

Hi Reddit! We're Radley Horton and Sarah Doherty, climate scientists and lead authors on the Climate Science Special Report. Ask Us Anything!

AmGeophysicalU-AMA <sup>1</sup> and r/Science AMAs<sup>1</sup>

<sup>1</sup>Affiliation not available

April 17, 2023

### **Abstract**

We're Radley Horton, Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York and Sarah Doherty, Senior Research Scientist at the Joint Institute for the Study of the Atmosphere and Ocean at the University of Washington in Seattle. We were both Lead Authors on the recent Climate Science Special Report (<http://www.globalchange.gov/content/cssr>), which focused on climate change in the U.S. and part of the Fourth National Climate Assessment. We're here to talk about how our climate is changing, what causes it, and what to expect in the years ahead. We're looking forward to your questions! We'll be back at 1pm ET to answer your questions, ask us anything! The AGU AMA series is conducted by the Sharing Science ([sharingscience.org](http://sharingscience.org)) program. Sharing Science: By scientists, for everyone. More at [sharingscience.agu.org](http://sharingscience.agu.org).

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AMGEOPHYSICALU-AMA [R/SCIENCE](#)

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What's a good hierarchy of things **the individual** should or shouldn't be doing to help limit global warming?

[the-real-apelord](#)

We can all take steps to limit our greenhouse gas emissions, for example by driving and flying less and by driving more fuel-efficient cars. Cutting back on eating meat, in particular beef, also cuts back on climate-warming emissions. But really there's no one answer in terms of the steps any single person can take to cut back their contribution to global warming. Fortunately our colleague has a great short video on this: <https://www.youtube.com/watch?v=Q48BvprCFr0&feature=youtu.be> As she says, ultimately we need to change the source of our energy from burning fossil fuels to other alternatives that don't produce greenhouse gas emissions. The reality is that there aren't currently a lot of alternatives available for many people. In the bigger picture if we want to slow global warming we need policy solutions that will allow us to make this switch. Policies at the local (city and state level) can be really important in this regard, as well of course as the national to international level. We encourage you to watch the video for more specifics!

How will the climate in England be affected in the future by the changing ocean currents?

[ieswideopen](#)

Sarah here. Thanks for this question, which lets us talk about a great example of how global warming will not be felt equally as uniform warming everywhere. England – and Europe generally – are most affected by changes in what's known as the Atlantic Meridional Overturning Circulation, or AMOC. This



is fed by what people in the U.S. know as the Gulf Stream. There is some indication that the AMOC circulation has slowed down, but there is a lot of uncertainty around whether this is driven by global warming from human activities. It is, however, expected that the AMOC will slow down as climate warms, for example due to an increase in the amount of freshwater dumped in to the north Atlantic as ice sheets melt. This decreases the sinking of surface waters, and slows the circulation. England/Europe are warmed by the AMOC, which brings warmer ocean water from the south to the north. The atmosphere above this warmer water is itself warmed, then flows over Europe. So if the AMOC does slow down with further global warming this would actually cool England and Europe.

Historically we've had multiple global climate "changes" previously, such as the Ice Age or [the Roman Warm Period](#). How does what we are currently experiencing differ from previous climate changes?

Also, I haven't done a huge amount of research into the area, but to my understanding nuclear power has a small carbon footprint. Is nuclear power a good option going forward, or are energy sources such as wind and solar "better"?

[Wilza30101](#)

Sarah here. This question comes up a lot, so I'm glad you asked it here! There are a few important differences between the current climate change and past climate changes (including long-ago climate changes, like previous ice ages and the warmer period when dinosaurs roamed the earth~) First, the rate of change: Large past climate changes occurred over a period of thousands to tens of thousands or even hundreds of thousands of years. Keep in mind that in terms of global, annual average temperature the difference between now and a full-blown ice age is about 5deg C (or 9 deg F). Not a lot! So the change we're looking at by the end of this century is potentially comparable to this same difference, but in the opposite direction (warming vs. cooling) – depending on what the world does in the coming decades in terms of emissions. Only in this case, the change would be happening in about 200 years, rather than 20,000. This is important because it makes it much more difficult for natural systems to adapt. Trees, for example, can only migrate so quickly. Second, it is very clear that human activities are the cause of the current climate change, and we know what we need to do to slow and then stop it: phase out the emissions of greenhouse gases. Third, in the past the planet didn't need to sustain 7.5+ billion people and growing. The world's economies are very much built around the existing climate state. While we can adapt to a slowly changing climate, for example by migrating away from low-altitude areas along coastlines, with the current and projected rate of change it will be difficult to adapt with sufficient speed, especially if many regions are stressed at once, as is expected. Note also that the change in global, annual average temperature in times like the Medieval Warm Period and the Little Ice Age was quite a bit smaller than what we're imposing on ourselves now. See the nice figure here for example: [https://en.wikipedia.org/wiki/Little\\_Ice\\_Age](https://en.wikipedia.org/wiki/Little_Ice_Age) (noting that current climate has warmed further since 2004!)

How frustrating is it to be told that your president doesn't believe in your research?

[Jearik](#)

One of the great things about working in the field of science is that you get to work with a bunch of people who are motivated by the same thing as you: First and foremost, to understand how things work! Activities like pulling together the Climate Science Special Report and other such assessments (like the Intergovernmental Panel on Climate Change reports) allow the scientific community to come together and determine our very best current understanding about issues like climate change. We are very confident that this process, while not perfect, produces robust, consensus statements – not ideologically-based conclusions. Just as we would hope public health decisions and our doctor's decisions about how to treat medical conditions would be based on the latest, best understanding of

diseases coming from the medical research community, we would hope, as citizens, that the best, most current scientific knowledge coming from our community of researchers would be used by policy-makers as the basis for decisions around the energy and climate issue.

What is the single, most succinct reference one could give climate change deniers to impact their beliefs?

[isene](#)

SkepticalScience.com is great for addressing the range of typical arguments against climate change being real and caused by humans. Unfortunately for many people science facts won't change their minds. See this great video by our colleague, Katharine Hayhoe: <https://youtu.be/nkMljbDtdo0> For these people, it would be better to discuss how climate change will affect the things they care about, or to simply talk about changes that would have benefits that also would address climate change, but without the need to put it in the context of climate change. For example there are studies and data to show that in many cases there are net economic benefits to switching to renewable energy from fossil fuels, regardless of climate change. One fact I find really compelling for some folks is that the Pentagon twice has done assessments (once under Pres. G. W. Bush and once under Pres. Obama) that give climate change as the biggest long-term risk to national security. This is because of, among other things, there will be many climate refugees from areas that are hard-hit by climate change and unable to adapt. We can already see how this plays out in places like Sudan, where much of the current conflict was driven in large part by limitations in natural resources with drought.

We saw likely effects of climate change with the increased severity of hurricanes this year. What are some other 'secondary' effects of climate change that the average person might not think about?

[thiney49](#)

Radley Horton here, happy to be with you today. Some effects can be thought of as secondary climate effects, and some can be thought of as secondary in the sense of being societal impacts of the climate changes. If we think of warming as the initial climate effect of increasing GHGs, secondary climate effects include a) sea level rise as the oceans warm and expand and land based ice (or its melt) makes its way to the ocean, b) changes in the planet's hydrological cycle, including more flooding in many regions, as well as more drought (perhaps seemingly paradoxically). Societal impacts include inundation of coastal infrastructure and homes, reductions in crop yields, and human health impacts associated for example with more heat, less cold, and changes in vector-borne diseases. Other examples of things people might not think of are 1) more extreme fires, because of soils and vegetation drying out faster due to higher temperatures and snow melt earlier in the season, and 2) ocean acidification as the oceans take up more CO<sub>2</sub>.

Crap I left my copy of the executive summary with my notes at the house!! I haven't had a chance to read the entire report yet, im sorry!! Ill try to remember my questions...

First, how many models did you look at to determine the amount of projected warming without human interaction? We are still below maximum sea level before the last ice age, so would we expect an equal amount of sea level rise eventually in addition to the damage done anthropogenically?

Also, a couple of the early figures in the summary refer to changes in earth temperature being iirc 1.8° F on average. Is that at the surface? Is that measured and interpolated across the surface or based on remote sensing methods?

This was by far the most thorough research ive seen. I skimmed through the references for a couple chapters of the report and the sheer volume of references is staggering. How long did your literature review process take?

Lastly, what is your go-to response to climate deniers? How can you possibly argue with someone who refuses to acknowledge the validity of science in general, not only climate science? The latter seems increasingly common nowadays.

Hopefully I can remember more questions I had and edit this post to reflect them later. THANKS!

[NikoSig2010](#)

Sarah here! There are lot of questions here so I'm going to quote them then answer them: "First, how many models did you look at to determine the amount of projected warming without human interaction?" There's a great project called the Climate Model Intercomparison Project ("CMIP") that coordinates climate model runs, then compares the results across different models. The models participating in CMIP all do the runs of both pre-industrial conditions and runs without human influences. It is the collective result of these runs that is used to determine what climate would be like in the absence of human activities (for example shown here [https://www.ipcc.ch/publications\\_and\\_data/ar4/syr/en/fig/figurespm-4.jpeg](https://www.ipcc.ch/publications_and_data/ar4/syr/en/fig/figurespm-4.jpeg)). Currently there are over 60 models in CMIP.

"We are still below maximum sea level before the last ice age, so would we expect an equal amount of sea level rise eventually in addition to the damage done anthropogenically?" Sea level takes a long time to fully respond to the change in the amount of energy in the Earth system. A fraction of the current sea level rise is due to the effects of coming out of the last Ice Age, though the consensus is that the majority of the current sea level rise is attributable to warming due to human activities. As stated in the Climate Science Special Report "During the Last Interglacial stage, about 125,000 years ago, global average sea surface temperature was about  $0.5^{\circ} \pm 0.3^{\circ}\text{C}$  ( $0.9^{\circ} \pm 0.5^{\circ}\text{F}$ ) above the preindustrial level [that is, comparable to the average over 1995–2014, when global mean temperature was about  $0.8^{\circ}\text{C}$  ( $1.4^{\circ}\text{F}$ ) above the preindustrial levels]. Polar temperatures were comparable to those projected for  $1^{\circ}\text{--}2^{\circ}\text{C}$  ( $1.8^{\circ}\text{--}3.6^{\circ}\text{F}$ ) of global mean warming above the preindustrial level. At this time, GMSL was about 6–9 meters (about 20–30 feet) higher than today. This geological benchmark may indicate the probable long- term response of GMSL to the minimum magnitude of temperature change projected for the current century." Neither of us are experts on sea level rise, but our colleague Bob Kopp is, and he will be doing a Reddit AMA, along with Katharine Hayhoe, on December 1 at noon EST! If you're interested in more on sea level rise, you should post your questions there.

"Also, a couple of the early figures in the summary refer to changes in earth temperature being iirc  $1.8^{\circ}\text{F}$  on average. Is that at the surface? Is that measured and interpolated across the surface or based on remote sensing methods?" Yes this is near-surface air temperature. It's based on a large number of both surface and remote-sensing measurements. There's a lot of complex analysis that goes into this, accounting for things like urban heat island effects. This is an example of where assessments – versus relying on just a single study – are really important.

"This was by far the most thorough research ive seen. I skimmed through the references for a couple chapters of the report and the sheer volume of references is staggering. How long did your literature review process take?" A lot of these papers are ones that the authors in each area of expertise would have read and been familiar with before working on the report. It's part of our job to keep up on the latest literature in our specific research area. But a great thing about participating in an assessment like this is that you always end up reading new papers, and you have to step back and look at all the literature collectively. This is a LOT of work (I don't keep track of the hours that go into this because it might scare me...) but also very rewarding, because in the end you learn new things, even as an expert in a given subject.

"Lastly, what is your go-to response to climate deniers? How can you possibly argue with someone who refuses to acknowledge the validity of science in general, not only climate science? The latter seems increasingly common nowadays." See our answer to this question in another thread. (In brief, for facts disputing the most common points arguing against climate change being real we like SkepticalScience.com but facts are often not what is needed...)

According to one study, emissions pathways consistent with governments' announcements imply a median warming of 4.7°–5.6° F (2.6°–3.1 °C) by 2100...

Do you think that we can expect more drastic GHG reduction commitments in the future?

[TheMercian](#)

Do you think that we can expect more drastic GHG reduction commitments in the future?

Radley here. That is the million-dollar question. I tend to think 'yes' but it is far from a sure thing. First, to recap where we currently are: The past three years have seen relatively constant levels of global greenhouse gas emissions. In some respects this is cause for hope, especially given that this has been a period of global economic growth. Thus, the old chestnut that ~'you cannot have economic growth without increasing CO2 emissions' appears to no longer be valid (to the extent that it ever was.) To be sure, however, this apparent leveling of global emissions is not sufficient. We need rapid decarbonization if we are going to meet a target of limiting global warming to 2 Celsius, thus avoiding the most severe impacts of climate change—keep in mind that we have already had about 1C of the aforementioned 2C of warming. And global commitments to date MAYBE limit us to 3C of warming, so there is a long way to go in terms of further emissions reductions needed. Now to your question of whether we can expect to get those commitments/further reductions. Reasons to think we might include: 1) the growing role of non-state actors like cities and corporations promoting emissions reductions, 2) evidence of ~price parity vs. carbon-intensive fossil fuels as renewables like solar and wind drop dramatically in cost, 3) signs that investors may demand the corporations and other actors disclose their life-cycle greenhouse gas emissions, as well as their vulnerability to the direct and indirect impacts of climate change, and 4) more and more countries and regions putting a price on carbon.

How is animal agriculture impacting climate? Would people reducing their meat consumption help?

[slvb99](#)

If people reduce their meat consumption, it will help to reduce greenhouse gas emissions (it will also help support global biodiversity, but that is arguably off-topic). Animal agriculture is an important part of the climate change story, albeit distant relative to the magnitude of fossil fuel combustion. It has been estimated that land use change associated with agriculture and forestry is responsible for more than 20 percent of global warming. (See for example IPCC 2014: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.) Animal agriculture is an important component. In many parts of the world, forests capable of taking up carbon dioxide continue to be cleared (thereby releasing CO2) to support meat production, which is extremely inefficient relative to most plant-based agriculture. From a caloric perspective, it is not an oversimplification to say that far more forest needs to be cleared to support a meat based diet than would need to be cleared to support a plant-based one. Livestock also emit greenhouse gases (methane especially) as well.

I've heard from multiple sources that if we zeroed CO<sub>2</sub> emissions now we couldn't prevent 2°C warming anyway. It does seem true, as in the last 4 years my town (in what was one of the most

temperate areas of the world) had temperatures that were 3-4 °C over the 1960-1990 mean.

Is this true? If so, why are we still bothering with ineffective measures like COP21 and not going for something radical?

[lucaxx85](#)

Thanks for this very relevant questions. The answer by "aClimateSciencist" is a good one. It's really important in particular to keep in mind that any amount of warming we can prevent might help keep us from reaching "tipping points" in the climate system. (There's some good reading in the Climate Science Special Report in Chapter 15 about tipping points/potential surprises if you're interested, <https://science2017.globalchange.gov/chapter/15/>). More to the point regarding your question: The Climate Science Special Report gives dates by which we'd need to zero CO2 emissions if we're going to stay below the total cumulative CO2 emissions we believe would keep us below 2deg C warming. The estimates give a range, since we don't know exactly what our future emissions will be (at the low or high end of what's likely): somewhere between 2033 and 2047. So it's not yet true that if we zero out emissions right now we would still reach 2deg C of warming – but it is true that that date is not too far away. (Note that if we find a way to capture/draw CO2 out of the atmosphere and store it somewhere that it can't escape back to the atmosphere – called "carbon capture and storage" this would allow us to stay below 2deg C while emitting more CO2 than this. But to date these technologies are not yet proven or affordable at the scale that would be needed.)

What are the incentives for authoring such a report? Is it a volunteer project much like the IPCC?

Besides the obvious focus on the U.S., how does the report's objectives differ from those of the IPCC?

[aClimateScientist](#)

My incentives (Sarah) for working on reports like this are two-fold: First, as scientists I think we have an obligation to communicate what we know about how the world works to the public and policy-makers, especially on issues like this that impact the public. Assessment reports like CSSR and IPCC include a really strong processes (the CSSR had 6 external reviews, including from the public, the National Academy of Sciences, and a slew of federal agencies) designed to produce pretty robust, consensus results. Second, it's a great learning process! It is a real privilege to get to collaborate with a collection of experts across the field of climate sciences and learn what they know -- and challenge what you think you know. (Yeah, scientists actually like this stuff...). The CSSR/NCA differs from the IPCC mostly in the focus on the U.S. and in giving specifics about regions and economic sectors (NCA vol 2) in the U.S. economy. This level of specificity is quite important for policy-makers to evaluate the costs, adaption options (how much sea level rise does my city need to plan for?) etc. -- information not really available via the IPCC. Also, as long as it is, it's still shorter than the IPCC reports!

How do you respond to people who cite that climate models are regularly updated to better fit what is happening? These people (sort of) have a point, in that you started with one model but needed to tweak it many times to fit the real world, instead of the other way around.

I suppose a broad example would be that initially the World was predicted warm 4 degrees by some time, but then later it's only 2 degrees, and so on.

I'm not doubting your work but what I'm trying to point out is reason enough for many to disregard the models. What do you say to that?

[ShitInMyCunt-2dollar](#)

Sarah here. aClimateScientist gave a pretty good answer; I'd encourage you to check out the link they provided. In brief, the models are not set up to continually match what is happening. Models from the 1970s were actually pretty dang good; even the original estimates by Svante Arrhenius about how much global warming we'd get by doubling atmospheric CO<sub>2</sub> were pretty on the mark! What *does* happen is that we constantly test the models against observations of the present-day and past, to try and improve the physics and other processes represented in the model. But again, I'd encourage you to follow the link given by aClimateScientist.

Which statistical software tools do you use (eg, R, SAS, arcgis)?

[uricamerica](#)

Sarah's answer: I'm a Matlab user...

What's your reaction when people say global warming is a myth cause winter is still cold?

[DogAteMyWookie](#)

Global warming, thankfully, will not take away our seasons! The earth will continue to be colder in winter than in summer, and temperatures will still be cold (below freezing) in plenty of places in winter. Also, with global warming the temperature of the earth averaged over the whole globe and the whole year will trend upward, but that does not mean that it will get warmer everywhere at all times. This is why the term "climate change" is really a better description of what is happening and what will happen. Having said that, temperatures ARE warming in the winter, and significantly. In fact in the U.S. they are warming more than in summer. If you go to the Climate Science Special Report Chapter 6 (<https://science2017.globalchange.gov/chapter/6/>), look at Figure 6.1. This shows that across most of the country wintertime average temperatures have warmed by more than 2.5deg F over most of the country over the past century. So while winter is still cold, it's not as cold as it used to be – and that trend is expected to continue.

What impact will climate change have on the planet if it continues to warm at the current rate or even begins to accelerate? What can we expect the future to be like? More natural disasters? Extinctions?

[Mozz12](#)

Radley here--We know that climate change modifies the frequency and intensity of events we have always experienced. For example, we get more frequent a) heat events, intense precipitation, and 'nuisance' coastal flooding. The further we push the climate system by burning fossil fuels and deforesting the tropics, the faster these extremes will change, and the greater the risk of surprises that our climate and impact models are ill-equipped to handle: think things like long term loss of some land-based ice sheets, forest die-back, loss of coral reefs, major changes in ocean and/or atmospheric circulation, and shocks to the global food supply. The probability of each of these surprises is difficult to quantify, but we can say with confidence that the further we push the system, the more likely these potentially catastrophic outcomes become. In terms of extinctions, it is important to note that we are already living during what has been called The Sixth Extinction (see Elizabeth Kolbert's book), partly due to climate change but partly due to other aspects of our modern human experience. As with climate extremes, climate change increases the magnitude of these (already high magnitude) extinctions.

What impact will climate change have on the planet if it continues to warm at the current rate or even begins to accelerate? What can we expect the future to be like? More natural disasters? Extinctions?

[Mozz12](#)

We're running out of time so I'll be brief and point you to the Climate Science Special Report, which describes the range of changes in climate will be under different warming scenarios. There are chapters on temperature (Chapter 6), precipitation (Chapter 7), droughts/floods/wildfires (Chapter 8) and Extremes storms (Chapter 9), among other things. Reading the Key Messages that lead each of these chapters will give you a good idea of what the projections are for the U.S. You can access these individual chapters here: <https://science2017.globalchange.gov> For impacts on species and ecosystems of these climate changes, keep an eye out for volume II of the National Climate Assessment the will come out later next year.

Where is the best place in the world for my kids to live so they have clean air, clean drinking water, and easy access to healthy food?

[cing\\_cent](#)

Where is the best place in the world for my kids to live so they have clean air, clean drinking water, and easy access to healthy food?

Radley here—I get this question a lot, and think about it myself. Still, I think the most important point to make is that the further we push the climate system by emitting greenhouse gases, the greater the risk that climate impacts become so severe as to cascade across all places, people, sectors, and ecosystems. Examples include human conflict and war, emergence and spreading of diseases to new regions, agricultural price shocks and supply chain failures in a globally linked economy, and the bursting of economic bubbles, once investors adequately price emerging risks. While we all should encourage adaptation based on the climate changes projected for our particular location, none of us should assume the preparing for local climate change eliminates all the risks you face. And we haven't even addressed the central question of what happens to the most vulnerable people and places if we do not dramatically cut emissions. Now that I got that off my chest, I will address your question more directly. Those places that experience relatively high baseline levels of the essential resources (you mention) today have a leg up. As do places that experience relatively few extreme climate events today, are projected to have relatively modest amounts of climate change, and have a high adaptive capacity. Some areas of non-low-lying land in the mid-high latitudes that tend to get their weather directly from a large and deep body of water to their immediate west may fit this bill. Think perhaps parts of the coastal Pacific-northwest, extending into Canada, or parts of the British Isles. There is probably something to this line of 'armchair' reasoning. But to my mind, a key point is that unless we reduce fossil fuel consumption and tropical deforestation dramatically, it may become exponentially more difficult to project the sundry ways that EVERY region could be indirectly impacted by climate change.

What is your advice to early career scientists who are passionate about the environment and solving climate change but have no idea where to even start?

[happyflarg123](#)

Sarah here. There are many things you could do; you don't even have to stick to pure science to effect change. People with a science background who can effectively communicate and work with the public, policy-makers, behavioral scientist, engineers, etc. are going to play a really important role on the solutions side. I think the most important thing is that you figure out what it is that excites you, what

you enjoy doing (writing? data analysis? teaching?) and start there. See what careers this opens up for you; then within that career you can have an impact on the issues that matter to you. For me the starting point was that I liked physics, because it explains the way the world works. For the first four years of my career I actually worked in the area of defense. It was sort of by chance that I ended up doing work related to the atmosphere within that job, and one thing lead to another and I decided to go to graduate school to get an advanced degree in atmospheric sciences. At each step I've been motivated by what I find interesting and exciting, and what kind of work I like to do on a day to day basis. I'd encourage you to do the same, and chances are that you'll end up in a position where you can work on things you care about!

Why do „important“ People think that climate change is not real? How could this affect us and our world?

### [DieRIGOLETTO](#)

I don't have any particular expertise on this question, but I will take a stab anyway, addressing the question as it relates to people in general. Like Tolstoy's unhappy families, perhaps there are a variety of reasons that people think climate change is unreal. Many people do not base their thinking around science. It does not help that greenhouse gases are invisible. For another, many people find it counterintuitive that something that exists in trace quantities could have a large impact. Some people have a tendency to be contrarian, almost instinctively rebelling against scientific consensus. Others rebel against the narrative that the arc of human development has had some major downsides that argue for some changes in the way we do things as a society. Some people do not have a scientific foundation. Some do not want to rock the boat among their peer-group or other networks. Some very small percentage probably have more direct financial motivations. No matter what the issue, it is so important to remember that many people can be receptive to new information, and are fundamentally acting in good faith. If we forget that, I think we are in (bigger) trouble.

Is climate change real?

### [The real Bottle](#)

Climate is definitely changing, and we can say with very high confidence that the changes in climate over the past century are overwhelmingly driven by human activities. This is a main finding of the Climate Science Special Report. The report opens with a 2-page summary of report "highlights" which point this out. If you want a bit more, the full Executive Summary (which opens with the highlights) would be a good read for you: <https://science2017.globalchange.gov/chapter/executive-summary/> I hope this helps answer your question! ~Sarah

There was a thread on Reddit the other day stating that the "hole" in the Ozone was at its smallest since 1980~ something.

Is that accurate? How does the Ozone (and it's "hole") affect climate change? and ... To what degree?

Thanks!

### [8Bells](#)

Sarah here! Thanks for this question. The link between the ozone hole and global warming is often a confusing topic. The ozone hole was quite a bit smaller this year; indeed, the smallest since 1988! There's a very good NASA piece on this here: <https://www.nasa.gov/feature/goddard/2017/warm-air->

[helped-make-2017-ozone-hole-smallest-since-1988](#) The recovery of the ozone hole, which we *might* be starting to see (or should soon!), is a great success story. The emissions of CFCs have declined dramatically thanks to the Montreal Protocol. As a result, the ozone hole is expected to start to "heal". In addition to the amount of ozone-depleting chemicals in the atmosphere, the size of the ozone hole is also determined by things like the atmospheric circulation, which can vary from year to year. This is because changes in circulation around Antarctica can change the temperatures in the stratosphere in winter and spring, and this affects the rate of chemical reactions. Indeed, this influence was at play in reducing this year's ozone hole – and it is also the reason we also saw a smaller ozone hole in 2002. The ozone hole affects global warming because ozone is a greenhouse gas. So the decrease in stratospheric ozone leads to a slight decrease in the amount of infrared radiation escaping to space, and therefore a negative "radiative forcing" – which produces climate cooling. The estimate of this radiative forcing is a decrease of about 0.05 Watts per square meter decline in energy in the Earth system between 1750 and 2011. (By comparison, the addition of greenhouse gases over this period has added about 3 Watts per square meter. As the ozone hole becomes smaller, this forcing will become smaller. Another link between the ozone hole and global warming is that the chemicals that deplete the ozone layer are also greenhouse gases, adding to climate warming. Some of the gases people started to use in place of CFCs that don't deplete ozone, hydrofluorocarbons, or HFCs, it turns out are also powerful greenhouse gases. The Montreal Protocol, enacted in 1989, reduces the emissions of ozone-depleting substances. This past year it was amended (the "Kigali Amendment") to also phase out HFCs, because of their climate-warming effect.

Have we or have we not reached the point of no return where ice melts releasing methane that in turn raises the temperature again to cause more ice to melt? Have we reached the point where the only solutions are massive carbon capture programs?

[Centurion902](#)

Hi! Sarah here. We are not yet at the point of no return... In fact it's important that there is no "point of no return" in that reducing the emissions of greenhouse gases at any point and in any amount will help. I answer the question about methane (clathrates and permafrost) in reply to another person. There is a chance that permafrost thaw will release more CO<sub>2</sub> and methane than we are currently accounting for, and that if this happens this will make it more difficult to reach targets for greenhouse gas concentrations and/or temperatures.

Regarding massive carbon capture programs, whether these are needed and used or not will depend on a) the decisions we make in the coming couple/few decades and the resulting emissions; b) the technical feasibility and cost of large-scale carbon capture & storage (which is not yet something we could do at large scale); and c) a process of economists, policy-makers and society in general weighing the economic and societal impacts of continuing "business as usual" vs. other options (mitigation, adaptation, carbon capture & storage, other geoengineering).

It's the calphate gun thing going to kill us all?

[SaintNattygrumpo](#)

Sarah here. Thanks for your question! Clathrates hold an enormous amount of methane, and indeed if it was all released to the atmosphere the result would be significant climate warming. However, right now the experts in this area tell us that the clathrates are not significantly destabilizing and are not expected to in the foreseeable future. There is also a lot of carbon stored as organics in permafrost. When permafrost thaws these organics are then available to decompose, releasing CO<sub>2</sub> and methane. We are seeing this starting to happen. A big uncertainty is how extensive permafrost thaw will be in the future and how much CO<sub>2</sub> and methane this will release. Currently, permafrost appears to be releasing

CO2 and methane at a faster rate than expected; understanding why is an active area of research. While CO2 and methane release from thawing permafrost is unlikely to “kill us all” :-), the large-scale thawing of permafrost and subsequent release of large amounts of CO2 and methane is one of the possible “big surprises” down the road which could significantly accelerate warming.

How certain is it that the West Antarctic Ice Sheet is headed for eventual collapse?

Given the potential that just this event can increase sea levels by six feet (or more?) over a hundred years, I think it's worrisome that this does not get more attention.

[the-player-of-games](#)

Sarah here! Thanks for this important question; the fate of the West Antarctic Ice Sheet is really important in the context of future sea level rise. This is a very active area of research. Recent observations have shown that glaciers on both the W. Antarctic Ice Sheet and the Greenland Ice Sheet are flowing towards the ocean at a faster rate than expected from forecasts and/or that mass is being lost at a faster rate than forecast. The glacial research community is still trying to understand what processes are leading to this. It appears that warm ocean water getting under the bottom of the glaciers is part of the reason. There are some very important new findings out of West Antarctica about the fact a couple of key glaciers are held back by points where they hit “grounding lines” – peaks in the sub-glacial terrain. Inland of these grounding lines the terrain dips back down in altitude, such that once the glaciers retreat sufficiently warm ocean water is free to flow under the glacier, far inland, eating away at the bottom of the glacier and allowing them to flow more rapidly out towards the ocean. In the report, we note that future sea level rise could be as much as 8 feet by 2100, if the West Antarctic ice sheet loss accelerates as some studies show it might. However, this is still very uncertain. Because it has such important consequences for sea level rise this is in fact getting a lot of attention in the glacial research and climate communities!

What's the most effective way an individual can reduce climate change? Plant trees? Donate?

[FabulousFoil](#)

There are a variety of good answers, which will vary somewhat by person. On many people's lists, I would expect to find: 1) flying less, 2) converting to renewable energy sources like solar and wind, 3) conserving energy (for example by weatherproofing your residence and adjusting your thermostat), 4) using more public transportation and/or a more fuel efficient or electric vehicle, 5) eating less meat, and 6) assuming a subject is important to you, you could consider speaking up about it in a variety of contexts including how it influences decisions you make about what you purchase, how you invest, and how you vote.

We know the Earth gets its heat from the Sun. We know that the Solar flux affects atmosphere (solar wind, Coronal Mass Ejections, flares, etc) which can cause massive disruptions. We know the Sun is currently in a downward trend in output with some astronomers worried we are headed to another Maunder's Minimum. Why is space weather and Solar output not accounted for in the models for climate change?

[rock\\_vbrg](#)

Sarah here. Thanks for your question, which is a good one. Solar input primarily affects climate through changes in the input of visible and near-visible wavelengths. These *are* accounted for in the models, as pointed out in Chapter 2 of the Climate Science Special Report. Changes at near-UV and shorter

wavelengths don't significantly directly affect the energy input to the Earth, but they do affect the concentrations of stratospheric ozone. Ozone itself a greenhouse gas, and changes in ozone can affect atmospheric circulation. This is an area of ongoing research. As such, this effect is not included in models. However, there is high confidence that the impact of these changes is small, especially relative to the impact of the increase in greenhouse gases added to the atmosphere over the industrial era. Regarding cosmic rays and clouds: The last Intergovernmental Panel on Climate Change assessment (available at: <https://www.ipcc.ch/report/ar5/wg1/>) addressed this. It concluded that, based on the collection of studies to date, there is "high agreement" that cosmic rays have not been shown to have a robust effect on clouds: "Changes in solar activity affect the cosmic ray flux impinging upon the Earth's atmosphere, which has been hypothesized to affect climate through changes in cloudiness. Cosmic rays enhance aerosol nucleation and thus may affect cloud condensation nuclei production in the free troposphere, but the effect is too weak to have any climatic influence during a solar cycle or over the last century (medium evidence, high agreement). No robust association between changes in cosmic rays and cloudiness has been identified. In the event that such an association existed, a mechanism other than cosmic ray-induced nucleation of new aerosol particles would be needed to explain it." IPCC AR5, Pg 56, Technical Summary More detail is given in the IPCC AR5 Section 7.4.6 if you are interested.