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Global Warming: Observations vs. Climate Models

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KEY TAKEAWAYS

The observed rate of global warming over the past 50 years has been weaker than that predicted by almost all computerized climate models.

Climate models that guide energy policy do not even conserve energy, a necessary condition for any physically based model of the climate system.

Public policy should be based on climate observations—which are rather unremarkable—rather than climate models that exaggerate climate impacts.

Average warming of the climate system over the past five decades has been widely attributed to greenhouse gas emissions—primarily carbon dioxide (CO_2)—from the burning of fossil fuels. This belief has led to calls for greatly reducing humanity's reliance on such fuels and a transition to "renewable" energy sources such as wind power and solar energy.

For the purposes of guiding public policy and for adaptation to any climate change that occurs, it is necessary to understand the claims of global warming science as promoted by the United Nations Intergovernmental Panel on Climate Change (IPCC).[1] When it comes to increases in global average temperature since the 1970s, three questions are pertinent:

1. Is recent warming of the climate system materially attributable to anthropogenic greenhouse gas emissions, as is usually claimed?

2. Is the rate of observed warming close to what computer climate models—used to guide public policy—show?

3. Has the observed rate of warming been sufficient to justify alarm and extensive regulation of CO_2 emissions?

While the climate system has warmed somewhat over the past five decades, the popular perception of a "climate crisis" and resulting calls for economically significant regulation of CO_2 emissions is not supported by science.

What Causes Temperature Change?

Before addressing how much warming has been observed, it is useful to explain what causes the temperature of anything—the climate system, the human body, a pot of water on the stove, a car's engine—to change. The underlying concepts are not difficult to grasp and are experienced by people on a daily basis.

Temperature Change Is Caused by an Imbalance Between Energy Gain and Energy Loss. One may picture an uncovered pot of water on a stove being heated over a very low flame. The water will warm rather rapidly when the stove is first turned on, then it will warm more slowly as the warm pot loses energy to its cooler surroundings. At some point, the water will stop warming altogether as the hot water loses energy to its surroundings just as fast as the flame puts energy into the pot. This state is called "energy balance" and it corresponds to a stable, constant temperature.[2]

Or one may imagine wearing a coat outside in the winter. People wear coats to reduce the rate of energy loss by their bodies. If people did not wear coats, their bodies would lose energy faster than they could generate heat through metabolism, and people would go into hypothermia. The coat helps to maintain energy balance by reducing the rate of energy loss by people's bodies.

As a final example, everyone has experienced how air temperature changes on a sunny day. The air warms through the morning and early afternoon. But by late afternoon, something curious happens: The temperature starts going down, even though the sun is still shining. This cooling happens because the rate of energy loss by the air becomes greater than the rate of energy gain from sunlight as the sun sinks lower in the sky.

In all of these examples, when energy gain equals energy loss, there is no temperature change. If there is an imbalance between rates of energy gain and energy loss, the temperature changes.

Recent Warming of the Climate System Corresponds to a Tiny Energy Imbalance

The average rate of energy gain by the global climate system from sunlight is variously estimated to be 235 to 245 Watts per square meter (W/m^2),[3] so, for purposes of discussion the assumption is 240 W/m^2. For global temperatures to remain approximately constant over time, the rate of energy loss by the system to outer space, which occurs through infrared (IR) "heat" radiation, must also be approximately 240 W/m^2.

But just how well do climate researchers know these numbers, and what is the evidence that there is a natural balance between them? The best satellite measurements from the National Aeronautics and Space Administration's (NASA's) Clouds and the Earth's Radiant Energy System's (CERES's) instruments are only accurate to a few W/m^2 (about 1 percent of the average energy flows[4]). To estimate the level of global energy imbalance, researchers use long-term measurements of the gradual warming of the global average oceans to estimate the energy imbalance. From the observed rates of warming of the deep ocean it is straightforward to compute that the current energy imbalance is only about 0.6 W/m^2,[5] which is a tiny fraction of the approximate 240 W/m^2 natural energy flows. This imbalance is thus considerably smaller (by about a factor of four) than the accuracy with which one can measure global average rates of energy gain and loss in and out of the climate system using satellites.

This is important because it means that some portion of recent warming could be natural. But since climate researchers do not understand natural sources of climate change, such as those that caused the Roman Warm Period of about 2,000 years ago, the Medieval Warm Period of about 1,000 years ago, and the Little Ice Age several centuries ago, most climate researchers simply assume that a similar event is not happening today.[6]

Instead of admitting that natural processes could be at work in causing climate change, "energy equilibrium" is what is assumed by the mainstream climate research community for the natural state of climate system unaffected by humans. The members of this community assume that the rate of energy input into the climate system from the sun is, on average, exactly equal to the rate of energy loss to outer space from IR radiation when averaged globally and over many years. The current, small roughly 0.6 W/m^2

imbalance in the approximate 240 W/m^2 energy flows in and out of the climate system is then entirely blamed on the burning of fossil fuels.

But this energy balance assumption for the Earth is a statement of faith, not science. As mentioned, a natural state of global energy balance cannot be demonstrated. Even using NASA's best satellite measurements of energy flows through the climate system.

Climate Models Assume Energy Balance, but Have Difficulty Achieving It

The projections of climate change in the news, and that form the basis of government efforts to reduce greenhouse gas emissions, come from computerized climate models run by climate research centers in various countries.[7] These projections are similar to weather forecast models but have additional enhancements that are not needed in short-term weather forecasts. The models are adjusted to produce no long-term climate change. In other words, the models assume that all climate change is unnatural, and then are used as "proof" of human-caused climate change when extra CO_2 is added to them. Of course, this is circular reasoning. There are also numerous potentially natural, or non-CO_2-related, reasons a climate may change.

The large number of climate models produce global warming rates which vary by about a factor of three between them (1.8°C to 5.6°C)[8] in response to a doubling of atmospheric CO_2 (2 x CO_2). In 2023, Earth's atmosphere was about 50 percent of the way to 2 x CO_2. Amazingly, this factor-of-three range of warming projections has not changed in the more than 30 years of climate-model improvements. This proves that climate-model forecasts are not, as is often claimed, based on proven physics. If they were, they would all produce about the same amount of warming.

As described above, temperature change is the result of energy imbalance, and all climate models have been tuned to produce energy balance in the absence of human-produced CO_2-equivalent emissions.[9] Without such tuning adjustments (one might call them "fudge factors," some of which are *ad hoc*), almost all models' temperature would slowly drift over time—that is, become progressively warmer or cooler. Despite this tuning, many models have been found to still have problems conserving energy.[10] Energy conservation (probably the most fundamental law in science, the First Law of Thermodynamics) should be a necessary requirement of any model used for energy policy decisions. The need for model tuning is unavoidable because the fundamental physical processes in the climate system (especially cloud

characteristics) are not known accurately enough to build a stable model from physical first principles alone. So, empirical adjustments must be made to those modeled processes so that the model will not spuriously warm or cool over centuries of model run time. Yet, even at this, many models fail.

The assumption that the climate system is in a natural state of energy balance also means that the models do not include any sources of long-term natural climate change. Again, this assumption is rather unavoidable since models can only include processes that climate researchers understand and can quantify, and that knowledge does not currently exist for natural sources of long-term climate change. While scientists often assume that long-term changes must come from some external forcing agent (such as increasing CO_2 or a change in solar activity), the Earth's climate is known to be a "nonlinear dynamical system," exhibiting chaotic fluctuations, such that long-term changes are possible without any external forcing.[11] For example, small-scale turbulence in the oceans has been shown to be capable of producing substantial chaotic changes in ocean heat content,[12] a result that invariably is blamed on humanity's greenhouse gas emissions.

As a result of the assumptions inherent in climate models, any claims they "prove" that warming is due to human activity are clearly disputable. There are no "fingerprints" of human-caused warming; for example, warming caused by any process will be more rapid over land than over oceans.[13]

While it is true that, based on theory, increasing CO_2 levels in the atmosphere should cause some warming, absent any other mitigating effect from the presence of that CO_2, just how much warming remains uncertain. It is entirely possible that much of the warming that has been observed (although over-predicted by the computer models) may indeed be due to anthropogenic greenhouse gas emissions. After all, greenhouse gasses, such as water vapor and CO_2, absorb and emit IR radiation,[14] which is all that is needed for there to be an atmospheric greenhouse effect (mostly due to water vapor) which keeps the Earth habitably warm and helps to sustain life. But just how much warming will result from humanity's role in all this remains considerably more uncertain than is generally realized.

The Direct Warming from a Doubling of CO_2 Is Only 1.2°C

How much warming does global warming theory say should occur from human greenhouse gas emissions? The public has been led to believe that models are fairly accurate in this regard, but the data show different results. Global warming theory indicates that a doubling of atmospheric CO_2 would cause only 1.2°C of direct warming if there are

no other changes in the climate system than temperature.[15] It is those other, indirect changes (called feedbacks) built into these models that greatly amplify the rather benign 1.2°C of warming in almost all climate models. These feedbacks lead to the wide range of current model projections of 1.8°C to 5.6°C of warming in response to 2 x CO_2. Current claims of a climate crisis[16] are invariably the result of reliance on the models producing the most warming, not on actual observations of the climate system which reveal unremarkable changes over the past century or more.

Climate Models Produce Too Much Warming

Climate models are not only used to predict future changes (forecasting), but also to explain past changes (hindcasting). Depending on where temperatures are measured (at the Earth's surface, in the deep atmosphere, or in the deep ocean), it is generally true that climate models have a history of producing more warming than has been observed in recent decades.[17]

This disparity is not true of all the models, as two models (both Russian) produce warming rates close to what has been observed, but those models are not the ones used to promote the climate crisis narrative. Instead, those producing the greatest amount of climate change usually make their way into, for example, the U.S. National Climate Assessment,[18] the congressionally mandated evaluation of what global climate models project for climate in the United States.

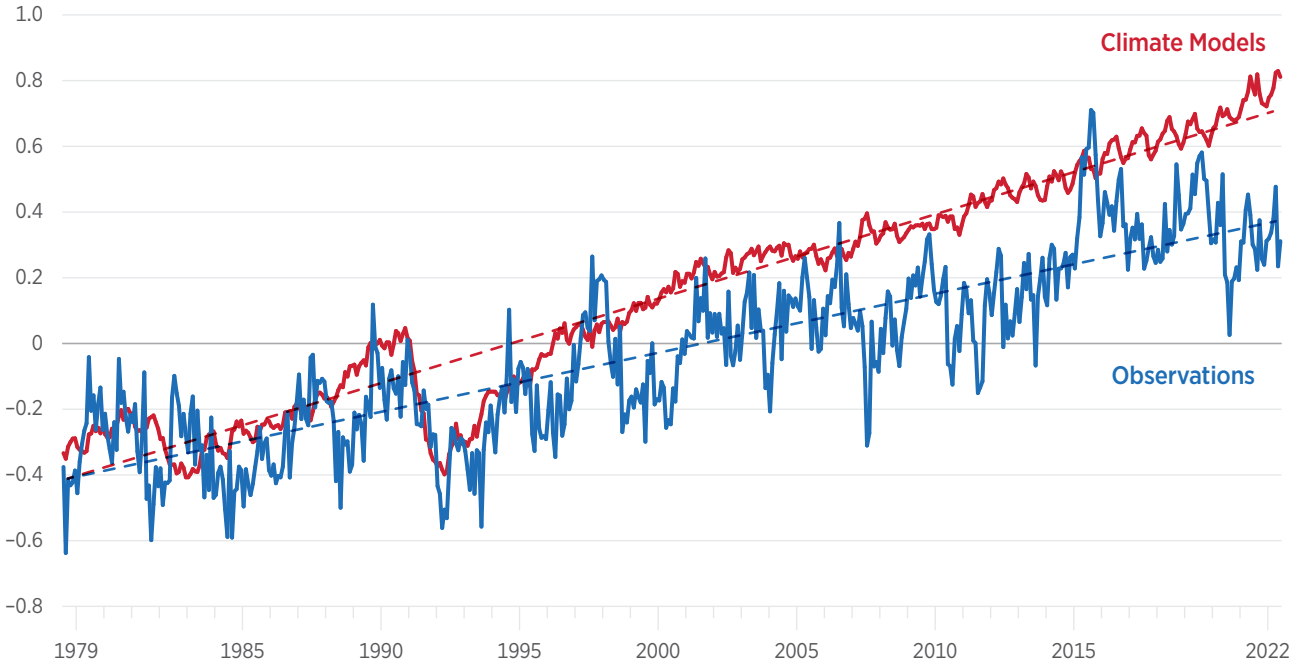
The best demonstration of the tendency of climate models to overpredict warming is a direct comparison between models and observations for global average surface air temperature, shown in Chart 1.

In this plot, the average of five different observation-based datasets (blue) are compared to the average of 36 climate models taking part in the sixth IPCC Climate Model Intercomparison Project (CMIP6). The models have produced, on average, 43 percent faster warming than has been observed from 1979 to 2022. This is the period of the most rapid increase in global temperatures and anthropogenic greenhouse gas emissions, and also corresponds to the period for which satellite observations exist (described below). This discrepancy between models and observations is seldom mentioned despite that fact that it is, roughly speaking, the average of the models (or even the most extreme models) that is used to promote policy changes in the U.S. and abroad.

CHART 1

Global Average Surface-Air Temperature Variations, 1979–2022

DEPARTURE FROM 1991–2020 AVERAGE, IN DEGREES CELSIUS



NOTE: Figures have been adjusted to align trends starting in 1979.
SOURCES: Author's calculations based on data from five different observation-based datasets and 36 climate models taking part in the sixth IPCC Climate Model Intercomparison Project, and KNMI Climate Explorer, "Starting Point," https://climexp.knmi.nl/start.cgi (accessed January 10, 2024).

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Summertime Warming in the United States

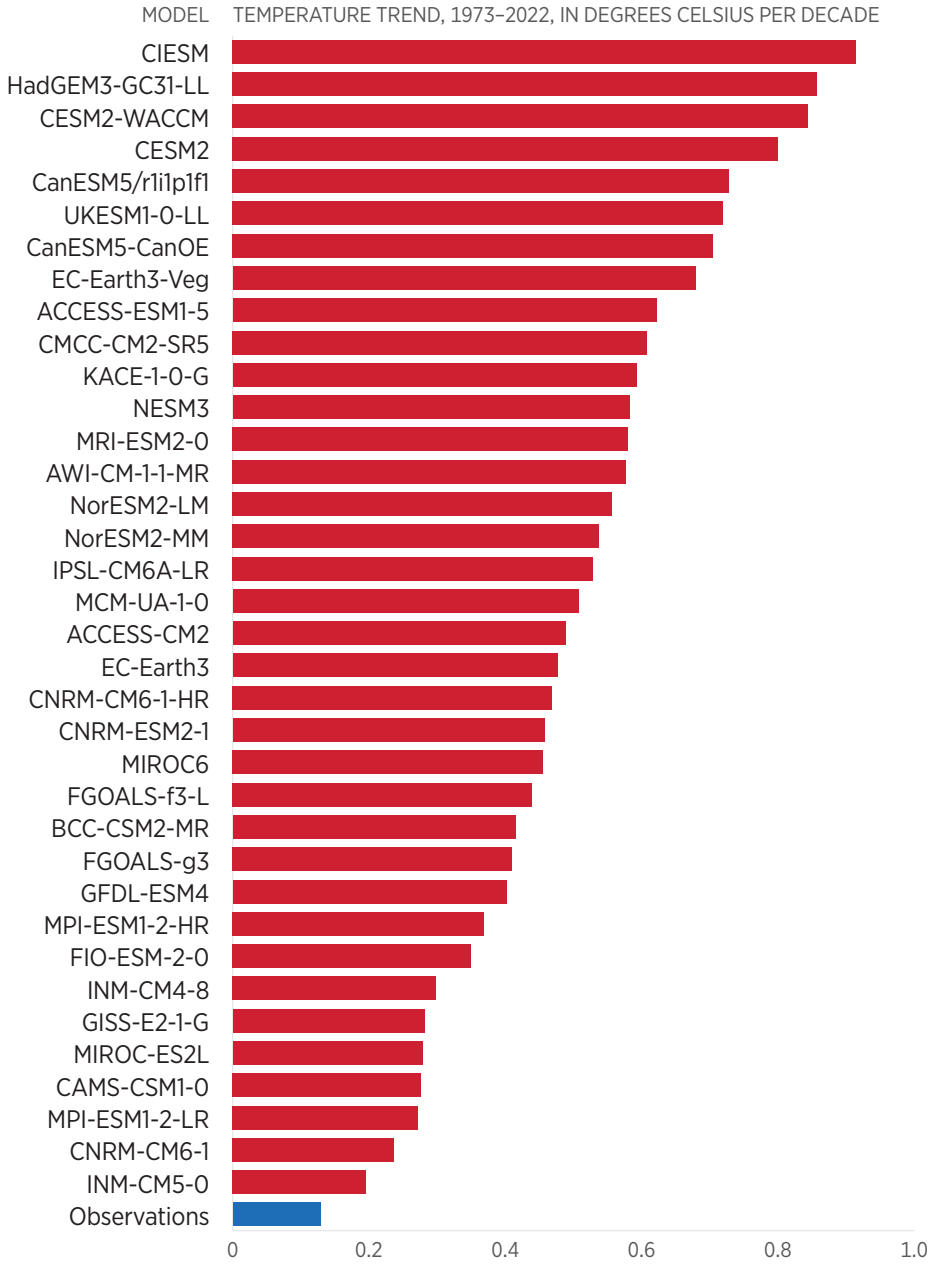
While global averages produce the most robust indicator of "global" warming, regional effects are often of more concern to national and regional governments and their citizens. For example, in the United States large increases in summertime heat could affect human health and agricultural crop productivity. But as Chart 2 shows, surface air temperatures during the growing season (June, July, and August) over the 12-state Corn Belt for the past 50 years reveal a large discrepancy between climate models and observations, with all 36 models producing warming rates well above what has been observed and the most extreme model producing seven times too much warming.

The fact that global food production has increased faster than population growth in the past 60 years[19] suggests that any negative impacts due

CHART 2

Climate Models Vastly Overstated Warming

The observed 12–state U.S. Corn Belt summer temperature trend for 1973–2022 is considerably less than that produced by all 36 climate models used to promote changes in U.S. energy policy.



SOURCES: Author's calculations based on data from five different observation-based datasets and 36 climate models taking part in the sixth IPCC Climate Model Intercomparison Project, and KNMI Climate Explorer, "Starting Point," https://climexp.knmi.nl/start.cgi (accessed January 10, 2024).

to climate change have been small. In fact, "global greening" has been documented to be occurring in response to more atmospheric CO_2,[20] which enhances both natural plant growth and agricultural productivity, leading to significant agricultural benefits.[21]

These discrepancies between models and observations are never mentioned when climate researchers promote climate models for energy policy decision-making. Instead, they exploit exaggerated model forecasts of climate change to concoct exaggerated claims of a climate crisis.

Global Warming of the Lower Atmosphere

While near-surface air temperatures are clearly important to human activity, the warming experienced over the low atmosphere (approximately the lowest 10 kilometers of the "troposphere," where the Earth's weather occurs) is also of interest, especially given the satellite observations of this layer extending back to 1979.[22] Satellites provide the only source of geographically complete coverage of the Earth, except very close to the North and South Poles.

Chart 3 shows a comparison of the temperature of this layer as produced by 38 climate models (red) and how the same layer has been observed to warm in three radiosonde (weather balloon) datasets (green), three global reanalysis datasets (which use satellites, weather balloons, and aircraft data; black), and three satellite datasets (blue).

As seen with the surface air temperature data in Chart 1, the climate models on average produced too much warming in the lower atmosphere since 1979: by 43 percent compared to weather balloons, by 55 percent compared to reanalysis datasets, and by 75 percent compared to satellite datasets.

So, it is clear that the latest state-of-the-art climate models produce too much warming compared to the observations. Yet, those models are used to guide policy in the U.S. and in other countries. This discrepancy is not widely appreciated by the public because seldom (if ever) do news media outlets publish stories that do not fit the narrative that humans are destroying the climate system.

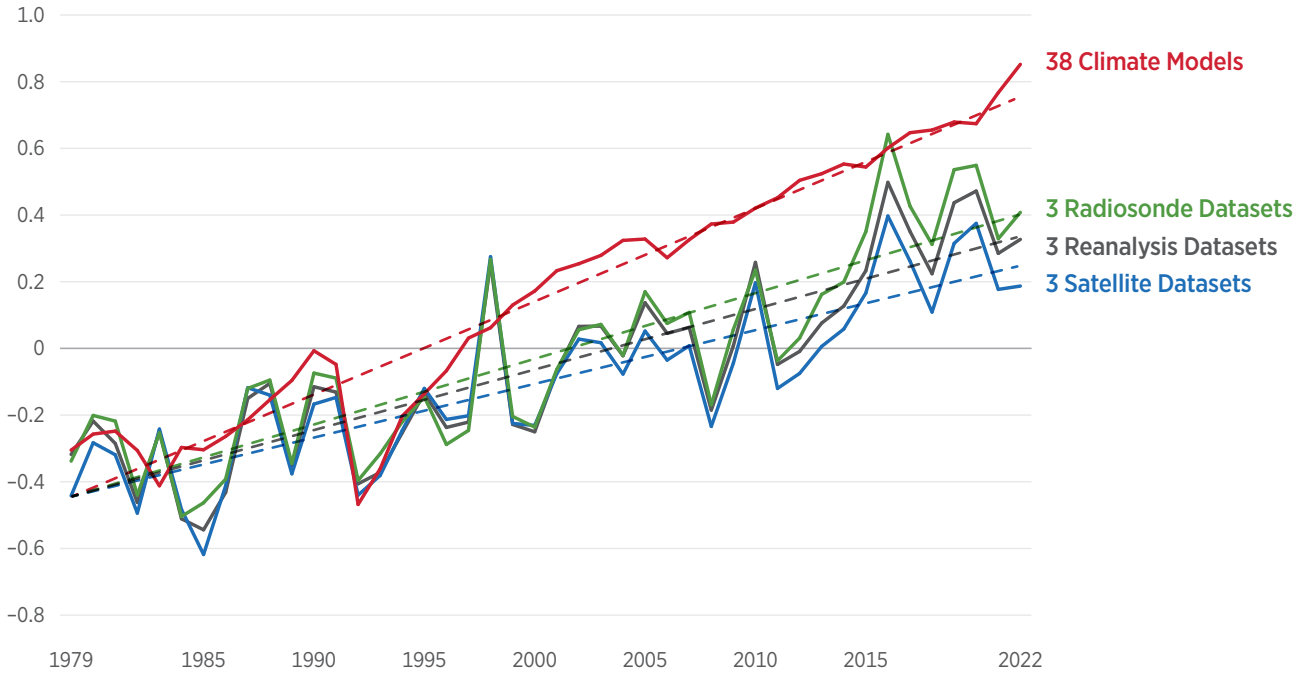
If Models Warm Too Much, What Do Current Warming Rates Show?

There is another, simpler way to model energy flows in the climate system to help answer the question, What do recent rates of global warming

CHART 3

Global Lower Atmospheric Temperature Variations, 1979–2022

DEPARTURE FROM 1991–2020 AVERAGE, IN DEGREES CELSIUS



NOTE: Figures have been adjusted to align trends starting in 1979.
SOURCES:

- Author's calculations based on data from Ross McKitrick and John Christy, "Pervasive Warming Bias in CMIP6 Tropospheric Layers," *Earth and Space Science*, Vol. 7, No. 9 (July 15, 2020), https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EA001281 (accessed January 10, 2023).
- Author's calculations based on data from American Meteorological Society, *State of the Climate in 2022*, https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/ (accessed January 8, 2023).

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say about future warming? These approaches assume that all the warming has been due to humans, which is likely not the case.

The accumulation of energy in the deep oceans and the observed rate of warming of the global land and ocean surface over the past 100-plus years has been analyzed by scientists[23] to determine just how much the climate system would eventually warm, and this leads to an estimate of 1.5°C to 1.8°C total future warming in response to a doubling of atmospheric CO_2 (2 x CO_2). Note: 1.5°C of future warming above pre-industrial times is often cited as a goal for a safe limit to future warming. As a result, special energy policies may not be needed to limit future warming to relatively benign levels.

A more recent analysis[24] of these energy flows that focuses on the warming observed on land in the deep oceans since 1970 (the period of highest-quality temperature measurements and most rapid warming and rise in atmospheric CO_2) produced a similar range of future warming of 1.5°C to 2.2°C in response to 2 x CO_2. Again, this assumes that all warming has been due to human activity.

But, might the Earth's atmosphere surpass 2 x CO_2 in the future? This depends on highly uncertain projections of future usage of fossil fuels. The good news is that nature is quite efficient at removing "excess" CO_2 from the atmosphere, and, depending on future rates of fossil fuel burning, it turns out that the atmosphere might not even reach 2 x CO_2.[25]

Why Do Climate Models Produce Too Much Warming?

The tendency for climate models to produce too much warming has at least two possible explanations.

First, it could be that the forcing—any imposed global energy imbalance—of the climate system[26] has been assumed to be too large. The forcing from increasing CO_2 (and other less-important greenhouse gases) is believed to be reasonably well understood. What is less well understood is the role of particulate air pollution, especially sulfate aerosols from coal and petroleum burning, either as a direct reflector of sunlight or an indirect one through their influence on clouds.

The second possibility is that climate models are too sensitive to forcing. That is, for a given imposed energy imbalance from increasing CO_2, they produce too much warming. For example, temperature-dependent changes in clouds and precipitation (the regulator of Earth's main greenhouse gas, water vapor) within the models could be unrealistically amplifying the relatively benign 1.2°C direct warming effect of 2 x CO_2.

What Else Besides Humans Could Be Producing Climate Change?

One claim that is often made is that humans must be causing recent warming since scientists do not know of any other reason. This argument is not from knowledge, though, but rather from a lack of knowledge. For example, it is simply not known what caused the coolness of the Little Ice Age several centuries ago, or the warmth of the Roman Warm Period (about 2,000 years ago), or the Medieval Warm Period (about 1,000 years ago). Similarly, the U.S. Dust Bowl of the 1930s existed before most CO_2

emissions occurred and it must have had a largely natural origin. Yet, if another Dust Bowl occurred today, it would certainly be blamed on human-caused climate change.

Some researchers have published unorthodox evidence for non-CO_2 origins of climate change, for example, through changes in the transport of energy from the tropics to high latitudes[27] and the sun's modulation of galactic cosmic rays, which in turn can affect cloud formation.[28] Since clouds are the Earth's natural sunshade, reducing global temperatures below what they would be in the absence of clouds, a solar effect on climate remains a possibility.

Another possibility is a natural change in the global ocean circulation. Earth's climate is considered a nonlinear dynamical system, capable of undergoing changes all by itself in the absence of forcing. Since the oceans are very cold (near 4°C, averaged over their full depth), any change in the slow overturning circulation of the global oceans would cause surface temperatures to change. And it is well known that even if warming (or cooling) originates entirely over the ocean it will be magnified over land.[29] This means that one cannot attribute warming to humans just because warming is larger over land than over the ocean.

Conclusion

Climate models produce too much warming when compared to observations over the past fifty years or so, which is the period of most rapid warming and increases in carbon dioxide in the atmosphere. The discrepancy ranges from over 40 percent for global surface air temperature, about 50 percent for global lower atmospheric temperatures, and even a factor of two to three for the United States in the summertime. This discrepancy is never mentioned when those same models are used as the basis for policy decisions.

Also not mentioned when discussing climate models is their reliance on the assumption that there are no natural sources of long-term climate change. The models must be "tuned" to produce no climate change, and then a human influence is added in the form of a very small, roughly 1 percent change in the global energy balance. While the resulting model warming is claimed to prove that humans are responsible, clearly this is circular reasoning. It does not necessarily mean that the claim is wrong—only that it is based on faith in assumptions about the natural climate system that cannot be shown to be true from observations.

Finally, possible chaotic internal variations will always lead to uncertainty in both global warming projections and explanation of past changes. Given these uncertainties, policymakers should proceed cautiously and not allow themselves to be influenced by exaggerated claims based on demonstrably faulty climate models.

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Endnotes

1. P. R. Shukla et al., eds., *Climate Change 2022: Mitigation of Climate Change*, "Summary for Policymakers," Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, UK: Cambridge University Press, 2023), https://www.cambridge.org/core/books/climate-change-2022-mitigation-of-climate-change/summary-for-policymakers/ABC31CEA863CB6AD8FEB6911A872B321 (accessed January 3, 2024).
2. D. B. R. Kenning, "Heat Balance," AccessScience, last reviewed August 2020, https://www.accessscience.com/content/article/a310400 (accessed January 3, 2024).
3. Kevin E. Trenberth, John T. Fasullo, and Jeffrey Kiehl, "Earth's Global Energy Budget," *Bulletin of the American Meteorological Society*, Vol. 90, No. 3 (2009), pp. 311–324, https://journals.ametsoc.org/view/journals/bams/90/3/2008bams2634_1.xml (accessed January 3, 2024).
4. Norman G. Loeb et al., "CERES Top-of-Atmosphere Earth Radiation Budget Climate Data Record: Accounting for in-Orbit Changes in Instrument Calibration," *Remote Sensing*, Vol. 8, No. 3 (2016), p. 182, https://www.mdpi.com/2072-4292/8/3/182 (accessed January 3, 2024).
5. A. Bagnell and T. DeVries, "20th Century Cooling of the Deep Ocean Contributed to Delayed Acceleration of Earth's Energy Imbalance," *Nature Communications*, Vol. 12 (July 29, 2021), https://www.nature.com/articles/s41467-021-24472-3 (accessed January 3, 2024).
6. Ian D. Campbell et al., "Late Holocene 1500 Yr Climatic Periodicities and Their Implications," *Geology*, Vol. 26, No. 5 (1998), pp. 471–473, https://pubs.geoscienceworld.org/gsa/geology/article-abstract/26/5/471/206910/Late-Holocene-1500-yr-climatic-periodicities-and?redirectedFrom=fulltext (accessed January 3, 2024).
7. Veronika Eyring et al., "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization," *Geoscientific Model Development*, Vol. 9 (2016), pp. 1937–1958, https://gmd.copernicus.org/articles/9/1937/2016/ (accessed January 3, 2023).
8. Gerald A. Meehl et al., "Context for Interpreting Equilibrium Climate Sensitivity and Transient Climate Response from the CMIP6 Earth System Models," *Science*, Vol. 6 (2020), https://www.science.org/doi/10.1126/sciadv.aba1981 (accessed January 3, 2024).
9. Frédéric Hourdin et al., "The Art and Science of Climate Model Tuning," *Bulletin of the American Meteorological Society*, Vol. 98, No. 3 (2017), pp. 589–602, https://journals.ametsoc.org/view/journals/bams/98/3/bams-d-15-00135.1.xml (accessed January 3, 2023).
10. Damien Irving et al., "A Mass and Energy Conservation Analysis of Drift in the CMIP6 Ensemble," *Journal of Climate*, Vol. 34 (2021), pp. 3157–3170, https://journals.ametsoc.org/view/journals/clim/34/8/JCLI-D-20-0281.1.xml (accessed January 3, 2023).
11. Lamont-Doherty Earth Observatory, "The Earth's Climate: A Non-Linear Dynamical System," http://ocp.ldeo.columbia.edu/res/div/ocp/arch/nonlinear.shtml (accessed January 3, 2024).
12. Thierry Penduff et al., "Chaotic Variability of Ocean Heat Content: Climate-Relevant Features and Observational Implications," *Oceanography*, Vol. 31, No. 2 (June 2018), pp. 63–71.
13. Craig Wallace and M. Joshi, "Comparison of Land–Ocean Warming Ratios in Updated Observed Records and CMIP5 Climate Models," *Environmental Research Letters*, Vol. 13 (2018), https://iopscience.iop.org/article/10.1088/1748-9326/aae46f (accessed January 3, 2024), and Gilbert P. Compo and Prashant D. Sardeshmukh, "Oceanic Influences on Recent Continental Warming," *Climate Dynamics*, Vol. 32 (2009), pp. 333–342, https://link.springer.com/article/10.1007/s00382-008-0448-9 (accessed January 3, 2024).
14. Center for Science Education, "Carbon Dioxide Absorbs and Re-Emits Infrared Radiation," undated, https://scied.ucar.edu/learning-zone/how-climate-works/carbon-dioxide-absorbs-and-re-emits-infrared-radiation (accessed January 3, 2024).
15. Brian E. J. Rose, "Advanced Topic: Climate Sensitivity and Feedback," The Climate Laboratory, 2022, https://brian-rose.github.io/ClimateLaboratoryBook/courseware/advanced-sensitivity-feedback.html (accessed January 3, 2024).
16. United Nations, "The Climate Crisis—a Race We Can Win," https://www.un.org/en/un75/climate-crisis-race-we-can-win (accessed January 3, 2024).
17. Paul Voosen, "Use of 'Too Hot' Climate Models Exaggerates Impacts of Global Warming," May 4, 2022, https://www.science.org/content/article/use-too-hot-climate-models-exaggerates-impacts-global-warming (accessed January 3, 2024).
18. U.S. Climate Resilience Toolkit, "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II," November 2018, https://toolkit.climate.gov/reports/impacts-risks-and-adaptation-united-states-fourth-national-climate-assessment-volume-ii (accessed January 3, 2024).
19. Craig D. Idso, "The Positive Externalities of Carbon Dioxide: Estimating the Monetary Benefits of Rising Atmospheric CO2 Concentrations on Global Food Production," Center for the Study of Carbon Dioxide and Global Change, 2013, http://www.co2science.org/education/reports/co2benefits/MonetaryBenefitsofRisingCO2onGlobalFoodProduction.pdf (accessed January 3, 2024).
20. Zaichun Zhu et al., "Greening of the Earth and Its Drivers," *Nature Climate Change*, Vol. 6 (2016), pp. 791–795, https://www.nature.com/articles/nclimate3004 (accessed January 3, 2024).
21. Kevin D. Dayaratna, Ross McKitrick, and Patrick J. Michaels, "Climate Sensitivity, Agricultural Productivity and the Social Cost of Carbon in FUND," *Environmental Economics and Policy Studies*, Vol. 22 (2020), https://link.springer.com/article/10.1007/s10018-020-00263-w (accessed January 3, 2024).

22. Roy W. Spencer, John R. Christy, and William D. Braswell, "UAH Version 6 Global Satellite Temperature Products: Methodology and Results," *Asia-Pacific Journal of Atmospheric Sciences*, Vol. 53 (2017), pp. 121–130, https://link.springer.com/article/10.1007/s13143-017-0010-y (accessed January 3, 2024).
23. Nicholas Lewis and Judith Curry, "The Impact of Recent Forcing and Ocean Heat Uptake Data on Estimates of Climate Sensitivity," *Journal of Climate*, Vol. 31 (2018), pp. 6051–6071, https://journals.ametsoc.org/view/journals/clim/31/15/jcli-d-17-0667.1.xml (accessed January 3, 2024).
24. Roy W. Spencer and John Christy, "Effective Climate Sensitivity Distributions from a 1D Model of Global Ocean and Land Temperature Trends, 1970–2021," *Journal of Theoretical and Applied Climatology* (2023).
25. Roy W. Spencer, "ENSO Impact on the Declining CO2 Sink Rate," *Journal of Marine Science Research and Oceanography*, Vol. 6 (2023), pp. 163–170.
26. Climate.gov, "Climate Forcing," https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-forcing (accessed January 3, 2024).
27. Javier Vinos, *Climate of the Past, Present, and Future: A Scientific Debate*, 2nd ed. (Madrid: Critical Science Press, 2022), https://judithcurry.com/wp-content/uploads/2022/09/Vinos-CPPF2022.pdf (accessed January 3, 2024).
28. Henrik Svensmark, "Influence of Cosmic Rays on Earth's Climate," *Physical Review Letters*, Vol. 81 (1998), pp. 5027–5030.
29. Gilbert P. Compo and Prashant D. Sardeshmukh, "Oceanic Influences on Recent Continental Warming," *Climate Dynamics*, Vol. 32 (2009), pp. 333–342, https://link.springer.com/article/10.1007/s00382-008-0448-9 (accessed January 3, 2024).