# Metamodel Recent posts 2022-05-24

## Contents



## Can we predict global climate tipping points?

*Nonlinearity generates tipping points, but it also make them hard to predict*

2022-05-03


If the globe warms slightly beyond 2°C, will we cross a climate tipping point that leads to runaway warming or catastrophe? Are we doomed if we don't stop the warming by 2030 (or 2050)? Predictions of imminent climate tipping points often capture the imagination of the media and the public. Aren't the harmful consequences of a steadily warming climate and its effect on extreme weather bad enough to spur action? Do we need even more things to worry about?

One reason to worry about new dangers is that we may need to take additional preventive action. But the solution to avoid crossing potential tipping points is exactly the same as the solution to mitigate steady climate change: reduce carbon emissions as quickly as possible to stay close to our current climate equilibrium.

Another reason to talk about potential tipping points is that it can help underscore the urgency for mitigating action. But it would be better to discuss tipping points in general terms, without implying that there are precise global warming thresholds or mitigation time intervals. Numbers associated with tipping points typically come with many caveats about the uncertainties. If the caveats are lost in translation to the public, the numbers can end up feeding into doomist narratives predicated on faux certainty.

Dystopian headlines about doomsday glaciers and methane bombs attract attention and may perhaps spur more climate activism in some people. Casual talk of climate tipping points as if they were imminent can push other people past real emotional tipping points. This can result in debilitating climate anxiety and passive sharing of "doomer memes", rather than activism.

Climate tipping points are associated with *amplifying* (or positive) feedbacks that make for a dramatic story. An example is the ice-albedo feedback, which goes like this: unusually warm conditions; more ice melts; less sunlight reflected; more heating and warmth; rinse, repeat. In a geologic instant (i.e., centuries to millennia), we end up with a hot, ice-free planet. Sounds rather scary. But surely we have had some unusually warm summers over the past several thousands of years which could have triggered this feedback. Why aren't we already ice-free?

That's because there's more happening behind the dramatic scenes of an amplifying feedback. There are *stabilizing* or negative feedbacks that act to counter it. The simplest one goes like this: unusually warm conditions; planet emits more heat; planet cools down; end of story. The stabilizing feedbacks don't garner much media attention because they are banal, but they collectively overwhelm the amplifying feedbacks and keep the climate stable. If amplifying feedbacks are swashbuckling pirates, stabilizing feedbacks are the boring navy that keeps them in check.

While our climate has been stable for the last ten thousand years, paleoclimatic data tell us that it has undergone abrupt changes before that (by geologic standards).[1] The worry then is that future global warming may disrupt the balance between amplifying and stabilizing feedbacks, resulting in an amplifying feedback that "runs away" unfettered, at least for a while until the stabilizing feedbacks catch up. Will this happen at 2°C of global warming, 3°, 5°, or beyond? The complex IPCC models suggest that the answer is "beyond", but these models aren't perfect and may not capture the slow amplifying feedbacks well. We can build simplified models to understand the amplifying feedbacks that generate tipping points, but these simpler models may not capture all the stabilizing feedbacks accurately. This precludes attaching specific numeric global thresholds or dates to climate tipping points that may lie in our future.

We know there are absolute local temperature thresholds that are relevant to current and future climates. An important one has to with the human body. A metric called wet-bulb temperature, that combines temperature and humidity, is used as a measure of heat stress on humans. Extended periods with wet-bulb temperatures exceeding about 35°C would be intolerable for humans. (The wet-bulb temperature threshold is lower than the normal human body temperature of 37°C because the body cools itself by sweating and transferring heat to cooler surroundings.)

Human society has adapted to a certain range of temperatures and departing from these temperatures causes harmful impacts. Some regions of the global are closer to the absolute wet-bulb temperature threshold than others, and the anthropogenic warming itself varies regionally. Therefore, the relative warming thresholds for harmful impacts will vary with the region. There are also other region-specific temperature thresholds that affect agricultural and ecological systems. For example, corals are very sensitive to the ambient temperatures. Ice sheets and permafrost also respond to regional temperatures.

Will continued regional warming cause the climate to soon cross a global tipping point? Nonlinearity in the climate system is often touted as a reason to be concerned about tipping points, because a nonlinear system can potentially switch between multiple equilibrium states. But nonlinearity is a double-edged sword: it adds interesting threshold behavior to a system, but it also takes away predictability. As Edward Lorenz showed using a simple model of deterministic chaos, nonlinear error growth can lead to rapid loss of predictive skill. Chaos associated with fast processes like weather reaches saturation for climate prediction, and can be quantified as stochastic noise or "certain uncertainty".[2] But this does not apply to slow climate processes like melting ice sheets and thawing permafrost, which are in the realm of "uncertain uncertainty". The initial conditions and the governing equations associated with these slow processes are poorly known. This means that nonlinear error growth will make it hard to accurately predict if and when any tipping points associated with these processes will be crossed.

Nonlinearity also prevents us from aggregating different local warming thresholds to come up with a single global warming threshold. Local thresholds associated with amplifying feedbacks can be studied

[1] Revealed: The 11 slides that finally convinced Boris Johnson about global warming (Carbon Brief)
[2] Can we predict global climate tipping points? (Metamodel.blog)

using relatively simple models, but to answer the global question, we must use comprehensive global climate models. These models compute the combined impact of many different regional processes. When we add together many different nonlinearities in a complex system, the different nonlinear transitions can get smeared out, making the global system respond in a "near-linear" fashion with increasing emissions. This can help explain why the IPCC models do not predict that we will cross any tipping point soon, even as they predict that global warming and its impacts will get much worse without mitigation.[3]

Consider global average surface temperature, which often figures in discussions of tipping points. It is the most commonly used measure to characterize climate change, although it may not be the scientifically most discerning metric. Models can estimate the relative trend in the global temperature with fairly good accuracy to simulate the observed warming (Figure 1, line). But the errors in the absolute global average temperature in model simulations are rather high (Figure 1, sidebar). Among different global climate models, the absolute global average temperature can range between 13°C and 15°C. For one model, 2°C warming means warming globally from 13°C to 15°C, whereas for another model, it means warming from 15°C to 17°C. Since a global 2°C warming translates into different local warming for different models and different regions, it is not possible to identify a hard global warming threshold for catastrophic impacts using current models. All we can say is that if the globe continues to warm, the risk of catastrophic local damage will increase rapidly.

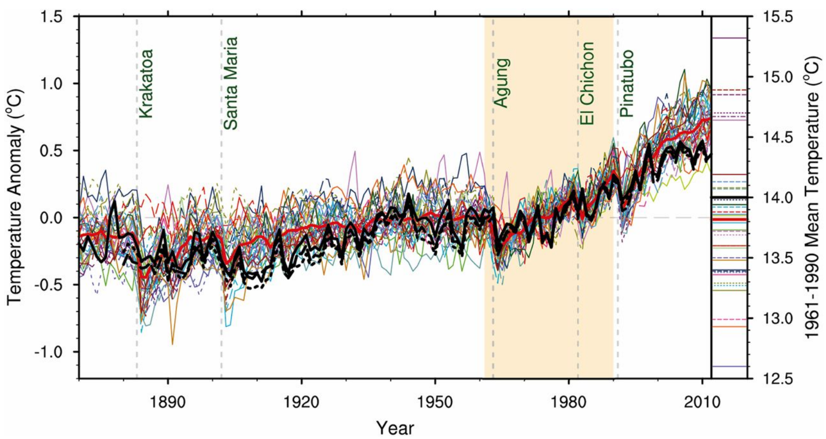


**Figure 1.** *Estimates of global-average surface temperature anomaly from model integrations performed in support of the fifth phase of the coupled model intercomparison project (CMIP5). Here, the observed anomaly (black) is estimated relative to the observed absolute time-average, while the model anomalies are estimated relative to each model's absolute time-average. Colored lines represent different models, with thick red denoting the model average, and the vertical dashed line denote volcanic eruptions. The small bar to the right of the figure shows the range of absolute global and time averaged model temperatures for the period 1961 to 1990. From Palmer and Stevens (2019)*

Global climate models do not predict a climate cliff's edge located at specific numbers like 1.5 or 2°C of warming, or by specific dates. But the higher levels of global warming predicted for unmitigated emissions can lead to unbearably harsh weather and climate in many regions, even without crossing any tipping points. Climate harm is more likely to occur by a thousand cuts rather than in one fell swoop. Any planetary warming threshold for tipping points that we can identify will be fuzzy. Does that mean we should worry less about exceeding 2°C global warming, because the local thresholds may be further away than we think? Not quite. A fuzzier global threshold also means that local thresholds for harmful impacts may be closer than we think. So, we need to act as quickly as we can to eliminate carbon emissions.

[3] Revealed: The 11 slides that finally convinced Boris Johnson about global warming (Carbon Brief)

(*Top image adapted from the poster for Pirates of the Caribbean: At World's End, using the Pieces of Eight font for the overlay text.*)

### Related articles

- Why are the (climate) numbers so round? (Metamodel blog)
- Debate about communicating tipping points (And Then There's Physics)
- Runaway tipping points of no return (RealClimate.org)
- Superrotation, idealized models, and GCMs (Isaac Held)

### Comments

*Note:* For updated comments, see the original blog post and the anouncement tweet.

- *Paul Pukite*:
  There are scales of non-linearity.
  - *R Saravanan*:
    True. The more nonlinear a system is, the more likely it will be to exhibit tipping point behavior, and the more difficult it will be to predict those tipping points (due to strong error growth).

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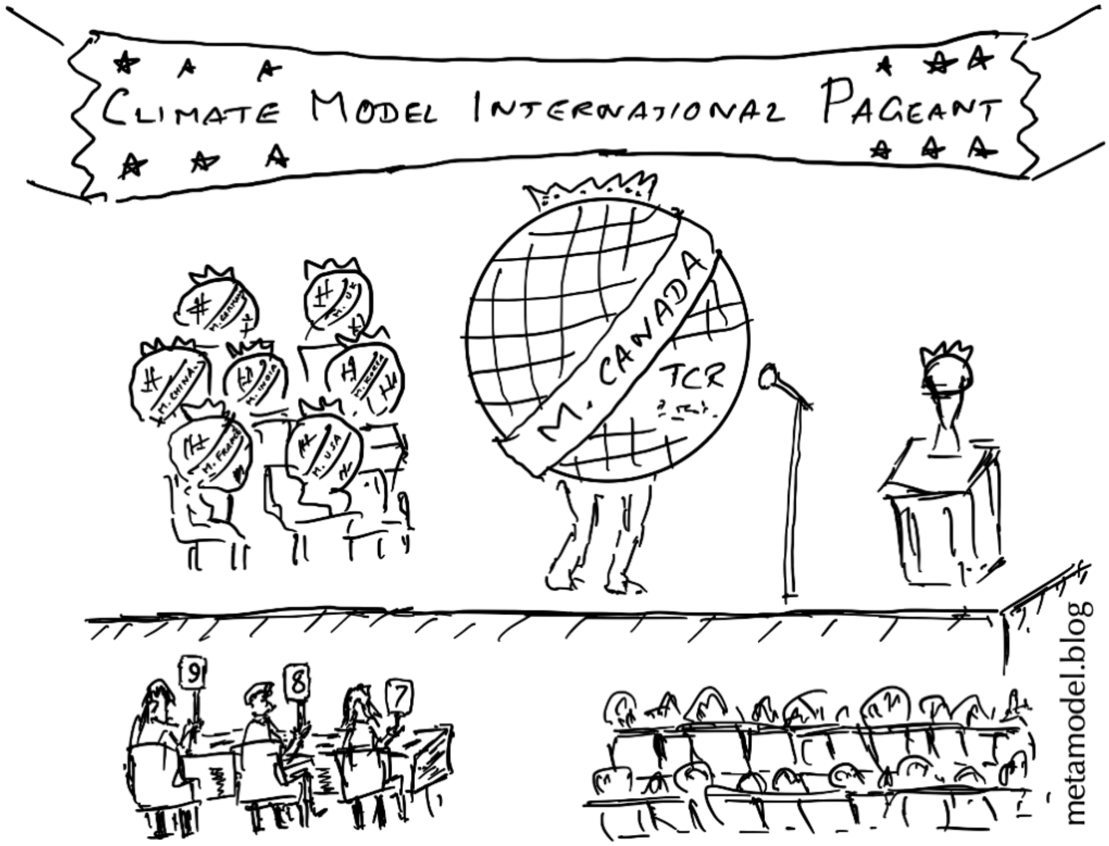
## How to judge a model beauty contest?

*Model meritocracy is a good idea, but the devil is in the details*

2022-05-10




Every 6–7 years, major climate modeling centers around the world submit their climate simulations to an organization called the Coupled Model Intercomparison Project (CMIP). CMIP distributes the simulation data so that scientists around the world can analyze and compare the models. But what criteria should we use to judge or rank models? How do you decide whether one model is better than another? Do we care about superficial beauty or inner beauty? These questions raise fundamental issues relating to climate modeling.

A useful analogy that distances these issues from climate jargon is the college application process. How do you judge a college applicant? In many Asian countries, the numeric score on a single exam decides which colleges you can get into, effectively determining your whole career. In the U.S., college applicants submit grade point averages and (increasingly optional) test scores, along with essays and a resume of extracurricular activities. A "holistic" process weighing all this information is used to make admissions decisions in selective colleges. Often selective colleges receive many more qualified applicants than they can admit. Teachers and coaching companies "teach to the test" to help the students get ahead. One proposed solution to reduce the intense competitive stress is to first identify all applicants who pass an acceptability threshold and then use a lottery to select those who are admitted. So putting a lot of effort into obtaining scores above some threshold (or even perfect scores) would not really help.

Consider, on the other hand, the stress-free process of attending a non-selective local college – say the Iowa Public Community College (IPCC) – that has a tradition of admitting all applicants. But one year, IPCC finds that some of the applicants have unusually low test scores (or be it grade point averages), even though they have good extracurricular activities on their resume. To deal with this, IPCC decides to suddenly become selective and notifies the applicants that only those with numeric scores above a threshold value will be admitted.

Although some current applicants may be miffed about the goalposts being moved after the ball has been kicked, the IPCC's decision may be acceptable as a short-term solution to maintain academic standards (to the extent measured by the numeric scores). But what are the long-term implications? Future applicants to IPCC may start to focus on improving the numbers that the college cares about, to the exclusion of factors like extracurricular activities that make them well-rounded. The newly selective community college should think long and hard before finalizing its new admissions policy

This is sort of the situation with the real IPCC, the Intergovernmental Panel on Climate Change, which uses the CMIP models for its assessments. In previous rounds of CMIP, explicit ranking of submitted models was not needed: Climate predictions were averaged among all the submitted models for assessment purposes, treating them equally. In the latest round of CMIP, the IPCC found that some of the submitted models were "running too hot", i.e., simulating too much warming in recent years, even if they were better in some other respects, like simulating regional climate features better. (The rationale for deciding what is "too hot" deserves its own discussion, but we'll just accept it for now.) If some models are running too hot, it will skew the average to be overly hot as well, resulting in "overprediction" of future warming when analyzing impacts.

To address this problem, the IPCC took a simple, if somewhat ad hoc, approach. Different models were weighted differently for averaging, based on how well they simulated the recent observed warming.[4] The models that overpredicted the recent warming were weighted less compared to the rest of the models.

Even after the IPCC report was released, many studies have continued to average across all the CMIP models equally, out of habit and due to convenience. A recent Comment[5] in Nature draws attention to this lack of awareness. The Comment reiterates that the models "running hot" should be downweighted when averaging. The issue is framed as "meritocracy" versus "democracy":[6] Treating all models as equal would mean a democracy, but assigning higher weights to the better models would be a meritocracy.

Computing and using model weights, as done in the IPCC assessment, can be a complicated process. What end users usually want is a simple recipe. Neither the IPCC nor the Nature Comment provide such a recipe, but a follow-up article[7] by the authors of the Comment suggests an alternative: *screening out models whose transient climate response (TCR) lies outside the likely (66% likelihood range) of 1.4C to 2.2C.* (TCR is the expected warming of global average temperature when the slowly increasing carbon dioxide concentration reaches double its value.)

The simple screening criterion is acceptable as a stopgap measure, as a practical "band aid" to fix an unexpected problem. But philosophically, it is a worrying development and should not be the long-term solution. It does not really address the hard question of why the physics-based models are "running too hot". The TCR-based screening criterion goes further than the IPCC weighting approach by imposing a statistical constraint on predictions from physics-based models. (The IPCC approach uses model simulations of recent warming to compute the model weights.) Essentially the physics-based global climate models are no longer predicting global-average temperature, but merely serve to add regional climate detail to the statistically constrained global-average temperature prediction (a procedure referred to as dynamical downscaling).

There is the danger that a simple recipe like the TCR-screening could become the de facto metric for distinguishing "good models" from "bad models" in the world of model meritocracy. Like college applicants, model developers are Pavlovian. They will respond to behavioral incentives to develop "good models" and the climate science community should be careful to provide the right incentives.

[4] Revealed: The 11 slides that finally convinced Boris Johnson about global warming (Carbon Brief)
[5] Can we predict global climate tipping points? (Metamodel.blog)
[6] MPs to get scientific briefing on climate after activist's hunger strike (The Guardian)
[7] When Negotiating a Price, Never Bid with a Round Number (Harvard Business School)

Established metrics are hard to dislodge even if they become counterproductive.[8] Hence this longish blog post.

**Evaluating climate models**

Much of our intuition about evaluating predictive models comes from simulations of precedented events occurring in relatively simple models. Global warming is an unprecedented event occurring in a highly complex system with many interacting components. By definition, our past prediction experience will be of limited use in characterizing unverifiable long-term predictions of an unprecedented event. We will need to reason from basic scientific principles to understand how best to do that. Here are some issues to consider:

*Global-average-temperature-centric thinking*: Global average temperature is an important and useful measure to study climate change, but it is not the only metric that's important. Climate impacts are determined by regional temperatures and rainfall, not the global average temperature. For example, a model could overestimate warming in the Northern Hemisphere and underestimate it in the Southern Hemisphere, but still end up with a small error in the global average. Such a model would be less useful than one that had the same global error uniformly, but would be weighted the same by a global-average metric. Similarly, a model that simulates the trends temperature well but not the trends in rainfall would also be less useful.

*Model tuning and linear thinking*: A climate model operates on a fairly coarse spatial grid, typically about 100x100 km (60x60 miles) in the horizontal, which cannot represent important processes like cloud formation. Approximate formulas, known as parameterizations, are used to represent clouds in models. The parameterizations have coefficients that are adjusted to make the simulations better fit observations – a process known as model tuning.[9] Often tuning is done explicitly, with varying degrees of effort and success, but sometimes it is implicit in the history of the modeling effort.[10]

It is commonly assumed that a model that simulates the recent observed global warming trend better should also be trusted make a more reliable prediction of the future trend. Strictly speaking, that is only true for linear models, where nonlinear interactions among different components are not important. Prediction models used in many fields, such as regression models, fall into this category of linear models. For nonlinear models that have been tuned to simulate spatially averaged quantities, there is an ambiguity when using the same averaged quantities for validation. We cannot be sure whether we are validating the fundamental accuracy of the representation of processes like clouds, or simply validating the efficacy of the tuning process.

Tuning is often described as model calibration. In simple models with few adjustable coefficients, the tuning process can estimate the "best" values of the unknown coefficients for each process, thus calibrating the model. In a complex nonlinear system with many adjustable coefficients, coefficients for one process may end up getting adjusted to cancel errors associated with a different process. Instead of calibration, we get compensating errors. The more averaged a tuning target is, the worse this problem.[11]

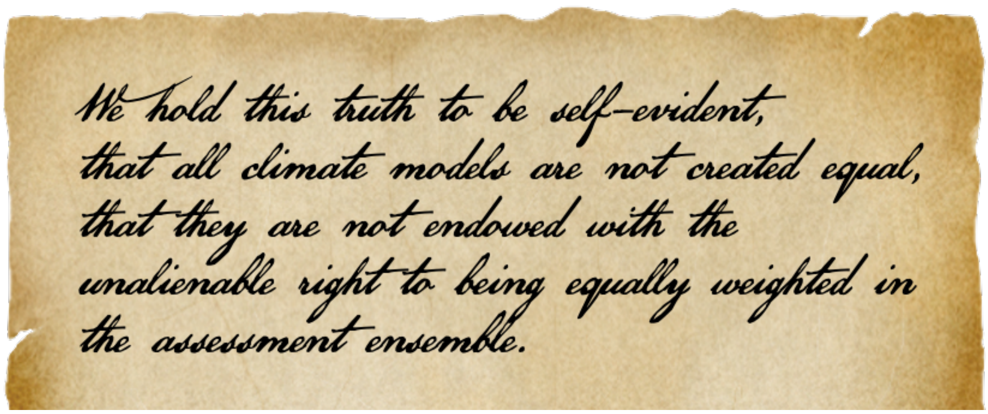
Consider a climate model with a poor cloud parameterization. This parameterization can have many well-adjusted coefficients tuned to compensate for errors in other components, enabling the climate model to simulate recent short-term warming well.[12] This simulation may even appear better than one using a more scientifically-sound, but less adjustable, cloud parameterization. But the long-term climate

[8] Why Intelligent Minds Like Elon Musk Embrace the Science-Backed No Round Numbers Rule of Negotiating (Inc.com)
[9] Sixth Assessment Report (IPCC)
[10] CDF collaboration at Fermilab announces most precise ever measurement of W boson mass to be in tension with the Standard Model (Fermilab)
[11] 1m, 1.5m, 2m — the different levels of social distancing countries are following amid Covid (ThePrint.in)
[12] Two meters? One meter plus? Social distancing rules prompt fierce debate in U.K. (Washington Post)

prediction using the poor parameterization can become less reliable, because the error compensation provided by the tuning is not guaranteed to be valid in a different climate.

Model tuning can definitely be beneficial in improving the fidelity of short-term (multidecadal) warming predictions of a model. But being able to tune parameterizations to *adequately simulate* recent warming should be considered a *necessary condition* for a good model rather than a *sufficient condition*.[13] There needs to be enough wiggle room in the definition of "adequately simulate" to allow a model with better parameterizations, but less successful tuning, to be considered acceptable.

**Declaration of Meritocracy**




With the increase in the number and complexity of climate models, the spread in their predictions has increased. Therefore, it makes sense to validate them carefully before using them for climate assessments. By assigning weights to model in AR6, the IPCC has thrown down the gauntlet on the notion of model democracy or treating all models as equal. [14] How do we transition to a model meritocracy?

It is easy to find fault with the scalar weighting metric used by the IPCC, but it will require a lot of constructive discussion to come up with more general merit criteria for models. It will be a challenge to keep the merit criteria simple enough for wide adoption but at the same time comprehensive enough to cover important aspects of the model. One option is a multifaceted threshold approach, where minimum benchmarks must be met in multiple metrics for a model to be considered acceptable. This may be better than a weighting approach because it won't incentivize overtuning (or overfitting) a model.

To return to the college admissions analogy, "teaching to the test" would be more acceptable if the test were broad enough and evaluated a range of skills. Using a single metric for assessing merit – like the ability to simulate the recent warming trend in global average temperature – is rather like buying a used car after a short test drive without looking under the hood. A well-tuned car will drive more smoothly, but will it also be reliable in the long haul? A thorough validation would require a mechanic to check engine parts under the hood of the car. A car that rattles a bit more during the test drive could still turn out to have more reliable parts under the hood and make for a better long-term purchase.

## Comments

*Note:* For updated comments, see the original blog post and the anouncement tweet.

- *R Saravanan*:

[13] Why protesters should be wary of '12 years to climate breakdown' rhetoric (oxfordmartin.ox.ac.uk)
[14] The Razor's Edge of A Warming World (GQ)

Not surprisingly, this post has attracted the attention of some who do not consider climate change to be a serious threat. Here's what the About page of this blog says:
Climate models are the essential tools used by IPCC to assess our climate futures and guide mitigation and adaptation. As a climate scientist who has worked with many different models over decades, I am keenly aware of their strengths as well as their limitations. This blog will critically examine climate and other models. The purpose is not to diminish the seriousness of the threat of climate change, but to increase the efficacy of the urgent actions needed to mitigate it.

- *Jim White*:
  As The Yogi said: «Predicting is very hard, especially about the future.»

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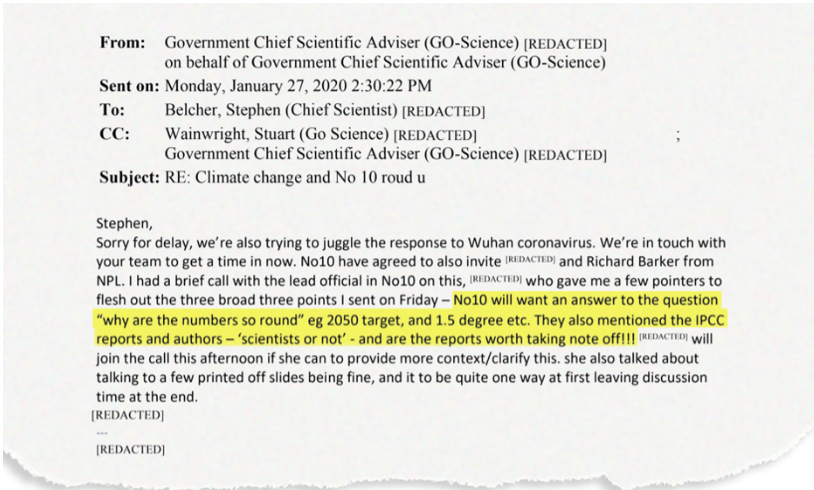
## Why are the (climate) numbers so round?

*Climate target numbers are approximate. Their roundness reflects that.*

2022-05-24


**Note to non-UK readers**: *No. 10, Downing Street is the official residence of the UK Prime Minister (like 1600 Pennsylvania Avenue for the US President). No. 11, Downing Street is the official residence of the Chancellor of the Exchequer, often considered the second-most powerful position (rather like the Vice President in the US, but with specific responsibilities similar to the Treasury Secretary).*



**From:** Government Chief Scientific Adviser (GO-Science) [REDACTED]
on behalf of Government Chief Scientific Adviser (GO-Science)
**Sent on:** Monday, January 27, 2020 2:30:22 PM
**To:** Belcher, Stephen (Chief Scientist) [REDACTED]
**CC:** Wainwright, Stuart (Go Science) [REDACTED] ;
Government Chief Scientific Adviser (GO-Science) [REDACTED]
**Subject:** RE: Climate change and No 10 roud u

Stephen,
Sorry for delay, we're also trying to juggle the response to Wuhan coronavirus. We're in touch with your team to get a time in now. No10 have agreed to also invite [REDACTED] and Richard Barker from NPL. I had a brief call with the lead official in No10 on this, [REDACTED] who gave me a few pointers to flesh out the three broad three points I sent on Friday – No10 will want an answer to the question "why are the numbers so round" eg 2050 target, and 1.5 degree etc. They also mentioned the IPCC reports and authors – 'scientists or not' - and are the reports worth taking note off!!! [REDACTED] will join the call this afternoon if she can to provide more context/clarify this. she also talked about talking to a few printed off slides being fine, and it to be quite one way at first leaving discussion time at the end.
[REDACTED]
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[REDACTED]

**Figure 1.** From *The 11 slides that finally convinced Boris Johnson about global warming* CarbonBrief.org

**From:** Metamodel.blog
**To:** No. 10, Downing Street, London
**Date:** Tuesday, May 24, 2022
**Subject:** Why are the numbers so round?

Dear No. 10,

I read with interest the article about the scientific briefing on climate that changed your mind about global warming.[15] The briefing underscores the importance of making science accessible to decision makers. One email leading up to that pivotal briefing includes an interesting nugget of a question (Figure 1). You asked, "why are the numbers so round", referring to the 2050 target year, 1.5 degree warming, etc.? That is indeed an excellent question, appropriately coming from someone who lives in a house numbered 10.

Like a politician who wants to move into 10 Downing Street but ends up at 11 instead, shooting past round numerical targets has been the subject of much discussion after the recently released IPCC climate report. Are we likely to overshoot the global warming target of 1.5°C or the net-zero target date of 2050? If the warming ends up being 1.6 or 1.7°C or net-zero is reached 5-10 years later, would climate cross a tipping point?[16] As there appears to be another UK climate change briefing in the offing,[17] this letter attempts to explain the "roundness" of climate numbers.

The sentence in that email snippet above that follows your "roundness" question suggests you are not sure if actual scientists wrote the IPCC reports. Rest assured that scientists were involved in writing the IPCC reports and coming up with the climate numbers. The roundness of the numbers is itself perhaps proof of that. In business, it is considered good practice to add false precision as a negotiating tactic: "if one party gives a round number, it gives the signal that the party doesn't really know what it's doing."[18] For example, faux precision is one explanation why Elon Musk offered to buy Twitter at $54.20 a share, instead of $54 or $55 a share.[19] But scientists aren't businessmen. When scientific thresholds are approximate, it is normal to round the numbers up or down, to avoid giving a sense of false precision and to make them memorable.

[15] Revealed: The 11 slides that finally convinced Boris Johnson about global warming (Carbon Brief)
[16] Can we predict global climate tipping points? (Metamodel.blog)
[17] MPs to get scientific briefing on climate after activist's hunger strike (The Guardian)
[18] When Negotiating a Price, Never Bid with a Round Number (Harvard Business School)
[19] Why Intelligent Minds Like Elon Musk Embrace the Science-Backed No Round Numbers Rule of Negotiating (Inc.com)

Scientists have determined that the trapping of heat by increasing concentration of carbon dioxide and other atmospheric gases (known as greenhouse gases) is responsible for the global warming that is happening.[20] Burning of fossil fuels used in transportation, power generation, and other human activities is increasing the concentration of these gases. As the globe warms, the climate changes from what we are used to, leading to harmful impacts like more heatwaves, intense rainfall events, and rising sea levels. We need to reduce the emission of the greenhouse gases to zero as soon as possible to stop further warming. The current goal is to eliminate carbon emissions by 2050, and to keep the warming below 1.5°C.

You are right to wonder if 1.5 degrees sounds too round to be a scientific constant. Fundamental science constants typically have more digits in them. For example, the current hot controversy in fundamental physics is over whether the mass of the W boson is 80,357 MeV/c2 or 80,433 MeV/c2.[21] Whatever the correct value of that physics number, it will not affect government policy. Round climate numbers like 1.5 or 2.0, on the other hand, are quite important for policy even if they lack the exactitude of fundamental physical constants. They are inexact because climate is a highly complex system with many interacting physical, chemical, biological, and human components.

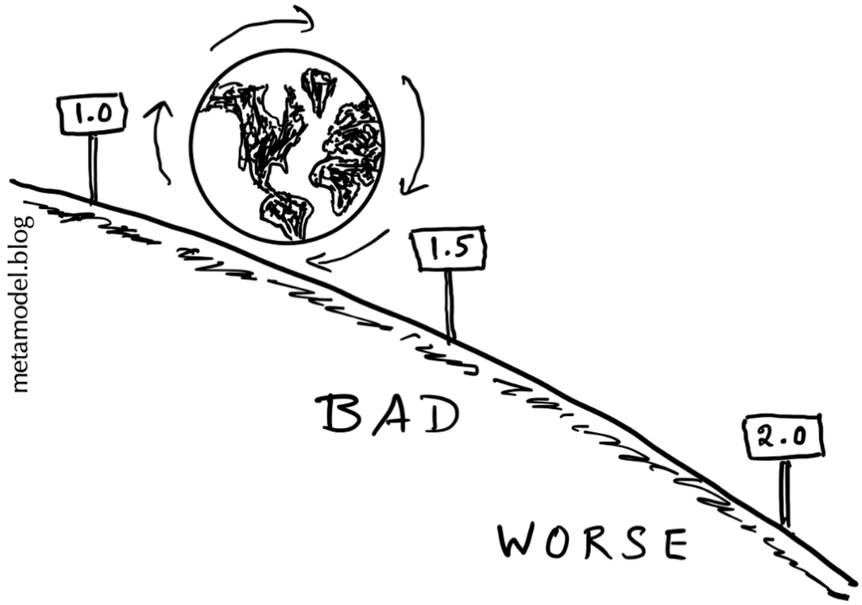
An example of a useful round number is the recommended social distancing threshold for Covid avoidance.[22] The World Health Organization recommends 1 meter distancing, and several countries follow that stringent recommendation. But some other countries recommend 1.5 meter distancing, the US recommends 1.8 meters (6 feet) and the UK recommends 2 meters.

Which is the correct number for social distancing? The answer would be "the largest practical one." The greater the social distancing, the lesser the health risk. Different numbers reflect the different risk tolerances, and different length units in the different countries.[23] Some people take the Covid distancing thresholds literally, believing that their risk of catching Covid increases dramatically if they cross this threshold even slightly. But many other factors, such as the ventilation and mask efficacy, can have a larger impact on the risk of catching Covid than social distancing.

Although social distancing illustrates the unit-dependence of thresholds, it is not the best analogy for climate thresholds. Because of the nonlinearity of climate impacts, the difference in harm between 1.5 and 2 degrees of global warming is far greater than that between 1.5 and 2 meters of social distancing. Every half degree of warming matters,[24] and many more regions will face serious harm as local warming thresholds are crossed.[25]

A better analogy for a climate threshold is your doctor telling you to keep your bad cholesterol level below 4.0 mmol/L (about 160 mg/dL in the US),[26] rather than keep it below a threshold with more digits of precision, say, 4.123. There is no health "tipping point" that is triggered if you "overshoot". You are unlikely to suffer a heart attack immediately if your bad cholesterol rises slightly above 4.0, but your risk will increase. If the average cholesterol level of the whole population increases, the number of cardiac disease-related deaths will increase rapidly.

[20] Sixth Assessment Report (IPCC)
[21] CDF collaboration at Fermilab announces most precise ever measurement of W boson mass to be in tension with the Standard Model (Fermilab)
[22] 1m, 1.5m, 2m — the different levels of social distancing countries are following amid Covid (ThePrint.in)
[23] Two meters? One meter plus? Social distancing rules prompt fierce debate in U.K. (Washington Post)
[24] Why protesters should be wary of '12 years to climate breakdown' rhetoric (oxfordmartin.ox.ac.uk)
[25] The Razor's Edge of A Warming World (GQ)
[26] Cholesterol test (Mayo Clinic)




The globe has already warmed 1.2°C above pre-industrial levels.[27] Our predictions are that the Earth's climate is currently barreling down the slope of ever worsening climate impacts rather than headed towards a cliff at 1.5°C (or 2.0°C).[28] The secret to success in climate mitigation, as it is in life, is to set challenging but achievable goals. A few years ago, 1.5°C appeared to be far enough in the future to serve as an achievable target for stabilizing global temperature, if aggressive steps to mitigate emissions were started immediately. It appears less achievable now, although exceeding the target in a single year is less worrying than the exceeding it in long term.[29]

The roundness of the warming targets depends upon the temperature scale. Those who live outside the United States surely know that water boils at 100°C, a rather round number. That's because the Celsius scale is defined that way. Water freezes at an even rounder 0°C. Again, that is because of the definition of the Celsius scale. These two scientific numbers completely define the temperature scale. *This means that no other scientific temperature numbers can be truly round — except by coincidence or because of rounding.*

On the Fahrenheit scale, the two commonly discussed warming thresholds, 1.5°C and 2°C, would correspond to 2.7 and 3.6°F respectively. In an alternate universe where everyone used the Fahrenheit scale, we might have chosen rounded warming targets of 3.0°F (1.67oC) or 3.5°F (and this letter might be addressed to 1600 Pennsylvania Avenue instead).

We should work hard – starting now – to keep global warming below our chosen target, be it 1.5°C or 2.0°C, or something in-between. But if we overshoot by a small fraction of a degree, the world will not end. Global warming thresholds should be taken **seriously, but not literally**.

## An even rounder target: net-zero

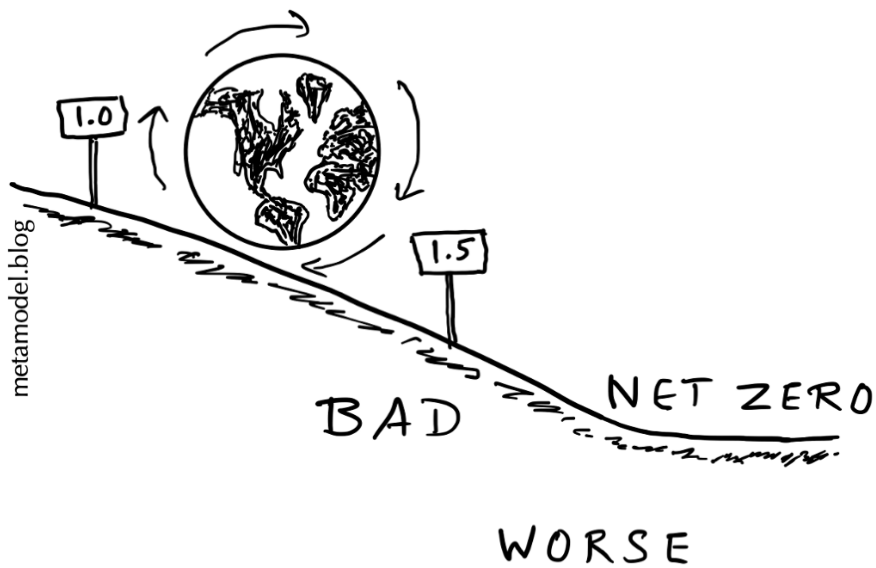
What about another very round number, net-zero, or reducing carbon dioxide emissions to zero? Why is the zero-emission target more appropriate than a target of, say, 3 Gigatons per year or -3 Gigatons

[27] How close are we to reaching a global warming of 1.5°C? (ECMWF/Copernicus)
[28] Thinking about Climate on a Dark, Dismal Morning (Scientific American)
[29] Climate limit of 1.5C close to being broken, scientists warn (The Guardian)

per year? (For reference, current fossil-sourced carbon dioxide emissions are about 36 Gigatons per year.) The roundness of net-zero turns out to be coincidental.

Early climate mitigation research focused on keeping carbon dioxide concentrations constant, but that would have led to continued warming over centuries, until the ocean absorbed enough heat to reach equilibrium. This was referred to as "committed warming." Subsequent research showed that if we reduce carbon emissions to zero, the land and ocean will continue to absorb carbon dioxide and steadily lower its concentration.[30] Coincidentally, the cooling effect of this CO2 absorption roughly cancels the effect of continued ocean warming. This means that we can expect global temperatures to stabilize shortly after emissions go to zero. (Ideally, all carbon dioxide emissions should cease, but in practice some unavoidable positive emissions may need to be offset by yet-to-be-perfected negative emissions technology.)

To explain it better: If the Earth is like the human body, carbon emissions keep putting additional blankets on the body.[31] Land and ocean are continually removing about half of these extra blankets. The remaining extra blankets add to the warming of the body. If carbon emissions stop and the number of blankets stays constant, the warming will continue for several more minutes until the human body reaches a warmer equilibrium. In the case of climate, it would take several more centuries to reach the warmer equilibrium. But land and ocean will continue to remove the carbon dioxide blankets even after emissions stop, reducing the number of blankets. This permits temperature to reach equilibrium sooner — within a few seconds in the case of the human body and within a few decades for the climate system.




If it were not for the coincidental cancellation between atmospheric carbon dioxide reduction and ocean heat uptake, we would have a less round (and non-zero) emissions target to stabilize global temperature. Alternatively, we may have had to choose a non-zero rate of warming as a practical mitigation target. Note that because of the uncertainty in climate and carbon cycle models, we cannot be absolutely sure that net-zero emissions will stabilize temperatures exactly:[32] Global temperatures

[30] Stabilizing climate requires near-zero emissions (Geophysical Research Letters)

[31] The actual greenhouse effect is more complicated than this, due to the shortwave feedback. See The Greenhouse Effect (And Then There's Physics)

[32] Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO2 (Biogeosciences)

may still trend upward slightly when we reach net-zero, or possibly trend down a bit, if the uncertainty works in our favor.

The year 2050 is the notional target for reaching net-zero. It was chosen for practical (and political) reasons based on assessments of how quickly emission reductions could be achieved. If we can reach net-zero by 2040 or 2045, all the better. What if we only reach net-zero by 2055 or 2060? We'll then have to bear the increasingly harmful impacts of the continued warming, but we aren't likely to cross a global climate tipping point.

Sincerely,

*metamodel.blog*

## Comments

*Note:* For updated comments, see the original blog post and the anouncement tweet.

- *Chris Wells*:
  Interesting, thought-provoking piece! Think this issue highlights the unavoidable connection between climate science and wider society, as well as the inherent trade-offs in different types of mitigation – and hence the need for a holistic overview contained in 1 (or a handful of) round number.
  Worth noting not everyone agrees Elon Musk is an «Intelligent Mind», and that his precise bid was likely influenced by other factors... https://www.nytimes.com/2022/04/14/business/e...

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