

CO₂: The Thermostat that Controls Earth's Temperature

The essence of the recent study by GISS climate scientists published in the October 15th issue of *Science*¹ shows that atmospheric CO₂ operates as a thermostat to control the temperature of Earth. (October 2010)

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There is a close analogy to be drawn between the way an ordinary thermostat maintains the temperature of a house, and the way that atmospheric carbon dioxide (and the other minor non-condensing greenhouse gases) control the global temperature of Earth. The ordinary thermostat produces no heat of its own. Its role is to switch the furnace on and off, depending on whether the house temperature is lower or higher than the thermostat setting. If we were to carefully monitor the temperature of the house, we would see that the temperature does not stay constant at the set value, but rather exhibits a “natural variability” as the house temperature slips below the set value and then overshoots the mark with a time constant of minutes to tens of minutes, because of the thermal inertia of the house and because heating by the furnace (when it is on) is more powerful than the steady heat loss to the outdoors. If the thermostat is suddenly turned to a very high setting, the temperature will begin to rise at a rate dictated by the inertia of the house and strength of the furnace. Turning the thermostat back to normal will stop the heating.

Atmospheric carbon dioxide performs a role similar to that of the house thermostat in setting the equilibrium temperature of the Earth. It differs from the house thermostat in that carbon dioxide itself is a potent greenhouse gas (GHG) warming the ground surface by means of the greenhouse effect. It is this sustained warming that enables water vapor and clouds to maintain their atmospheric distributions as the so-called feedback effects that amplify the initial warming provided by the non-condensing GHGs, and in the process, account for the bulk of the total terrestrial greenhouse effect. Since the radiative effects associated with the buildup of water vapor to near-saturation levels and the subsequent condensation into clouds are far stronger than the equilibrium level of radiative forcing by the non-condensing GHGs, this results in large local fluctuations in temperature about the global equilibrium value. Together with the similar non-linear responses involving the ocean heat capacity, the net effect is the “natural variability”

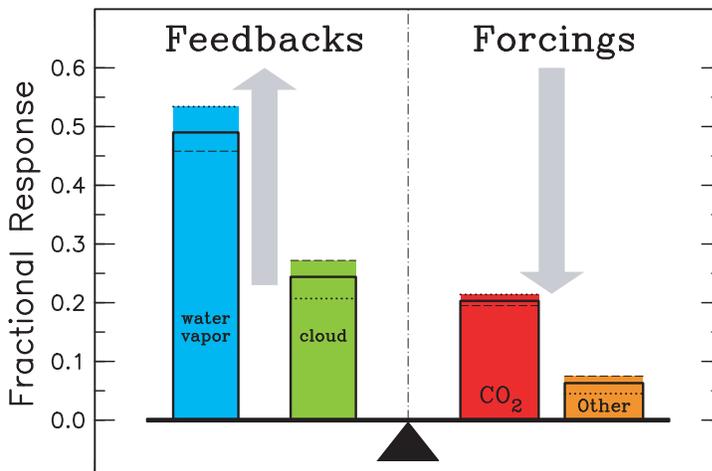


Fig. 1. Attribution of individual atmospheric component contributions to the terrestrial greenhouse effect, separated into feedback and forcing categories. Dotted and dashed lines depict the fractional response for single-addition and single-subtraction of individual gases to either an empty or full-component reference atmosphere, respectively. Solid black lines are the scaled averages of the dashed and dotted line fractional response results. The sum of the fractional responses must add up to the total greenhouse effect. The reference model atmosphere is for 1980 conditions.

that the climate system exhibits regionally, and on inter-annual and decadal timescales, whether the global equilibrium temperature of the Earth is being kept fixed, or is being forced to re-adjust in response to changes in the level of atmospheric GHGs.

This assessment comes about as the result of climate modeling experiments which show that it is the non-condensing greenhouse gases such as carbon dioxide, methane, ozone, nitrous oxide, and chlorofluorocarbons that provide the necessary atmospheric temperature structure that ultimately determines the sustainable range for atmospheric water vapor and cloud amounts, and thus controls their radiative contribution to the terrestrial greenhouse effect. From this it follows that these non-condensing greenhouse gases provide the temperature environment that is necessary for water vapor and cloud feedback effects to operate, without which the water vapor dominated greenhouse effect would inevitably collapse and plunge the global climate into an icebound Earth state.

Within only the past century, the CO₂ control knob has been turned sharply upward toward a much hotter global climate. The pre-industrial level of atmospheric carbon dioxide was about 280 ppm, which is representative of the inter-glacial maximum level of atmospheric CO₂. During ice age extremes, the level of atmospheric CO₂ drops to near 180 ppm, for which the global temperature is about 5 °C colder. The rapid recent increase in atmospheric CO₂ has been attributed to human industrial activity, primarily the burning of fossil fuels. This has pushed atmospheric CO₂ toward the 400 ppm level, far beyond the inter-glacial maximum. The climate system is trying to respond to the new setting of the global temperature thermostat, and this response has been the rise in global surface temperature by about 0.2 °C per decade for the past three decades.

It has been suggested that we are well past the 300 to 350 ppm target level for atmospheric CO₂ beyond which dangerous anthropogenic interference in the climate system would be expected to exceed the 25% risk tolerance for impending degradation of land and ocean ecosystems, sea level rise, and inevitable disruption of the socio-economic and food-producing infrastructure³. This prospect of a rising risk of triggering unacceptable environmental consequences makes reduction and control of atmospheric CO₂ a serious and pressing issue for humanity, worthy of real time attention.

Radiative modeling analyses of the terrestrial greenhouse structure described in a parallel study in the *Journal of Geophysical Research*² found that water vapor accounts for about 50% of the Earth's greenhouse effect, with clouds contributing 25%, carbon dioxide 20%, and the minor greenhouse gases (GHGs) and aerosols accounting for the remaining 5%, as shown in Fig. 1. Thus, while the non-condensing greenhouse gases account for only 25% of the total greenhouse effect, it is these non-condensing GHGs that actually control the strength of the terrestrial greenhouse effect since the water vapor and cloud feedback contributions are not self-sustaining and as such, only provide amplification. Because carbon dioxide accounts for 80% of the non-condensing GHG forcing in the current climate atmosphere, atmospheric carbon dioxide therefore qualifies as the principal control knob that governs the temperature of Earth.

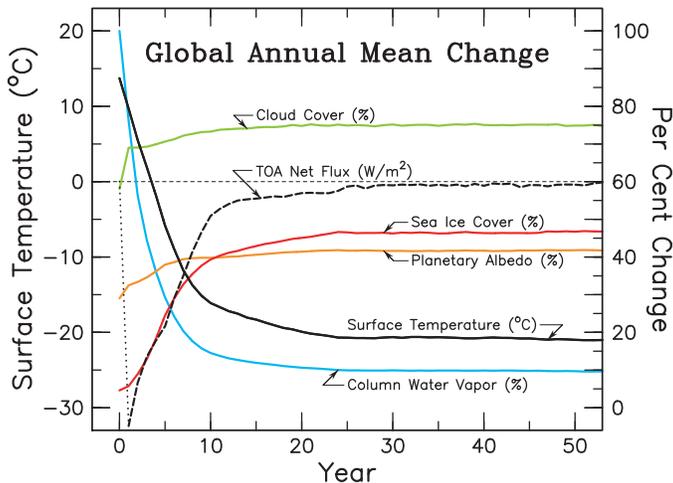


Fig. 2. Time evolution of global surface temperature, top-of-atmosphere (TOA) net flux, column water vapor, planetary albedo, sea ice cover, and cloud cover, after zeroing out all the non-condensing greenhouse gases. The model used in the experiment is the GISS 2°× 2.5° AR5 version of ModelE with the climatological (Q-flux) ocean energy transport and the 250 m mixed layer depth. The model initial conditions are for a pre-industrial atmosphere. Surface temperature and TOA net flux utilize the left-hand scale.

The numerical climate experiment described in Fig. 2. demonstrates the fundamental radiative forcing role of the non-condensing GHGs, and the feedback (only) role of water vapor and clouds. This climate modeling experiment was performed using the GISS modelE general circulation coupled atmosphere-ocean climate model by zeroing out all of the non-condensing greenhouse gases. Doing this removed the radiative forcing that sustains the temperature support for water vapor and cloud feedbacks, causing rapid condensation and precipitation of water vapor from the atmosphere, collapsing the terrestrial greenhouse effect, and plunging the Earth into an icebound state.

The scope of the climate impact becomes apparent in just 10 years. During the first year alone, global mean surface temperature falls by 4.6 °C. After 50 years, the global temperature stands at -21 °C, a decrease by 34.8 °C. Atmospheric water vapor is at ~10% of the control climate value (22.6 to 2.2 mm). Global cloud cover increases from its 58% control value to more than 75%; the global sea ice fraction goes from 4.6% to 46.7%, causing the planetary albedo of Earth to increase from ~29% to 41.8%. This has the effect to reduce the absorbed solar energy to further exacerbate the global cooling.

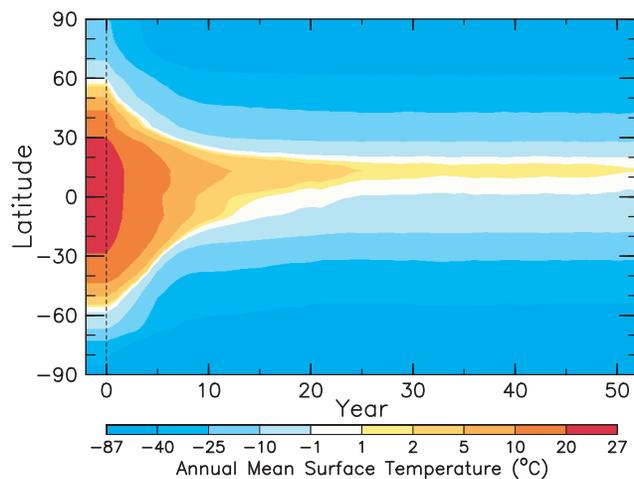


Fig. 3. Zonally averaged annual-mean surface temperature change following the zeroing out of non-condensing greenhouse gases.

After 50 years, one third of the ocean surface still remains ice-free, even though the global surface temperature is colder than -21 °C. At tropical latitudes, incident solar radiation is enough to keep the ocean from freezing. While this thermal oasis within an otherwise icebound Earth appears to be stable, at least on the short timescale illustrated, further calculations with an interactive ocean are needed to verify the potential for long-term stability. The surface temperatures in Fig. 3 are only marginally warmer than 1 °C within the remaining low latitude heat island.

From the foregoing, it is clear that CO₂ is the key atmospheric gas that exerts principal control (80% of the non-condensing GHG forcing) over the strength of the terrestrial greenhouse effect. Water vapor and clouds are fast-acting feedback effects, and as such, they are controlled by the radiative forcing supplied by the non-condensing GHGs.

The bottom line is that atmospheric carbon dioxide acts as a thermostat in regulating the temperature of Earth. The rapid increase in atmospheric carbon dioxide due to human industrial activity is therefore setting the course for continued global warming. Because of the large heat capacity of the climate system, the global surface temperature does not respond instantaneously to the sharp upturn of the carbon dioxide thermostat, which at this moment stands at 386.80 ppm compared to the normal interglacial maximum level of 280 ppm. Since humans are responsible for changing the level of atmospheric carbon dioxide, they then also have control over the global temperature of the Earth. Humans are at a difficult crossroad. Carbon dioxide is the lifeblood of civilization as we know it. It is also the direct cause fueling an impending climate disaster. There is no viable alternative to counteract global warming except through direct human effort to reduce the atmospheric CO₂ level.

The basic physics for the present study is rooted in the high precision measurements documenting the rise of atmospheric carbon dioxide and other greenhouse gases as fully described in the IPCC AR4 report, and in the comprehensive HITRAN database⁴ of atmospheric absorption data. The radiative transfer calculations involve well-understood physics that is applied to the global energy balance of the Earth, which is maintained by radiative processes only, since the global net energy transports must equal zero. This demonstrates the nature of the terrestrial greenhouse effect as being sustained by the non-condensing GHGs, with magnification of the greenhouse effect by water vapor and cloud feedbacks, and leaves no doubt that increasing GHGs cause global warming.

References

¹Andrew A. Lacis, Gavin A. Schmidt, David Rind, and Reto A. Ruedy, 2010: [Atmospheric CO₂: Principal control knob governing Earth's temperature](#). *Science*, **330**, 356–359, doi:10.1126/science.1190653.

²Schmidt, G.A., R. Ruedy, R.L. Miller, and A.A. Lacis, 2010: [The attribution of the present-day total greenhouse effect](#). *J. Geophys. Res.*, in press.

³Hansen, J., Mki. Sato, P. Kharecha, *et al.*, 2008: [Target atmospheric CO₂: Where should humanity aim?](#) *Open Atmos. Sci. J.*, **2**, 217–231, doi:10.2174/1874282300802010217.

⁴L.S. Rothman, I.E. Gordon, A. Barbe, *et al.*, 2009: [The HITRAN 2008 molecular spectroscopic database](#). *J. Quant. Spectrosc. Radiat. Transfer*, **110**, 533–572.

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