Strange weather in the multiverse of climate

Metamodel.blog/R. Saravanan

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We cannot predict our weather universe but we can choose our emission multiverse

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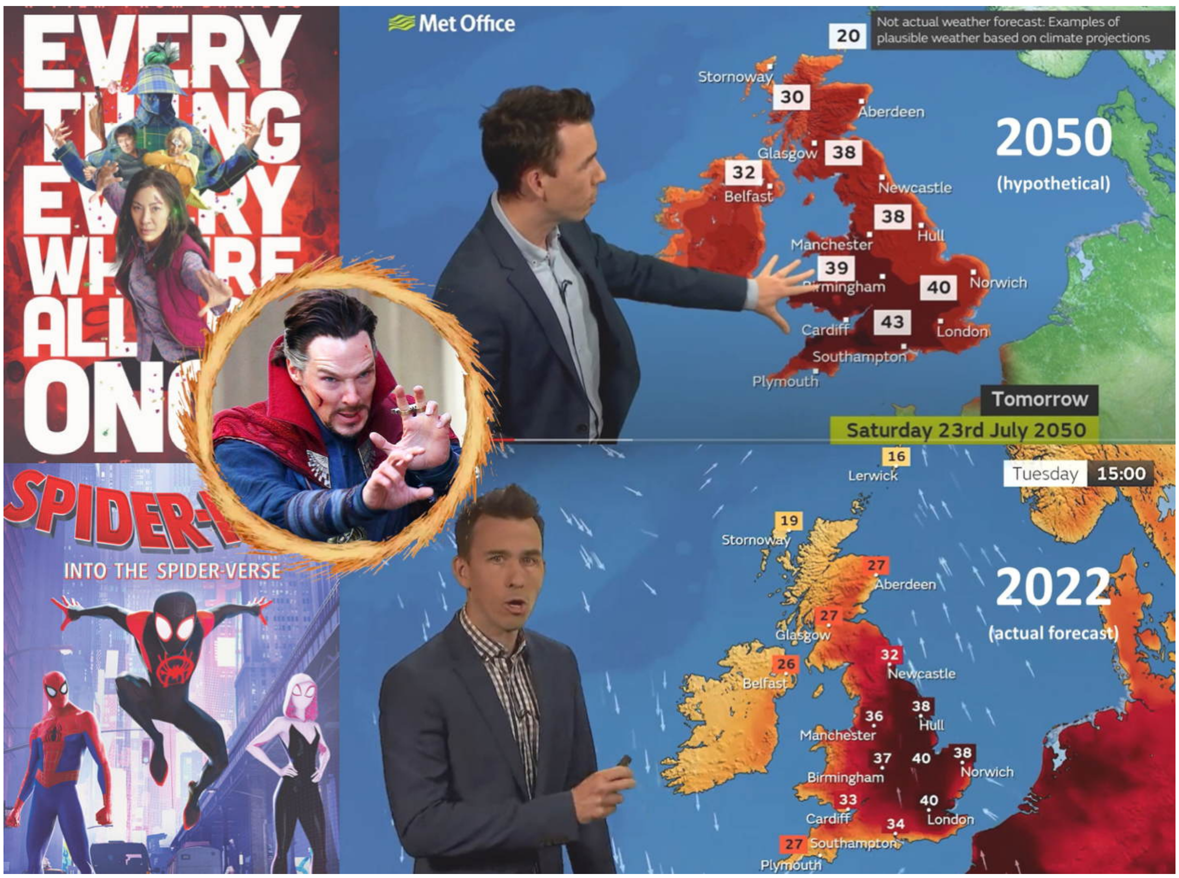

Imagine that our universe is just one slice of bread in the grand cosmic loaf of the multiverse.[1] That's a popular description of the physics concept of the multiverse. But the multiverse is not considered essential for everyday applications of physics, even if it makes for good pop-sci narratives. If one were to use Occam's Razor to slice up the multiverse loaf, one could even argue that the concept of the multiverse adds unnecessary complexity.

[1] A Physicist Explains Why Parallel Universes May Exist (NPR.org)

Although it may be speculative in physics, the multiverse can be quite useful in understanding climate prediction. We usually define climate as the time average of weather, typically over thirty years or so. When climate itself is changing over that period, this definition becomes less useful. Enter the multiverse.

Imagine that our weather universe is just one slice of bread in the grand loaf of the climate multiverse. The same weather events—like heat waves or hurricanes—occur across the multiverse, but in a different order in each weather universe. We can then define climate as the average across the multiverse. As climate changes over time, the multiverse average also changes.[2] We cannot predict which weather universe we will live in, but we can try to predict the average properties of the multiverse we will live in. This is a complex scientific concept that is often hard to explain to a lay audience. Thankfully, the slew of recent movies about the multiverse, or multiple versions of the universe, may make it easier.

Although other sci-fi movies have relied on the multiverse before,[3] *Spiderman: Into the Spider-Verse* was the first to use it in its title. If you are into Marvel blockbusters, watching *Spiderman: No Way Home* or *Dr. Strange and the Multiverse of Madness* is good preparation for this blog post about the climate multiverse. If you prefer something more arty (or downright weird), then surviving a viewing of *Everything Everywhere All at Once* may be even better preparation. (After all, climate models have been described as trying to predict everything everywhere all at once.[4])

Not appreciating the multiverse aspect of climate prediction can lead to confusion about the impact of climate change on extreme weather. In July 2022, Britain experienced unprecedented heat waves, with temperatures exceeding 40°C in some locations. Ironically, in 2020, the UK Met(eorological) Office had predicted a similar heat wave as hypothetically occurring in July 2050, using computer models, as part its forecasts from the future program (Figure 1).[5] Does the fact that such a strong heat wave occurred 28 years earlier than "predicted" mean that our climate models are underpredicting the severity of climate change? That is indeed one possible explanation. But there is an alternative explanation—and that involves the multiverse.

[2] In normal climate terminology, we refer to the multiverse as the *ensemble*. We refer to individual universes as *members* of the ensemble. When the climate isn't changing, the time average is equivalent to the ensemble average, according to the ergodic hypothesis. In a changing climate, that is no longer the case.

[3] 14 movies and shows about the multiverse, from 'Spider-Man: No Way Home' to 'Everything Everywhere All at Once' (BusinessInsider.com)

[4] Three reasons why climate change models are our best hope for understanding the future (TheConversation.com)

[5] How we make our 2050 'forecasts', and why we do them (Uk Met Office)

Figure 1 *Top panel shows a hypothetical heat wave forecast for 23 July 2050 (as simulated on a model) that was published in 2020 by the UK Met Office. Bottom panel shows the actual heat wave forecast for 19 July 2022.* [From a tweet][6]

1.1 A multitude of multiverses

If we had a perfect model of the universe and perfect knowledge of its current state, could we predict the future perfectly? Philosophers once believed this was possible, and they named the super-intellect that could make such a prediction as Laplace's De-

[6]In 2020, the @metoffice produced a hypothetical weather forecast for 23 July 2050 based on UK climate projections. Today, the forecast for Tuesday is shockingly almost identical for large parts of the country. [Tweet by @SimonLeeWx](https://twitter.com/SimonLeeWx/status/1547957062000267267) (Twitter)

mon.[7] Laplace's Demon could predict the future of our single universe, and there would be no need to invoke the multiverse. However, quantum uncertainty and classical chaos dashed the prospects of there being a Laplace's Demon, opening the door to the multiverse of predictions.

We only have imperfect models of a subset of the universe, called climate models, and we can never measure the current state of the climate perfectly. Therefore, we can never predict the future perfectly. To account for our imperfect knowledge, we predict the future of a multiverse, rather than our single real universe. The hope is that the set of future predicted universes, the predicted multiverse, includes the future of our real universe.

In climate prediction, we deal with three types of multiverses (Figure 2). The first type is the *weather multiverse*. Since we do not know the initial climate state perfectly, we carry out predictions for several slightly different initial states. Due to the Butterfly Effect of chaos, even minor differences in the initial state will lead to completely different weather conditions after a few weeks, generating the weather multiverse.

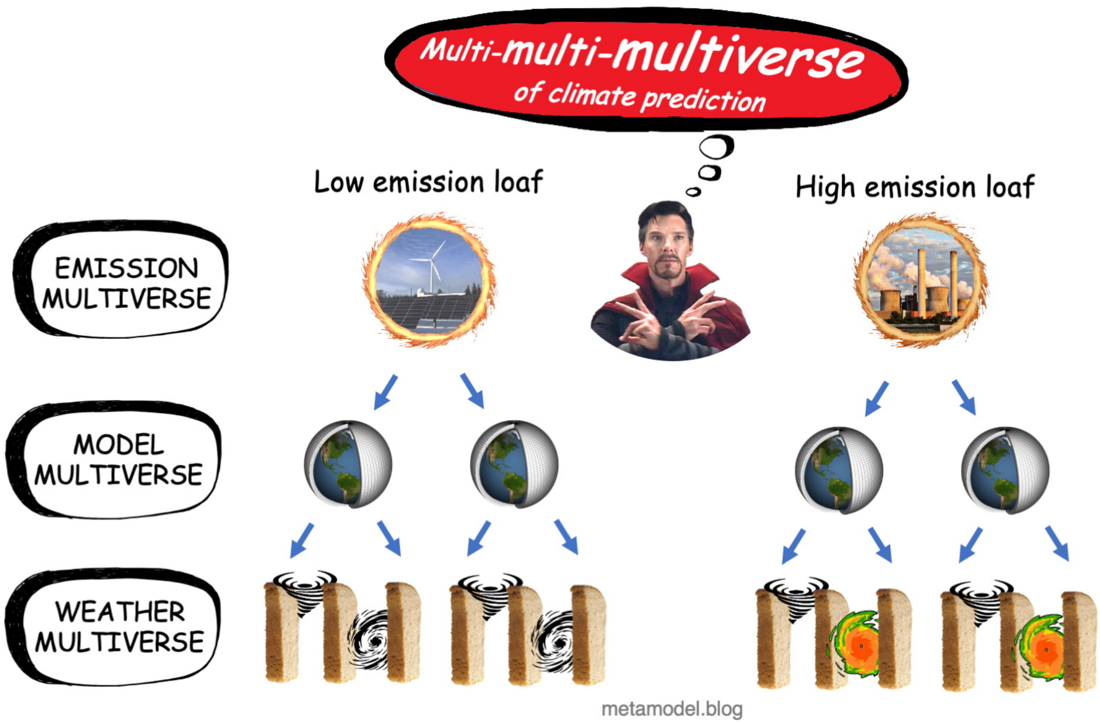

Figure 2 *Three types of multiverses in climate prediction. The bread slices at the bottom represent different predicted universes with random sequences of weather events. Assuming our models are good, the real universe will be one of those slices, but we can never tell exactly which one. By controlling emissions, we select the loaf that the slice will be chosen from. (The color of the hurricane graphic in the high emission loaf indicates that some weather events will be stronger in a warmer world.)*

Say we make a prediction starting from 2020 using a climate model. One predicted universe may have an extreme heat wave (with 40°C temperatures) occurring in July 2050, but another predicted universe may have it occurring in July 2022 (Figure 1). If we simulate only a few predicted universes, then we may miss out on the one where the

[7] Ch.2, The Climate Demon: Past, Present, and Future of Climate Prediction (ClimateDemon.com)

heat wave occurs earlier. This could explain why the UK Met Office made a hypothetical prediction of the extreme heat wave in July 2050, but a real event occurred much earlier. The larger the weather multiverse, the more likely that it includes the real universe. It has been estimated that we may need 50 or more universes in the weather multiverse to adequately span the range of weather variations.[8]

There can be another reason the extreme heat wave occurred earlier in the real universe than in the predicted multiverse. If the climate model is imperfect, and tends to systematically underpredict the warming, then even a larger multiverse may not capture the extreme heat waves. To handle model imperfections, we need another type of multiverse, and we can call it the *model multiverse*. We construct several climate models, each with somewhat different structures for scientific equations. The expectation is that while some models may underpredict the warming, others will overpredict it to compensate. For example, one model may predict that the Arctic will be ice free by 2050 whereas another may predict slower Arctic ice loss. We carry out predictions with different climate models to generate the model multiverse.

There is the need to invoke yet another multiverse type. Our climate models represent just a subset of the universe, because they predict only the physical, chemical and biological aspects of the climate system using scientific equations. But the rest of the universe also affects climate. This includes human activities resulting in carbon emissions. There are no scientific equations to predict human actions a century into the future. So we simply make different sets of plausible assumptions, called *scenarios*, about how humans may behave in the future and then calculate the resulting carbon emissions. Thus we generate the *emission multiverse*, where we predict the future for different carbon emission scenarios.

To top it all, the three types of multiverse are not additive; they are multiplicative (Figure 2). Say there are 50 universes in the weather multiverse, corresponding to different initial states. We may have 20 different equation structures in the model multiverse. We may choose 4 scenarios for the emission multiverse. This means that all the loaves in the grand multi-multi-multiverse of climate will have a total of $50 \times 20 \times 4 = 4000$ slices, each corresponding to a different predicted universe!

1.2 Risk assessment and the multiverse

To properly assess climate risk, we need to consider all three types of multiverses. This can be quite complicated, rather like a cross between the multilayered plot of the movie *Inception* and the multiverse plot of *Everything everywhere all at once*.

Quantitative risk assessment requires assigning probabilities to each universe in a multiverse. For the weather multiverse, we can assume an equal probability or likelihood for each universe, because the memory of the initial state is quickly lost and the distribution becomes random. That’s why impact risk assessment using past weather data can be quite accurate up to a decade or so, when climate change effects are still small. We don’t need to consider different emission scenarios because the scenarios would not yet have diverged sufficiently. We may still need to consider different models, but global model errors would still be small because they haven’t yet had time to build up.

Beyond a few decades, risk assessment gets more complicated because the different emission scenarios diverge and global model errors build up. *Purely probabilistic assessment of risk is no longer possible*, because we cannot assign objective probabilities

[8] How large does a large ensemble need to be? (S. Milinski et al., 2020; Earth System Dynamics)

to the different model or emission multiverses.

For model differences, we can assess the spread of among the models but we cannot assign a specific likelihood to a model universe that is appropriate for all predicted variables. For emissions, we can consider the worst-case scenario, the best-case scenario, and a few scenarios in between. Risk assessments frequently consider just a single, typically the worst-case, emission scenario rather than the full emission multiverse. This can be misleading because it could lead to the worst-case scenario being treated as the most likely scenario, by default.

Often, risk assessments ignore the weather multiverse, even though it is usually the largest of the three multiverses, because it is not important for predicting global average temperature.[9] But accurate risk assessment requires consideration of regional climate change, not just the global averages. Models also continue to exhibit large errors in their simulation of regional climate, underscoring the need for a sufficiently large model multiverse to assess uncertainty. Trimming (or ignoring) the weather/model multiverse types can lead to underestimation of the spread in risk, especially for climate impacts that depend nonlinearly on temperature or rainfall.

1.3 Extreme weather in the multiverse

In recent years, it has become increasingly common to attribute individual extreme and unprecedented weather events, such as heat waves, cold spells, droughts, floods, or hurricanes, to climate change. How do we scientifically make this attribution? To answer that, we need to consider not just whether the event is extreme or unprecedented in our weather universe, but also whether it is so in the multiverse.

Consider five simulated weather universes for the period 1950—2100 using a single climate model for a high emission scenario. Figure 3 shows the predicted occurrence of extreme hot days in Dallas, Texas, during the month of July. We see that the likelihood of extreme hot days increases as global warming continues unabated, but their occurrence is quite irregular among the different universes. Inhabitants in the top universe may be less worried about climate change in 2022, because they experience fewer extreme hot days than inhabitants in the bottom weather universe, although both suffer the same amount of global warming.

[9] What to expect when you're expecting a better climate model (Metamodel.blog)

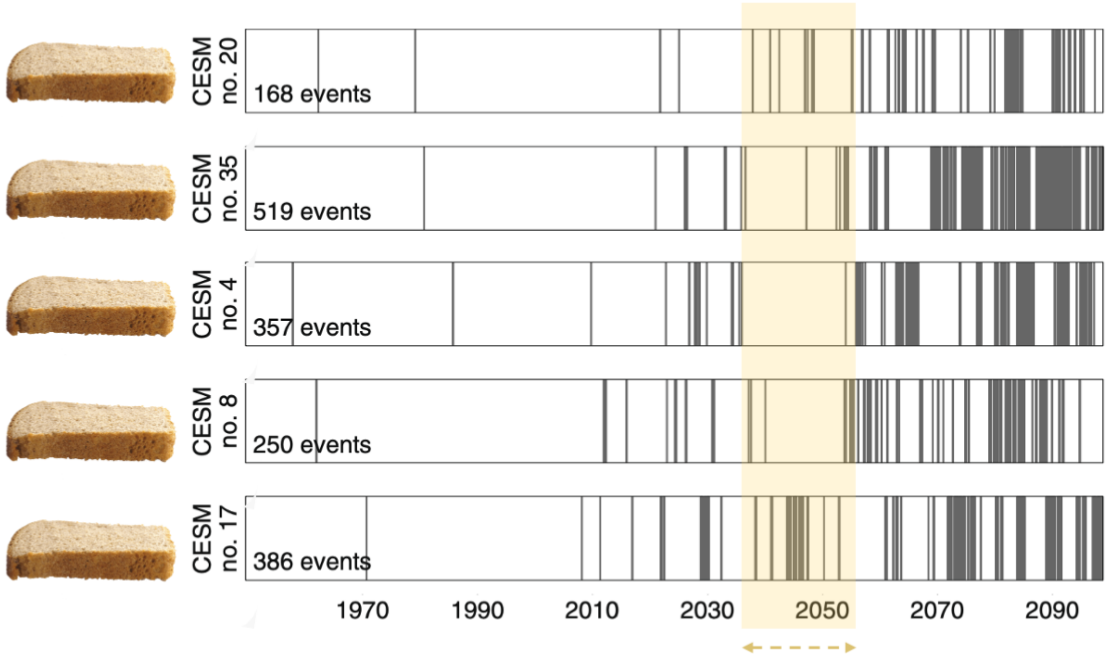

Figure 3 *Occurrence of extreme summer heat in the weather multiverse, with each bread slice denoting a single universe. Vertical bars mark the occurrence of July days that exceed the historical (1950–1999) 99.9th temperature percentile for the model grid box containing Dallas, Texas, in five simulated weather universes of the CESM climate model between 1950-2100, under a high emission scenario (RCP 8.5; now considered implausible). Lightly shaded region denotes the period 2035—2055. (Note that exceeding the monthly 99.9th percentile is roughly a one-in-30-year event before 2000 but happens more frequently later.)* [Adapted from Deser et al., 2020][10]

Note that even a decade from now, between 2035—2055, the middle universe experiences few extreme hot days (Figure 3), which could lead its inhabitants to conclude that global warming isn't affecting Dallas. But the inhabitants of the bottom universe, which experiences many extreme hot days, would draw a different conclusion. This underscores how the randomness of weather can dominate locally, even as the average temperature warms globally.

The rareness and irregularity of extreme events, as illustrated in Figure 3, means that we should carry out careful statistical and modeling analysis before reaching conclusions about the relationship between global warming and local weather. We should not just rely on our personal intuition or experience to draw such conclusions.

There is an international organization of scientists, the *World Weather Attribution* (WWA), that carefully analyzes extreme weather events. The WWA has concluded that global warming makes all heat waves more frequent, as was indeed the case with the 2022 UK heat wave.[11] Rainfall is also becoming more intense, although it is often harder to quantify exactly by how much. For some other types of extreme events, such as droughts, climate change may not always be a major factor.

[10] Insights from Earth system model initial-condition large ensembles and future prospects. (C. Deser et al., 2020; Nature Climate Change)

[11] Without human-caused climate change temperatures of 40°C in the UK would have been extremely unlikely (WorldWeatherAttribution.org)

Climate change did not significantly affect the 2021 drought in Southern Madagascar, according to the WWA, even though some media headlines claimed otherwise.[12] Extreme cold spells are also frequently blamed on climate change, even though the scientific argument for changes in the polar vortex amplifying cold spells is far from settled.

Global warming makes many extreme weather events more frequent and intense. Drawing public attention to climate change by linking it to extreme weather is therefore a good thing. But just as we shouldn't consume too much of a good thing like sugar, we should also be wary of "overattribution" of extreme weather. Reflexively and dramatically blaming every weather-related disaster on climate change can have negative consequences like amplifying climate anxiety and climate fatalism. Attributing disasters primarily to global warming can also divert attention from other, more easily fixable, local socioeconomic vulnerabilities that amplify those disasters.[13] For example, blaming climate change for flooding events can detract from a history of poor urban planning.

To make proper attribution, we need to determine scientifically if an extreme weather event, say event X occurring in 2022, was *significantly* affected by climate change. For unprecedented extreme events, we lack sufficient data to statistically analyze past events similar to X. Therefore, we have to use models. We use one or more climate models to generate two weather multiverses from 1850 to 2022: 1. A *factual weather multiverse* where greenhouse gases increased to their current concentrations from their 1850 pre-industrial values. This multiverse experiences global warming, as recorded in the historical data. 2. A *counter-factual weather multiverse* where we go back in time to 1850 and deliberately hold greenhouse gas concentrations fixed at their pre-industrial values. This multiverse experiences no global warming.

For each weather multiverse, for the year 2022, we count the number of times events similar to event X have occurred in the different universes. If the factual multiverse has many more events similar to X than the counter-factual one with the manipulated timeline, then we can blame global warming for its more frequent occurrence. The larger our multiverse populations and the better our climate models, the more accurately we can assign such blame. (Assigning blame for heat waves is easier than assigning blame for floods or droughts, because models are much better at predicting temperature changes than rainfall changes.)

1.4 Fate and free will in the multiverse

Climate prediction is extremely complex. It differs greatly from many simpler kinds of prediction that you may be familiar with from other disciplines. The pop culture notion of the multiverse allows us to illustrate this complexity, which is often glossed over by those predicting inevitable climate doom with certainty. Predictions with such fateful certainty can only happen in a simplified model universe that does not really belong in the multiverse of comprehensive models.

If you are a decision maker and someone presents you with predictions of future climate or assessments of climate risk, it is worth asking how they handled the three multiverse types. Hopefully, a better understanding of the climate multiverse can help you make more informed decisions in tackling the serious and urgent threat of climate change.

[12] Factors other than climate change are the main drivers of recent food insecurity in Southern Madagascar (WorldWeatherAttribution.org)

[13] Stop blaming the climate for disasters (E. Raju et al., 2022; Communications Earth & Environment), Politics of attributing extreme events and disasters to climate change (M. Lahsen and J. Ribot, 2021; WIREs Climate Change), and It's Not Just Climate: Are We Ignoring Other Causes of Disasters? (Yale Environment 360)

We don't have the superpower to choose which weather universe we will live in, because the dice roll of fate makes that choice. We have some power to trim the model multiverse with more research, but progress is not guaranteed.[14] We do have the superpower (i.e., free will) to control which emission multiverse we will live in. If we act to reduce emissions quickly, we will end up with a slightly warmer multiverse with fewer extreme heat waves and heavy rainfall events. If not, we will end up with a much warmer multiverse with many more (and stronger) such events.

1.5 Comments

Note: For updated comments, see the original blog post.

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[14] What to expect when you're expecting a better climate model (Metamodel.blog)