TYPE Frontiers in Science Editorial
PUBLISHED 14 November 2023
DOI 10.3389/fsci.2023.1256273

Check for updates

Warming ends when carbon pollution stops

Michael E. Mann*

Department of Earth and Environmental Science, University of Pennsylvania, Philadelphia, PA, United States

OPEN ACCESS

EDITED BY
Frontiers in Science,
Frontiers Media SA, Switzerland

REVIEWED BY
Shawn Marshall,
University of Calgary, Canada

*CORRESPONDENCE
Michael E. Mann
mmann00@sas.upenn.edu

RECEIVED 10 July 2023
ACCEPTED 03 October 2023
PUBLISHED 14 November 2023

CITATION
Mann ME. Warming ends when carbon pollution stops.
Front Sci (2023) 1:1256273.
doi: 10.3389/fsci.2023.1256273

KEYWORDS
carbon budget, thermal inertia, climate change, CO_2, net zero, Zero Emissions Commitment, committed warming

An Editorial on the Frontiers in Science Lead Article
The Zero Emissions Commitment and climate stabilization

Key points

- Improved Earth system models now consider the complex interplay between the oceans and terrestrial biosphere and their key role of actively drawing down carbon from the atmosphere, showing the direct and immediate impact of our efforts to reduce carbon emissions.
- Long-term warming will largely be determined by carbon dioxide (CO_2) emissions but aerosols and short-lived, human-generated greenhouse gases such as methane must also be considered.
- Caveats to the Zero Emissions Commitment (ZEC) and climate stabilization involve the precise magnitude of the carbon budgets that remain for avoiding critical warming thresholds, as well as processes such as the warming of the deep ocean and its consequences, including rising sea levels.
- At this point, the obstacles to climate action are neither physical nor technological but political, which means they can be overcome with the right sense of urgency. What is most urgently required is a rapid phaseout of human-induced activities that produce carbon pollution.

A recent article in *The Hill* insisted that “scientists failed for decades to communicate” (1) the threat of climate change. The scientific paper on which the article was reporting did not really say that—it was instead providing a more nuanced discussion of sea level rise “tail risk”. But the irony here is that the opposite of what was asserted by the news article is arguably true. If anything, we scientists have failed to communicate the prospects for *averting* catastrophic warming.

In the days when I was working on my PhD, in the early 1990s, we were taught that the warming of the planet would persist for decades even if we suddenly stopped burning fossil fuels and emitting carbon into the atmosphere. This is due to what is known as “thermal inertia”—the slow, sluggish response of the oceans. Climate models showed that surface warming would continue for 30 years or more, as the oceans slowly continue to warm, even after carbon pollution ceases. This so-called “committed warming” would seem to render our efforts to avert disaster somewhat futile. Even if we turned off the metaphorical carbon faucet, the water level of warming would continue to rise. Extending the metaphor, that water would soon spill from our kitchen sink onto the kitchen floor. With apologies to Greta Thunberg, rather than burning, our house would instead be flooding.

But that picture is fundamentally incomplete—there is a "drain" too in the form of the ocean carbon cycle. That drain causes the water level, i.e., the planetary temperature, to stabilize. Through a somewhat fortuitous coincidence of nature, there are offsetting tendencies in ocean physics and ocean chemistry. The positive "thermal inertia" (the physics) is almost perfectly offset by a negative "carbon cycle inertia" (the chemistry). To be more specific, the rate at which the ocean surface tends to continue to warm up due to the carbon already emitted is nearly identical to the rate at which the oceans absorb and bury atmospheric carbon dioxide (CO_2), lowering the atmospheric greenhouse effect and cooling the lower atmosphere and surface. The two effects essentially cancel each other out. And so, instead, we get an essentially flat temperature curve—the stable metaphorical water level—when human carbon emissions approach zero.

In the old days, climate modelers would simply set the atmospheric CO_2 constant to represent a scenario in which human carbon emissions cease. However, this amounted to an erroneous implicit assumption of zero carbon cycle inertia. In the newer, more realistic modeling framework, based on more comprehensive Earth system models, the oceans as well as the terrestrial biosphere are allowed to play an interactive role in the behavior of the system, which includes the key role of actively drawing down carbon from the atmosphere.

While this new more realistic framework emerged more than a decade ago (2), only far more recently has it truly penetrated public climate discourse. Arguably, both scientists and journalists are at fault (3) for the continued notion that we are due decades of additional warming even after we cease fossil fuel burning and other activities generating carbon pollution. We now know this is not true.

This is hardly a minor technical matter. It fundamentally changes our sense of agency in averting disaster. It means our efforts to reduce carbon emissions have a direct and immediate impact. It is the reason we can meaningfully define a "carbon budget"—there is a fixed amount of fossil fuel we can afford to burn and stay below critical planetary temperature levels such as 1.5°C or 2.0°C. We can estimate that budget and work toward policies that can keep us collectively within it, at least in principle.

Old habits die hard, and some scientists have remained skeptical of this revised understanding. Indeed, I myself took several years to accept the paradigm-shifting implications of this finding. But this finding appears quite robust, having been affirmed by a solid body of work over the past decade. The current state of the science is adroitly summarized in a comprehensive new review "*The Zero Emissions Commitment and climate stabilization*" by a team of nearly two dozen experts on this research topic in the current *Frontiers in Science* Lead Article by Palazzo Corner et al. (4).

Palazzo Corner et al. focus on the "Zero Emissions Commitment" or "ZEC", which is defined as how much warming (if any) we can expect upon reaching zero carbon emissions. Technically, that is zero "net emissions", as the possibility exists—at least theoretically—for artificial drawdown of atmospheric carbon, i.e., so-called "negative emissions". Yet there is no evidence at present that such technology could be deployed at scale let alone in the rapid timeframe now necessary. To the extent that the ostensible promise of negative emissions technology may be little more than a techno-optimistic mirage, my preference is to omit the "net" prefix. What is truly required is a rapid phaseout of anthropogenic activities that produce carbon pollution.

Palazzo Corner et al. show that, on average, the various models used in the recent "ZECMIP" intercomparison study indicate a ZEC close to zero, at least on a 50-year timescale (greater uncertainties apply for longer timescales due to uncertainties in the longer-term behavior of, e.g., the global carbon cycle and for larger amounts of cumulative carbon emissions). For at least 1000 gigatons (trillion tons) of emitted carbon ("GtC") (thus far, for comparison, we have burned about 680 GtC, so it is plausible we can remain below that limit), the average ZEC across models is not only close to zero but very slightly negative (just under −0.1°C).

There is nonetheless a substantial range in estimated ZEC among the various individual models: anywhere from a cooling of −0.3°C to a warming of +0.3°C. Palazzo Corner et al. note, accordingly, that there is a roughly 66% likelihood that additional warming will be less than 0.3°C once zero emissions are reached. Conversely, that implies a 33% chance the warming could be more than this. Given we are currently at roughly 1.2°C warming relative to the pre-industrial era, that could mean reaching the oft-cited threshold for catastrophic warming of 1.5°C even if we were somehow to bring carbon emissions to zero today. While there is a good chance we would avert 1.5°C warming in that scenario, to paraphrase Clint Eastwood, we must ask ourselves one question: do we feel lucky?

Now, there are certainly some additional caveats to this story, and they are explored in some detail by Palazzo Corner et al. First of all, ZECMIP features only a subset of available climate system models, and the inferences drawn are quite limited beyond the 100-year time horizon, where the behavior of long-response components of the climate system—the ice sheets, the deep ocean, etc.—remains a bit vague. Unsurprisingly, there is a large degree of variation in model predictions beyond that time horizon, with some models indicating that additional warming could eventually kick in. Given the complexities of the ocean carbon cycle in particular and ocean mixing processes more generally (which are relevant for both carbon and heat burial), the seemingly coincidental balance between positive climate inertia and negative carbon cycle inertia is tenuous and subject to possible revision as scientific understanding continues to advance.

Another wild card is that other factors besides CO_2 come into play when we examine future global temperature scenarios. Among these are sulfate aerosols (which exert a cooling effect) and black carbonaceous aerosols (which exert a warming effect) from coal burning and other short-lived greenhouse gases generated from human activity, such as methane, nitrous oxide, and lower atmospheric ozone pollution. In most scenarios, the effects of these competing short-term radiative constituents cancel each other out, constituting a near zero sum game as we phase out fossil fuel burning and the other underlying anthropogenic activities that generate them. But this depends on the details of policies impacting those activities, including, in the case of methane, agriculture, hydroelectric dam construction, and natural gas extraction. The cancellation is also dependent on us getting the radiative physics right. In the case of sulfate aerosols—particularly so-called "indirect effects" such as cloud nucleation—there is still substantial uncertainty. So, while long-term warming will largely be determined by what happens to CO_2, these other contributors will matter too if the activities producing them continue.

Yet another caveat involves the precise magnitude of the carbon budgets that remain for avoiding critical warming thresholds. The amount of CO_2 that can still be emitted for a 50% chance of staying below 1.5°C of warming is conventionally estimated to be roughly 100 GtC. At the current rate of emissions, we would run through that budget in less than a decade. Yet that estimate may be overly liberal as it is dependent on other assumptions. Among these is how

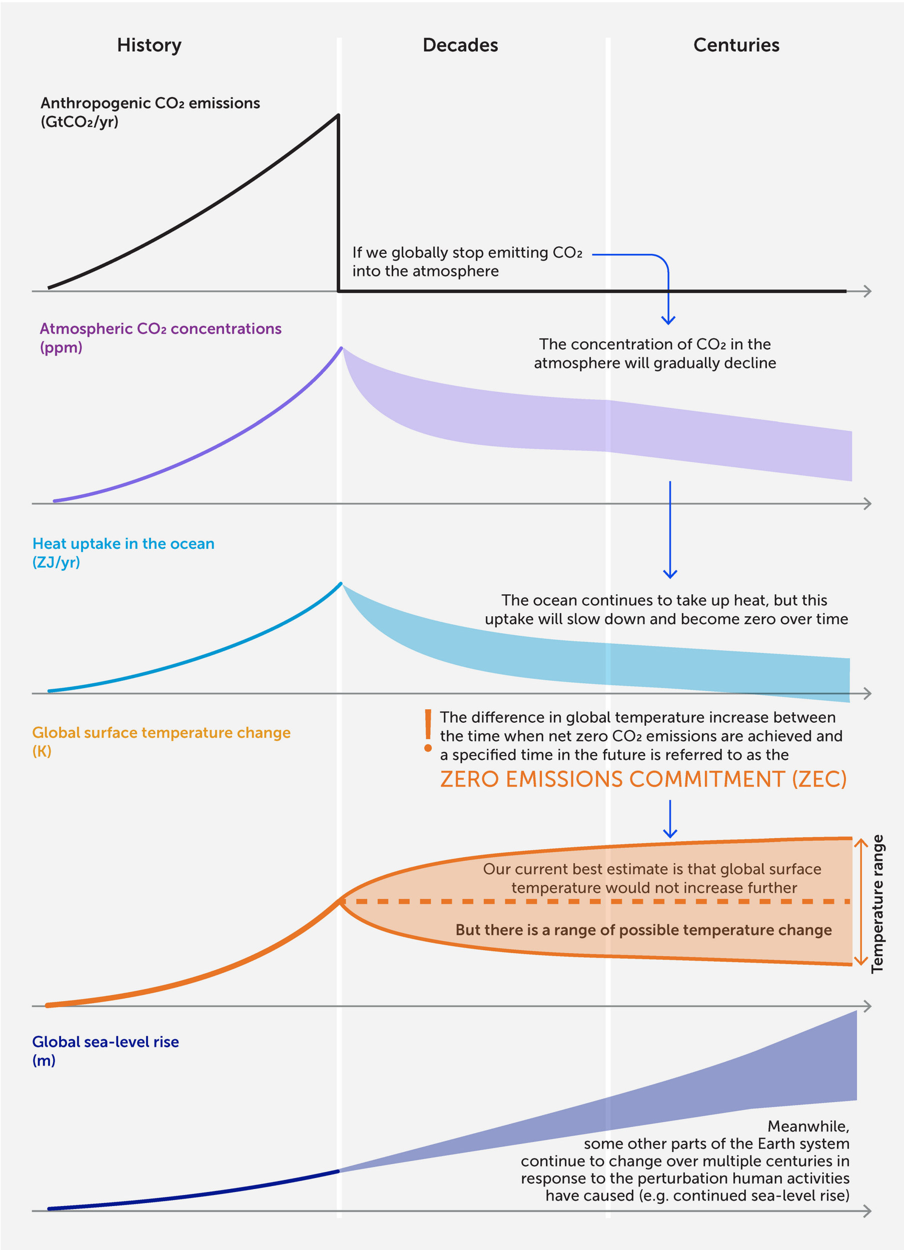

FIGURE 1
Reproduced from Figure 1 in Palazzo Corner S, et al. 2023, licensed under CC BY-SA 4.0. Stylized schematic of how atmospheric carbon dioxide (CO_2) concentrations, ocean heat uptake, and global surface temperature can evolve under net zero CO_2 emissions. Process timescales are illustrative. **Comment (MM):** This shows the average response of climate models for a scenario of sudden instantaneous cessation of global carbon emissions (black curve); the trajectories for CO_2 concentrations (light purple); ocean heat uptake (cyan); surface temperature (orange); and sea level rise (dark blue).

we define the pre-industrial baseline relative to which net warming is measured. It has typically been taken to be the late 19th century (the mid-point of the first 50 years of available widespread surface temperature measurements). There is evidence, however, that human-caused warming began before that, perhaps as early as the mid-18th century. Taking into account the earlier human-caused warming potentially reduces the budget for averting 1.5°C warming by as much as 40% (5).

But the most significant caveat of all is that surface temperatures are not the only things that matter during the climate crisis. While some impacts, like extreme weather events, appear to be tied to surface warming, others, like rising sea levels and ice sheet destabilization, depend on the warming of the deep ocean. That would continue for decades and centuries to come (see Figure 1 from Palazzo Corner et al., 2023). Our earlier sink analogy, while useful for understanding the competing impacts on the warming level, is an imperfect one: even if surface temperature levels are constant, actual (rather than metaphorical) water levels will continue to rise for some time.

Moreover, as the ocean continues to absorb atmospheric carbon, ocean acidification—which impacts coral reefs and other calcareous ocean biota, such as mollusks and crustaceans—would continue to worsen, threatening food webs in the ocean. So, the penalty of procrastination remains, underscoring the importance of decarbonizing our societal machinery as rapidly as possible if we are to remain within our adaptive capacity as a civilization.

Nevertheless, this new study offers hope. At a time when climate advocates have become disillusioned by the lack of progress—and this is understandable given the "commitment gap" that still remains between what has been promised and what is required—this latest study reminds us that the obstacles to climate action are neither physical nor technological. At this point, they remain political. History teaches us that political obstacles can be overcome, so there remains both urgency and agency when it comes to the ongoing climate battle.

Statements

Author contributions

MM: Visualization, Writing – original draft, Writing – review & editing.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Elbein S. *Catch-22: Scientific communication failures linked to faster-rising seas* (2023). The Hill. Available at: https://thehill.com/policy/energy-environment/4057045-catch-22-scientific-communication-failures-linked-to-faster-rising-seas/ (Accessed July 10, 2023).

2. Meinshausen M, Meinshausen N, Hare W, Raper SC, Frieler K, Knutti R, et al. Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature* (2009) 458 (7242):1158–62. doi: 10.1038/nature08017

3. Hertsgaard M, Huq S and Mann ME. *How a little-discussed revision of climate science could help avert doom* (2022). Washington Post. Available at: https://www.washingtonpost.com/outlook/2022/02/23/warming-timeline-carbon-budget-climate-science/ (Accessed July 10, 2023).

4. Palazzo Corner S, Siegert M, Ceppi P, Fox-Kemper B, Frölicher T, Gallego-Sala A, et al. The Zero Emissions Commitment and climate stabilization. *Front Sci* (2023) 1:1170744. doi: 10.3389/fsci.2023.1170744

5. Schurer A, Cowtan K, Hawkins E, Mann ME, Scott V, Tett SFB. Interpretations of the paris climate target. *Nat Geosci* (2018) 11:220–1. doi: 10.1038/s41561-018-0086-8