64
0.011	0.16
0.011	−0.16
0.012	−0.78
0.012	−0.47
0.012	−1.62
0.012	0.56
0.013	0.22
0.014	0.15
0.015	1.14
0.015	−0.36
0.016	−1.28
0.016	−0.40
0.017	1.90
0.017	−0.41
0.017	−0.05
0.018	−0.64
0.018	0.41
0.019	1.45
0.019	−0.73
0.019	1.60
0.021	0.92
0.021	−1.71
0.022	0.87
0.022	0.52
0.022	0.75

Continued

0.023	0.05
0.023	−1.08
0.023	1.43
0.024	−2.18
0.024	−1.45
0.024	−0.63
0.024	−1.85
0.025	0.73
0.025	1.89
0.025	1.18
0.025	−0.95
0.026	−0.93
0.026	−0.93
0.026	0.92
0.026	0.17
0.026	0.68
0.026	−1.82
0.027	1.29
0.028	2.90
0.029	0.43
0.029	2.04
0.029	1.39
0.029	−0.46
0.030	0.50
0.030	0.60
0.030	0.64
0.030	−0.79
0.033	1.14
0.034	0.99
0.036	2.08
0.036	0.08
0.037	0.33
0.037	0.36
0.043	1.61
0.045	0.64

Table S4. Comparison between the average global temperature record [1] [2] [3] and the calculated changes in the average global temperature from Equations (3)-(5), Figure 8, Figure 9 & Figure 12.

Year	Avg. Global	Avg. Global Temp. from Equation (3)	Avg. Global Temp. from Equation (4)	Avg. Global Temp. from Equation (5)
	Temp. Deg. C	Temp. Deg. C	Temp. Deg. C	Temp. Deg. C
1880	13.34	13.34	13.34	13.29
1881	13.38	13.38	13.38	13.33
1882	13.37	13.37	13.37	13.32
1883	13.28	13.27	13.27	13.22
1884	13.20	13.21	13.21	13.16
1885	13.22	13.25	13.25	13.20
1886	13.24	13.27	13.27	13.22
1887	13.20	13.26	13.25	13.20
1888	13.35	13.37	13.36	13.31
1889	13.41	13.43	13.42	13.38
1890	13.15	13.22	13.21	13.16
1891	13.25	13.28	13.28	13.23
1892	13.20	13.25	13.24	13.19
1893	13.18	13.23	13.22	13.17
1894	13.20	13.27	13.26	13.21
1895	13.27	13.32	13.31	13.26
1896	13.41	13.42	13.41	13.37
1897	13.41	13.44	13.43	13.38
1898	13.24	13.30	13.29	13.24
1899	13.35	13.41	13.40	13.35
1900	13.43	13.47	13.47	13.42
1901	13.35	13.43	13.42	13.38
1902	13.26	13.34	13.33	13.28
1903	13.14	13.24	13.23	13.18
1904	13.05	13.17	13.16	13.10
1905	13.23	13.31	13.30	13.25
1906	13.30	13.39	13.38	13.33
1907	13.13	13.19	13.18	13.12
1908	13.08	13.19	13.18	13.12
1909	13.07	13.19	13.18	13.12
1910	13.11	13.23	13.22	13.16
1911	13.06	13.18	13.16	13.11

Continued

1912	13.17	13.25	13.23	13.18
1913	13.19	13.30	13.28	13.23
1914	13.37	13.47	13.45	13.41
1915	13.41	13.49	13.47	13.43
1916	13.19	13.26	13.25	13.19
1917	13.12	13.19	13.17	13.11
1918	13.22	13.28	13.26	13.21
1919	13.26	13.34	13.32	13.27
1920	13.28	13.35	13.33	13.28
1921	13.35	13.43	13.42	13.37
1922	13.27	13.36	13.34	13.29
1923	13.25	13.35	13.33	13.28
1924	13.27	13.36	13.34	13.29
1925	13.33	13.42	13.40	13.36
1926	13.43	13.52	13.49	13.45
1927	13.33	13.41	13.39	13.34
1928	13.32	13.42	13.40	13.35
1929	13.18	13.26	13.24	13.18
1930	13.40	13.48	13.45	13.41
1931	13.46	13.54	13.51	13.47
1932	13.38	13.49	13.46	13.42
1933	13.25	13.34	13.31	13.26
1934	13.40	13.49	13.46	13.42
1935	13.35	13.44	13.41	13.36
1936	13.39	13.47	13.44	13.40
1937	13.49	13.56	13.53	13.49
1938	13.48	13.59	13.56	13.52
1939	13.51	13.59	13.56	13.53
1940	13.67	13.70	13.67	13.64
1941	13.78	13.78	13.75	13.72
1942	13.62	13.66	13.63	13.60
1943	13.61	13.66	13.63	13.59
1944	13.79	13.80	13.77	13.75
1945	13.70	13.70	13.66	13.63
1946	13.50	13.58	13.54	13.51
1947	13.47	13.56	13.53	13.49

Continued

1948	13.45	13.55	13.52	13.48
1949	13.43	13.52	13.48	13.44
1950	13.35	13.42	13.38	13.33
1951	13.51	13.57	13.54	13.50
1952	13.55	13.61	13.57	13.53
1953	13.64	13.71	13.67	13.64
1954	13.41	13.50	13.46	13.41
1955	13.37	13.48	13.44	13.39
1956	13.32	13.39	13.35	13.30
1957	13.58	13.63	13.59	13.55
1958	13.64	13.70	13.66	13.63
1959	13.59	13.66	13.62	13.58
1960	13.56	13.62	13.58	13.54
1961	13.60	13.68	13.63	13.60
1962	13.62	13.69	13.65	13.62
1963	13.63	13.71	13.67	13.63
1964	13.37	13.46	13.41	13.37
1965	13.44	13.53	13.48	13.43
1966	13.49	13.58	13.53	13.49
1967	13.50	13.60	13.55	13.51
1968	13.48	13.57	13.51	13.47
1969	13.61	13.66	13.60	13.56
1970	13.57	13.66	13.60	13.56
1971	13.45	13.56	13.50	13.46
1972	13.54	13.60	13.54	13.50
1973	13.71	13.81	13.74	13.72
1974	13.44	13.54	13.47	13.43
1975	13.52	13.65	13.58	13.55
1976	13.44	13.53	13.46	13.41
1977	13.72	13.81	13.74	13.71
1976	13.63	13.72	13.65	13.61
1979	13.73	13.81	13.73	13.70
1980	13.79	13.87	13.79	13.77
1981	13.84	13.94	13.86	13.85
1982	13.70	13.78	13.70	13.67
1983	13.87	13.97	13.88	13.87

Continued

1984	13.67	13.76	13.67	13.64
1985	13.67	13.77	13.68	13.65
1986	13.75	13.86	13.76	13.74
1987	13.90	13.98	13.89	13.87
1988	13.91	14.02	13.92	13.91
1989	13.81	13.92	13.82	13.79
1990	13.96	14.07	13.97	13.96
1991	13.90	14.01	13.91	13.89
1992	13.74	13.86	13.75	13.73
1993	13.80	13.91	13.80	13.78
1994	13.86	13.98	13.87	13.85
1995	13.98	14.11	14.00	14.00
1996	13.83	13.94	13.83	13.81
1997	14.03	14.13	14.01	14.01
1998	14.17	14.28	14.16	13.29
1999	13.96	14.11	13.99	13.33
2000	13.94	14.07	13.95	13.32
2001	14.08	14.21	14.08	13.22
2002	14.14	14.27	14.14	14.18
2003	14.16	14.28	14.15	14.18
2004	14.10	14.22	14.09	14.11
2005	14.19	14.34	14.20	14.24
2006	14.15	14.29	14.15	14.19
2007	14.14	14.31	14.17	14.21
2008	14.06	14.22	14.08	14.10
2009	14.16	14.30	14.15	14.18
2010	14.25	14.39	14.24	14.29
2011	14.09	14.26	14.10	14.13
2012	14.15	14.31	14.15	14.19
2013	14.19	14.35	14.19	14.23
2014	14.25	14.39	14.23	14.27
2015	14.45	14.59	14.42	14.50
2016	14.52	14.65	14.48	14.57
2017	14.43	14.58	14.41	14.48
2018	14.35	14.49	14.32	14.38
2019	14.47	14.61	14.43	14.51

Table S5. Annual changes and percentage changes from average (949 mm) for land precipitation data and computed changes in concentration of water vapor and evaporation 1901-2015 [30], **Figure S2**.

Year	ΔPrecip mm	ΔPrecip %	ΔEvap mm	ΔEvap %	ΔTPW mm	ΔTPW %
1901	−20.97	−2.21%	−20.99	0.00%	0	0
1902	−49.04	−5.17%	−49.08	−2.95%	−0.24	−0.03%
1903	−14.28	−1.50%	−14.32	3.67%	−0.26	−0.03%
1904	−26.91	−2.84%	−26.93	−1.32%	−0.18	−0.02%
1905	−28.24	−2.98%	−28.18	−0.12%	0.35	0.04%
1906	−6.81	−0.72%	−6.78	2.27%	0.20	0.02%
1907	−12.72	−1.34%	−12.80	−0.62%	−0.49	−0.05%
1908	−4.53	−0.48%	−4.52	0.88%	−0.01	0.00%
1909	2.01	0.21%	2.01	0.70%	0.00	0.00%
1910	−0.11	−0.01%	−0.09	−0.21%	0.09	0.01%
1911	−29.90	−3.15%	−29.92	−3.13%	−0.14	−0.01%
1912	−22.70	−2.39%	−22.67	0.77%	0.18	0.02%
1913	−27.37	−2.88%	−27.35	−0.48%	0.11	0.01%
1914	−30.15	−3.18%	−30.07	−0.28%	0.43	0.05%
1915	−10.82	−1.14%	−10.81	2.04%	0.06	0.01%
1916	43.04	4.54%	42.95	5.67%	−0.57	−0.06%
1917	14.01	1.48%	13.97	−3.04%	−0.20	−0.02%
1918	−10.88	−1.15%	−10.85	−2.61%	0.23	0.02%
1919	−34.68	−3.65%	−34.66	−2.50%	0.15	0.02%
1920	−3.32	−0.35%	−3.31	3.31%	0.03	0.00%
1921	10.86	1.14%	10.90	1.51%	0.21	0.02%
1922	17.97	1.89%	17.94	0.75%	−0.19	−0.02%
1923	8.75	0.92%	8.74	−0.96%	−0.04	0.00%
1924	10.27	1.08%	10.27	0.17%	0.04	0.00%
1925	−9.45	−1.00%	−9.42	−2.07%	0.16	0.02%
1926	−16.15	−1.70%	−16.11	−0.69%	0.24	0.02%
1927	10.13	1.07%	10.08	2.77%	−0.27	−0.03%
1928	1.71	0.18%	1.72	−0.87%	0.03	0.00%
1929	−5.22	−0.55%	−5.29	−0.73%	−0.41	−0.04%
1930	−30.07	−3.17%	−29.97	−2.59%	0.55	0.06%
1931	−14.18	−1.49%	−14.16	1.68%	0.16	0.02%
1932	−13.85	−1.46%	−13.87	0.04%	−0.14	−0.01%
1933	3.53	0.37%	3.47	1.84%	−0.38	−0.04%

Continued

1934	8.38	0.88%	8.44	0.53%	0.39	0.04%
1935	−1.12	−0.12%	−1.14	−1.00%	−0.14	−0.01%
1936	6.69	0.71%	6.71	0.84%	0.08	0.01%
1937	−6.30	−0.66%	−6.26	−1.36%	0.23	0.02%
1938	−2.64	−0.28%	−2.62	0.39%	0.07	0.01%
1939	5.77	0.61%	5.77	0.89%	0.01	0.00%
1940	−25.58	−2.70%	−25.54	−3.29%	0.28	0.03%
1941	−24.18	−2.55%	−24.15	0.16%	0.21	0.02%
1942	−3.15	−0.33%	−3.20	2.22%	−0.32	−0.03%
1943	−6.08	−0.64%	−6.08	−0.29%	0.00	0.00%
1944	−5.11	−0.54%	−5.05	0.12%	0.38	0.04%
1945	−3.98	−0.42%	−4.02	0.12%	−0.28	−0.03%
1946	−5.89	−0.62%	−5.94	−0.19%	−0.32	−0.03%
1947	19.01	2.00%	19.00	2.64%	−0.04	0.00%
1948	6.78	0.71%	6.78	−1.28%	−0.03	0.00%
1949	0.06	0.01%	0.04	−0.70%	−0.09	−0.01%
1950	28.66	3.02%	28.61	3.02%	−0.26	−0.03%
1951	−6.15	−0.65%	−6.08	−3.65%	0.39	0.04%
1952	0.65	0.07%	0.66	0.72%	0.09	0.01%
1953	14.05	1.48%	14.09	1.43%	0.26	0.03%
1954	38.16	4.02%	38.07	2.54%	−0.55	−0.06%
1955	38.81	4.09%	38.80	0.09%	−0.05	−0.01%
1956	47.53	5.01%	47.49	0.93%	−0.22	−0.02%
1957	3.73	0.39%	3.83	−4.59%	0.61	0.06%
1958	14.93	1.57%	14.96	1.18%	0.19	0.02%
1959	25.22	2.66%	25.20	1.09%	−0.12	−0.01%
1960	22.99	2.42%	22.98	−0.22%	−0.10	−0.01%
1961	21.00	2.21%	21.02	−0.20%	0.14	0.01%
1962	13.03	1.37%	13.04	−0.83%	0.04	0.00%
1963	−1.60	−0.17%	−1.60	−1.53%	0.04	0.00%
1964	9.87	1.04%	9.76	1.21%	−0.65	−0.07%
1965	−16.76	−1.77%	−16.73	−2.78%	0.16	0.02%
1966	8.28	0.87%	8.30	2.65%	0.13	0.01%
1967	9.41	0.99%	9.42	0.13%	0.05	0.01%
1968	−11.64	−1.23%	−11.66	−2.21%	−0.09	−0.01%
1969	3.16	0.33%	3.20	1.58%	0.23	0.02%

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Continued

1970	18.52	1.95%	18.52	1.63%	−0.02	0.00%
1971	−0.30	−0.03%	−0.34	−1.98%	−0.24	−0.03%
1972	−15.66	−1.65%	−15.65	−1.60%	0.11	0.01%
1973	37.75	3.98%	37.84	5.65%	0.51	0.05%
1974	28.67	3.02%	28.55	−0.97%	−0.70	−0.07%
1975	27.76	2.92%	27.81	−0.07%	0.28	0.03%
1976	−6.45	−0.68%	−6.50	−3.61%	−0.31	−0.03%
1977	−11.18	−1.18%	−11.06	−0.47%	0.72	0.08%
1978	9.13	0.96%	9.10	2.13%	−0.23	−0.02%
1979	22.22	2.34%	22.25	1.40%	0.22	0.02%
1980	9.43	0.99%	9.46	−1.34%	0.16	0.02%
1981	13.34	1.41%	13.37	0.42%	0.19	0.02%
1982	−17.80	−1.88%	−17.88	−3.28%	−0.43	−0.05%
1983	−27.15	−2.86%	−27.07	−0.96%	0.47	0.05%
1984	0.48	0.05%	0.39	2.90%	−0.55	−0.06%
1985	−4.62	−0.49%	−4.61	−0.52%	0.01	0.00%
1986	−20.23	−2.13%	−20.19	−1.63%	0.23	0.02%
1987	−33.06	−3.48%	−33.01	−1.34%	0.33	0.03%
1988	21.19	2.23%	21.21	5.72%	0.08	0.01%
1989	14.73	1.55%	14.68	−0.68%	−0.27	−0.03%
1990	2.93	0.31%	3.00	−1.22%	0.41	0.04%
1991	−16.56	−1.75%	−16.59	−2.05%	−0.16	−0.02%
1992	−39.38	−4.15%	−39.45	−2.40%	−0.41	−0.04%
1993	−24.94	−2.63%	−24.92	1.54%	0.13	0.01%
1994	−4.04	−0.43%	−4.01	2.21%	0.17	0.02%
1995	−15.11	−1.59%	−15.05	−1.15%	0.35	0.04%
1996	17.10	1.80%	17.02	3.39%	−0.46	−0.05%
1997	−3.65	−0.38%	−3.57	−2.16%	0.48	0.05%
1998	10.18	1.07%	10.25	1.47%	0.41	0.04%
1999	33.50	3.53%	33.42	2.45%	−0.48	−0.05%
2000	47.26	4.98%	47.24	1.47%	−0.10	−0.01%
2001	−3.13	−0.33%	−3.07	−5.29%	0.37	0.04%
2002	−11.94	−1.26%	−11.91	−0.92%	0.15	0.02%
2003	3.70	0.39%	3.71	1.66%	0.02	0.00%
2004	15.37	1.62%	15.34	1.24%	−0.16	−0.02%
2005	10.25	1.08%	10.30	−0.52%	0.29	0.03%

Continued

2006	36.23	3.82%	36.21	2.74%	−0.12	−0.01%
2007	10.51	1.11%	10.52	−2.70%	0.04	0.00%
2008	32.71	3.45%	32.66	2.34%	−0.25	−0.03%
2009	−4.50	−0.47%	−4.47	−3.90%	0.19	0.02%
2010	53.87	5.68%	53.91	6.16%	0.26	0.03%
2011	49.00	5.16%	48.93	−0.51%	−0.38	−0.04%
2012	3.97	0.42%	3.99	−4.73%	0.13	0.01%
2013	3.37	0.35%	3.38	−0.05%	0.09	0.01%
2014	0.18	0.02%	0.20	−0.33%	0.11	0.01%
2015	−1.39	−0.15%	−1.30	−0.15%	0.53	0.06%