Science AMA Series: we are Ken Caldeira, a professor and climate scientist at Stanford University, and Ben van der Pluijm, Editor-in-Chief of AGU's publication Earth's Future and professor at University of Michigan. Ask Us Anything!

AmGeophysicalU-AMA [1] and r/Science AMAs[1]

[1]Affiliation not available

April 17, 2023

Abstract

Ben and Ken: Thanks for offering many great questions, Redditers. We hope that our responses advanced the conversation about global climate change and possible solutions that include climate engineering. We certainly enjoyed this interaction. Signing off, Ken and Ben. Hi reddit! I'm Ken Caldeira and I work on a broad array of issues including the physical climate system, global energy systems, ocean acidification, and geoengineering. With the exception of the ocean acidifcation work, all of our research is based on performing simulations using computer models. Solar geoengineering involves trying to cool the Earth by deflecting some incoming sunlight away from our planet. Studies have shown that actions like putting small particles in the stratosphere could reflect some sunlight away from the Earth, potentially taking our climate back to a point similar to pre-industrial revolution. Of course, we know for sure about only one habitable planet, and toying around with this planet at the required scale would pose great risks – but allowing the Earth to warm from our greenhouse gas emissions also poses grave risks. Given that it is going to take time to transform our energy system into one that does not dump its waste in the atmosphere, what is the best path forward? I'm Ben van der Pluijm and I work in hazards geology and societal impacts of global change. The goal of 2016's Paris Agreement to limit global warming to 2 degrees C (3.6 degrees F) is ideal, but unlikely from voluntary greenhouse gas emission reductions alone. Building on our remarkable history of engineering applications to overcoming societal challenges, climate engineering should be included as a viable solution for reducing the impacts of global warming. Climate engineering takes two approaches: (1) Carbon dioxide removal, and (2) solar radiation management. The former addresses the cause of climate warming by removing greenhouse gas from the atmosphere ("treat the illness"). The latter offsets the warming effects of greenhouse gases by allowing Earth to absorb less solar radiation ("treat the symptoms"). Given their worldwide impact, planning must occur on a global scale, involving all nations, large and small, rich and poor, and not be limited to a few technologically advanced, wealthy countries. We're looking forward to answering questions about environmental change and dealing with the impacts for human society, and whether various geoengineering techniques could really be expected to reduce climate damage and decrease damage to both ecosystems and people. We were here from noon to 2 PM EST to answer your questions. Thanks for Asking Us Anything!

the WINNOWER

REDDIT

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AMGEOPHYSICALU-AMA R/SCIENCE

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CORRESPONDENCE:

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Can you give us insight on how much the recent defunding of EPA will effect people like you or the climate as a whole? Should we all be worried or is it not that big of a deal?

Labrond

Ben: I am not currently nor have been funded in the past by EPA, but, like all of us, have benefited

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from their work to secure our air and water quality, for example. I am quite concerned about curtailing such activities, which are in our best interest. I kinda like safe air and clean water.

Can you give us insight on how much the recent defunding of EPA will effect people like you or the climate as a whole? Should we all be worried or is it not that big of a deal?

Labrond

Ken: A reduction in Federal funding will cause the United States to lose scientific leadership. Also, young people do not want to go into a field that does not seem to have a good future. The United States is giving up its position of scientific leadership.

What's the single most effective evidence of climate change when convincing skeptics?

drsjsmith

Ken: I think the instrumental record of surface temperature is the most compelling evidence of temperature change. The fact that the stratosphere is cooling while the lower atmosphere warms is the most compelling piece of evidence that greenhouse gases are behind this warming. Almost everything else (solar variability, changes in ocean heat fluxes, etc) would cause both the stratosphere and near-surface temperatures to move together. The fact that stratospheric temperatures are moving in the opposite direction to surface temperatures is a real smoking gun pointing to our greenhouse gas emissions as the culprit.

What's the single most effective evidence of climate change when convincing skeptics?

drsjsmith

Ken: The most compelling single piece of evidence is the instrumental temperature record over the past 150 years or so. That doesn't prove that humans are the cause, but it proves that our planet is getting warmer.

What's the single most effective evidence of climate change when convincing skeptics?

drsjsmith

Ben: Thanks for asking this important question. Responses will vary, but personally I always highlight sealevel rise as evidence (more ice cap melting from warming) and as impact (coast-oriented human society).

I understandably get a sense of dread when I read headlines like, "CO2 LEVELS HAVE PASSED THE POINT OF NO RETURN". What does that mean quantitatively, and does it really mean that climate change as a result of carbon emissions is now out of our hands? Are there still steps that can be taken as a species to slow/stop/reverse it? How about on national level? How about on an individual level?

pilgrim_pastry

Ken: I am not a fan of these 'point of no return' declarations. Our CO2 emissions may cause damage and suffering, but humans will not go extinct as a result of our emissions. We will always deal with

whatever conditions we have. The question is not one of how do we survive, but rather how do we want to live?

I understandably get a sense of dread when I read headlines like, "CO2 LEVELS HAVE PASSED THE POINT OF NO RETURN". What does that mean quantitatively, and does it really mean that climate change as a result of carbon emissions is now out of our hands? Are there still steps that can be taken as a species to slow/stop/reverse it? How about on national level? How about on an individual level?

pilgrim_pastry

Ben: I hear you. First, having CO2 in the atmosphere is good for us, making for habitable surface conditions. Modern CO2 increases will take decades to show their full impact. Adding more CO2 (and methane) will increase these impacts. We should try to minimize future increases as they have significance impact for human society, but perhaps also consider reducing them. The good news: we'll ultimately deal with change one way or another.

Correct me if I'm wrong but climate change is not an issue at the national level but more at the global level. With such ignorance and denial by leaders of some of those nations, United States particularly, it seems like changing ones worldview is a bigger problem than coming up with or implementing ideas to slow climate change. Nations like the United States were built on coal is it conscionable to tell another nation or enforce carbon tax on emerging nations doing the same?

Edit: fixed syntax error

bosnickcm

Ken: Climate change is an issue at every level. The problem is that costs are borne by the individual in the here-and-now but benefits are to the whole world for thousands of years into the future. It is this game theoretic challenge that makes this such a difficult problem.

Correct me if I'm wrong but climate change is not an issue at the national level but more at the global level. With such ignorance and denial by leaders of some of those nations, United States particularly, it seems like changing ones worldview is a bigger problem than coming up with or implementing ideas to slow climate change. Nations like the United States were built on coal is it conscionable to tell another nation or enforce carbon tax on emerging nations doing the same?

Edit: fixed syntax error

bosnickcm

Ben: climate change is a shared issue. As a large and wealthy nation, the US should take a lead in addressing the impacts and solutions to change, regardless of our past role. Past behaviors provide valuable lessons for the future. We are in this together.

Carbon dioxide removal and solar radiation management are both likely to be useful and necessary tools for dealing with climate change - but how are we planning to pay for them? Do you envisage some sort of carbon tax in various countries to raise funds? Governments just deciding to do it on their own? Private donors? What is your most likely source of funding?

bondpeddler

Ken: Carbon dioxide removal is thought to be expensive and paying for it will be at least as challenging as paying for CO2 emissions reduction. On the other hand, putting sulfate aerosols in the stratosphere is relatively cheap and would be in the noise of budgets of big countries. The main issue with solar geoengineering is adverse impacts and risk, not direct financial cost of deployment.

Carbon dioxide removal and solar radiation management are both likely to be useful and necessary tools for dealing with climate change - but how are we planning to pay for them? Do you envisage some sort of carbon tax in various countries to raise funds? Governments just deciding to do it on their own? Private donors? What is your most likely source of funding?

bondpeddler

Ben: For starters, a changing climate is expensive already. I am not an economist, but do believe that full-cost accounting is the first step in understanding true environmental cost. Then, any remediation efforts may not look too bad. In today's economic world structure, a carbon tax certainly will have an impact. If governments don't step up, hopefully foundations are willing to support action. Also industry can (and should) play a role.

Is there a plan to somehow pull carbon dioxide out of the atmosphere and pump it back into the ground? And if there is what exactly are the mechanics to making that work?

CatboyInAMaidOutfit

Ken: There are proposed industrial approaches that use a caustic solution to remove CO2 from the atmosphere, and then use chemical processes similar to what is used in the pulp and paper industries to remove that CO2 from solution. The CO2 gas can then be compressed and pumped underground. It is all technically feasible but it is not cheap.

Two parter: 1. With the exception of budget cuts, what would you say is the most potentially harmful piece of legislation currently threatening the environment? 2. What is the simplest change the average American can make to help slow the progression of climate change?

BruceTheSpruceMoose

Ken: 1. I am not up on all the bits of legislation up before Congress, but there seems to be a flood of bad policy moving through the process and it is hard to know which piece is worst. 2. I think the simplest change the average American can make is to get politically involved and make it clear to politicians that voting the wrong way on climate issues means you won't get reelected.

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redditWinnower

Ken: Great! I hope I don't say anything too stupid.

Ben: Excellent.

Is it possible with current technology and data for scientists to rule out the possibility that the effects of global warming might just be some sort of 'cycle' the earth naturally gets over time?

This is not dismissing damage done to the environment (which is obvious and proven), just slightly questioning the 'ultimate cause' (pollution)

The question comes from curiosity as it seems that most of the data humanity has on the subject and history logs of weather in general is barly 100~ years old which might seem a lot but if we put it into planetary life cycle could be nothing.

We could be witnessing something else entirely and reading it wrong (for example magnetic pole reversal as discussed in Discovery)

ShikukuWabe

Ken: Today, atmospheric CO2 is increasing at a rate that is about 100x greater than natural variations. Only about half of our CO2 emissions remain in the atmosphere, so we know that these CO2 emissions are due to us. It would challenge physics to explain how CO2 could rise so quickly without causing climate to get hotter. We know that most of the temperature increase over the past 50 years was due to human activity.

We know that planetary temperatures were very high 100 million years ago when the dinosaurs were around, but it took millions of years for the Earth to get that warm. The main problem is not so much the state of the climate system but how fast climate is changing. It is changing too fast for many ecosystems and human systems to keep up with.

What are some struggles with renewable power integration? Say we wanted to go 100% renewable by 2050, what would be the biggest obstacle during the transition?

Tramony

Ben: As you know, our current infrastructure is based on fossil fuel energy. In the US 80+% of energy is still produced this way. Once the obstacle for energy transition was technology, but today the obstacle is mostly infrastructure (transportation, gird, etc) and embedded interests (industry, job sectors, etc). Price is no longer a large issue.

What are some struggles with renewable power integration? Say we wanted to go 100% renewable by 2050, what would be the biggest obstacle during the transition?

Tramony

Ken: One of the biggest challenges is dealing with the intermittency of wind and solar electricity generation. Another big challenge is how to decarbonize things like aviation, which today depends on dense liquid fuels. Ultimately, it is largely a question of willingness to pay more for something that works a little less well, but is better for the environment.

..."and toying around with this planet at the required scale would pose great risks"

What kind of risks?

DMAC55

Ken: There are at least two types of risks: environmental risks and socio-political risks. For environmental risks, I worry most about unknown unknowns. We have only one planet and its operation is very complex. If we interfere in its operation, there is a very good chance we will screw things up. Most of the known environmental risks, however, do not seem as bad to me as the risks of high CO2 alone. The socio-political risks include: inducing complacency in a techno-fix, so people do not feel a need to stop dumping CO2 pollution in the sky; possible international conflict over whether to deploy a geoengineering system; etc.

What is the impact of the weakening polar vortex?

I've read in books/ heard Al Roker mention how it affects the weather, but how exactly?

Krefish

Ken: I am not an expert on this, but some people theorize that as the temperature difference between the equator and the north pole gets less, the jet stream is less confined to a west-to-east flow and starts waving around more. With these deep waves in the jet stream, tropical air gets pulled farther north and Arctic air gets pulled further south. Thus there is the potential that global warming can induce more temperature variability and possibly be responsible for record cold events. This is, admittedly, speculative and the topic of current research.

How do you feel about Naomi Klein's book 'This Changes Everything' and its conclusion that capitalism is at the Crux of the climate issue and can only be solved by reevaluating that part of our society?

Jdf121

Ken: If we have to wait to save the climate problem until capitalism is overthrown, we will be waiting too long. The climate problem is not that hard to solve technically. We just need to decide that we are willing to pay for it. Economists estimate that solving the climate problem might cost 2% of GDP. Compare this with the 17% of GDP the US now spends on health care or approximately half of that it spends on the military. We could be more efficient on delivering health care or spend less on the military and easily have enough resources to solve the climate problem.

How do you feel about Naomi Klein's book 'This Changes Everything' and its conclusion that capitalism is at the Crux of the climate issue and can only be solved by reevaluating that part of our society?

Jdf121

Ben: I have not read the book, but heard the arguments. One could also argue that capitalism will support change if you and I decide to make our choices accordingly. For example, oil companies find and sell oil because we buy it, right?

As professors in climate science and related fields, what are your reactions to how the new presidential administration is handling climate science?

Krefish

Ken: Good policy depends on good science. It is not clear to me that the current Administration sufficiently values good science, and thus my expectations for good policy are quite limited.

Do you agree with Chomsky that, along with nuclear war, climate change is the biggest threat to humanity currently?

RiotSloth

Ken: Climate change represents an unprecedented challenge because our individual actions over the next years and decades will affect what this entire planet will be like for the next many thousands of years. I wrote an article for Scientific American on what might happen if we do not curtail emissions (https://www.scientificamerican.com/article/how-far-can-climate-change-go/). I don't think climate change is an existential threat to humanity in that we will not go extinct as a species, but it is a threat to the well-being of large numbers of people around the world and far into the future.

Do you agree with Chomsky that, along with nuclear war, climate change is the biggest threat to humanity currently?

RiotSloth

Ben: Yes. In fact, war and environmental change have always been threats to human society, in the past and into the future. Today, we may be more sensitive to environmental change then ever before.

I feel that a large gap exists between science findings and science journalism, particularly when it comes to climate change. What are some questions that a layperson, such as myself, should ask when trying to find accurate answers to complicated science questions?

Grimroulf

Ken: There are some good web sites, like http://realclimate.net/ that provide accurate answers. Science is mostly incremental, but science journalism has a need to make everything sound new and revolutionary. So, it is often a challenge for journalists to get their editors to agree on good placement of their stories if they go into detail about how this new piece of research is mostly just another piece of a very large mosaic.

With regards to the actual science you do, where can one find a good overview of the theory you use for your models and the models themselves?

I've seen several links to raw data such as from ocean temperature buoys and ice core samples. But what I'd love to get my hands on (mainly also to solidify my own knowledge of how much we know for

certain and what's still uncertain) is the models and their underlying theories.

mephistophyles

Ken: The basic theory is Newton's laws of motion and things like Stefan-Boltzmann law. Much of climate science is just a branch of classical physics, so the foundations can be found it basic physics textbooks. If you google 'textbook climate physics' you can find a bunch of good basic textbooks. I am sure there is a good review of the basic theory on the web somewhere, but I am not sure where. (Reddit readers, do you have a suggestion?)

What sort of opportunities are available for mathematics PhD candidates to impact climate change with their research?

jbillz95

Ken: Mathematics PhD candidates who are wanting to engage in applied problems can apply to a job opening I have right now on optimization of idealized near-zero emission energy systems: http://carnegieenergyinnovation.org/index.php/jobs/ I am sure other jobs are out there, but I am not sure what. Solving problems depends on native ability and good skills. Domain knowledge is easy for smart people to learn.

Solar radiation management (particularly through the injection of sulphate aerosols in the stratosphere) is a form of geoengineering that has seen significant interest among researchers as a potential way to buy time of society can't get its act together to reduce emissions quickly enough. As researchers who have worked extensively on the subject, what do you see as the relative pros and cons of this geoengineering approach?

ZekeHausfather

Ken: The pros are that solar geoengineering with stratospheric aerosols is pretty cheap and easy, and we know from volcanic eruptions that it will basically will work and not cause the world to end. The main cons are that there are likely to be both environmental and sociopolitical downsides that are hard to predict. Risk aversion suggests we would do better to try to reduce our interference in complex Earth-system processes, and that increasing our interference is likely to lead to unforeseen problems.

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ZekeHausfather

Ben: SRM as you describe would allow us to turn action on and off at will. That is good. However, we must be sure that the neighbors agree with such action. This requires dialogue and shared decision-making.

How concerned are you about methane release from thawing permafrost and seabeds? Recently an article was reported on that said there's a real possibility of climate catastrophe from this in as little as ten years.

r4gt4g

Ken: I think of methane release from permafrost as a second order problem that could potentially worsen climate change by 10% or so. Given all of the uncertainty in climate sensitivity and biogeochemical feedbacks, I do not see permafrost uncertainty as the biggest concern. For example, uncertainty in cloud responses adds more uncertainty to climate projections than does uncertainty in permafrost feedbacks. It is something to keep an eye on, but the pace of heat diffusion and the role of methanophilic bacteria suggests that melting permafrost is unlikely to be a game changer. A concern, a risk, but not the best obsession.

Can't reforestation be used now to draw down and sequester CO2 (via burial, biochar, buildings...) on a global scale? Aside from the removal of CO2 cheaply and without new tech, new forests could provide habitat restoration, soil erosion control, and potentially be a sustainable source of resources for communities. Are there barriers on current reforestation efforts?

Aximill

Ken: Reforestation can help, but there is just not enough land on Earth for reforestation to take up all of the industrial CO2 we are emitting. Reforestation is usually a good thing to do, but we just can't do enough of it for it to be the primary way we address the climate problem.

How long do you think we have before climate change gets really bad for humans?

WisperingPenis

Ken: This is a tough question because climate change will not be felt mostly as a change in the average but rather a change in the extremes. It is not possible to say definitively how much an extreme event is due to climate change and how much is natural. Also, when extreme events happen, the damage is due both to our social systems and the natural systems. So, was the destruction of much of New Orleans with Katrina due to climate change? How much was climate change? How much was natural? How much was due to poor work by the Army Corps of Engineers? Hard to say.

That all said, the thing I worry about the most is if heat stress or drought starts causing crops to fail with greater frequency in the tropics. Some people have associated political strife in Syria in part to drought that might be partially associated with climate change.

All disasters are multi-causal and involve complex interactions between human and natural systems. But it seems to me, when people find it harder to grow food because of heat or drought, the chances for war and human migration increase, and that can create further knock-on problems.

Climate change does not occur in isolation. It occurs in the context of other human activities (and natural systems). Where these systems are already worn thin, climate change may tear the fabric.

How does the flux in carbon and sulfur emissions into the atmosphere effect aeromicrobial acitivity? And how will this subsequently effect cloud formation and albedo?

imikoe

Ken: This is largely an unknown. Cloud responses are very difficult to predict. As far as I know, no modern climate model even considers aeromicrobes.

How does the flux in carbon and sulfur emissions into the atmosphere effect aeromicrobial acitivity? And how will this subsequently effect cloud formation and albedo?

imikoe

Ben: I don't know the answer, though someone likely has explored aspects of this question. This is why climate engineering should be part of the discussion, so we can research and understand the implications.

No matter how it is produced, the world is using more and more energy much of which ends up as heat. Does this contribute to global warming? Or is it negligible? For example, wind is turned into electricity and powers a microwave oven, or even a computer which generates heat.

GreyDeck

Ken: We wrote a paper on this exact topic. Today, the warming from our cumulative CO2 emissions is about 100x greater than the direct thermal warming from our energy use. Over its lifetime in the atmosphere, the CO2 from burning a lump of coal heats the Earth more than 100,000 times more than the direct heating from the burning coal. http://onlinelibrary.wiley.com/doi/10.1002/2015GL063514/full

No matter how it is produced, the world is using more and more energy much of which ends up as heat. Does this contribute to global warming? Or is it negligible? For example, wind is turned into electricity and powers a microwave oven, or even a computer which generates heat.

GreyDeck

Ben: My Michigan colleague Mark Flanner works on this and, in short, says it is very, very small (1%). Have a look at this site: https://skepticalscience.com/Waste-heat-vs-greenhouse-warming.html

Assuming (as I do) that anthropogenic climate change is real, and assuming (as I fear) we will not be able to change our behaviour in time for climate change to significantly impact the planet as a whole, is there work being done to come up with things we can do to actively intervene and stop or limit climate change through technological means?

jeroen94704

Ken: Yes. Since at least 1965 people have been thinking about ways to cool the Earth by reflecting more sunlight to space. Some of these ways seem technically feasible and with low direct costs. However, they entail substantial risk. A good overview can be found here: https://nas-sites.org/americasclimatechoices/other-reports-on-climate-change/climate-intervention-reports/

I recently read a paper that found fracking was producing more leaks than we had previously thought. Is methane in the atmosphere a problem that should be talked about more? Also what damage are we doing to the Earth by using fracking and what consequences might we see? Thank you very much for your time and I wish you the best of luck in your mission

Diltron24

Ken: There are several issues with fracking. To me, the central question is whether we want to be expanding fossil fuel industries that depend on dumping waste CO2 into the sky at a time when we know that we need to be phasing out such industries. Methane releases associated with fracking are

substantial, but with good management policies these emissions can be curtailed. It is much harder to prevent the CO2 from combustion of that methane from reaching the atmosphere. Of course, when fracking is poorly implemented, there is the potential for substantial local environmental hazard.

I recently read a paper that found fracking was producing more leaks than we had previously thought. Is methane in the atmosphere a problem that should be talked about more? Also what damage are we doing to the Earth by using fracking and what consequences might we see? Thank you very much for your time and I wish you the best of luck in your mission

Diltron24

Ben: Fracking indeed targets the release of the greenhouse gas methane that is buried in geologic (typically shale) formations. The goal is to catch this released gas, but, yes, some escapes. Such leaks are tracked by EPA and NASA agencies, for example. The bigger issues with fracking are subsurface pollution (like groundwater) and fossil fuel burning. Methane is converted to CO2 for energy production, a greenhouse gas, which contributes to atmospheric warming. As a geologist I also want to mention human-induced earthquakes from fracking, but that is for another AMA.

What tipping point do you think will end the corporate-sponsored mass denier movements in the west? Or are the courts likely to do it first?

Taste_the__Rainbow

Ken: I push back on the "tipping points" framing. Most changes in the climate system will, I think, be fairly progressive and continuous. Tipping points can happen in social systems, where there is a phase change in human attitudes towards something. It is, of course, challenging to try to create that social tipping point. I guess that I am doing a little but to try to create that tipping point by doing this Reddit AMA.

What tipping point do you think will end the corporate-sponsored mass denier movements in the west? Or are the courts likely to do it first?

Taste_the__Rainbow

Ben: the problem with the notion of "tipping points" is that climate change is gradual on the human scale. Perhaps looking back we will see the aggregate of impacts as a tipping point, but day-to-day we see mostly annoyances. Their costs might be the ultimate driver for changing our practices. My fellow geologists in a future, far, far away will likely see a tipping point in our reaction.

Hi there -- thanks for doing the AMA, and let me preface my question with the statement that I'm fairly up to date about how rapidly the earth has started to warm in recent years, and because I live in the Canadian sub-arctic I have seen these changes first hand (and they're staggering). I'm also aware that humanity has basically gone "over the cliff", and we're now in between going over the edge and hitting the ground, leaving geo-engineering as the only viable way to avoid human extinction at this point.

Question 1: I know the spraying of sulfur dioxide in the stratosphere is commonly mentioned as an attainable way of deflecting solar radiation. However SO2 also breaks down ozone, which would make it unsuitable for sustained use. Are there any other compounds currently being considered? Compounds that could remain in the stratosphere for some time, and accomplish the same as SO2 or better?

Question 2: Are you aware of any serious (= large budget) programs currently concerned with artificial CO2 sequestration? I saw a calculation the other day of the energy required to draw all excess carbon out of the air and store it, and the number was just astronomical. Do you consider it likely humanity can start sequestering carbon on an industrial scale in the next 10 years?

Thank you!

NorthernTrash

Ken:

Q1: Other compounds are being considered include calcium carbonate and other particles. SO2 has the advantage that it can be released as a gas and oxidizes to form sulfate particles of the right size, is cheap, etc. It is hard to grind solids sufficiently small and disperse them in the stratosphere without clumping etc.

Q2: Power plant smokestacks have about 10% CO2 in them, whereas the atmosphere has about 0.04% CO2 in it. As long as we have power plants burning fossil fuels, it will likely be easier to get the CO2 out of the smokestack than out of the atmosphere. I see large scale atmospheric CO2 removal as a bit of a pipe dream, and only something that might be done at scale after our entire energy system is decarbonized and then we are trying to clean up the mess we have previously made. In other words, at this time, I would focus on emissions reduction and not carbon dioxide removal.

Do you believe engineering alone can save us? Looking in the past you can see that a lot of engineering for the environment could be seen as "bandaids" and ended up having their own problems. This allows people to continue living their current lifestyles without making any sacrifices. Do you believe this is sustainable in the long run?

TannerL22

Ken: Ultimately, it is improved social systems that will save us. Engineering can help (especially energy systems engineering), but we need social systems that more closely align individual incentives with the greater public good. Today, too many people benefit personally by doing things that harms the broader public interest. Without addressing this issue, it is hard to see how we are going to successfully address any of the major pressing problems that we face.

Hey Ken,

You mentioned your work on Ocean Acidification does not involve computer modeling. Why is that?

how do effects in plankton population and some of the very low trophic level species ripple up to higher trophic levels, i.e. fish we eat. Is the effect non-linear, and is it measurable?

Also, the whole idea of C02 can be viewed as a tragedy of the commons problem, to which "there are no technical solutions" -Harding. Geoengineering definitely contradicts this premise, but I was wondering what your thoughts are.

Also What further reading would you recommend on Ocean Acidification, and are there any potential artificial intelligence applications that you think are promising?

Thank you for your time.

Gorelamy

Ken: We have published work doing computer modeling of ocean acidification (for example, http://iopscience.iop.org/article/10.1088/1748-9326/8/3/034003/meta). However, I started feeling that there was only so much more we could learn from modeling without new data, so I shifted the ocean acidification part of my research program to be primarily observationally based. A report on some of that research can be found here: http://www.nature.com/news/landmark-experiment-confirms-ocean-acidification-s-toll-on-great-barrier-reef-1.19410

Corals are relatively easy to understand because one class of organisms (corals) are the architects of the entire ecosystem. In open ocean ecosystems, it is unclear what the loss of certain types of organisms at the base of the food chain will mean for organisms higher up in the food chain. Very difficult to predict with models and very difficult to address this question experimentally.

A good place to start reading about ocean acidification is: http://www.whoi.edu/OCB-OA/FAQs

I don't know much about artificial intelligence. A little more human intelligence or perhaps more important, wisdom, is sorely needed.

1) Geoengineering is a tempting solution to climate change, but is controversial because it may serve to complicate the current problem. What are some potential negative effects of geoengineering, and how do you work those into your simulations? If you do think geoengineering could work, how can you ensure it won't cause more problems than it solves?

2) Ocean acidification: I know you aren't biologists, but can you discuss how this may affect calcareous plankton species? How resilient are they, or is the entire marine food web facing a collapse? What are some other important things the layman should understand about ocean acidification?

smalltowel

Ken: 1) We do not 'work problems into simulations' but rather problems are identified because of simulations (e.g., risk to ozone layer, risk that some areas may experience excessive drying). The reason we are doing scientific research in this area is to provide people with information that they would need to help decide whether expected benefits would outweigh possible risks.

2) It is unclear what ocean acidification will mean for marine plankton. It is clear that it requires more energy to make calcium carbonate shells or skeletons in more acidic waters, but what this will mean for individual species or ecosystems is hard to predict. Ocean acidification is an ongoing global experiment that I would prefer not to see us running.

How fucked are we? Because from what I've read, the basic models most commonly used — which are gloomy enough — don't take into account methane emissions. So it seems like we're in a much more dire FUBAR state than anyone not on the fringe will publicly admit.

ballgame

Ken: I am an optimist about human ability to adapt and create new technologies to make our lives better. Globally, education, longevity, health, etc, have been improving. I see climate change as something that will slow overall improvement. I don't think it will send us back to the dark ages.

On the other hand, there are important equity issues. Rich people in rich northern countries can build gated communities, watch Fox News, and block out the rest of the world fairly successfully. However, if you are a poor person in the Sahel or in India, you won't be so lucky.

A question is whether the rich person in the gated community will really be able to block out the poor person outside the gates forever. (BTW, our new President's immigration policies seem aimed at

narrowing these gates and strengthening the surrounding walls.)

Curbing CO2, methane, etc is politically and practically very, very hard. Will geoengineering be our only option? How smart are we to pull this off?

lerxst1

Ken: Phase changes in social systems are possible. People used to accept slavery and no longer accept slavery. Few people foresaw the fall of the Soviet Union. Few people thought Congressional Republicans would be supporting protectionist trade policies and support a pro-Russian President. So, the unexpected can and does happen.

I am still hoping for and working towards a change in social attitudes towards using the sky as a waste dump for our CO2 pollution. I am hoping this will result in a major transformation of how we obtain and use energy. But, I don't want to put all of my eggs in one basket, so I also want to understand whether and how geoengineering options might be able to reduce suffering and damage in both human and natural systems.

How do you feel about the recent budget proposal by our new administration with the budget cuts to climate change organization like NASA and EPA?

TakeMeDrunkImHome22

Ken: It saddens me to see how little some of our politicians appreciate the value of good science, or even of facts in general. To many of our politicians, the only facts that seem to matter are political facts. We like to think that people make decisions based on facts, but instead it seems like we are sinking into tribalism where people support decisions or hold beliefs based on feelings of tribal membership rather than analysis. It feels like we are drifting from rationalism back to some sort of medievalism, and this is very troubling to me as a scientist, and a source of some anguish.

How do you feel about the recent budget proposal by our new administration with the budget cuts to climate change organization like NASA and EPA?

TakeMeDrunkImHome22

Ben: Today's attack on science is deeply concerning. As Feynman said, "It is that scientific knowledge enables us to do all kinds of things and to make all kinds of things." We are in this together, each contributing in our own way. Unwelcome scientific information is part of that equation, as are searches for solutions.

What is your opinion on the moral hazard posed by geoengineering, that treating the symptoms rather than the addiction simply enables us addicts to keep destroying ourselves?

Splenda

Ken: When we have a cancer patient, we want to treat the underlying disease and not just the symptoms, but we want to address the symptoms also. If CO2-emissions reduction is the cure for the disease, solar geoengineering might be able to provide symptomatic relief.

Regarding whether solar geoengineering would reduce incentives to reduce emissions, that is a real risk and should be considered. However, I have also found that talking about solar geoengineering is a

way to get people who (because of their tribal identity) do not like to consider climate change risks to start considering those risks and what we might do about them. I know people who have come to the conclusion that we need to transform our CO2-polluting energy system who got into the problem by looking at geoengineering solutions.

The end game of a very high-CO2 world with a thick layer of aerosols in the stratosphere sounds like a dystopian future. It doesn't take too long thinking about geoengineering to understand that it doesn't absolve you of the need to transform your energy system.

What is your opinion on the moral hazard posed by geoengineering, that treating the symptoms rather than the addiction simply enables us addicts to keep destroying ourselves?

Splenda

Ben: We have been discussing the impacts of our "addiction" (your term) for years now, with limited progress. Climate engineering introduces a solution that would combat near-term impacts while we transition to alternatives.

What specific evidence can I point to to make my hillbilly relatives open their stupid eyes about the reality of climate change?

Fidesphilio

Ken: Language is very important. You might ask your older relatives if they notice that the weather is different from how it was when they were a kid. Weather is something we are all familiar with, whereas climate is something abstract. Maybe if you try talking to them about the kind of weather they typically get, you would get further than talking about climate.

Another thing that helps is optimism on solutions. Economists estimate that solving the climate problem will cost something like 2% of GDP. That is something less than 1 year's worth of economic growth. Maybe you could say, 'Hey, you know, if we are willing to wait until year 2101 to be as well off as we would otherwise be in year 2000, we could avoid the risk of melting ice caps, making people in the topics unable to grow their food, etc, etc." With all of the anti-immigration sentiment stirred up by Trump, perhaps the argument that you want people to be able to continue living in the tropics, and not create massive migrations, might play well.

It is a tough question.

Lets say all the ice melted (places like Greenland and Antarctica), due to climate change, what would be the outcome? I can guess the ocean levels would rise, but what else?

DriftShade

Ben: Based on the volume of ice on Greenland and Antarctica (that is, non-floating ice), a full melt would result in >75m (>250 feet) sealevel rise. This ignores the additional rise from a warmer ocean. Such large rise is very unlikely for the near future, but even a 1m (3feet) rise has major consequences for human society. Just consider the relocation needs alone.