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The Sun and the Troposphere Control the Earth's Temperature

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Abstract:

The basis for this study is the flow of energy from the Troposphere to space and the role that water vapor and carbon dioxide (CO₂) play in affecting the flow. Then, it analyzes the radiation profiles and compares them to the ratio of water molecules to CO₂ molecules. Examining the radiation profiles of water vapor and CO₂ showed the overlap made it virtually impossible to separate the warming effects. Calculating the ratio of water vapor molecules to CO₂ molecules by proven physics and chemistry is accurate for separating the individual warming effects. The results of a quantitative examination show water vapor has 1,000 to 7,000 times more impact on the Earth's temperature than CO₂. The warming effect of CO₂ versus concentration is linear. In contrast, the warming effect of water vapor versus concentration is curved. The lowest level of the atmosphere, the Troposphere, has most of the air mass and water vapor and exercises control over the Earth's temperature. Energy leaving the Troposphere flows virtually unhindered to space. The Sun is Earth's primary energy source, and its natural variations control its temperature.

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1. INTRODUCTION

This current study is a follow-up to the paper published in 2023 titled “Laws of Physics define the insignificant warming of Earth by CO₂” [1]. It uses the results of the ratios of water vapor molecules to carbon dioxide (CO₂) molecules to provide new insights into how greenhouse gases, such as water vapor and CO₂, affect the Earth’s temperature.

This current study is at the end of a line of studies starting in 2014, which aims to provide quantitative results. To put into perspective the role of water vapor in determining the Earth’s temperature, a paper in 2014 using the psychrometric model of the Troposphere [2] showed “that on average, water vapor accounts for approximately 96% of the current global warming. Therefore, the factors controlling the amount of water vapor in the atmosphere control atmospheric temperature.” This paper also followed the lead of the Intergovernmental Panel on Climate Change (IPCC) at the time. It showed the radiative forcing of CO₂ diminishing approximately logarithmically as the level increases in the atmosphere. A paper in 2017 [3] stated quantitatively: “Water vapor content measured as the ratio of the number of water molecules per CO₂ molecule varies from 1:1 near the Poles to 97:1 in the Tropics.” The 2023 paper [1] uses many more measurements to show this ratio is closer to 0.3 to 108.

Currently, there are two parallel views of the Earth’s atmosphere. One theory is that water vapor is the main greenhouse gas, and the other greenhouse gases do not have a measurable effect on the Earth’s temperature. The second theory is that non-condensing greenhouse gases, i.e., they are above their boiling points and act as ideal gases, such as carbon dioxide (CO₂) and methane, drive the Earth’s temperature.

The basis for the first theory is the psychrometric chart, which is a proven mathematical model of the Earth’s atmosphere. The basis is the scientific knowledge accumulated over the past 500 years by scientists such as Amedeo Avogadro, Robert Boyle, Blaise Pascal, Sir Issac Newton, and Joseph Priestly [4]. These scientists were diligent and accurate and used the best knowledge available at the time. The confirmation of the accuracy of their work came with the conversion of the psychrometric chart to a computer program, Humidair. The limits of thermodynamic properties of dry and moist air are from 173.15K (-100°C) to 372.15K (99°C) at pressures to 5MPa [5]. The accuracy is

sufficient that if warming by CO₂ was significant, the early researchers would have found it.

The Humidair psychrometric model [5] has five measurable input properties: dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity, and barometric pressure. Calculable properties are humidity ratio, specific volume, specific enthalpy (heat content), and water vapor pressure. For example, in the Supplementary information, i.e., the Excel calculations, the input of dry bulb temperature (column H) and relative humidity (column I) can calculate the humidity ratio (column R) in grams of water per kilogram (kg) of dry air and dew point (column W), enthalpy (columns AC and AH), and specific volume (column AL).

The psychrometric chart was invented in 1904 by Willis Carrier [4]. Many heating, ventilating and air conditioning (HVAC) engineers use it almost daily to design heating and ventilation systems for buildings and homes, proving its validity.

The second theory began in the 1800s. For example, Eunice Newton Foote conducted experiments by exposing glass tubes filled with various gases to the Sun and measuring the temperature increase. The temperature in the glass tube with CO₂ increased significantly more than the other gases [6]. From her 1856 paper: “On comparing the Sun’s heat on different gases, I found it to be in hydrogen gas 104°, in common air 106°; in oxygen 108°; and in carbonic acid gas; 125°.” Her conclusion was: “An atmosphere of that gas (CO₂) would give our earth a high temperature.” Many experiments by others followed. The new technology of satellites measuring the radiation spectrum coming from the Earth began in 1970. The results gave rise to the concept that the warming effect of CO₂ was about one-half that of water vapor and that some other non-condensing greenhouse gases had a measurable impact on the Earth’s temperature.

The data set for the recent paper published in 2023 [1] and developed by the Humidair psychrometric program is the same data set used in Reference [7]. The twenty locations are as follows: four above the Arctic Circle, six in mid-latitudes north, three on the equator, one in the Sahara Desert, five mid-latitudes south, and one in Antarctica. Eight are west longitude, and twelve are east longitude. Temperature and relative humidity measurements recorded on the 21st of the month for twelve months are input to the Humidair psychrometric

program. The result is a data set of 240 points. These results show the ratio of water vapor molecules to CO₂ molecules ranges from 0.3 in the Polar regions to 108 in the Tropics. New technology improves the quantity and quality of information. In this case, the latest technology is AccuWeather on a smart phone, which became available in 2007 [8]. It has access to millions of weather stations.

Further, evidence accumulates that increased CO₂ is caused by increased temperature and vice versa, as in a paper published in September 2023 [9]. The framework of evidence from the analyses suggests a unidirectional, potentially causal link with temperature as the cause and CO₂ as the effect.

The basis for our current study is data measured and recorded at ground level, at a height of two meters, in the Troposphere. The radiation measurements used are at the top of the atmosphere. This study aims to understand the primary forces that control Earth's temperature. It does not consider the less critical details, including El Niño, La Niña, and cosmic rays.

The columns and cells are given for the location of various properties to help the reader become familiar with the psychrometric mathematical model of the Earth's atmosphere, e.g., Column BK and cell H164.

2. QUANTITATIVE DETERMINATION OF THE WARMING EFFECTS OF WATER VAPOR AND CO₂

The design of the following description is to help the reader determine the calculation methods from the Excel spreadsheet. The formulas are behind each cell. For people who do not have the Humidair program behind Excel, the results are in blue, but the formulas are not behind the blue cells. The inputs to Humidair are temperature and relative humidity. The inputs are the same for the calculation of each output. The only

change is to the Humidair code. For example, code W gives the humidity ratio as kilograms of water per kg of dry air. Code Tdp gives the dew point in degrees C; Hm gives the enthalpy of moist air in kilojoules; Ha gives the enthalpy of dry air; Va gives the specific volume in cubic meters per kg of dry air. The Humidair program calculates the enthalpy above and below zero. Because McMurdo Station is the base, add the enthalpy at McMurdo to the enthalpy of each location. Thus, the enthalpy in the Excel spreadsheet is the enthalpy above that of McMurdo. See columns AC (moist air) and AH (dry air).

The Humidair program calculates water vapor as grams per kg of dry air. For a valid comparison with CO₂, it must also be in grams per kg of dry air. The measurement of CO₂ in the atmosphere is reported daily as "ppm." This measurement is the mole fraction. For example, 420 ppm is 0.000420 moles per mole of dry air. The conversion to grams per kg of dry air is (0.000420 x 44 x (1000/29)) = 0.64, where 44 is the molecular weight of CO₂, and 29 is the molecular weight of air.

The Excel spreadsheet calculations provide the basis for determining the warming effects of water vapor and CO₂, as in Table 1.

The Excel calculations for Figure 1 start by determining the difference between the enthalpy (heat content) of moist air (column AC) and dry air (column AH) between McMurdo and a specific location. This value is the amount of enthalpy attributed to moist air. Divide this difference by the moist air enthalpy (column BN). Calculate the difference in temperature between McMurdo and the location of interest (BO) and multiply it by enthalpy attributed to moist air (BN). Divide this value (BP) by the contribution to the CO₂ (BF) temperature. The result is Figure 1, which shows water

Table 1: Data from Supplementary Information, the Excel Spreadsheet Calculations [1]

	A	B McMurdo		C Mogadishu	
			Cell		Cell
1	Temperature	-37°C	H57	32°C	H51
2	Dry air enthalpy	0.0 kilojoules	AH57	69.4 kilojoules	AH51
3	Moist air enthalpy	0.0 kilojoules	AC57	117.5 kilojoules	AC51
4	Dew point	-41.1°C	W57	23.8°C	W51

vapor contributes more to the warming of the Earth than CO₂ by a range of between 1,000 and 7000. The warming effect of CO₂ is negligible.

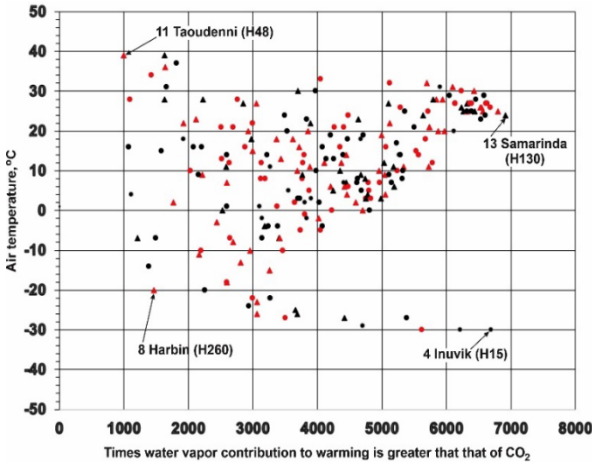


Figure 1: Water vapor contribution to Earth's temperature (column BS) is substantially greater than that of CO₂.

3. THE WARMING BY CO₂ IS LINEAR RATHER THAN CURVILINEAR

Even though the warming by CO₂ is too small to measure, we can show that its warming effect is linear. Figure 2 shows air temperature versus the enthalpy (heat content) for dry air between McMurdo Station in Antarctica and Taoudenni in the Sahara Desert. The result for the 240 points of the data set is a straight line. This is not unexpected because the enthalpy of each gas in the atmosphere is proportional to its weight in kg/kg dry air, specific heat, and temperature difference in °C, i.e., kg x (kJ/kg K) x K = kJ (columns BC x cell BD9 x column BD). The weight, specific heat, and difference in temperature are linear.

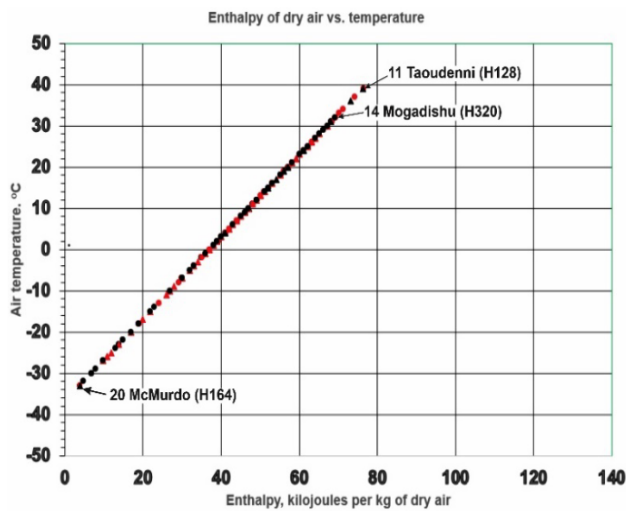


Figure 2: Air temperature vs. dry air enthalpy (column AH), kilojoules per kg of dry air, for 240 observations.

The gases in the atmosphere, except for water vapor, are nitrogen, oxygen, argon, carbon dioxide, neon, helium, methane, krypton, and trace species [10]. These gases are above their boiling points and, therefore, act as ideal gases.

This fact that the relationship is a straight-line contrast with the IPCC formula in the Third Assessment Report, section 6.3.5, where $\Delta RF = 5.35LN(C/C_0)$, which indicates warming by CO₂ is the curve of a logarithmic function.

Figure 3 shows the air temperature versus the enthalpy for moist air between McMurdo Station in Antarctica and Taoudenni in the Sahara Desert. Water vapor is below its boiling point and is not an ideal gas. That is why the plot curves.

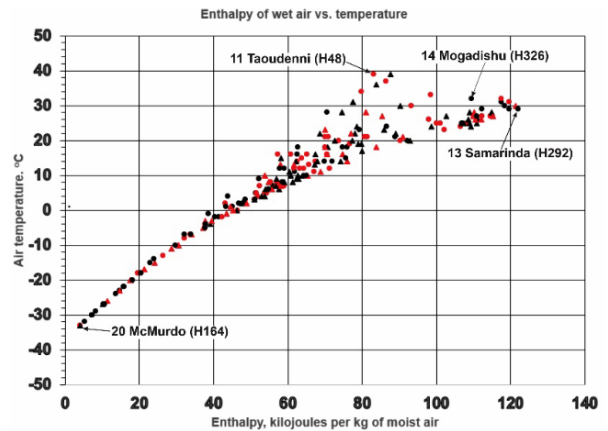


Figure 3: Air temperature vs. enthalpy (column AC), kilojoules per kg of moist air, for 240 points.

Figure 4 shows the data in Figure 3 is reproducible. The basis for Figure 4 is 400 points recorded from January 30, 2022, to February 3, 2022, at 5 am, 11 am, 5 pm, and 11 pm.

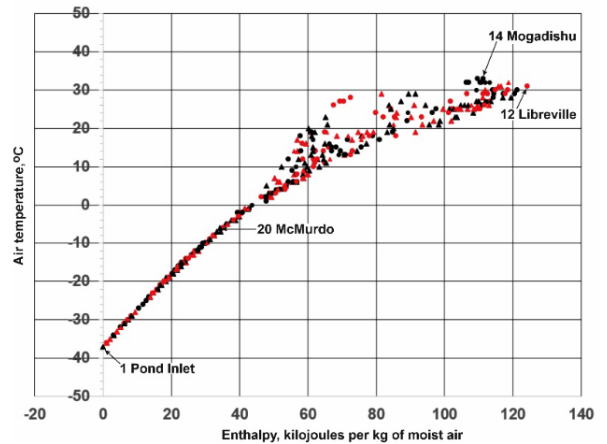


Figure 4: Air temperature vs. enthalpy, kilojoules per kg of moist air, for 400 points.

The curvature caused by water vapor is evident in the set of 400 points. Thus, if the warming effect of a gas, measured as radiative forcing, is curved, then the basis is water vapor.

4. THE EARTH'S ATMOSPHERE FROM THE SURFACE TO THE TOP OF THE ATMOSPHERE

The layers in the atmosphere, Figure 5, stretching from the Troposphere at the Earth's surface to the top, influence the radiation observations at the top of the atmosphere. Radiation observations taken by interferometer from a satellite in 1970 at the top of the atmosphere are available at [11].

The Troposphere extends upward an average of 13 km [12]. It contains approximately 75 to 80% of the total mass of the atmosphere and 99% of the water vapor. The height of the top of the Troposphere varies with latitude. It is lowest over the poles and highest at the equator, and by season—it is lower in winter and higher in summer. It can be as high as 20 km, 12 miles or 65,000 feet, near the equator and as low as 7 km, 4 miles or 23,000 feet, over the poles in winter [13].

The next layer is the Stratosphere, which extends to approximately 50 km. It has about 19% of the atmosphere's mass. Next, the Mesosphere extends up to 80 km and contains about 0.1% of the air mass. The Troposphere is the lowest. Most of the atmosphere's mass (about 75-80%) is in the Troposphere. Clouds occur in the Troposphere, and virtually all weather occurs within this layer. The Troposphere is by far the wettest layer of the atmosphere. The other layers contain very little moisture.

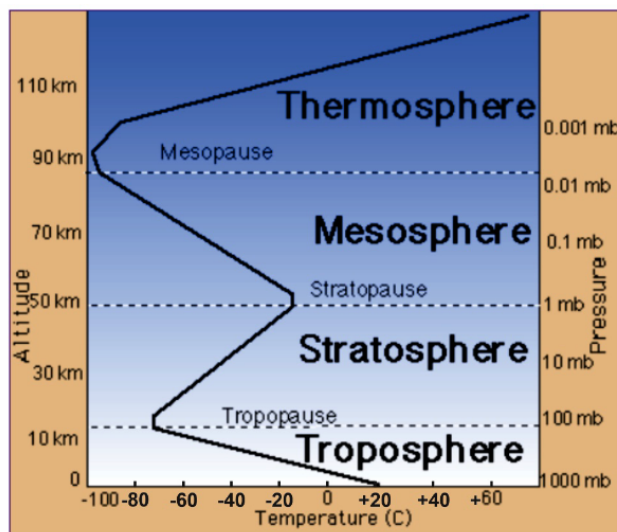


Figure 5: The layers in the Earth's atmosphere. Adapted from [14].

Air pressure and density also decrease with altitude upward to the tropopause, the boundary between the Troposphere and the Stratosphere. In Figure 5, the ratio of water molecules to CO₂ molecules is 0.3 at the coldest temperature in McMurdo in the Antarctic Polar region, as per the Excel calculations (AT57). There is a maximum of 0.070 grams of water per kg of dry air (R57) at McMurdo.

At the top of the Troposphere, the temperature is -70°C and air pressure of 0.1 bar. Using the maximum water vapor of relative humidity of 100%, calculations by the Humidair program show water vapor is 0.016 grams per kg of dry air. Thus, the ratio of molecules of water vapor to molecules of CO₂ is $(\approx 0.3 \times (0.016/0.070)) = 0.069$ molecules of water vapor per molecule of CO₂ at the top of the Troposphere.

These values compare with the two-meter level, where the ratio of water molecules to CO₂ is 94.5 (Cell AT51) at Mogadishu. The warming result of CO₂ at Mogadishu is too small to measure (Cell BF51) at the two-meter level. Thus, the warming effect at the top of the Troposphere is less than at the two-meter level by a factor of $0.07/94.5 = 0.00074$. Therefore, the amount of blocking by greenhouse gases above the Troposphere compared to the two-meter level is immeasurably small. There is no reason for this to change in the Stratosphere and Mesosphere. Thus, energy leaving the Troposphere flows virtually unhindered to space [15].

It is clear from Figure 5 that there is much less material in the Stratosphere and the Mesosphere than in the Troposphere. The satellites orbit at the top of the atmosphere, so the measurements are at the top. Still, the measurements are actually of the radiation leaving the Troposphere. Thus, the Troposphere effectively controls the radiation profile.

5. RADIATION ATTRIBUTED TO THE SAHARA DESERT APPEARS THE SAME AS AT GUAM

Figure 6 compares the 1970 radiation measurements at Guam, in the Tropics, and over the Sahara Desert. The radiation measurements should be different because Guam is in the Pacific Ocean and very humid compared to the dryness of the Sahara Desert.

Both Taoudenni in the Sahara Desert and Guam are in the Tropics that range between 23.5°N and 23.5°S. The latitude of Taoudenni is 22°41'N, and Guam is 15.1°N. For reference, the horizontal scales of both figures are the same.

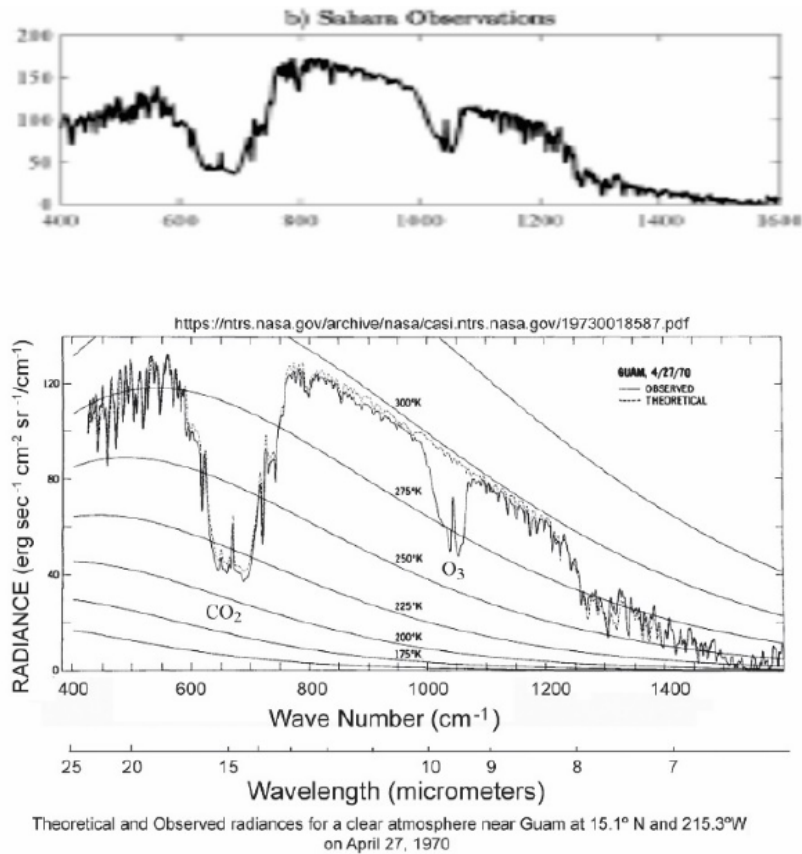


Figure 6: Comparison of radiation at Guam in the Tropics. Figure 1 from [10].

From Column AT of the Excel calculations, the range of water molecules to CO₂ molecules is 10.7 to 31.0 at Taoudenni in the Sahara Desert. The ratio of water molecules to CO₂ in McMurdo Station in Antarctica is 0.3 to 40 [1]. Thus, the two radiation profiles should be similar.

Thus, it appears the radiation attributed to the Sahara Desert could equally well be classified as being in the Tropics, such as Guam, where the ratio of water and CO₂ molecules is 84 to 108. Thus, in our analysis, we use the radiation profile over Guam.

Envision Figure 6 as a grid of squares of vertical and horizontal units. Each square represents an amount of heat measured in Wm⁻². By comparing the number of squares under the water vapor curve with the number of squares in the dip attributed to CO₂, the dip is 15% to 20% of the area for water vapor. Thus, the dip in CO₂ reduces the radiation to space by water vapor by 15% to 20% [16].

This area's corresponding ratio of water molecules to CO₂ molecules is 84 to 107. Thus, one molecule of CO₂ per ≈100 molecules of water vapor would have to block the radiation from 15% to 20% of the water vapor

to cause the dip in the radiation curve. This effect of one molecule appears unlikely and casts further doubt on the split between water vapor and CO₂ obtained by radiation measurements.

6. THE RADIATION PROFILE AND THE RATIO OF WATER MOLECULES TO CO₂ MOLECULES

Figure 7 shows the observations of the radiation leaving the Earth at the top of the atmosphere for three locations. Opposite each site is the corresponding ratio of water molecules to CO₂ molecules in the Troposphere at the exact locations [10].

The radiation measurements are for a clear sky.

As the ratio of water to CO₂ diminishes, so does the significant dip in the curve attributed to CO₂ in the Sahara Desert curve. In the Antarctic curve, the drop disappears, and a bulge appears. A reasonable conclusion is that the dip is unrelated to CO₂ because the relationship is always the number of water molecules to one CO₂ molecule. The significant change is in the water vapor content; the ratio falls from 108 to 0.3 molecules of water vapor per molecule of CO₂. The warming effect of CO₂ appears to be negligible. This

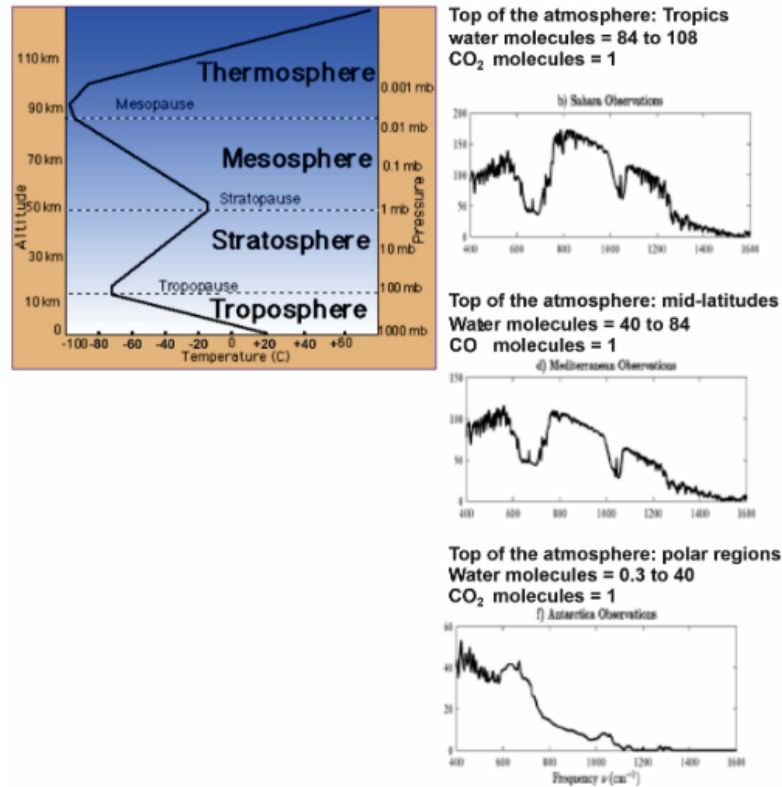


Figure 7: Top of atmosphere radiation versus the ratio of water molecule to CO₂ molecules in the Troposphere. Adapted from [10] and [13].

effect is consistent with the results in [1] — the warming effect of CO₂ is too small to measure, i.e., insignificant.

In conclusion, if infrared radiation recycles in the Stratosphere and Mesosphere, it is tiny and dominated by CO₂. In contrast, the recycling of energy from the upper levels of the Troposphere back to the surface of the Earth is essentially by water vapor.

7. THE VALIDITY OF THE SPLIT BETWEEN WATER VAPOR AND CO₂ BY RADIATION MEASUREMENTS

Separating the radiation flux of CO₂ from that of water vapor is difficult. Because there is always more water vapor than CO₂, except where the temperature is below approximately -30°C, the temperature versus enthalpy will show the curved relationship of moist air as in Figure 3. Thus, there is a problem with the logarithmic IPCC formula $\Delta RF = 5.35 \ln(C/C_0)$. The base is Myhre *et al.* (1998) [17]. On page 2717, Figure 1 shows a distinct curve for radiative forcing (Wm⁻²) versus concentration of CO₂. This curve is characteristic of water vapor. Thereby indicating the relationship plotted is not that of CO₂; otherwise, the line would be straight.

Figure 8 from the NASA Earth Observatory [18] shows the overlap between radiation absorbed by water vapor and CO₂ in the approximately 15-micron wavelength range [19,20]. This figure shows that separating the radiation absorption by water vapor from that of CO₂ to compare the warming effects of each is almost impossible. Thus, comparing the warming impact of water and CO₂ based on radiation measurements gives erroneous results.

8. EARTH’S ENERGY BALANCE IS A MODEL OF THE TROPOSPHERE

The Troposphere is where climate action occurs. The simplified average energy balance model is in Figure 9. It is adapted from Stephens *et al.* (2012) [21]. In the simplified format, the Sun’s input is 100 units for ease of relating flows to the input.

The back radiation of 101 units is infrared radiation as are the 117 and 71 units. The infrared radiation flows back and forth from the Earth to the greenhouse gases at the speed of light. To maintain the average flow of 101 units back to Earth, 79 units must be recycled back to the greenhouse gases. Condensation forms clouds at higher, cold levels of the atmosphere and by cosmic

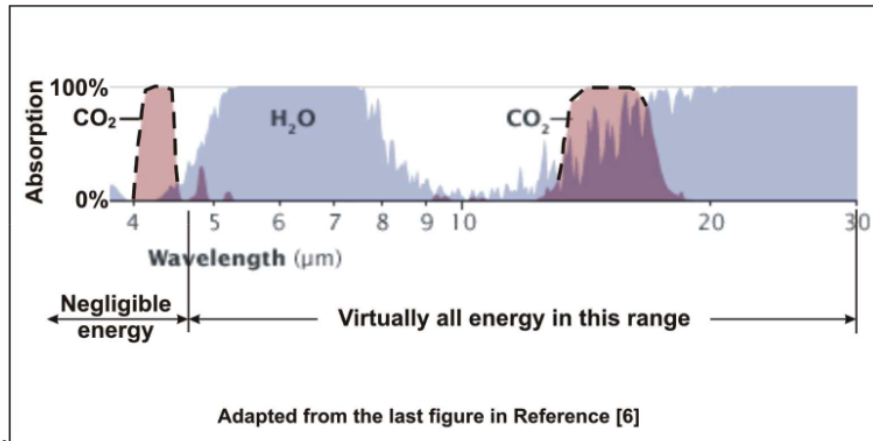


Figure 8: The absorption by CO₂ and water vapor are in competition over the wavelength range of IR from 5 to 30μm.

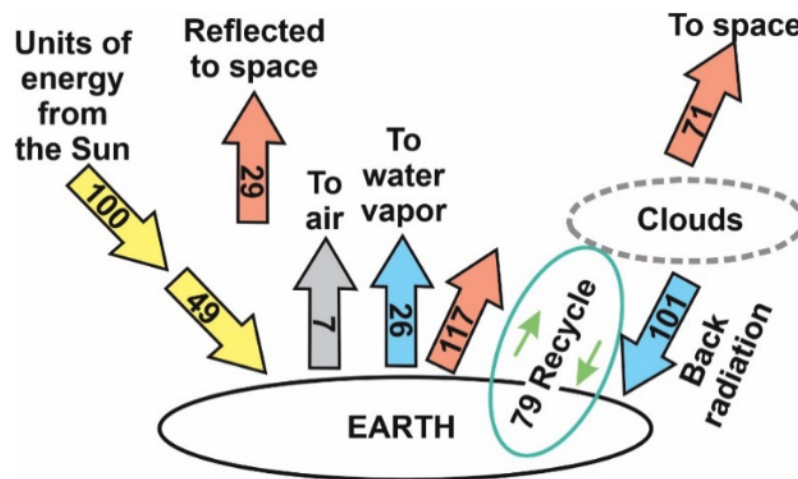


Figure 9: The energy flows in the Troposphere. Sun energy to Earth = 100 units to space = 29 + 71 = 100; Absorbed by the Earth's surface = 49 + 101 = 150; Emitted from the Earth's surface = 7 + 26 + 117 = 150; Recycle to balance the loss to space = 150 – 71 = 79; Global warming = 117 - 71 = 46 [22].

rays. The 71 units of heat released from the clouds flow towards space.

Figure 9 shows the importance of water vapor in the atmosphere because, on average, 26%, or about one-quarter, of the Sun's energy sent to Earth evaporates water to water vapor.

The split of back radiation between water vapor and CO₂ is nearly impossible because of the radiation overlap, as shown in Figure 8.

9. THE EARTH'S TEMPERATURE IS CONTROLLED BY THE SUN

Only water, as it changes phase from a solid to a liquid to a gas by the action of the Sun, influences the Earth's temperature. It is the changing energy output of the Sun that is critical. A discussion of the Sun's energy output over time is in Reference [23].

In mid-2020, the projection by the IPCC of the Earth's temperature to 2030 is 1.5°C above preindustrial levels, as in Figures 10 and 11. People who study the Sun are projecting that the Earth's temperature will fall to the preindustrial level by 2030.

We are now three years later and have a record of the Earth's temperature measured by satellite. January temperatures are the coldest in the northern hemisphere. These temperatures are falling in line with the projections by the people who study the Sun, such as those of Habibullo Abdussamatov [24,25] and Valentina Zkarkova [26, 27].

Figure 11 shows these projections and the change in temperature from mid-2020 to October 2023. The January temperatures have fallen in line with the projections. The satellite temperature measurements in Figure 11 show the October 2023 temperature [28] is above the 1.5°C indicated by the media as a danger

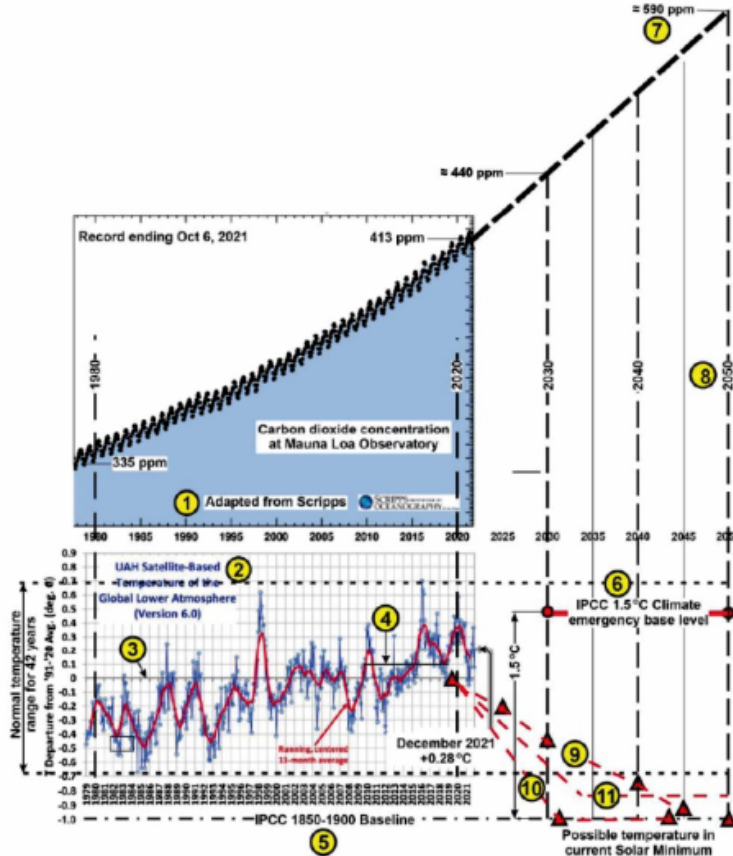


Figure 10: Figure 1 from Reference [22] shows satellite temperature versus CO₂.

point. No credible, measurable climate disaster occurred because of this temperature.

The evidence is that the Sun continues in a solar minimum.

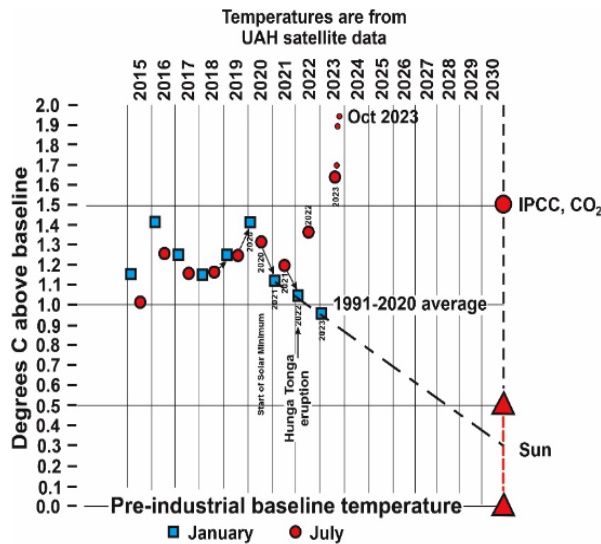


Figure 11: Temperatures by satellite measurement to October 2023.

Usually, volcanic eruptions discharge ash into the atmosphere that cools the Earth. However, when the vast Hunga Tonga submarine volcano, 150 meters below the ocean surface, erupted on January 15, 2022, it thrust vast quantities of water high into the Stratosphere and Mesosphere [29,30]. The water vapor from this event reduces the energy flow away from the Troposphere and warms the Earth. This water could explain why the satellite temperatures are increasing temporarily, as in Figure 11.

10. SUMMARY AND CONCLUSIONS

This study builds on the quantitative record of previous studies starting in 2014 and continuing to early 2023. It builds on the Excel calculations of Reference [1], which result from the measurement of temperature and relative humidity at twenty locations recorded on the 21st of the month for twelve months.

The data show water vapor is one thousand to seven thousand times more effective at warming the atmosphere than CO₂. The warming effect of CO₂ is linear with concentration. CO₂ is above its boiling point,

and the relationship is linear. Water vapor is below its boiling point, and the relationship with concentration is curved.

Examination of the Earth's atmosphere from ground level to the top of the atmosphere allows an assessment of the magnitude of each layer's role in determining the Earth's temperature. The layers are the Troposphere closest to the Earth, with 75% to 80% of the atmosphere's mass and virtually all water vapor. The next layer up is the Stratosphere, with about 19% of the atmosphere's mass, then the upper layer, the Mesosphere, with about 0.1% of the mass. There is so little water vapor and CO₂ above the Troposphere that energy leaving it flows unhindered to space.

A comparison of the radiation profiles from the top of the atmosphere with the ratio of water molecules to CO₂ molecules in the Tropics, the mid-latitudes, and the Polar regions shows the radiation profile depends on the amount of water vapor in the atmosphere.

This study identifies three methods of showing that the warming effect of CO₂ is too small to measure: (a) In 1904, the psychrometric model of the atmosphere was invented [4], (b) Then, in April 2023, proven physics and chemistry showed warming by CO₂ is too small to measure [1], (c) In September 2023, temperature causes changes in CO₂, CO₂ does not change temperature [10]. The basis for these is actual measurements in the Troposphere.

The science presented in this study leads directly to the following conclusions:

- 10.1. This study confirms quantitatively that the warming effect of CO₂ is too small to measure, i.e., negligible. In contrast, warming by water vapor is 1,000 to 7,000 times greater than CO₂.
- 10.2. The warming effect of CO₂ is linear with concentration, i.e., the number of molecules per cubic meter. In contrast, the warming effect of water vapor with concentration is curved.
- 10.3. The ratio of water molecules to CO₂ molecules is 0.0010 from the top of the Troposphere through the Stratosphere and Mesosphere to the top of the atmosphere. This amount is too small to affect the flow of energy to space significantly.
- 10.4. The radiation profile at the top of the atmosphere is essentially the same as at the top of the Troposphere.

- 10.5. Separating water vapor's warming effect from CO₂ by radiation profiles is nearly impossible.
- 10.6. Comparison of three radiation profiles with the ratio of water molecules to CO₂ molecules shows the warming effect of CO₂ is negligible.
- 10.7. The Sun is the primary energy source and its variation controls the Earth's temperature. The Sun determines the Earth's temperature, it is currently in a solar minimum.
- 10.8. The Hunga Tonga eruption pushed the global temperature past the Paris Accord target of 1.5°C, but this will be a temporary spike. There appear to be no credible negative effects.
11. Note: For those readers who wish to check the Excel calculations or learn more about the Humidair psychrometric program, Humidair is available for rent at \$29.95 U.S. for five months or \$149.95 U. S. per copy from <https://www.megawatsoft.com/humid-air-properties-application.aspx>

ACKNOWLEDGEMENTS

We wish to acknowledge the contribution of Orval A. Mamer, now deceased, to our understanding of how to calculate the weight of CO₂ in the atmosphere in grams per kg of dry air. Also, his contribution to our knowledge is that: "gases in the atmosphere above their boiling points act as ideal gases." Howard Hayden provided much valuable consultation on various issues over time.

SUPPLEMENTAL MATERIALS

The supplemental materials can be downloaded from the journal website along with the article.

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