FROM CHAT

Mo Sami: Please correct me if I'm wrong... I think of "weather" as the mood; and the "climate" as the personality. So, in addition to time, context matters too? Right?

> *I like it. Speaking of mood, the late Wally Broecker famously said that climate is an angry beast, and we are poking it with sticks. https://www.nature.com/articles/d41586-019-00993-2 Do with that as you like.*

Caroline Ward: What is the effect of Methane (is it similar to CO2)?

> *Yes, in general. Like CO2, methane (CH4) is a greenhouse gas. It is a very effective absorber of "heat" (or longwave/infrared radiation) and, because of Kirchhoff's Law, it is also a very effective emitter of heat back toward the surface once it has absorbed some that is trying to escape to space. Anyway, methane is more potent than CO2, but is found in smaller concentrations than CO2. Right about now, the concentration of CH4 is only about 1900 parts per billion (c.f. 415 parts per million for CO2) but like I said, pound-for-pound, CH4 is more potent, so it is still very important. You can track methane, along with CO2 and other greenhouse gases including nitrous oxide here: https://gml.noaa.gov/ccgg/trends_ch4/*

LISA Thompson: As a nurse scientist studying air pollution, I am wondering if the climate models have included, over time, the attribution of particulate matter from simple cooking stoves (used by 40% of the global population) and the effect black carbon exerts on ice, both at the tropics but also transported to the poles via Hadley cells. At the same time, PM can cool the planet (like volcanic ash?) Question: what is the contribution of PM from these cooking fires on climate change, or anthropogenic sources?

> *Great question, Lisa. In general, climate models do include aerosols, but not at such a fine-grained detail level as "BC aerosols from cook stoves." It is more of a bulk quantity where everything up to volcanic eruptions are lumped into one distribution of aerosols over time. There is, as you point out, a cooling effect of aerosols in most cases, such as how volcanoes cause short-term dips in the global temperature trend. Interestingly, aerosols might even explain the slowdown of warming back in the 50s and 60s (dirty aerosol emissions), but this is still an active area of scientific investigation and debate.*

Stefan Wheat: Can you speak more to the role of oceans in absorbing this heat and how those changes may be impacting our ocean's currents?

> *Hi Stefan! Yes, the oceans have absorbed a substantial fraction of the excess heat being trapped in the climate system by greenhouse gases, but there's even more to it. The ocean plays a key role in mediating the response to this forcing for the entire climate system, including the atmosphere, and delivers some of the major impacts directly. The ocean has already absorbed some 30 percent of the anthropogenic CO2 emitted, which is a double-edged sword at the front lines of climate change. On one hand, that's 30 percent less CO2 remaining in the atmosphere, which at least temporarily dampens the level of greenhouse forcing. On the other hand, the CO2 entering the ocean has severe consequences for marine life (e.g., through ocean acidification). Thus, physical oceanography acts as something of a mediator between climatic change and the other various subdisciplines of oceanography, including marine biology and chemical (or biogeochemical) oceanography. Meanwhile, the ocean is also absorbing the majority of the excess heat trapped near the surface by greenhouse gases. Due to the great heat capacity of water, the ocean has served to slow the overall warming of the climate system as we humans feel it, but the upper ocean has indeed warmed and expanded. The more visceral consequences of climate change, such as rising seas and worsening tropical storms, are striking but still remain dependent on how much CO2 we decide to emit over the coming decades.*

Ronda Seifert: Looking at the amount of CO2 compared to previous deglaciations, we appear to be much higher, but we don't seem to be experiencing an equivalent 3-4 degrees C or so of temperature rise from pre-industrial average that those previous deglaciations had. What is the cause for that apparent delay in warming? And do you expect the warming to rapidly increase?

Absolutely. In short, there are natural delays built into the system. We know with certainty that if we stop emitting greenhouse gases like CO2 this very minute, the atmosphere will continue to warm for decades. It's baked in now. Also, you can't look at the glacial/deglacial cycles of CO2 and temperature and see the lag because the time resolution of those data are not sufficient. There were also other processes at play over the course of the glacial cycles – most importantly, they were driven by Milankovitch cycles (very slow changes in Earth's orbital geometry). The climate has feedbacks between temperature and CO2 that obfuscate the time lag between CO2 and temperature when you try to look for it there. See also my response to Stefan Wheat above about how the atmosphere is not the only thing that is warming.

Richard Champlin: In one sentence, what is the difference between weather and climate?

Hi Richard. I understand the appetite for such things, but not everything can be explained in one sentence, unless you are OK with being given an answer that merely tricks you into thinking you understand it but is actually incomplete or even worse—incorrect. I prefer not to trick you. Please bear with me. Weather vs. climate is an arbitrary distinction between variability in atmospheric conditions at different time scales. Shorter-term things (hours to maybe weeks), we tend to call weather. Longer-term variability (weeks to years to centuries and beyond) we tend to call climate. Where to draw the line between weather and climate is like deciding between "short" and "tall." It's a continuum.

Olivia Zhou: Why does greenhouse gas only affect energy going out, but not the radiation coming in?

The radiation coming in from the sun (a.k.a. solar radiation) passes right through greenhouse gases because of their shorter wavelength (this is also why we call solar radiation "shortwave" radiation). The length of the waves relative to the size and shape of molecules determines what will happen when that radiation meets that molecule. It turns out that longwave radiation has wavelengths that CO2, CH4, etc. are well suited to intercept, convert to internal energy, and re-radiate as heat/longwave radiation.

Maria McLean: I'm interested to hear more about the implications of water vapour and methane as well - as they are potent GHG's as well.

For methane, please see response to Caroline Ward above. Water vapor is trickier, though. It exists in large quantities in the atmosphere naturally, and unlike the other greenhouse gases like CO2, it is NOT a "well-mixed" greenhouse gas. If you look at a global map of water vapor, the tropics have a lot of it, while the high latitudes have not so much. It varies substantially with climate variability from year to year as well (like with El Nino events, for example). What makes water vapor even more interesting and complicated in terms of its role in climate changes is that there are feedbacks that could be quite important. For example, if we warm the ocean, they will evaporate more water vapor into the atmosphere, which will warm the atmosphere more (being a greenhouse gas), which will warm the ocean more, evaporate more … around and around we go.

Andrew Lewandowski: Can you talk about how F gases and other high GWP molecules play a role compared to CO2, CH4, and NOx?

The chemistry is a bit outside my lane, but by "F gases" do you mean something like sulfur hexafluoride? If so, this is a good starting point for some background and how it has evolved in measurements since 2018:
https://gml.noaa.gov/ccgg/trends_sf6/

Lori Herrick: Is that 930 ppm even life sustaining?

Good question, Lori. I don't think anyone is suggesting ~1,000 ppm will cause serious threats to our lives directly. When you sit in an office with your door closed, or fall asleep at night with the windows closed, the CO2 concentration in your room is building up and typically far exceeds 1,000 ppm. The threats to humanity from 1,000 ppm will be indirect—that level of greenhouse gas forcing will cause warming, sea level rise, heat waves, drought, more intense

hurricanes, and so on—and THOSE are the things that will cause harm. But while CO2 levels that high probably won't cause death directly, there may actually be some serious consequences to prolonged exposure to higher CO2. For example, I wrote a paper along with a cognitive neuroscientist and environmental engineer a couple years ago about how high CO2 in schools and/or the workplace may have some negative cognitive impacts. Here's my paper, and another major paper that inspired our study.
Paper: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GH000237
Press release: https://penntoday.upenn.edu/news/continued-CO2-emissions-will-impair-cognition-Penn-Boulder-study
Other paper that inspired ours: https://dash.harvard.edu/handle/1/27662232

Maria McLean: There are other times in geological time when CO2 has been higher than it is now, correct? This is an argument I hear.. my understanding is that while this is true - not when humans were alive. Interested in more on this.

Yes, it surely was, but it was a very different context. No humans, the continents were in different places, and the Earth was just in a different stage of its evolution than we are talking about now. We have excellent constraints on the CO2 over the past 800,000 years. Before then, the error bars are very big. As you say, it doesn't diminish the scientific evidence that links the recent rise in CO2 to human activities. There is no serious debate about that.

Richard Luce: is there a point at which the CO2 concentration makes it impossible to breathe oxygen--regardless of the impact of increasing temp on climate?

Please see my response to Lori Herrick above.

Kathryn Moore: This is terrifying to me! What are our best case scenarios versus worst case?

Shoot. I wish I knew which slide/graph inspired this question. Feel free to email me and elaborate on your question.

regina gomez: The graph shown comparing past glacial cycles versus our current contribution make people think we should be seeing some bigger drastic events. How do you tell people this is a continuum and they need to stop waiting for one big and bad event?

I would argue we are seeing a rapid rise in extreme events. That said, you are right. It is a continuum. This is why it is so sneaky and hard to inspire action. With COVID, it all happened so fast compared to climate change and actions were taken, but climate change is happening just the same… just too slow to perceive from one day to the next. If you figure out an answer to this excellent question, please let me know.

Stanley Wei: I've seen these graphs of global temperature on the millions of years scale at the Smithsonian and wonder what it means that current variation of temperature is within the variation of temperature on the millions of year scale. I'm not by any means questioning the seriousness of climate change, but wondering how to intellectually incorporate this additiona information. https://www.climate.gov/news-features/climate-qa/whats-hottest-earths-ever-been

Hi Stanley. Please see my response to Maria McLean and others above. It's funny, though. Some people use these facts (Earth was warmer millions of years ago, CO2 was higher millions of years ago) to suggest we Earth scientists don't know what we're talking about. In fact, it is we Earth scientists who figured that stuff out about how the climate was millions of years ago. They are useful analogs sometimes, and we like to learn from them. At the end of the day, we know the reasons why Earth was insanely hot 50, 100, 250 million years ago, and none of those reasons are happening today. The warming that is happening today is because of human emissions of greenhouse gases. Of that there is no serious debate among credentialed scientists.

Siri Wood, PATH (Seattle): Would be interesting to see these SSPs combined with various epidemiological models, in light of impact of COVID, for example, or beyond.

I agree. While COVID had a modest impact on CO2 emissions for one year, it did not impact the concentration of CO2 in the atmosphere. To bring concentration down, that would have to happen year after year, and in bigger percentages (kind of depressing, no?). Some of my colleagues here at CU Boulder and at the nearby National Center for Atmospheric Research (NCAR) even did some climate model experiments and found no detectable imprint of COVID on global warming.

Stanley Wei: Here's the figure I'm referring to. I can't figure out how to cut and paste the image itself into the chat https://www.climate.gov/media/11332

Please see my response to you above. I noticed the figure in the climate.gov article.

Sarang Baman: On the bar graph of energy sources used, it looked like the predicted energy usage would be many orders of magnitude greater than our current usage - did I read that chart correctly?

I don't know about orders of magnitude. (Reminder that orders of magnitude are 10, 100, 1000 … times.) Current use is about 500 EJ. The highest SSP brings it to 1,750 EJ. This is a reasonable prediction, but will depend on policies, technology, population, and all the rest.

Bernadette Longo: You did not review or mention CO2 sinks?

Hi Bernadette. Are you referring to natural sinks (like the ocean and terrestrial biosphere) or human-invented sinks like technology that captures CO2 from the air? I will assume the former. Yeah, mostly in the interest of time, I didn't talk about CO2 sinks. But we know that the ocean and terrestrial biosphere have taken up some half of all the CO2 that humans have emitted. Imagine if they did not. Our current CO2 concentration would be much higher, and atmospheric warming would be even greater than it has been. Not that it's all a good thing. Ocean acidification is a serious, potentially existential problem we have to tackle and it happens because the ocean is absorbing CO2 for us.

Jaswinder Legha: Hearing this information might make some say "It's too late. Might as well just enjoy our lives to the fullest." How to respond to this attitude and resignation?

I would be lying if I said I didn't feel the same way sometimes. Actually, I don't feel like it's too late, because as a scientist I know that it is not too late (by the physics). What I feel more is that no matter what scientists say and activists do, policies will not change. I do hold onto some hope, though. Look at the Montreal Protocol of the late 80s—technically, we can do this.

Britt Wray: I've read that we've warmed 1.1 degrees C already, I've also read that we've warmed 1.2 already. Which do you and your colleagues subscribe to? The difference is significant so hoping to fact check this.

Hey Britt. Yes, 0.1°C is significant, but I hate to say it—the distinction you are referring to is just semantics. What it comes down to is what your definition of the baseline is. In most cases, the base period is something meant to represent "preindustrial" levels. Maybe the warming has been 1.1°C relative to 1900-1950, but it was 1.2°C relative to 1880-1930. You see what I mean? It's not something that divides scientists at all. Of course, this is very important to be on the same page about when crafting policy. One thing I found rather absurd is that the Paris Agreement (with its target of limiting global warming to 2°C above preindustrial) does not clearly specify a definition of preindustrial!

Ronda Seifert: Thwaites Glacier's ice shelf is destabilizing and may break up in the next 5-10 years or even sooner. It represents about 2 ft of sea level rise (with more behind it) - what does a 2 ft rise in sea level mean in practical terms? And how quickly is that expected to happen?

There are some neat tools here where you can see for yourself at various locations around the world: https://sealevel.climatecentral.org/ I like to use this in my freshman intro courses on climate change.

Ingrid Brudenell: What about increasing methane?

Please see my response to Caroline Ward above.

Sarika Modi: Do we have any data recently with decrease in human derived activities with COVID pandemic?

Please see my response to Siri Wood above. The pandemic caused a short-term reduction in human CO2 emissions (5-10%), which had no discernable impact on CO2 concentration or global warming. 90-95% of a large number is still a large number.

Richard Champlin: How do you counter the claims by Trump supporters that this is all a hoax?

I don't bother trying to convince Trump supporters that climate change is not a hoax. Is it worth it? If someone has decided on ideological grounds that a scientific fact is false, their minds will not be changed by hearing or reading more from a scientist. Only in the rarest of circumstances can this be achieved. If you are a close friend or family member of such a person, and you really take the time to meet them where they are, agree on shared values, gain trust, etc., maybe then you can change their mind. Ask yourself the same question but about vaccines. It can be done, but not by more science.

Tejkaran Charan: What does the extreme scenario looks like on the ground. Does the temp. On grounds become 70 degrees or more ? Large scale ocean acidification and loss of biodiversity ?

Hi Tejkaran. It's not all or nothing, and certainly some of these questions will depend on region. I would suggest reading through the Summary for Policymakers (SPM) part of the latest (6th) IPCC Report. You can access it for free here: https://www.ipcc.ch/assessment-report/ar6/

FROM EMAIL

Emailed: Thank you for your informative presentation this morning. One question I have is: In once sentence, is it possible to explain the difference between weather and climate to the lay person (i.e. a Trump supporter who claims Climate Change is all a liberal hoax)?

Hi there. Yes, I think it is possible to explain the difference between weather and climate to a lay person (regardless of who they vote for). I don't think the weather/climate definitions are a controversial topic, actually. Please see my response to Richard Champlin near the top of this document. Weather and climate is a continuum of variability in the atmosphere (and ocean, etc.) form hours to millennia. Where you draw the line between weather and climate is up to you, but it's arbitrary.

Emailed: I've read that we've warmed 1.1 degrees C already, I've also read that we've warmed 1.2 already. When I look it up in reputable publications, I find both answers. I've also heard diff things from colleagues. Which do you and your colleagues subscribe to? The difference is significant so hoping to fact check this with you, as I write 1.2 in my forthcoming book but I don't want to get it wrong.

Oops… looks like I did address this one in a response to Britt Wray above.