The New Post-IPCC Climate Science

A Darker Frame for our Options and Our Future

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Relevant Background

- M.S. in Aerospace ‘76 Univ. Az, thesis: developing numerical computer codes modelling non-equilibrium viscous fluid flow
- Thermal analyst, design for Atlas/Centaur rockets and space missions for General Dynamics in San Diego
- Thermal design lead for General Dynamics’ proposal for the International Space Station
- Stanford University PhD program in Applied Physics ‘78/‘79, but left for unrelated personal necessity to Los Angeles, finishing PhD in Astronomy at UCLA 1984. Grad research projects included:
- -- Application of chaos theory to barred spiral galaxies, numerical simulation development
- -- First application of new technique “Smoothed Particle Hydrodynamics” to stellar disruption around black holes
- -- Dissertation; novel use of ANOVA techniques to merge discrete stellar Doppler data with nuclear dispersion measures to make consistent dynamical models of disk galaxies and spheroid galaxies, with application to the Andromeda system. Planetary nebulae observational work at Kitt Peak National Obs.
- Post doctoral fellowship at Steward Observatory, galaxy clustering dynamics of Cold Dark Matter models and observational galaxy cluster data
- **UC Santa Cruz Astronomy**, lecturer and visiting researcher in late ‘80’s and ‘90’s. Part of the Joel Primack - led Dark Matter team modelling numerical evolution of cosmic structure in Primack’s Cold+Hot Dark Matter theory and confronting with observations, and with Sandra Faber *et al.* team defining the emerging Fundamental Plane describing dissipative stellar systems
- **At Cabrillo College** first Department Chair of Astronomy, wrote and distributed the RPHOT photoelectric photometry software package to observatories in ’90s, built Cabrillo Observatory with help from Cabrillo’s Construction Engineering Management students. CCD camera systems and software, astrophotography
- Member of the Ground Team for the NASA/JAXA Hayabusa asteroid mission to Australia in 2010, in charge of spectrophotometry of re-entry vehicle to evaluate heat shield performance.
- Switched major focus to climate science in 2010, developed course **“Astro 7 – Planetary Climate Science”** whose main focus is current Earth climate change – physical science, engineering options, policy, confronting climate denialism, psychopathologies, and the Thermodynamics of Civilization

The IPCC AR5 was Completed in 2013

- Since then, four years of new science shows a dramatically less sanguine situation, yet policy white papers continue to use the obsolete IPCC carbon budgets.
- **This lecture will describe…**
- -- missing climate forcings and
- -- missing climate feedbacks
- -- other recent discoveries which the IPCC did not include in its models or scenarios.
- Also:
- -- the **Reward Structure** of the political, scientific, and economic bodies involved, as a frame for how to interpret claims in light of agendas.
- **The next IPCC AR6 is not due till 2022. We can't wait that long to meaningfully confront the dramatically different world we face.**

First: The Motivational Context…

- Unfortunately, the U.N. IPCC process is fraught with motivations and agendas which seek to minimize the communication of the actual climate future which peer-reviewed research in scientific journals shows we face.
- Let’s list these and then support that statement…

A. It's a Consensus Document

- Hundreds of scientists contribute to the writing of the IPCC documents
- *"Authors for the IPCC reports are chosen from a list of researchers prepared by governments and participating organizations, and by the Working Group/Task Force Bureau, as well as other experts known through their published work. The choice of authors aims for a range of views, expertise and geographical representation, ensuring representation of experts from developing and developed countries and countries with economies in transition." (source)*
- Yet – it's a consensus document and that means that only the lowest levels of "alarm" can get approval, despite what published research says, and yet the specified purpose is digestion of published research relevant for climate policy formation. **Cross purposes!**

B. The Culture of Science: Dry and Understated

- Making alarming claims which later prove false is considered a more severe risk to career - especially if you are under political pressure to understate - than is making conservative statements which later prove to be too mild.
- It's also more embarrassing; no one wants to be associated with the archetypal bearded cartoon guy in a robe on the street corner

If you're in the prime of your career as a scientist, this is <u>not</u> where you are eager to go

C. Threats Against Climate Scientists, Targeted as the Highest Profile "Alarmists"

- Fossil fuel funded "Climategate" false attacks on climate scientists unleashed a large volume of hate mail, threats to scientists and their families, FOI fishing expeditions, and other intimidations against scientists who are not psychologically self-selected for, nor trained to deal with, such attacks.
- These intimidations indeed tend to water down and/or silence many scientists' public statements and to water down the wordings in their peer-reviewed papers.
- This is reflected in the IPCC summary documents, which, at idealized best, is a summary of available published work

Of course, it's only gotten worse with the new Anti-Science Administration

- Scientists were **scrambling to save** critical NASA, NOAA, EPA, and other climate data before the Trump administration took over.
- ***"Rogue Scientists Race to Save Climate Data From Trump"***
- **Students organized impromptu hack-a-thons** to save irreplacable EPA, NOAA, NASA and other scientific data sets before they could be destroyed or worse – altered in today's new "alternative facts" paradigm.
- **"1984"** became the new 2017 best-seller as people tried to digest and adjust to what may be coming

We Need a New Rebel Alliance

(but I digress – back to the IPCC…)

As a consequence, scientists have been slow to speak with the Cognitive/Emotional/Moral force necessary for effective communication

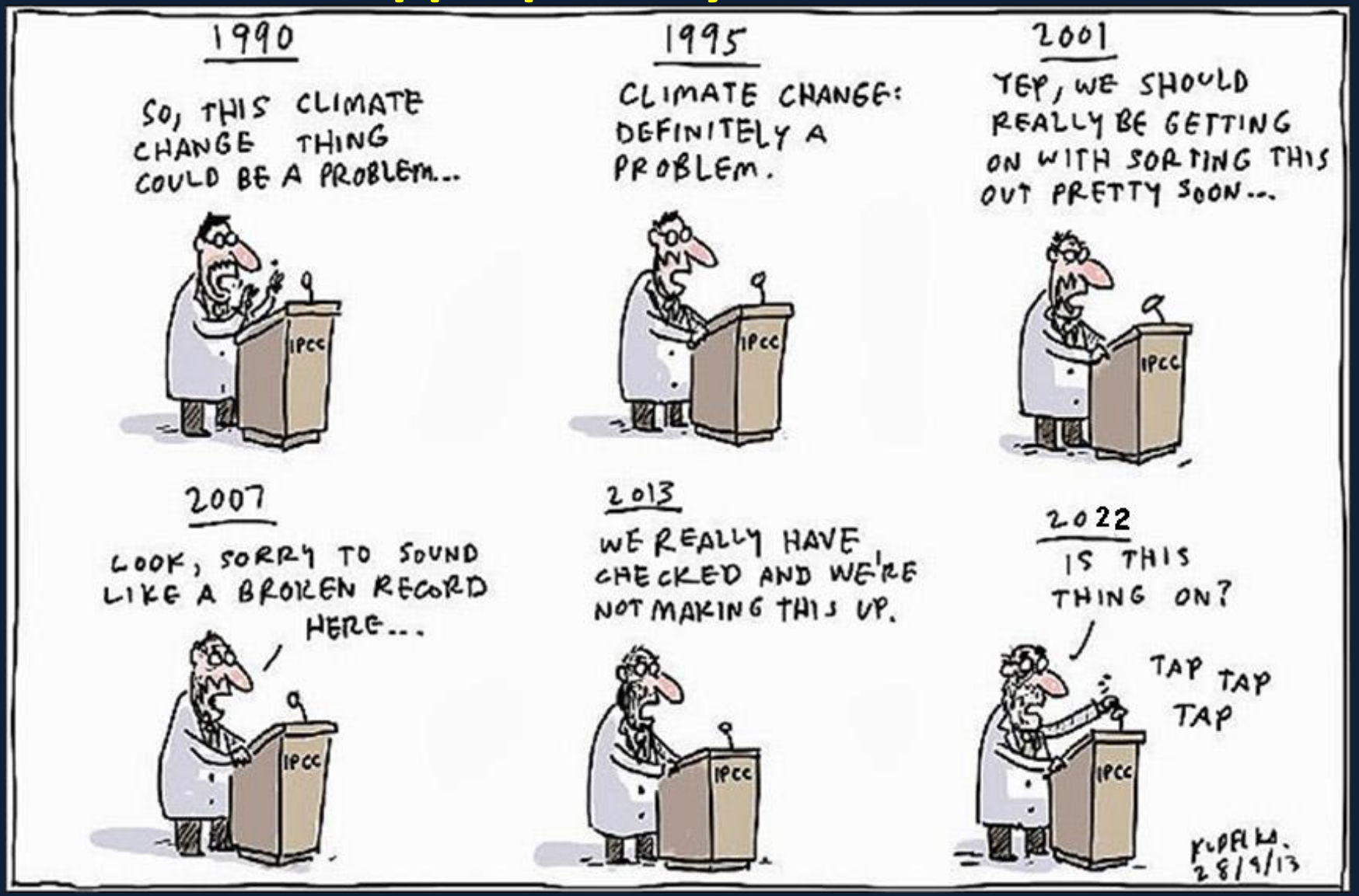
- This is not controversial – they know it, they admit it, and it's due not just to the intimidation, threats, and hatred they've been subjected to by the right wing climate denial community, and the political meddling in the IPCC process…
- It's also due to the science culture: the unemotional, "rational" ethos which initially was inviting to young people who were attracted to science after fleeing the irrationality common in much of everyday life.
- Glaciologist **Dr. Eric Rignot** expresses it well (AGU '14 interview (4:29)) and even more poignantly **here**, by Jet Propulsion Labs Earth scientist **Peter Kalmus**. Key quotes on following slides…

Writes Dr. Kalmus…

- *"**I'm afraid to publish this article.** Why? Because I'm a climate scientist who speaks out about climate change, and in speaking out I may be risking my career. But I do so anyway, out of love—love for my two young sons, for others' kids, for wild animals, for this beautiful planet…*
- *"But **many scientists—myself included—worry that standing up for what we know to be true**, or advocating for a particular action in response to anthropogenic change that we find deeply disturbing, will make us look biased or unprofessional. We're afraid that if we speak out, we'll lose our funding or be labeled as politicized or alarmist."*

- *"And when we have something scary to say, we employ the dry and precise language of science…."*
- *"However,* ***when climate scientists don't speak out, we're inadvertently sending a message that climate change isn't urgent. If the experts—the scientists on the front lines, the people who know—are so calm, dispassionate, and quiet, how bad can it really be?"***
- ***"I experience a surreal tension between the terrifying changes unfolding within the Earth system and the Spock-like calm maintained within the scientific community****."*
- *"Following a formal scientific talk about dying forests or disappearing glaciers, for example, audiences commonly ask a few questions on instrumentation or methodology, and then quietly shuffle out."…*

When the stakes are climate chaos and mass extinctions, the IPCC scientists (with rare exceptions) haven't been appropriately forceful communicators

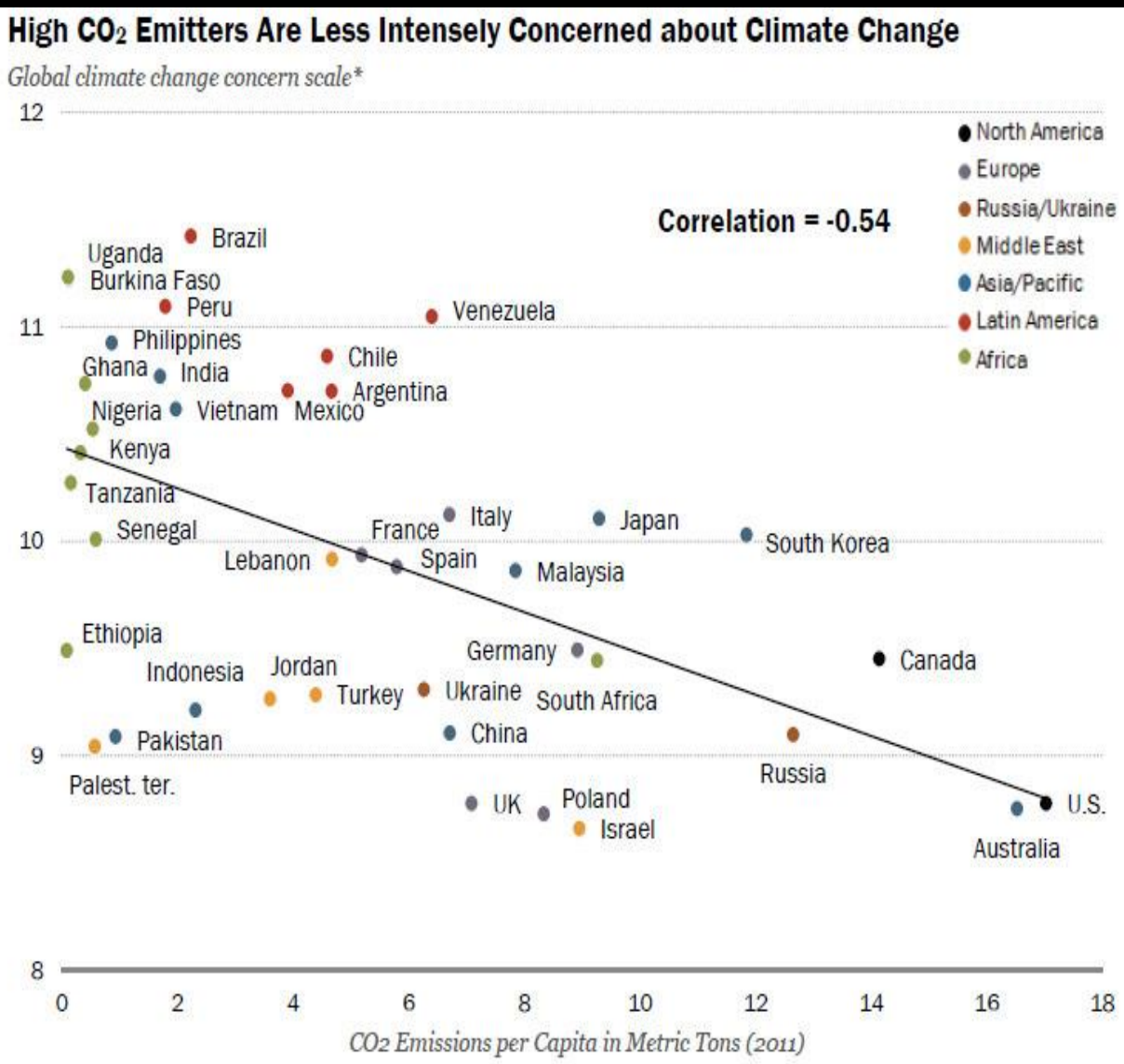


D. Political Interference in IPCC Summary Statement for Policy Makers

- Exxon-Mobil successfully lobbied the George W. Bush administration to push hard to have IPCC Chair climate scientist Robert Watson replaced by a more industry-friendly chair; R. K. Pachauri, whose background is economics.
- Current IPCC Chair is Hoesung Lee, also an economist, and brother of the former South Korean Prime Minister

IPCC scientists “final” documents are then gone over by political representatives

- These representatives are predominantly from the largest, richest countries. Countries with the highest carbon emissions, countries dominated by the largest fossil fuel corporations on Earth.
- *“According to Dr. David Wasdell, who leads (in IPCC) on feedback dynamics in coupled complex global systems for the European Commission's Global System Dynamics and Policy (GSDP) network, ‘Every word and line of the text previously submitted by the scientific community was examined and amended until it could be endorsed unanimously by the political representatives.’" (source linked in this article)*



* Concern about global climate change is measured using a three-item index ranging from 3-12, with 12 representing the most concerned about climate change. Respondents were coded as 4 if they believe climate change is a very serious problem; if they think climate change is harming people now; and if they say they are very concerned that climate change will harm them personally at some point in their lifetime. The mean score for each country is used in this analysis. (See Appendix for more details.)

Source: Spring 2015 Global Attitudes survey. Q32, Q41 & Q42. Data for CO_2 emissions per capita from World Bank Data Bank, accessed August 5, 2015.

PEW RESEARCH CENTER

Yet, the highest CO2 emitters are the most politically motivated to minimize the perception of climate danger

“A Document of Appeasement” – Prof. David Wasdell (source)

- *“Wasdell said that the draft submitted by scientists contained a metric projecting cumulative total anthropogenic carbon dioxide emissions, on the basis of which a 'carbon budget' was estimated – the quantity of carbon that could be safely emitted without breaking the 2 degrees Celsius limit to avoid dangerous global warming. He said that* ***the final version approved by governments significantly amended the original metric to increase the amount of carbon that could still be emitted. (and this is the version Policy people use)”***

The +2C "Carbon Budget" - Fundamental flaws

- **Wasdell:** *"The total carbon budget according to this estimate is about 1,000 gigatonnes of carbon (GtC) – although over 531 GtC was emitted already by 2011, leaving 469 GtC left. Applying the 'corrected non-linear function' reduces this available budget to just '280 GtC' – this figure does not account for the role of greenhouse gases other than CO2, including the potential impact of thawing permafrost or methane hydrates"*
- Note, **from Nobel Laureate Steven Chu**, that the CO2 equivalent of all human GHG's (*i.e.* including CFC's, HFC's, methane, nitrogen oxides, etc.) is not 410 ppm but 500 ppm today in mid 2017.

If included, they would reduce the budget much further. Current emissions reduction pledges, therefore, still guarantee disaster.

- Wasdell's paper reads:
- *"... present levels of international contribution towards the reduction of emissions still led to a cumulative total of 2,000 GtC by the year 2100. That left an emissions reduction gap of some 1,097 GtC between promised reductions and the 903 GtC required to prevent temperature increase exceeding the policy goal of 2°C."*
- ***"The summary for policymakers is a document of appeasement, not fit for purpose. In reality, if my calculations are correct, we not only don't have much of a carbon budget left, we have already overshot that budget – we're in overdraft."***

Wasdell's claims about the politicization of the IPCC's summary reports for policymakers are corroborated by other scientists...

*In a **letter** addressed to senior IPCC chairs dated 17th April, Prof Robert Stavins - a lead author for the **IPCC's Working Group 3** focusing on climate mitigation - complained of his "frustration" that the government approval process **"built political credibility by sacrificing scientific integrity."***

Far from being the "Summary for Policy Makers" he called the document the "Summary by Policy Makers".

Incredibly, 75% of the text of the document written by the scientists was deleted by the policy people before they would sign off on it (National Geographic)

And more… this report continues…

- *Oxford University's **Prof John Broome**, a IPCC WG3 lead author: "At our IPCC meeting, they treated the **SPM** (**S**ummary for **P**olicy**m**akers) as though it were a legal document rather than a scientific report. To achieve consensus, the text of the SPM was made vaguer in many places, and its content diluted to the extent that in some places not much substance remained."*
- *"Far from being too alarmist, these criticisms suggest that the IPCC's summary reports are too conservative. Like Wasdell, Broome describes how **'a coalition of countries led by Saudi Arabia' at the April approval session in Berlin 'insisted' that all 'figures' depicting increases of greenhouse gas emissions in countries classified by 'income group' should be deleted."***
- *"Saudi Arabia, he said, also 'wanted to delete all references to any part of the main report that mentioned income groups…' **in the end Saudi Arabia, got its way completely."***
- ***As for future reports… IPCC lead author Dr. David Victor says he "can't imagine that the national governments that participate around the world in the IPCC process agreeing to any substantial reforms in that area "(i.e. can't imagine they'd agree to reform towards keeping a firm separation between the scientific conclusion communication and meddling by the diplomats).***

What Wasdell points out is supported by many other scientists in the IPCC Process

- *"Although the caveats are listed in the IPCC assessment, the report (IPCC AR5) does not adequately highlight economic and technical challenges or modelling uncertainties, says* ***David Victor****, a political scientist at the University of California, San Diego, who participated in the IPCC assessment. Victor does not place all the blame on scientists glossing over the problems: when researchers drafted the assessment's chapter on emissions scenarios and costs, he says, they included clear statements about the difficulty of achieving the 2 °C goal. But the governments — led by the EU and a bloc of developing countries — pushed for a more optimistic assessment in the final IPCC report. "We got a lot of pushback, and the text basically got mangled," Victor says."* ***(from this Nature article "Is the +2C World a Fantasy?" (Tolleson 2015)***

…Too conservative indeed. Subsequent climate observations are Significantly WORSE than IPCC Projections of just a few years earlier

- **Key projection misses are…**
- 1. Anthropogenic emissions rates (too optimistic)
- 2. Global temperature trend (actual at highest end of range)
- 3. Arctic sea ice area and volume (dramatically too rosy)
- 4. Continental polar ice sheet disintegration (understated)
- 5. Sea level rise rates (understated, too slow)
- 6. Ocean acidification rates (understated, too slow)
- 7. Melting permafrost (**no melt modelled at all**)
- 8. Arrival of key tipping points in the climate system (they made no mention of any timing whatsoever)

And yet we invariably see policy proposals, “white papers”, and rosy techno-fix proposals which consistently use these dangerously understated old projections.

Even today in 2017

Why?

E. The Reward Structure

Motivations for the Key Groups

- You cannot properly interpret the publications and claims you read unless you understand the **Reward Structure (RS)** for the people and institutions involved.

RS: For Publication of Papers in Peer Reviewed Science Journals

- Science journals: Are supported by dues-paying PhD holding members of the various branches of the respective sciences.
- *Here are the **top 20 science journals** publishing climate science, as judged by citations from climate science researchers.*
- *The journal **Nature** is #1*

RS: Science Journals - The editor is compensated. The society members who referee and publish papers, are not

- No editor wants to degrade the quality of his journals by giving a blind-eye to junk papers. He'll be fired, and it reflects badly on his career and his future
- No scientific society member wants to see junk papers published in HIS journals. It reflects badly on the prestige of his scientific field, on the quality of the researchers, and indirectly, himself.

A member asked to referee a submitted paper has no motivation to green-light a poor paper…

- (unless he just doesn't have time to read it carefully, but then… it's OK to decline to referee for this reason).
- …the editor will be asking him to referee because this is a paper within his expertise. Indeed, the submitted paper may be from a "competitor". There is definitely a friendly competition - if you can prove by evidence that your ideas are correct and the current paradigm is wrong, it will be very good for your career. You gain respect if you set an errant field on a new, better direction.
- So the **Reward Structure** motivates publication of quality papers with fidelity to good scientific method

To Clarify: the Difference Between the Criticisms of the IPCC Process, and the Scientists' Own Publication Quality

- I have **great respect** for the IPCC scientists' publications in peer-reviewed journals, and the rest of climate scientists taken as a whole. New (2017) independent research confirms yet again that there is no bias in climate science published research such as has now made the main-stream media that **plagues** the money-soaked motivations of bio-medical research.
- But I have **little respect for the IPCC process**, and have advocated on blog sites that the IPCC scientists divorce themselves from the U.N. and publish their hard work of synthesis independently.

RS: For Industry "Trade Journals" It's the Money. Follow the Money

- Trade journals (*e.g.* "**Energy and Environment**" are financially supported by industry groups. The "coin of the realm" here is not solid science – it's **Coin**. It's **Profits**. Truth takes a back seat if necessary.
- Good science can still happen… if it doesn't interfere with profits. And sometimes this is true… but in climate this is rarely true.
- Honesty in climate science will hurt the profits of Fossil Fuel corporations.
- Honesty may even hurt the profits of renewable energy industries. Claims in "white papers" can be over-hyped, and engineering or physics troubles underplayed or ignored.
- In the case of renewable energy companies, there's the temptation to oversell, to hype the promotion of their product and their ideas beyond what is legitimate, in the interest of getting funding.

Example: Corporate junk science on the harmful effects of Biphenol-A on Humans

Independent Science Shows Harmful Effects from BPA, while Industry Science Shows None

A recently-published review of scientific studies shows that, in the last 7 years (through November 2005), 151 studies on the low-dose effects of BPA have been published.(37) None of the 12 studies funded by the chemical industry reported adverse effects at low levels, whereas 128 of 139 government-funded studies found adverse effects. These many studies were conducted in academic laboratories in the U.S. and abroad. Even the 12 industry-funded studies have flaws, however. Of the industry studies, two had their positive controls fail—an indication that the entire experiment had failed, not that BPA had not caused an adverse health effect.

	Adverse health effect	*No effect*
Plastics Industry funded	*0*	*12*
Government funded	*128*	*11*

Another industry study concluded BPA caused no adverse effect, but an independent analysis of the experiment's data by scientists convened by the National Toxicology Program of the U.S. Department of Health & Human Services concluded that in fact there was an adverse effect. Industry scientists had misreported their own results. The chemical industry relies on an incomplete review of scientific studies by an effort funded by the American Plastics Council at the Harvard Center for Risk Analysis. The panel funded by the American Plastics Council only considered 19 studies in concluding in 2004 that the weight of the evidence for low-dose effects of BPA was weak.(38) As of November 2005, there were 151 published studies on the low-dose effects of BPA.

The Reward System: Policy People

- They are intermediaries between the scientists and the politicians, and are more often directly employed by the politicians, or business interests
- Even if not, they are judged successful to the extent they sell the virtue of their idea for policy changes or engineering inventions to address climate change.
- Policy ideas often come out as "White papers". Also typical in business as well.

“White papers”- Are not subjected to peer review

- They have not been examined with healthy skepticism from other scientists. They’re “position papers”, or promotionals and the like.
- Politicians want to look good to the media and the voters, so they pressure for good-looking policy spin from their people.
- Deputy director of the UK’s Tyndall Climate Centre at East Anglia University - Prof. Kevin Anderson - has described this in real life in blistering detail.

From this talk by Prof. Kevin Anderson, in conversation with political climate policy senior people

- **Political scientist** (at request left un-named): *"Too much has been invested in +2C for us to say it's not possible – it would undermine all that's been achieved. It'll give a sense of hopelessness, that we may as well just give in"* – (30 min into **the talk**)
- **Anderson:** *"Are you suggesting we have to lie about our research findings?"*
- **Political scientist:** *"Well, perhaps just not be so honest – more **dis**honest…"*

And From the Same Talk…

- …this exchange with a senior government scientific advisor and high-up in the IPCC…
- *"We can't tell them (ministers and politicians) it's impossible. We can say it's a stretch and ambitious, but that with political will, +2C is still a feasible target"*
- Yet this person then gave his personal <u>private</u> judgment that indeed +2C was impossible nonetheless (this was in reference to the 2013 IPCC AR5; talk given in early 2015, and temperatures and emissions have significantly worsened since then)

Nobel physics laureate Richard Feynman, after his elegant and unexpected demonstration of the flawed "O" rings as cause of the 1986 Challenger Space Shuttle Disaster, to colleagues on a knowing but embarrassed NASA panel, and TV cameras… had this great quote:

For a successful technology, reality must take precedence over public relations, for nature cannot be fooled.

(Richard Feynman)

izquotes.com

Techno schemes which must “work” successfully in the post-IPCC climate science world….

- …generally don’t. So it’s less surprising perhaps that nearly all adopt the overly rosy official (but obsolete and doctored – review page 18 and afterwards) IPCC carbon budgets as a much easier bar to clear.
- More on climate action proposals in the later talk I’m preparing - **“Climate Action: A Critical Review of Climate Proposed Solutions”**
- That talk will include both policy and technology. It’s too big to combine with all the new science here and so, on the advice of interested people for these talks, I’ve agreed to separate them into separate talks.

That's the Stake-holders' Motivational Background: Now We're Ready for The Meat of This Presentation:

The new Post-IPCC Climate Science and how it relates to the IPCC published models, scenarios, and future forecasts

IPCC Models: Missing Physics

- The climate system has amplifying feedbacks which, in the past 3 million yrs, have swung the planet between cold glacial phases and warm interglacials, and now human civilization has added more.
- These feedbacks explain why, in the pre-human past, triggers with only mild astronomical forcings can make such large shifts into and out of the Ice Ages.

And: when humans force the system orders of magnitude faster than nature alone, the amplifying feedbacks can operate much faster. Not including them, is serious

- First; we'll do the comparatively less important missing physics.
- Then we'll examine the more troubling new physics

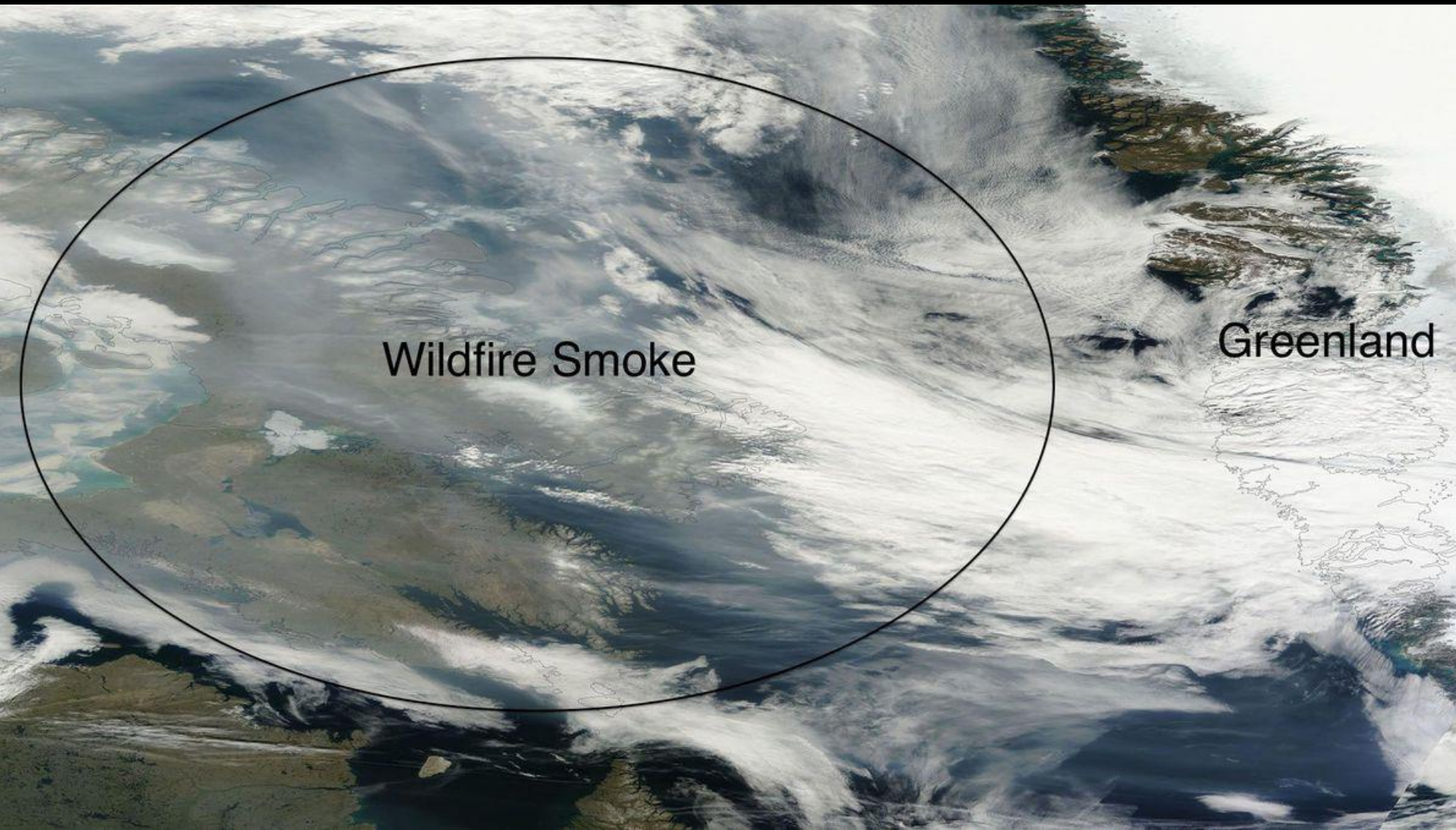
IPCC Models Do Not Include: Soil Carbon Loss from Warming Soils

- **Crowther *et al.* 2016** show that this feedback alone will raise CO2 emissions rates by 17% - as much as the entire U.S. contributes to global CO2. (Lead author interview, and discussion)
- IPCC Earth System Models instead assumed the "greening of the Arctic" would sequester carbon. But detailed studies show that will be overwhelmed by the increased metabolism of soil microbes which release CO2.

IPCC Models Do Not Include: Increasing wildfires and their smoke (80+% are human-caused: Balch *et al.* 2016)

Record heat in winter is killing the great Boreal forests as insect infestations are no longer killed by winter cold. Dead trees turn to wild fires, sending smoke to the Arctic and Greenland (lower right)

Wildfires darkening the Greenland Ice Cap



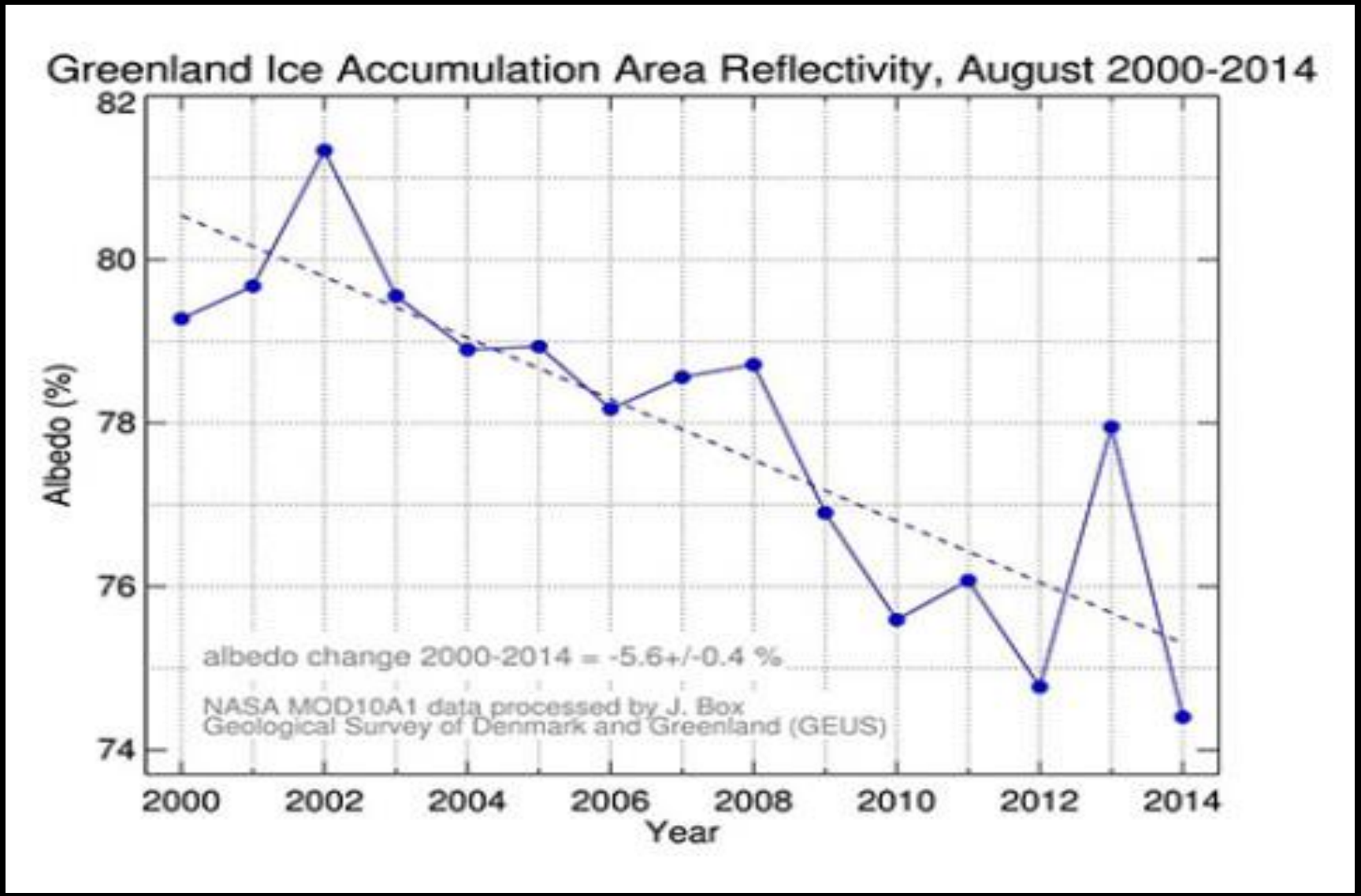
Amplifying feedback: Hotter climate => more drought, more insects => more tree death => more wildfires => darker ice => more heat absorption => Hotter climate=>…

IPCC Models Do Not Include: Surface meltwater generates algae and other microbe colonies which further darken the ice, absorbing more sunlight

IPCC Models Do Not Include: Wildfires on the thawing tundra itself

Greenland Ice in Summer, Darkening Rapidly. Yes, that's ice below

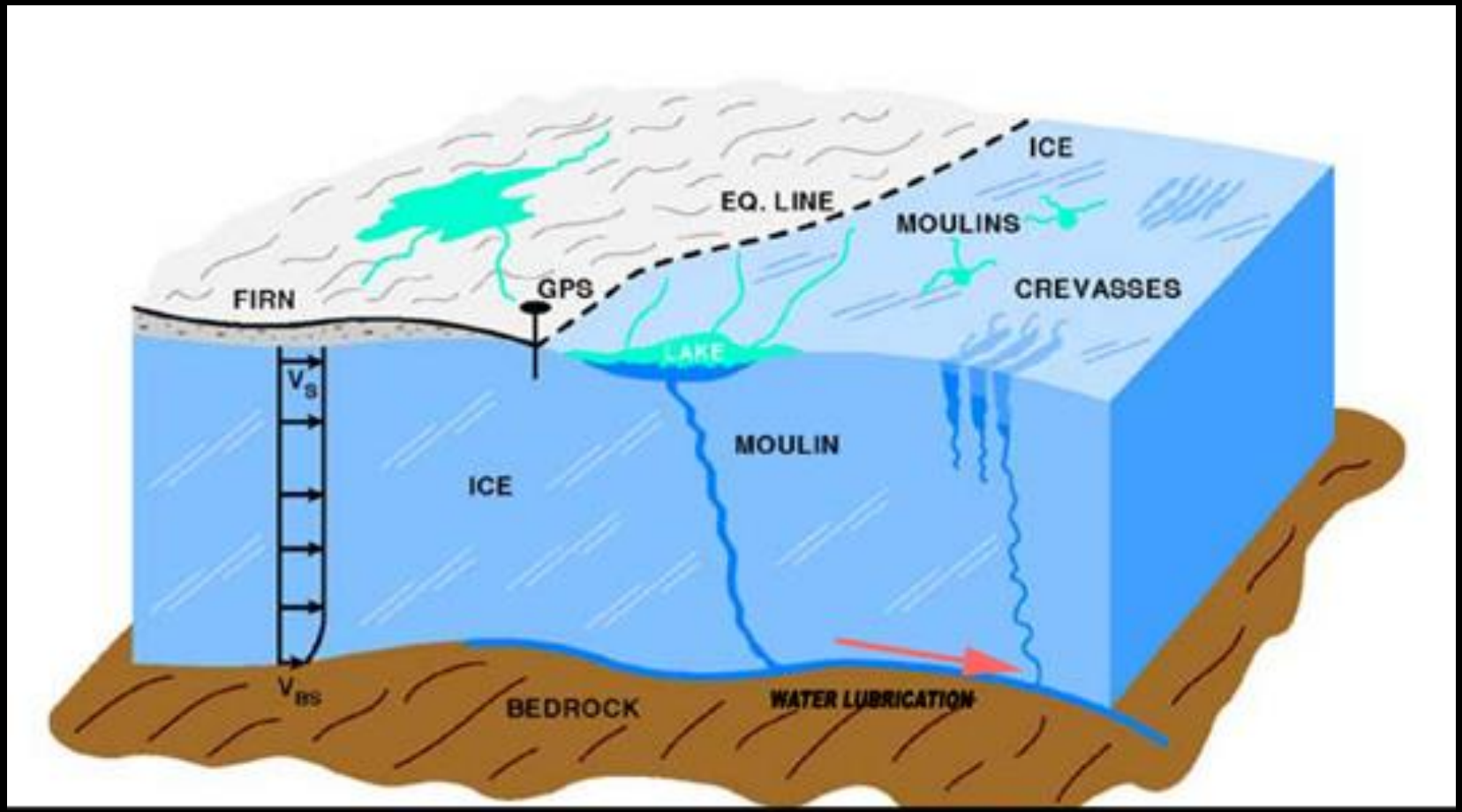
And So - IPCC Models Do Not Include: Albedo dropping in the Cryosphere. August is the most sensitive time of year: it's warm, and the sun is still well above the Arctic horizon.



IPCC Models Do Not Include:

Surface melt on Greenland generating rivers of water driving hydro-fracturing, driving heavier water through lighter ice, generating moulins – giant holes taking water miles deep to the base of the ice sheet

The resulting water flows soften the ice sheet base, accelerating sliding to the sea at twice the rate expected.

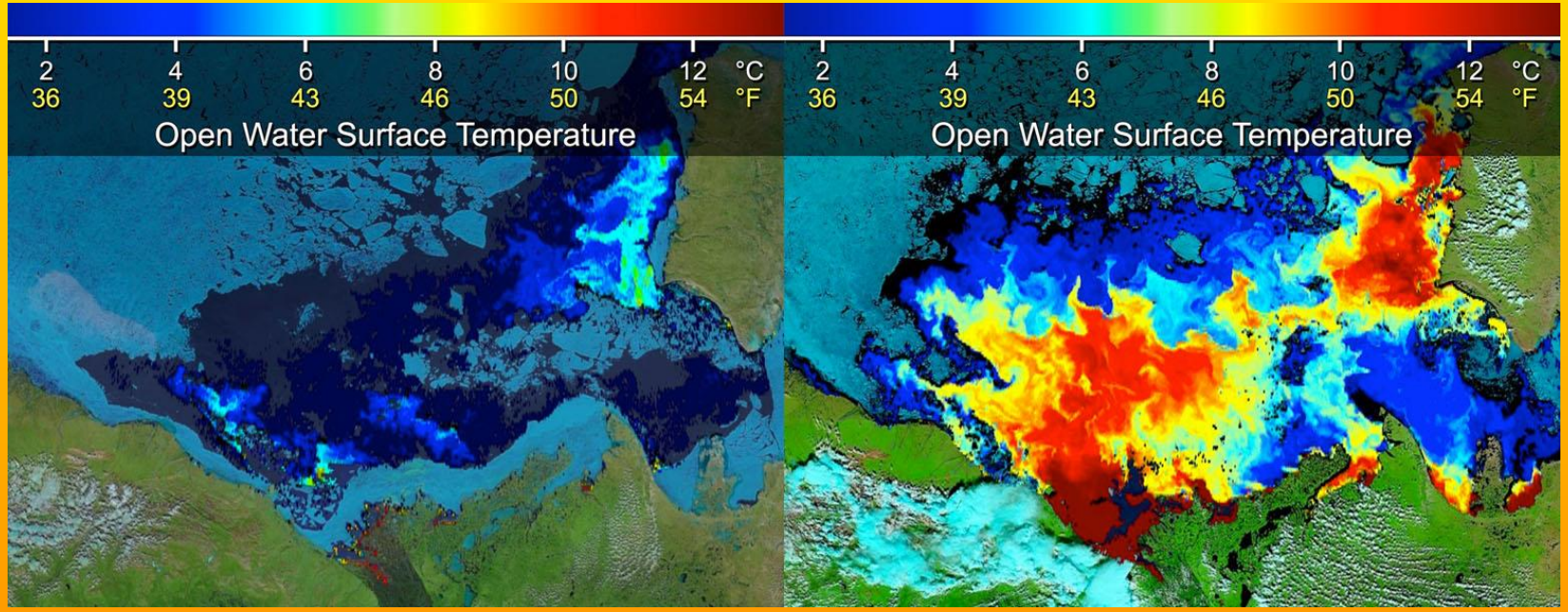


GLACIOLOGICAL FEATURES OF A MOULIN

IPCC Models Do Not Include: The intrusion of warm Atlantic waters into the Arctic Ocean…

- …melting the floating Arctic Ocean ice from below.
- The cause? Growing meltwater from Greenland, adding a cold low density freshwater cap to the ocean there, inhibiting sinking through the thermocline, forcing the now subsurface warm current further north (**Polyakov *et al.* 2017**), closer to, and even right into, the Arctic Ocean Basin
- The heat added to Arctic Ocean ice is fully equal to that added from the rising air temperatures, **~doubling the rate of heating of the Arctic ice**

IPCC Models do not include: Added large heat influx from warmer waters in the rivers draining into the Arctic Ocean (Ngheim *et al.* 2014, described here)

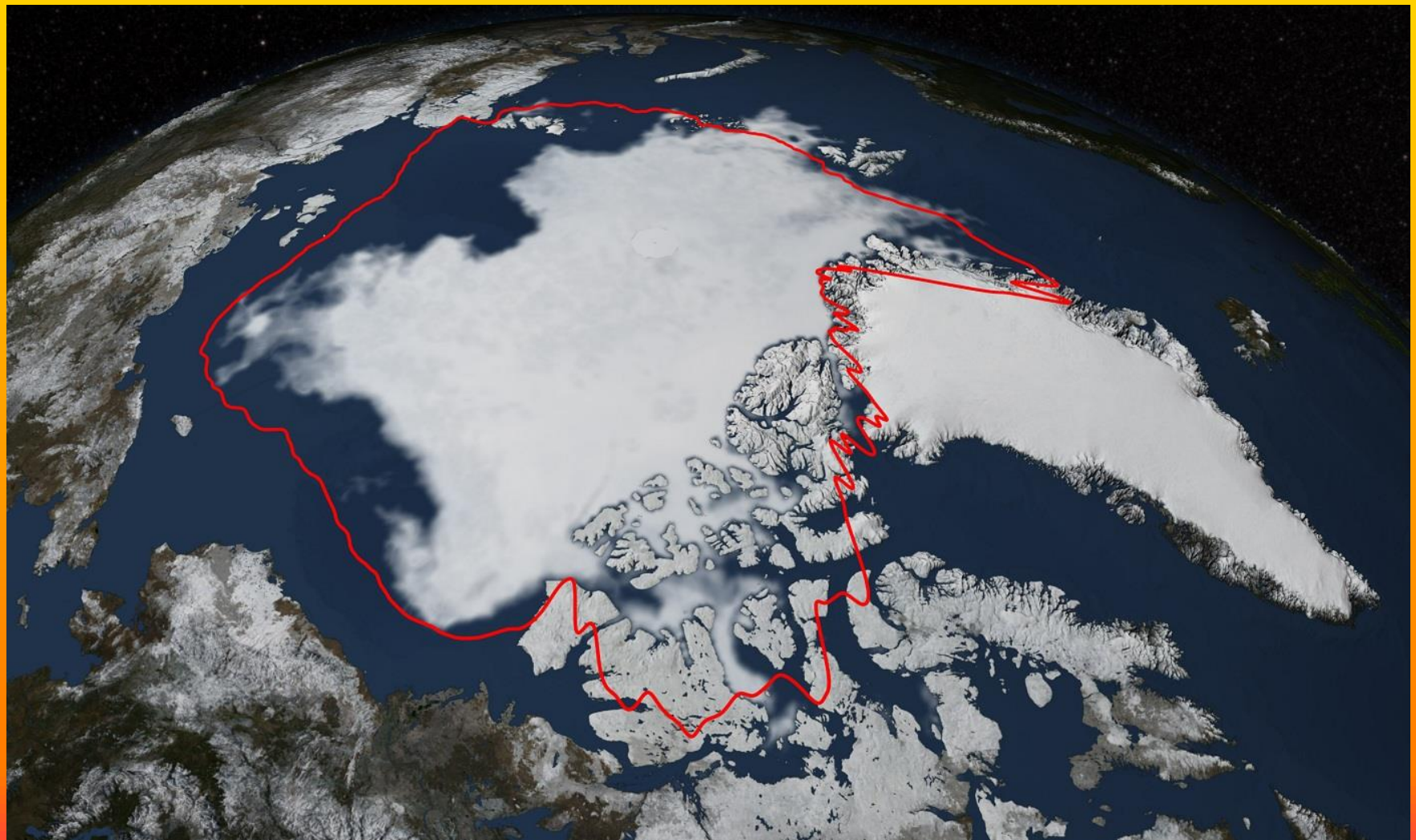


- These images show sea surface temperatures of the Beaufort Sea where Canada's Mackenzie River discharges into the Arctic Ocean, as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra spacecraft. The image at left was obtained June 14, 2012, before discharged waters from the Mackenzie River (located in the bottom center of the image) broke through the adjacent sea ice barrier (shown in light blue) stuck along the shore of the Mackenzie River delta. The image at right, acquired July 5, 2012, shows the extensive intrusion of heat carried by the river waters once they breached the sea ice barrier (shown in yellow, orange and red). Scientists saw an increase of 11.7 degrees Fahrenheit **(+6.5 degrees Celsius)** in the surface temperature of the open water, which enhanced sea ice melt.

IPCC Models Do Not Include: Reversal of Soil Carbon back to the Atmosphere

- Soil carbon is driven out by increasing heat and soil drying, both related to climate change.
- Under the current trend ("business as usual") roughly 60 Gt of carbon escapes from soils by 2050, adding roughly 17% to direct anthropogenic emissions of CO2 (Crowther *et al.* 2016)

IPCC Models Do Not Include: Non-linear breakup of thinning Arctic sea ice, driven by wind and waves as more open wind-fetch appears, and subsequent iceberg drift south past Greenland.

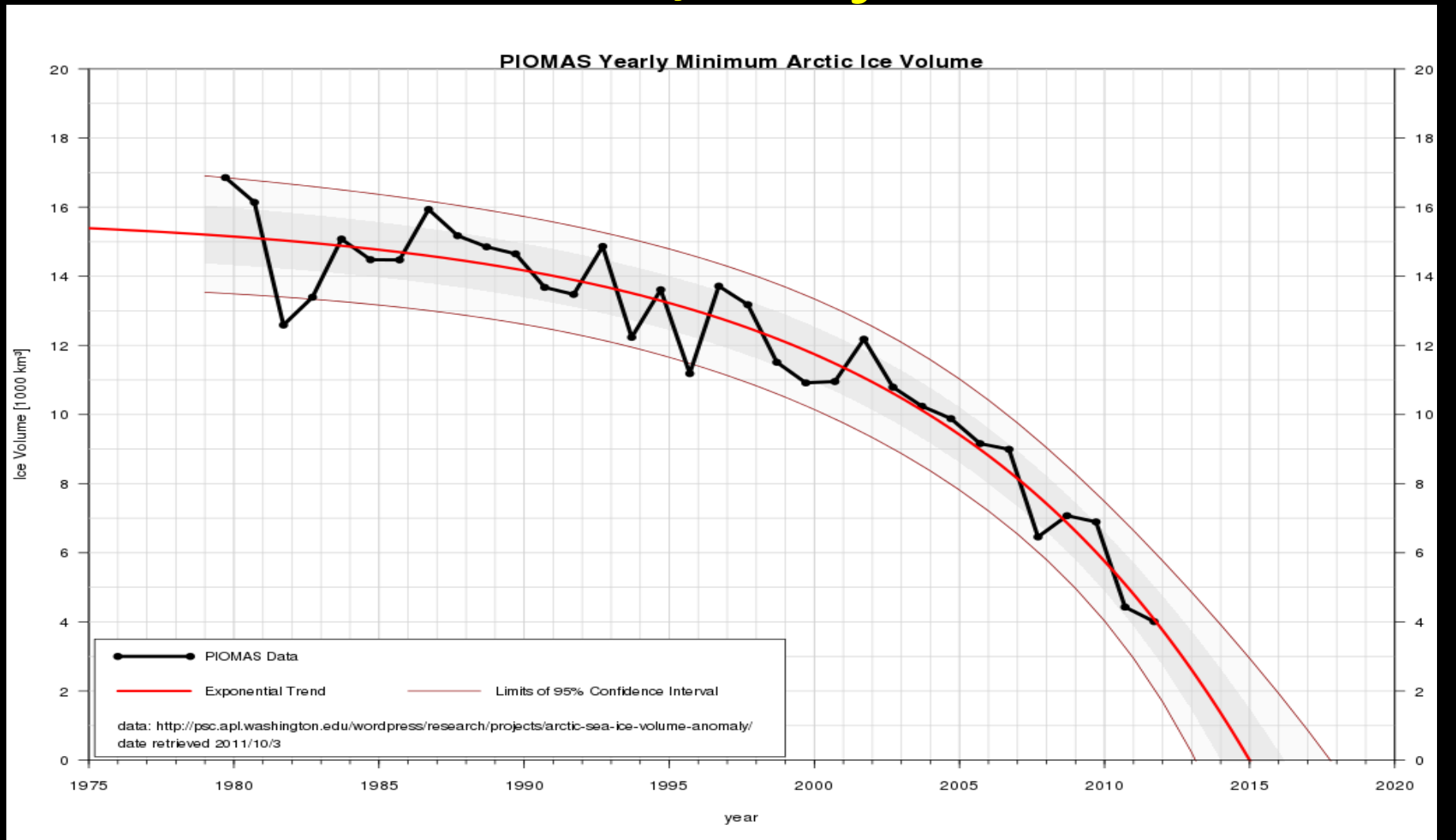


ALL of these and earlier effects contribute to the dramatic underestimation of sea ice loss

MINIMUM ANNUAL ARCTIC SEA ICE: **IPCC MODELS** VS **OBSERVATIONS**

base chart: http://www.realclimate.org/index.php/archives/2012/04/arctic-sea-ice-volume-piomas-prediction-and-the-perils-of-extrapolation/
modified by Barry Saxifrage (VancouverObserver.com and VisualCarbon.org) to include orange line showing PIOMAS volume data
in 1,000s of km3 from http://psc.apl.washington.edu/wordpress/research/projects/arctic-sea-ice-volume-anomaly/data/

The Arctic Ocean: Only a few years away from losing all of its summer ice. Plotted here is ice VOLUME, not just surface area



The Missing Physics We've Shown Here is Significant

- **But, far more significant and dire are the biggest effects, which I'll talk about now:**
- --The PCF: Permafrost Carbon Feedback
- --Methane fraction from the Arctic
- --ECS dependence on climate state
- --Shutdown of AMOC; consequences
- --Brief intro to the **Thermodynamics of Civilization** and effects on the IPCC Emission Scenarios

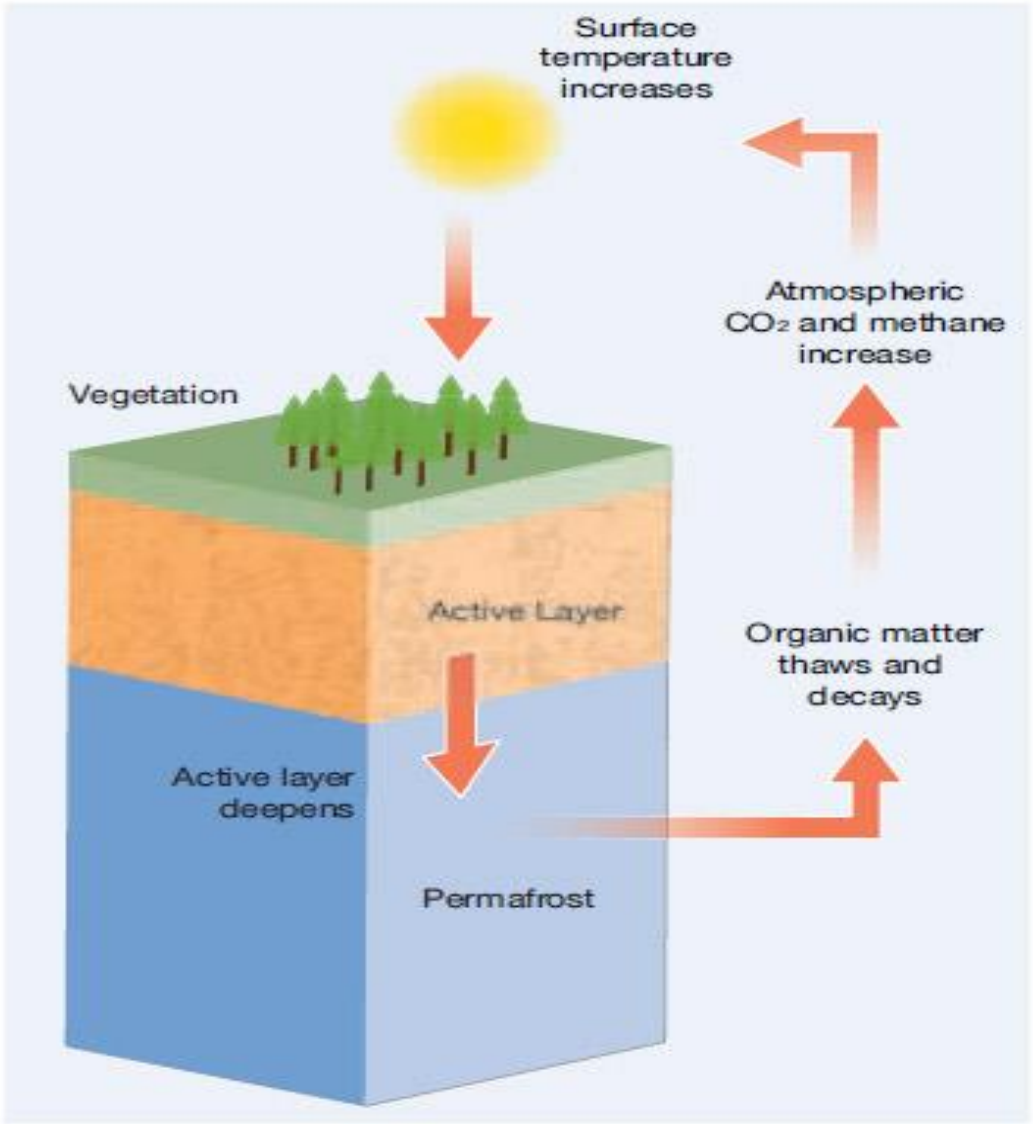


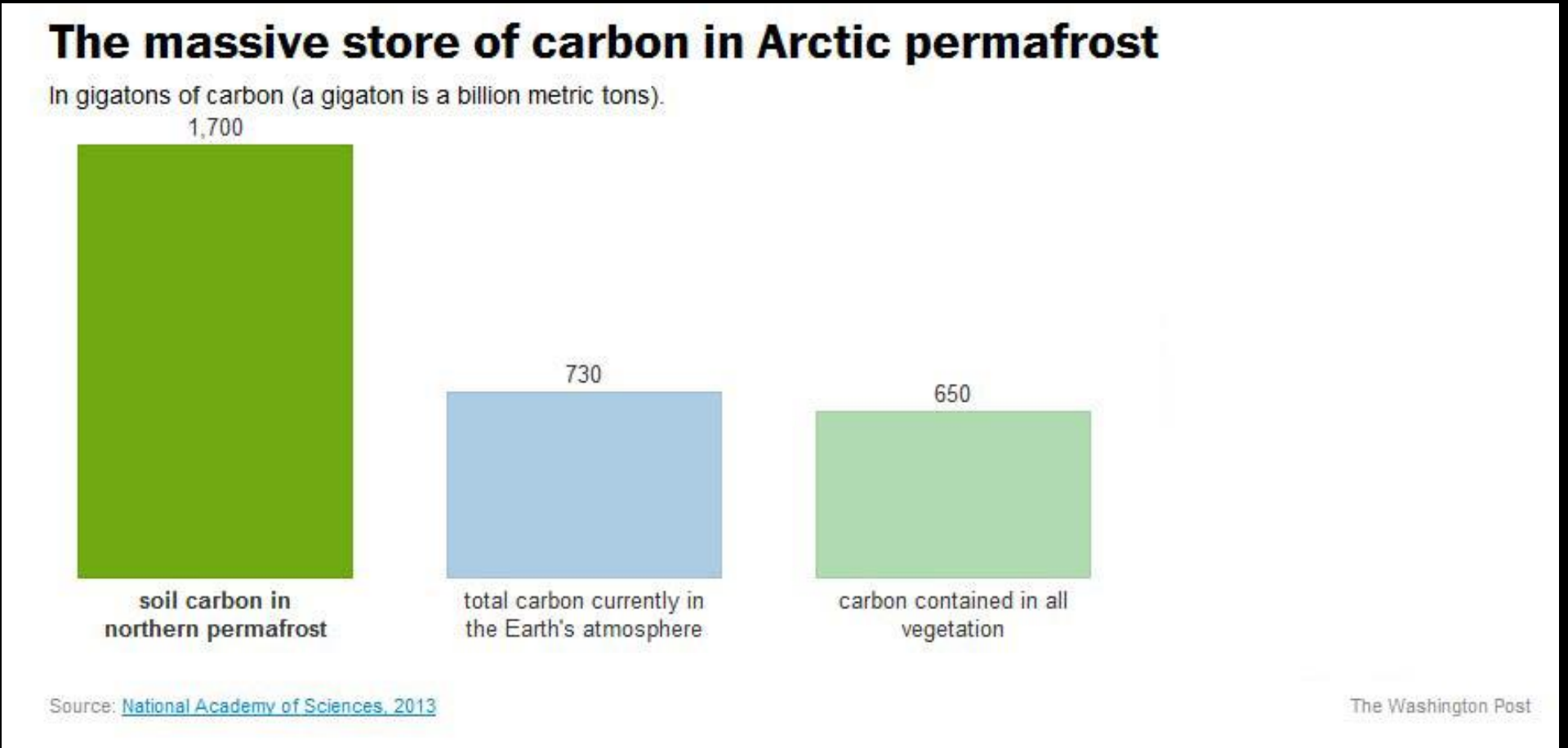
Figure 21: The permafrost carbon feedback is an amplification of surface warming due to the thaw of organic material currently frozen in permafrost, which will then decay and release CO_2 and methane into the atmosphere.

The Permafrost Carbon Feedback

In the Entire Synthesis IPCC AR5 Report, methane is mentioned only twice

- In section 2.2.1 on 21st century temperature change… *"This range assumes no major volcanic eruptions or changes in some natural sources (e.g., methane (CH_4) and nitrous oxide (N_2O)), or unexpected changes in total solar irradiance."*
- And in section 2.3 where the risk is mentioned but not quantified…*"There is a high risk of substantial carbon and methane emissions as a result of permafrost thawing. {WGII SPM, 4.2-4.3, Figure 4-8, Box 4-2, Box 4-3, Box 4-4}"*
- ***In other words, methane as direct human emissions is included in IPCC scenarios, but not the resulting "natural" (sic) emissions from the tropics and Arctic which our GHG warming sets in motion, except a rather limp warning that it is a danger.***

There's more carbon in the permafrost than in the entire atmosphere plus the entire biosphere's vegetation… combined



So is the Carbon Release in Thawing Permafrost Incorporated into the IPCC Assessment Reports and Projections?

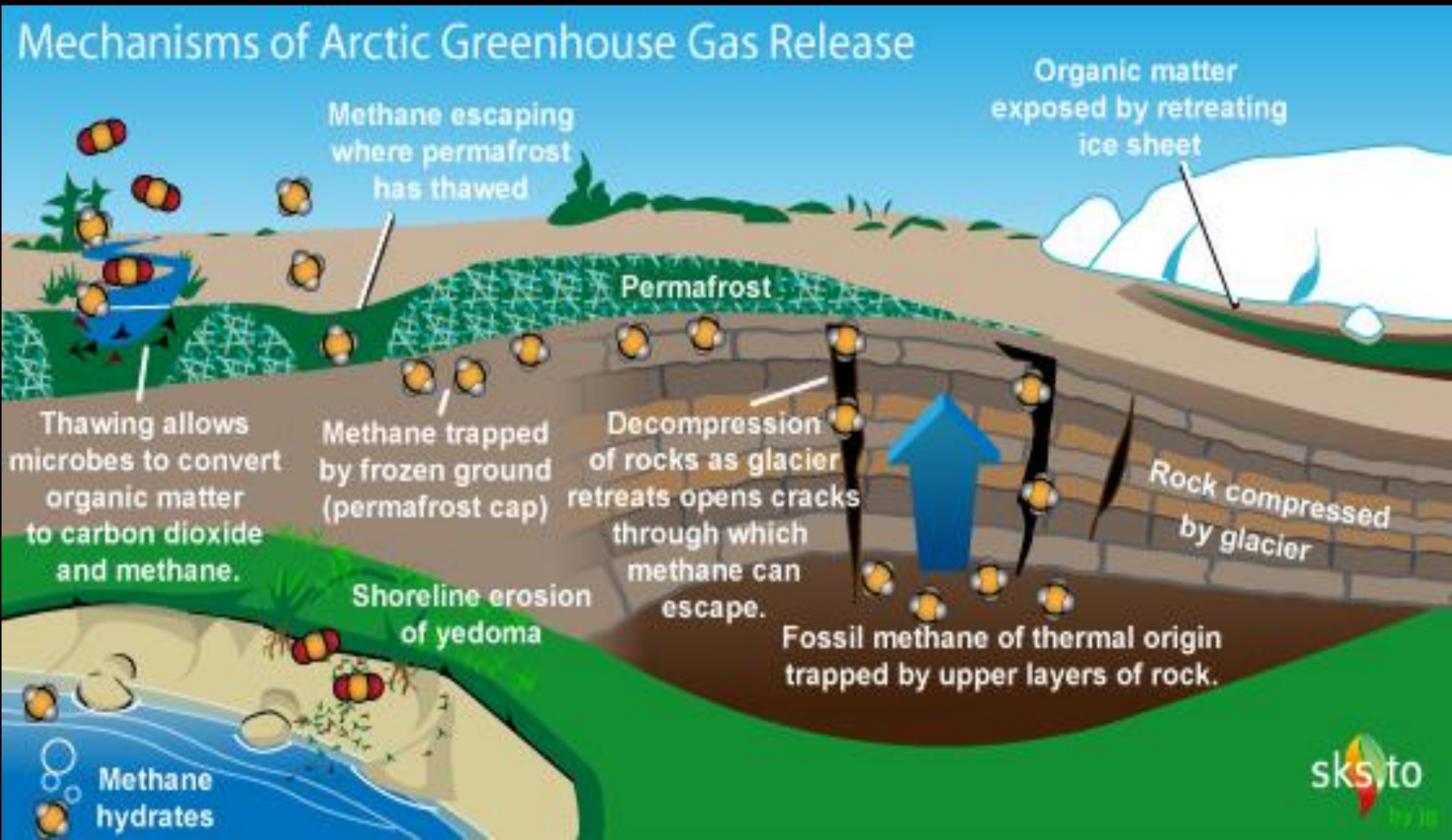
- **No.**
- *"The concept is actually relatively new,"* says Dr. **Kevin Schaefer** of the **National Snow and Ice Data Center** at the University of Colorado in Boulder. *"It was first proposed in 2005. And the first estimates came out in 2011. Indeed, the problem is so new that it has not yet made its way into major climate projections",* Schaefer says.

- ***"None of the climate projections in the last IPCC report (AR5) account for permafrost," says Schaefer. "So all of them underestimate, or are biased low."***
- ***It's "a true climatic tipping point, because it's completely irreversible," says Schaefer. "Once you thaw the permafrost, there's no way to refreeze it." (source)***

From the U.N. Environmental Programme Report

- *"The effect of the permafrost carbon feedback on climate has not been included in the IPCC Assessment Reports. None of the climate projections in the IPCC Fourth Assessment Report include the permafrost carbon feedback (IPCC 2007).*
- ***Participating modeling teams have completed their climate projections in support of the Fifth Assessment Report, but these projections do not include the permafrost carbon feedback. Consequently, the IPCC Fifth Assessment Report, due for release in stages between September 2013 and October 2014, will not include the potential effects of the permafrost carbon feedback on global climate."***

The Many Ways of Arctic Greenhouse Gas Release…



Pathways of Permafrost Carbon Release

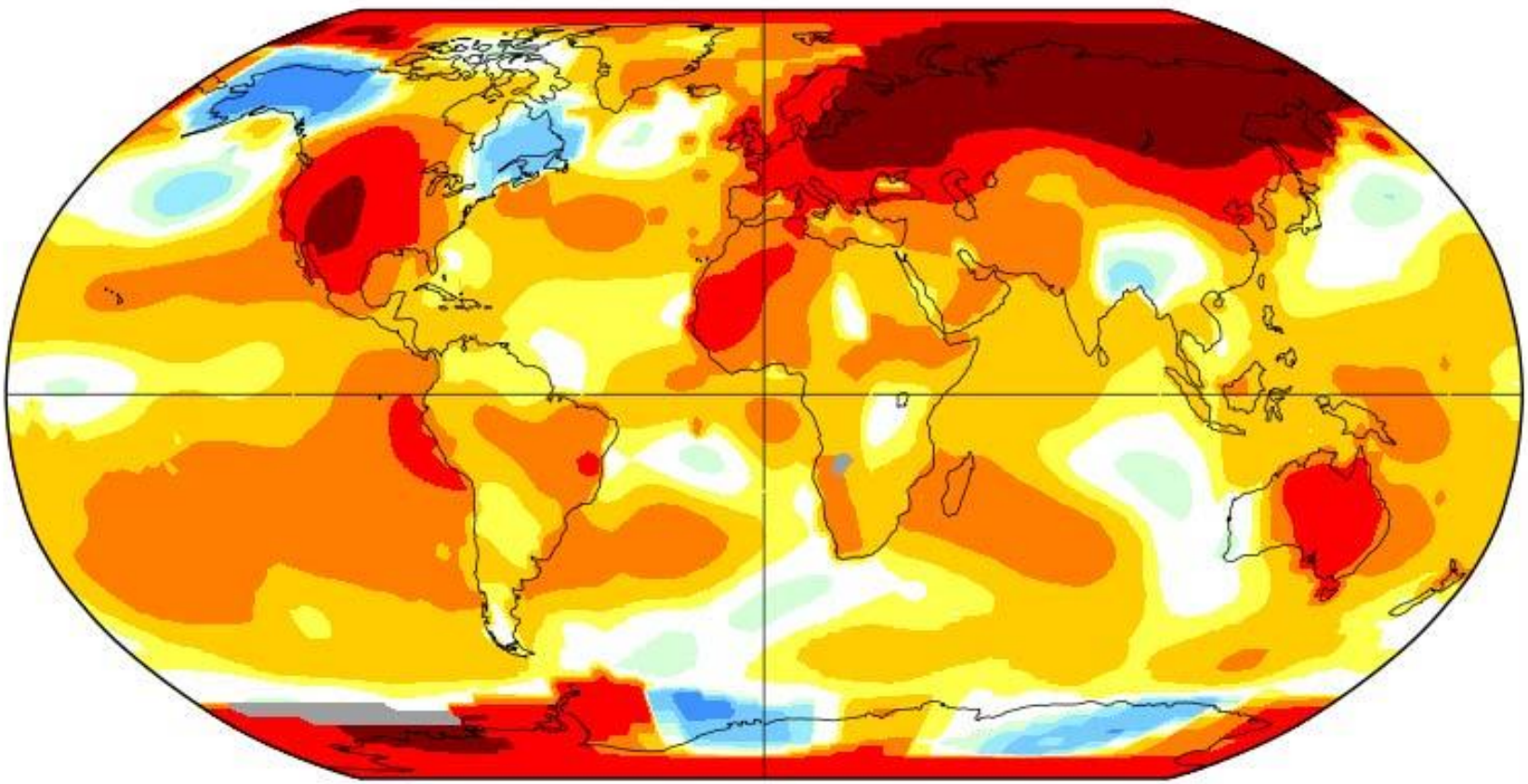
- Wildfires, increasing 200-560% by 2100, depending on RCP scenario (this may be a severe underestimate, based on observations at lower latitudes)
- Coastline melt/erosion -> carbon release to ocean and atmosphere
- Insects, consume soil carbon and release CO2 and methane
- Direct soil and Arctic lake methane outgassing
- Soil structural failure, release of deeper carbon in **"thermo-karst"** hollows within thawing land
- **These and others are all strongly temperature dependent, and much higher for higher human CO2 emissions scenarios**

When Does the Permafrost Thaw and Carbon Release Really Kick In?

Vaks *et al.* 2013, just after the IPCC AR5 publication cutoff for inclusion. Paleo data shows that the tipping point for the melt of all Siberian permafrost (and therefore all global permafrost), occurs by +1.5C above pre-industrial temperatures, if held.

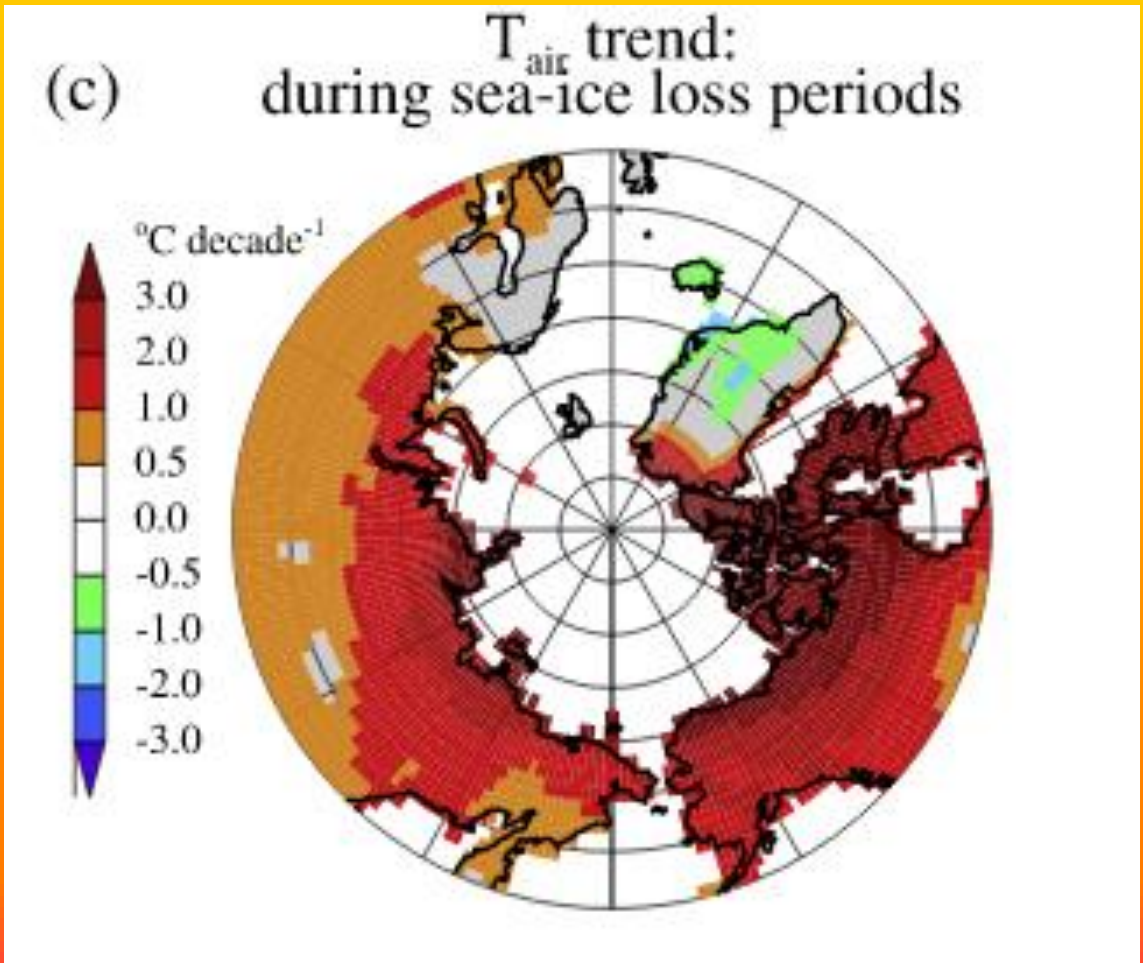
- From the paper's conclusion section: *"Warming of ~1.5°C (i.e., as in MIS-11) may cause a substantial thaw of continuous permafrost as far north as 60°N and may create wetter conditions in the Gobi Desert. Such warming is therefore expected to markedly change the environment of continental Asia and can potentially lead to substantial release of carbon trapped in the permafrost into the atmosphere." (see **interview on YouTube**)*
- **How Close Are We…..?**

Last month, we were at +1.4C (1.13C + 0.254C to convert 1951-80 back to Pre-Industrial baseline), and rising very rapidly. The Permafrost - much hotter still

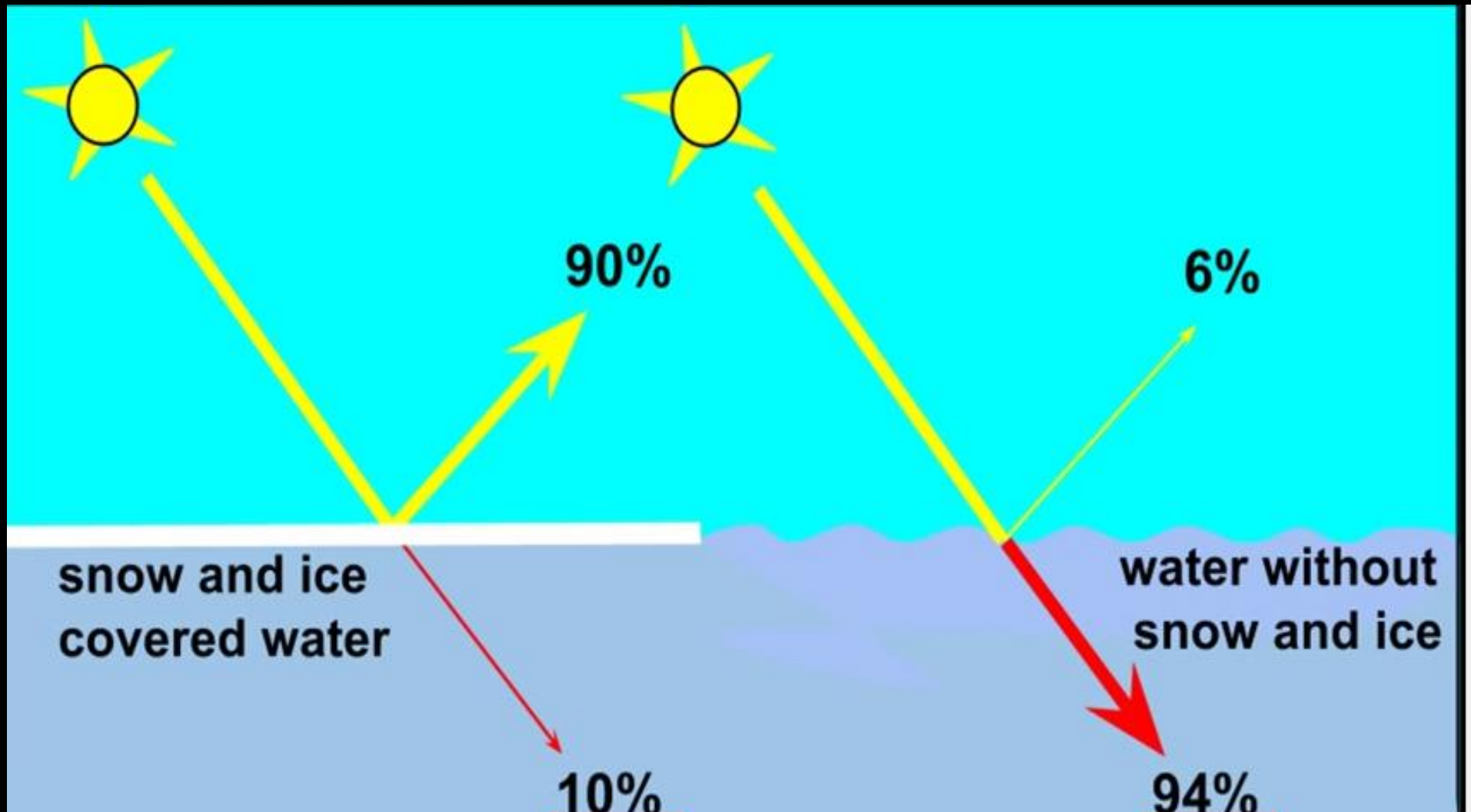


It is the Loss of the Arctic Ocean's Ice …which once REFLECTED ~90% of sunlight, turns to open ocean which now ABSORBS ~90% of sunlight (if it's sunny). show this sends a pulse of heat 1500 km south of the Arctic shorelines (Lawrence *et al.* 2008).

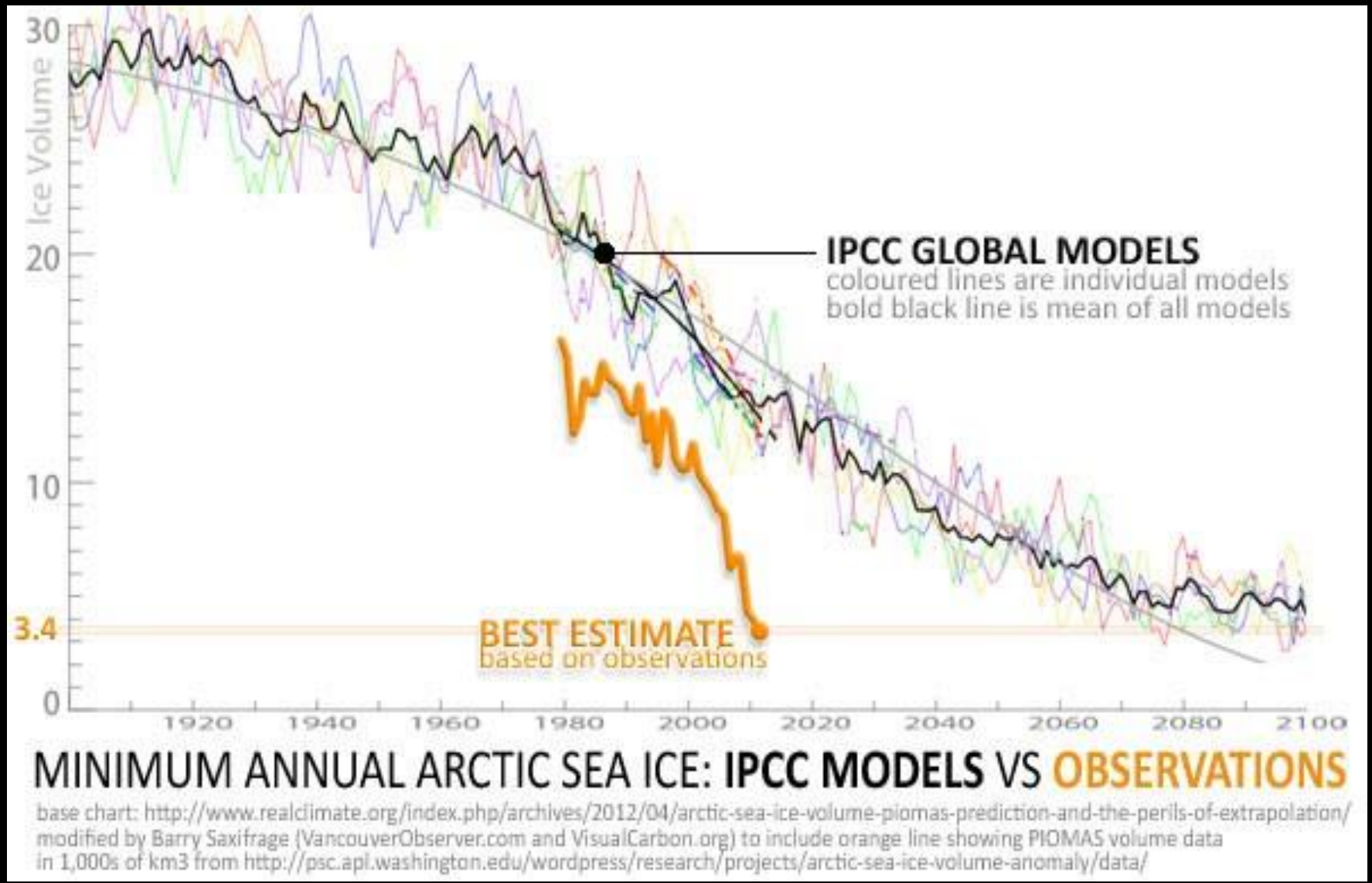
Below: temperature trend map. Sharp in Siberia, but even sharper in North America. So if Siberia melts, North America will as well, and likely sooner



It's a Very Large Heating Effect Applied to Millions of Square Miles in the Polar Ice Region

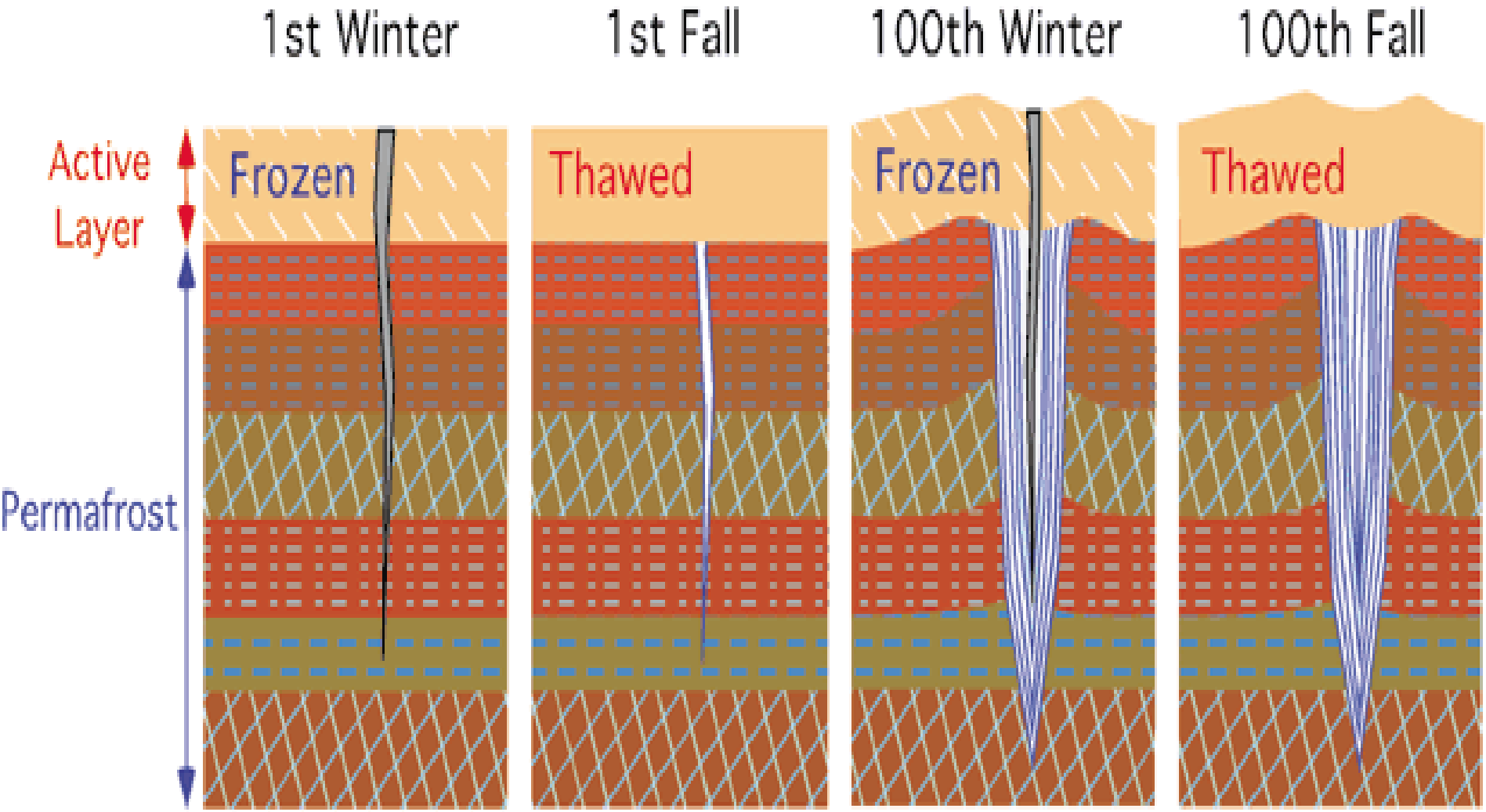


And as we saw, the Arctic Ocean Ice covering has plunged to near zero - melting far faster than the IPCC models



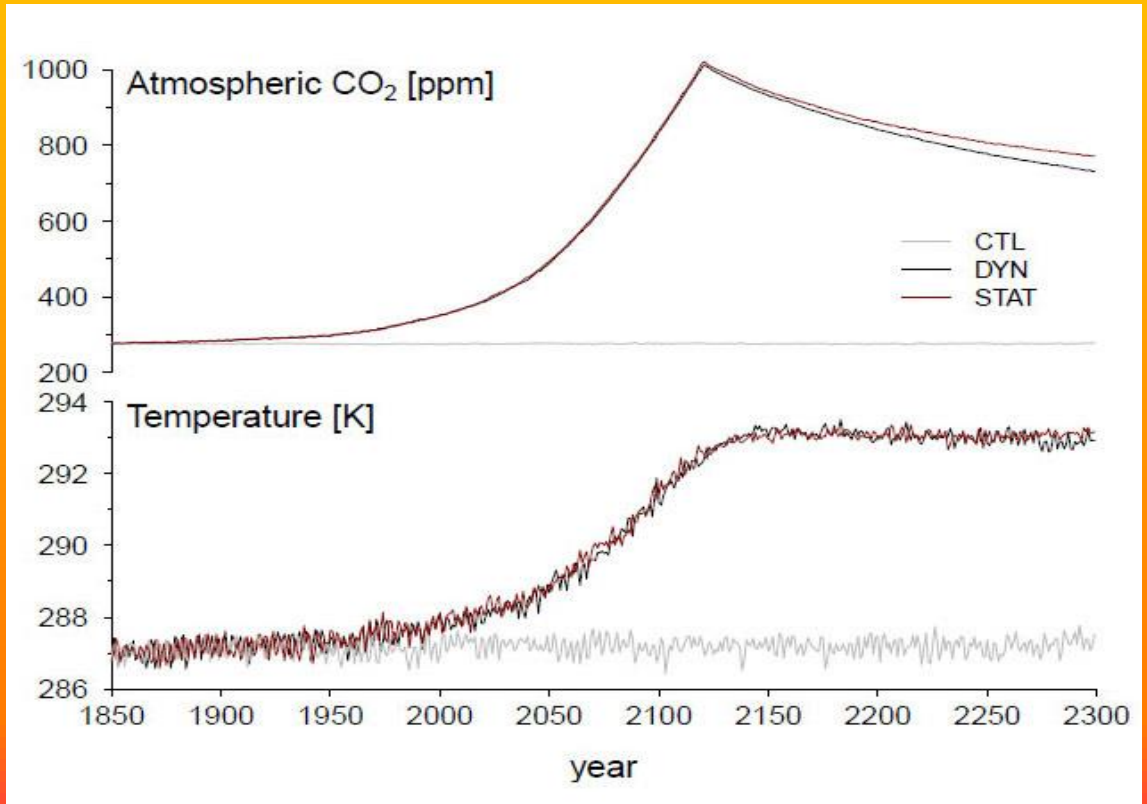
- ***"The scientific community has had the assumption that this cold permafrost would be protected from climate warming, but we're showing here that the top of the permafrost, even if it's very cold, is very sensitive to these warming events,"*** **- Anna Liljedahl**, the lead author of the study and a researcher at the University of Alaska in Fairbanks, told the **Washington Post**.

Taliks expand the area of unfrozen permafrost, over time, by exposing deep frozen permafrost to warmth Liljedahl *et al.* (2016)

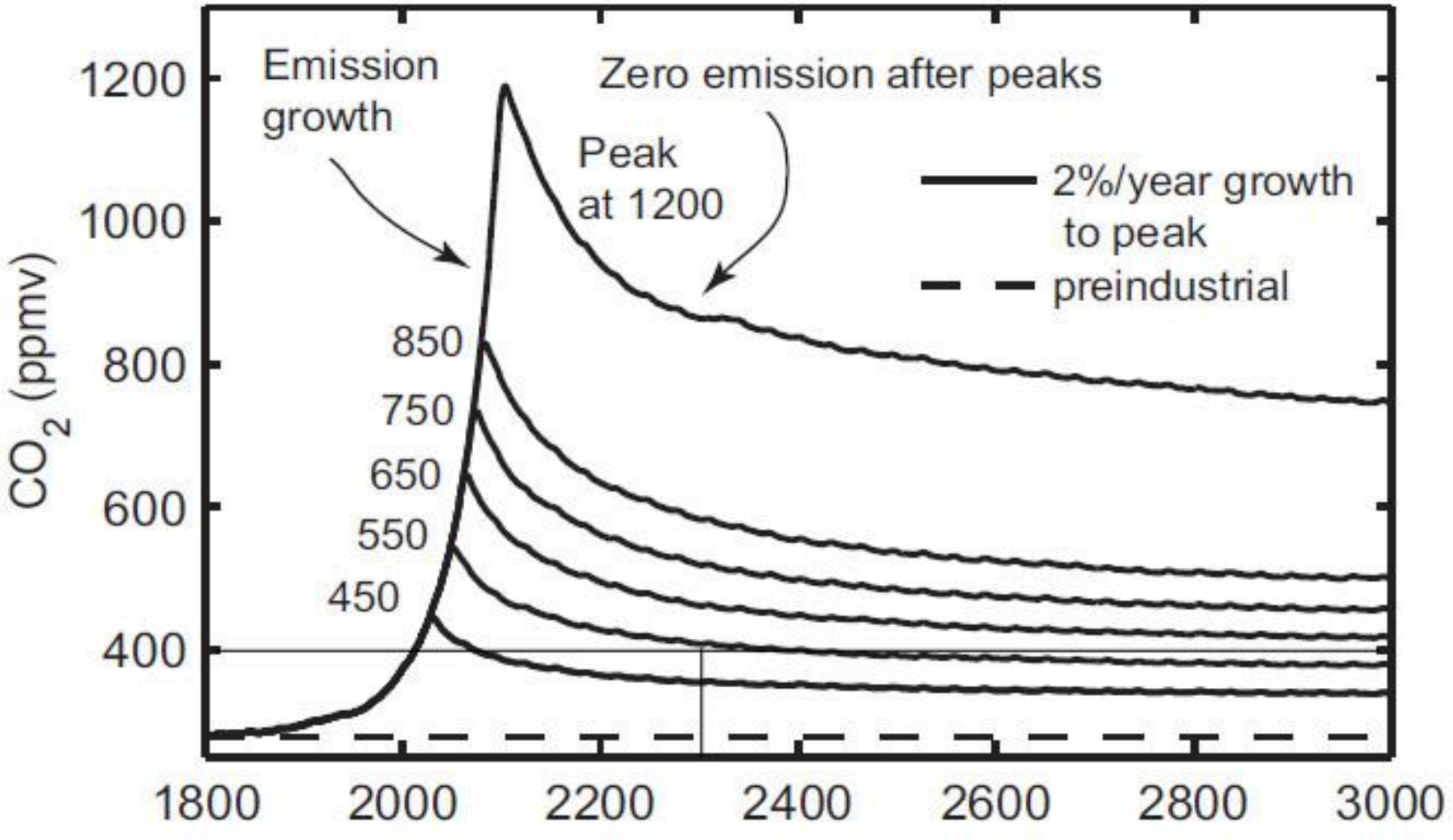


How Will This Thawing Permafrost - Neglected in IPCC Models - Affect Atmospheric CO2 and Methane Levels?

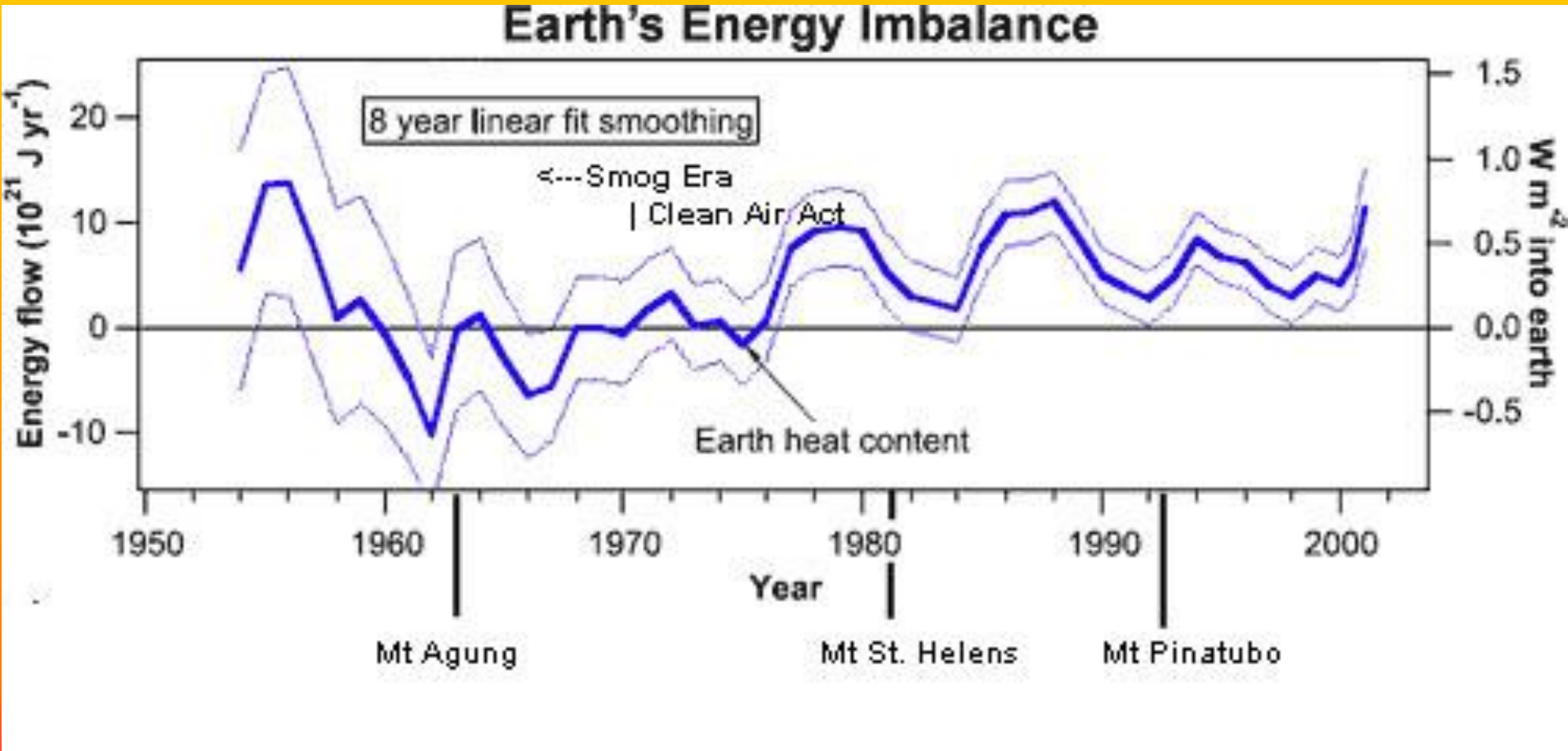
IPCC Assessment Reports had been using the work of Solomon *et al.* 2009 , Mathews and Weaver 2010, and others. They showed that, absent significant systemic emission changes, ending all human GHG emissions would allow the ocean and land to absorb CO2 and bring atmospheric CO2 down somewhat.



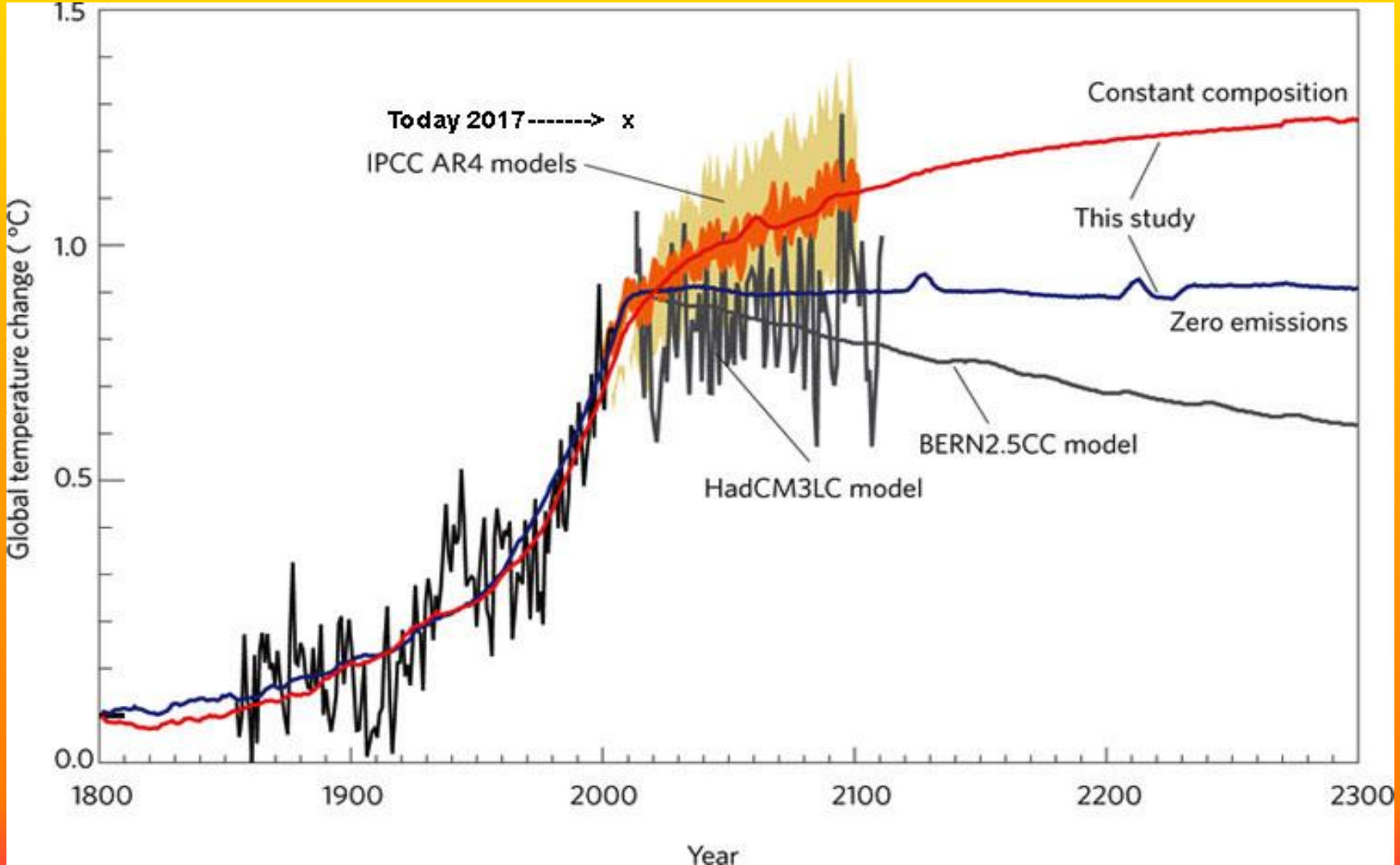
Atmospheric CO2 – Next 1,000 years. From Solomon *et al.* 2009. Assumed "Business as Usual" then instantaneous end of CO2 emissions. CO2 only slowly declines over the next ~200 yrs, then levels out (<u>But not included: damaging effect on ability of plants and soil microbes to sequester the carbon at assumed rates).</u>



Temperatures, however, would NOT come back down, due to (1) the existing radiative imbalance of +0.6 W/m^2, and (2) to the large thermal inertia of the now hotter oceans, which have absorbed 93% of our Greenhouse Heating.



From Matthews and Weaver (2010) here. (but no permafrost thaw included). Zero emissions after 2009 leads to flat temperatures. Constant CO2 composition (orange) leads to continued rising temperatures.



But Now Let's Include the Permafrost Carbon Feedback.
CO2 first, and Later, Methane as well

MacDougall *et al.* 2012 re-calculated atmospheric CO2 assuming an immediate end to all human CO2 and sulfate emissions, but including the Permafrost Carbon Feedback. Note that CO2 does not fall, instead flattening, assuming Equilibrium Climate Sensitivity ECS = 3.0C

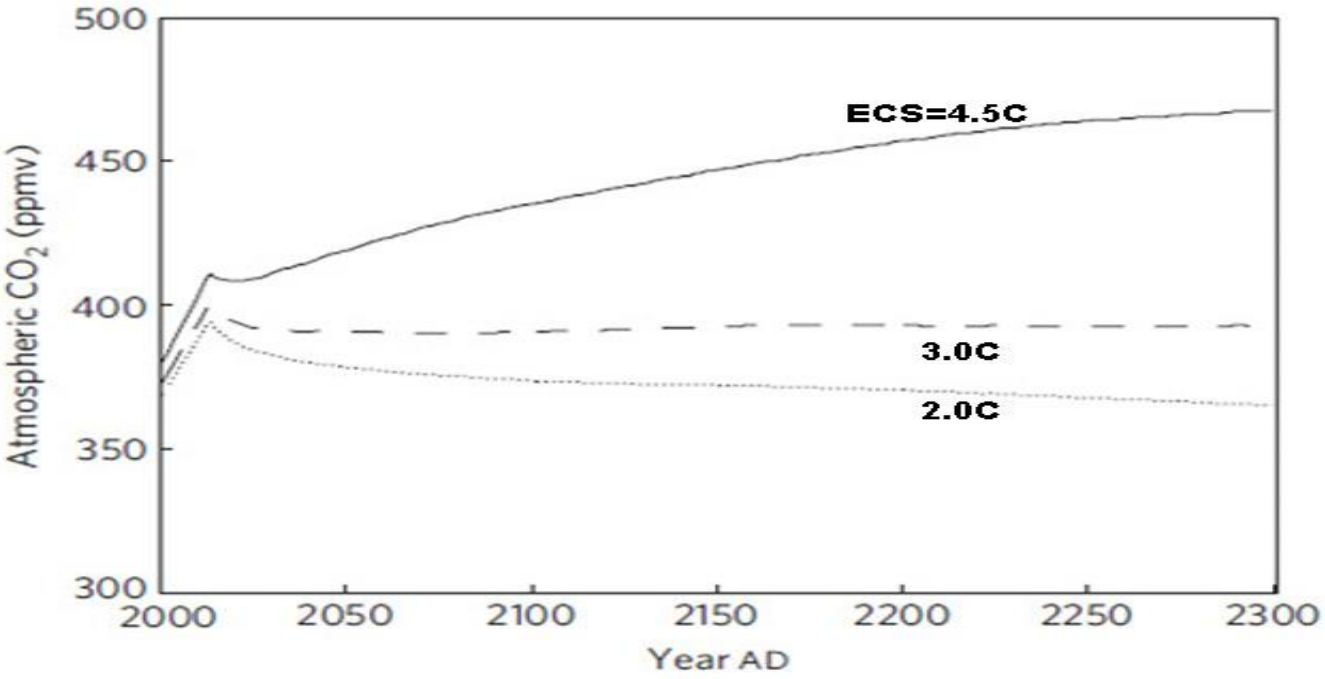
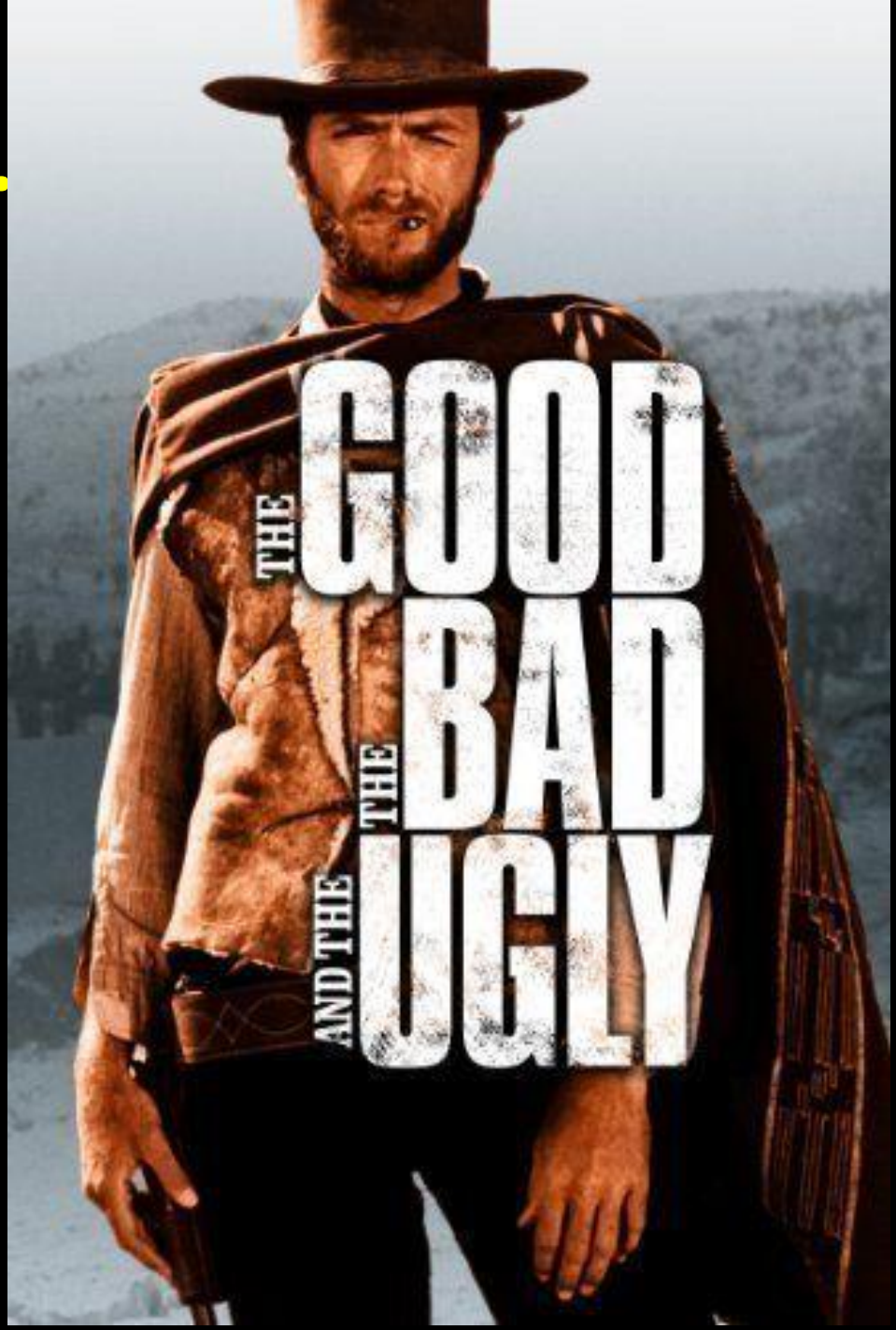


Figure 3 | Evolution of atmospheric CO_2 concentration in response to a cessation of anthropogenic CO_2 and sulphate emissions in the year 2013. The dotted line represents the response for a climate sensitivity (to a doubling of CO_2) of 2.0 °C, the dashed line a climate sensitivity of 3.0 °C and the solid line a climate sensitivity of 4.5 °C.

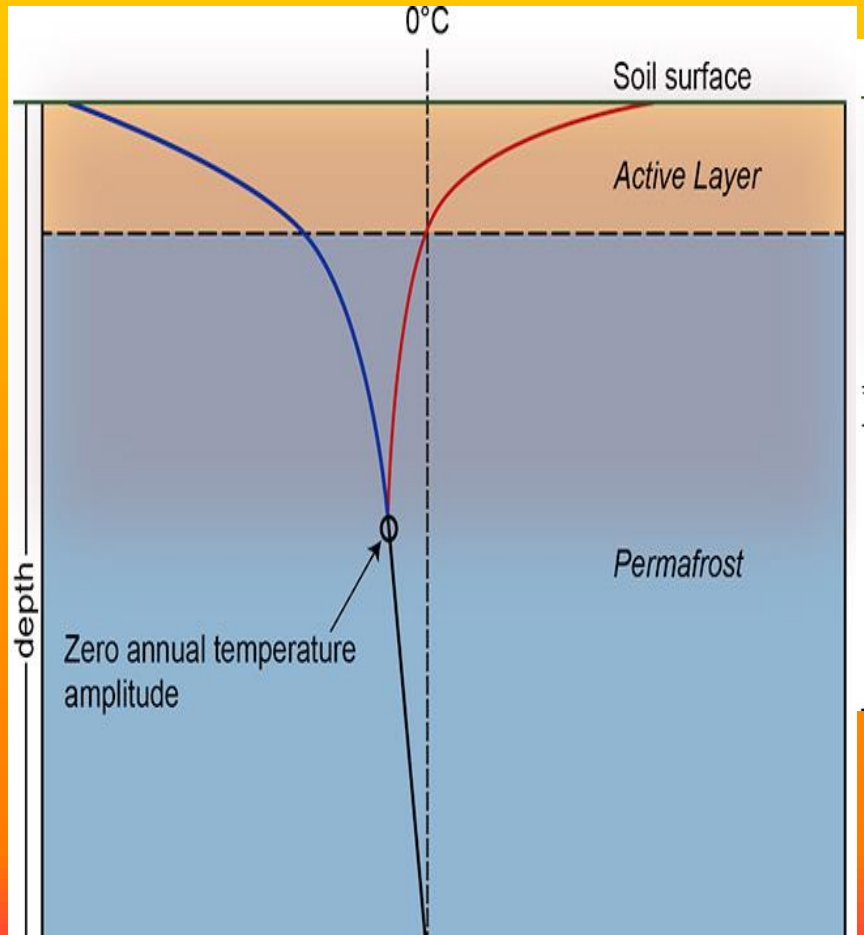
New: Refinements….

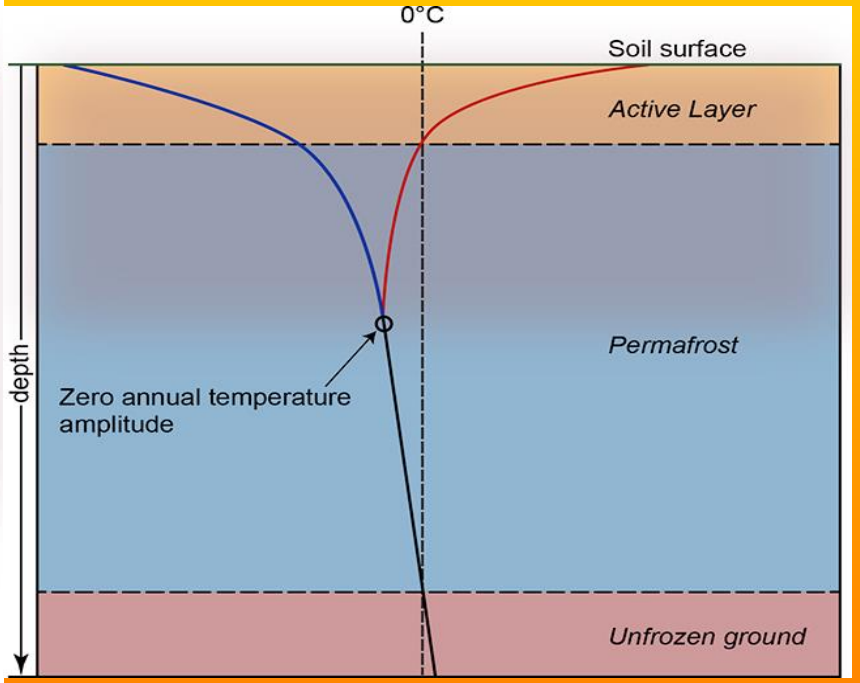
- THE GOOD
- THE BAD
- THE UGLY



THE GOOD

Schadel *et al.* 2014 refines the depth of the Active Layer (the annual freeze/thaw layer near surface). It's smaller than the earlier estimate used by MacDougall's 2012 work.

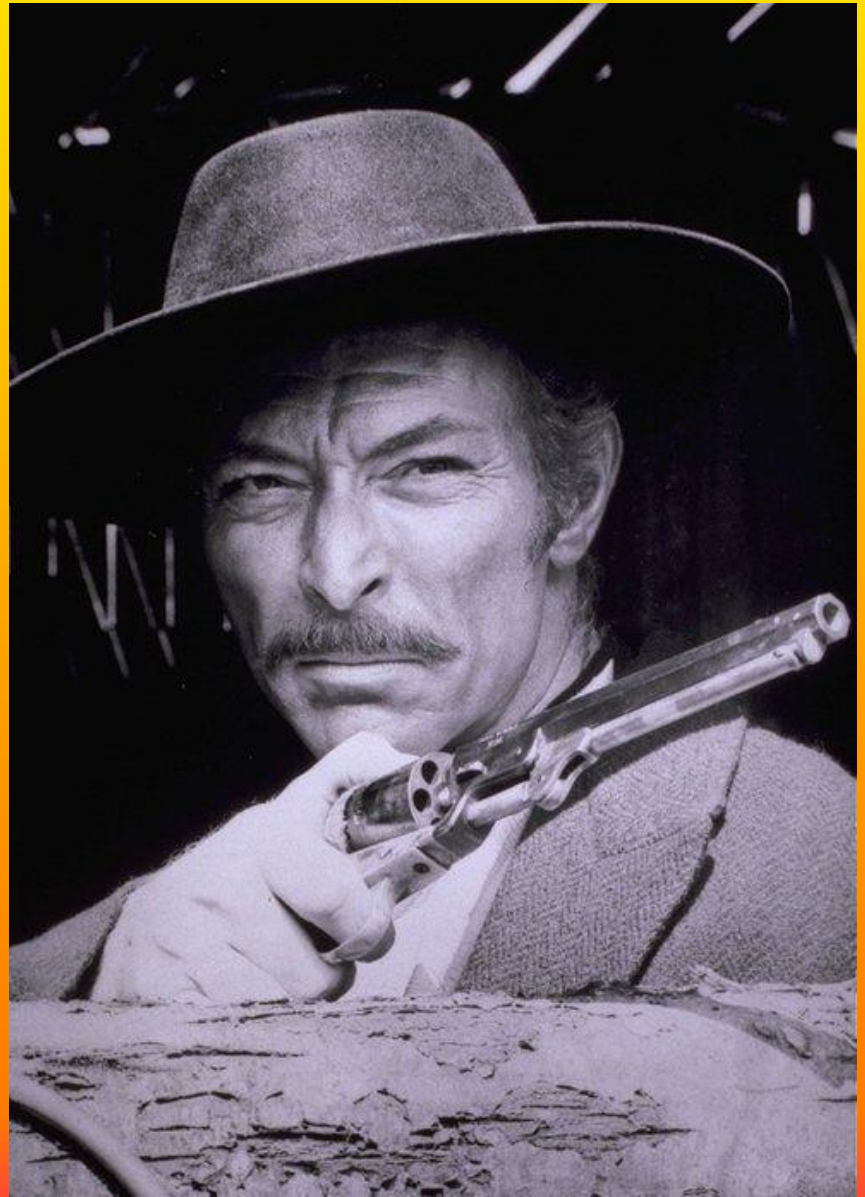




Putting this into a newer version of their modelling, **MacDougall and Knutti 2016** find the permafrost carbon loss rate will be only about ~60% of that shown in **MacDougall *et al.*'s 2012** study, whose graphs we just showed.

Alas, this 2016 study does not break out CO2 *vs.* ECS, so we'll have to do this 60% correction ourselves starting from the original 2012 study…

THE BAD



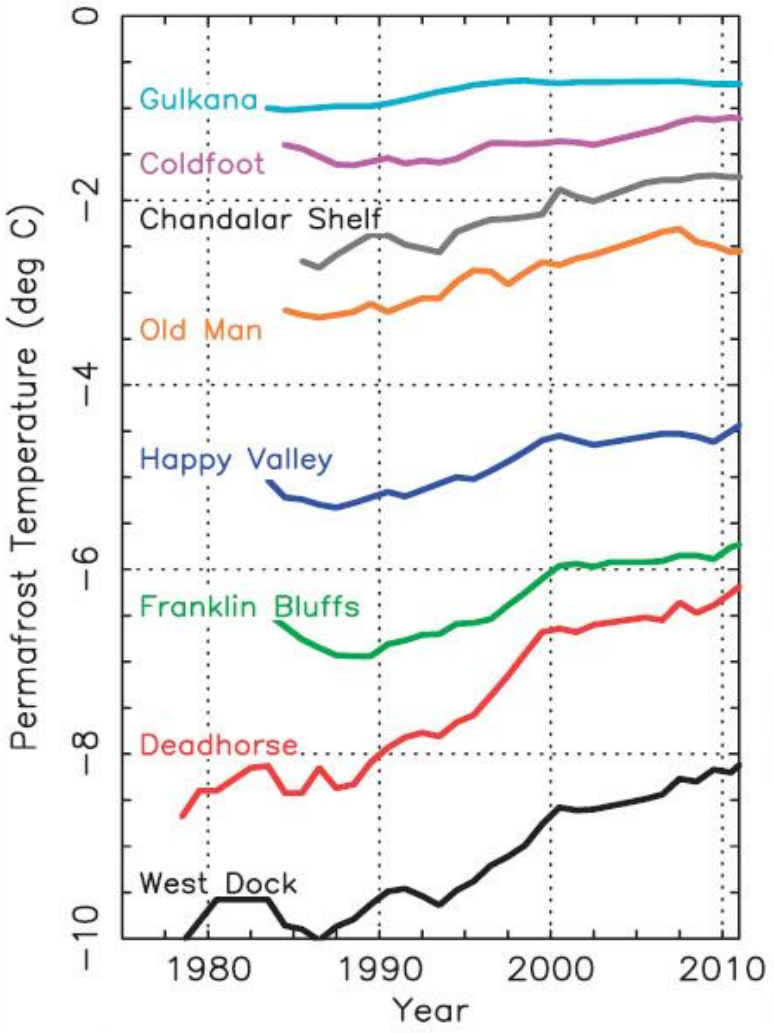
The IPCC Models Did Not Include:

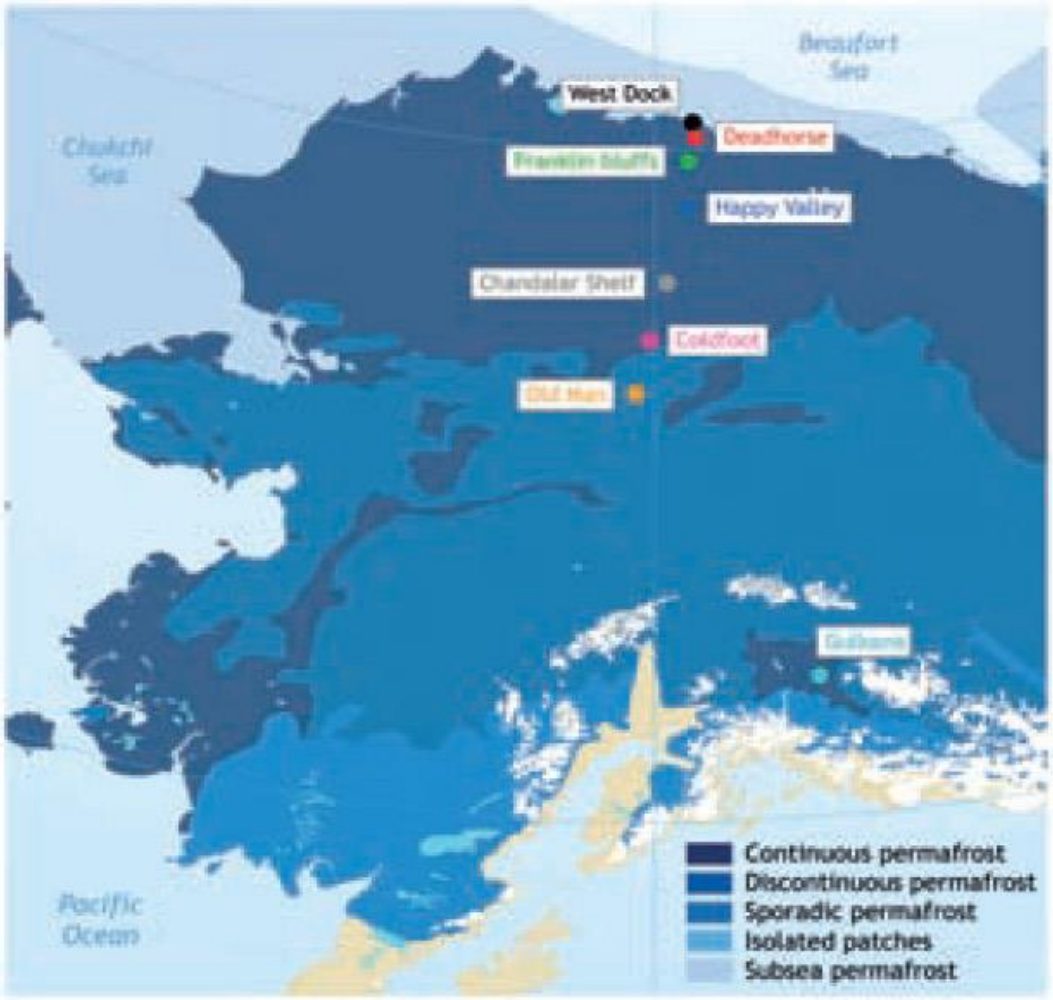
Important Aspects of Methane…

While methane from livestock and tropical areas was estimated and included in IPCC models, **Arctic methane was not**.

Not only was the **Permafrost Carbon Feedback ignored**, along with its CO2 release, so is the permafrost thaw-induced rising release of Arctic methane.

The rising permafrost temperatures in Alaska. On pace for significant loss within a few decades





IPCC Models Do Not Include: trapped methane in frozen lakes, which is quickly released when the permafrost thaws

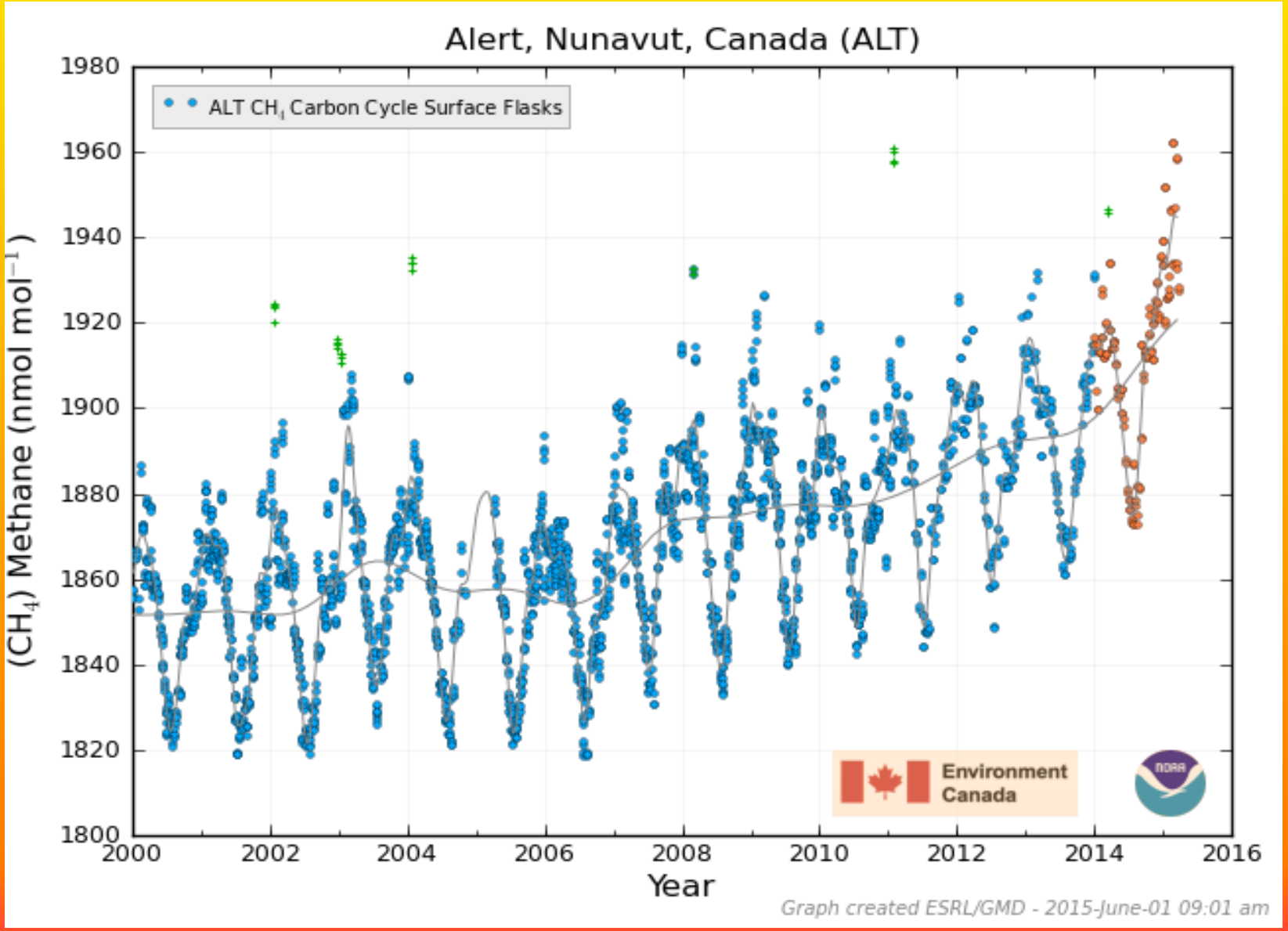
IPCC Models Do Not Include: Pingos melting and filling with deep methane, then exploding and leaving large craters. While it would take many many thousands of such craters to be a significant force in climate…

… more are being discovered all the time

Now in 2017, scientists are discovering…

- …Over **7,000 new domes filled with methane** and *"are ready to explode"*, in the Yamal and Gydan Peninsulas alone

Atmospheric Methane – accelerating in past ~10 years, especially during past 2 years



The latest data makes clear the acceleration happening during the past decade

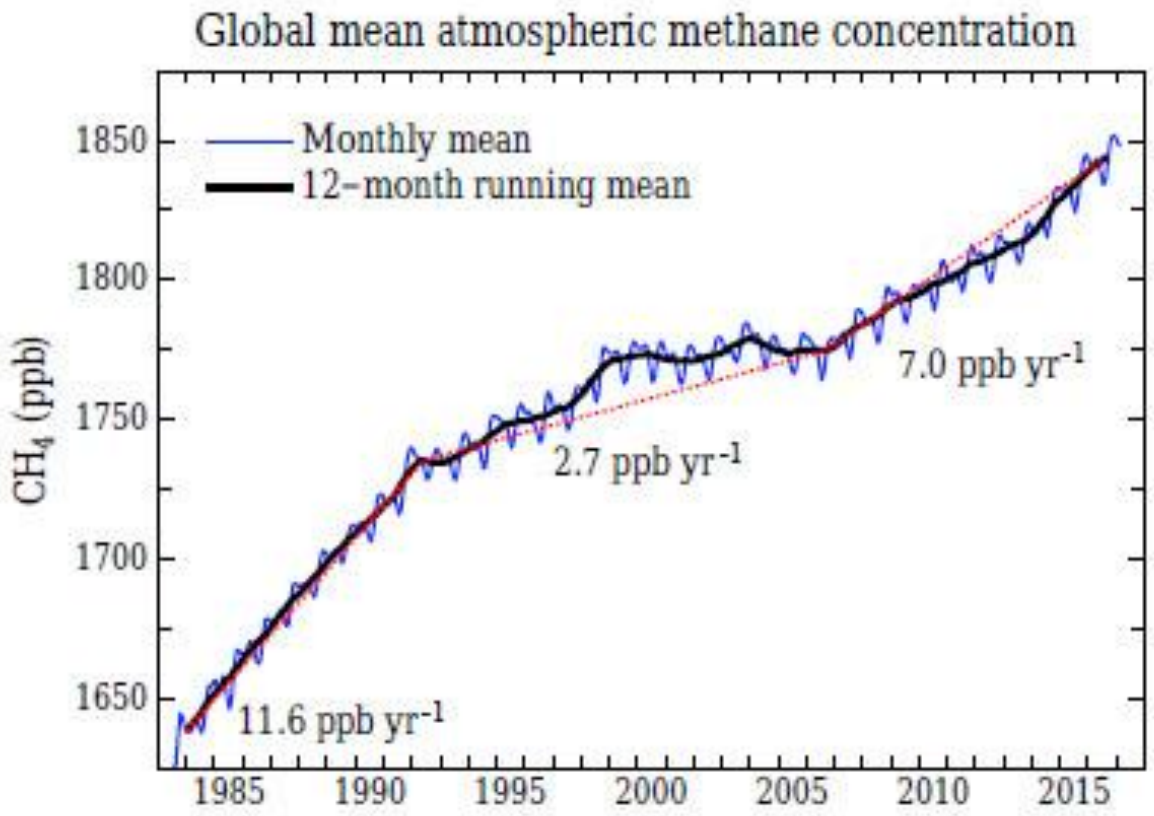
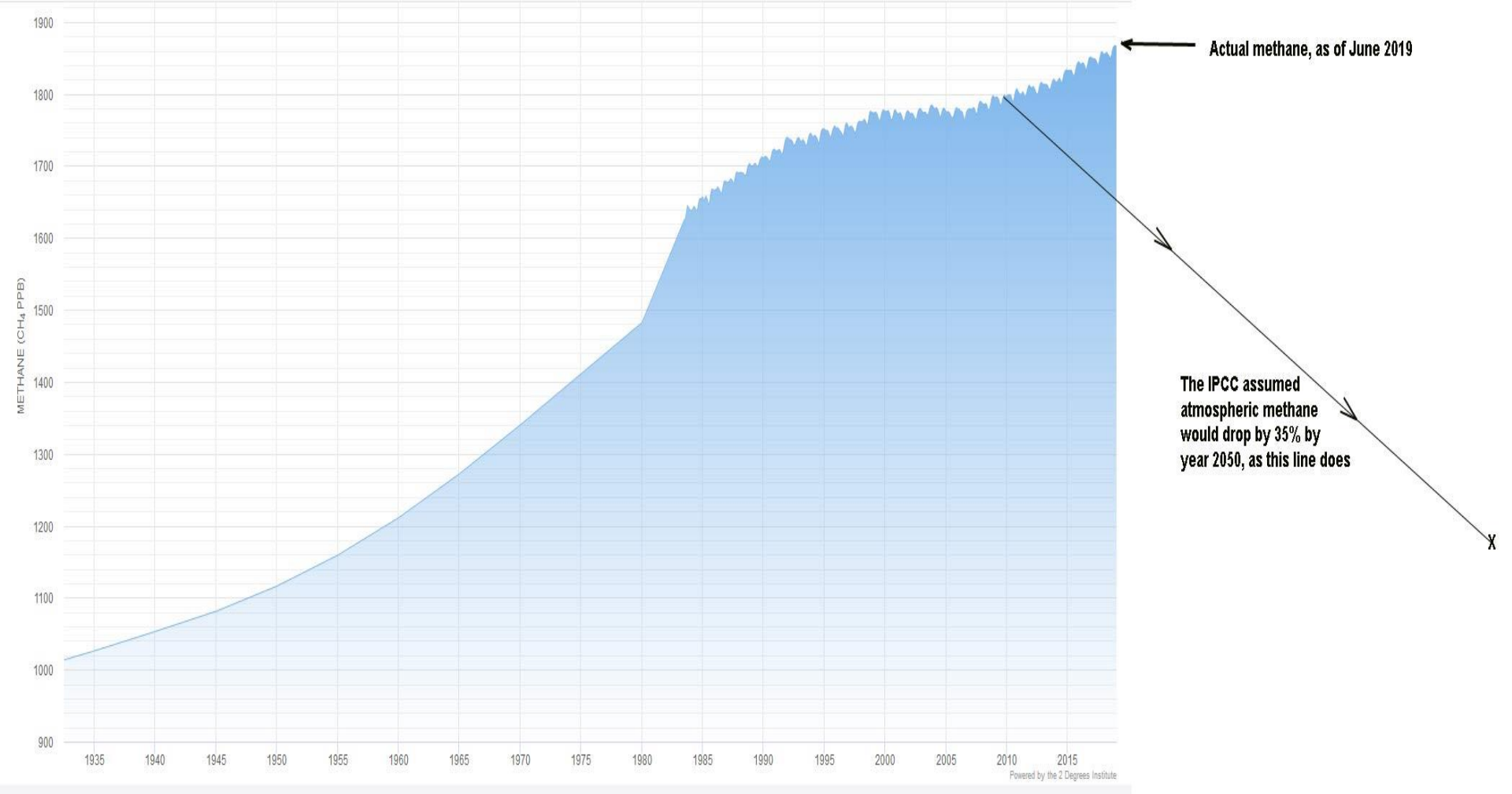
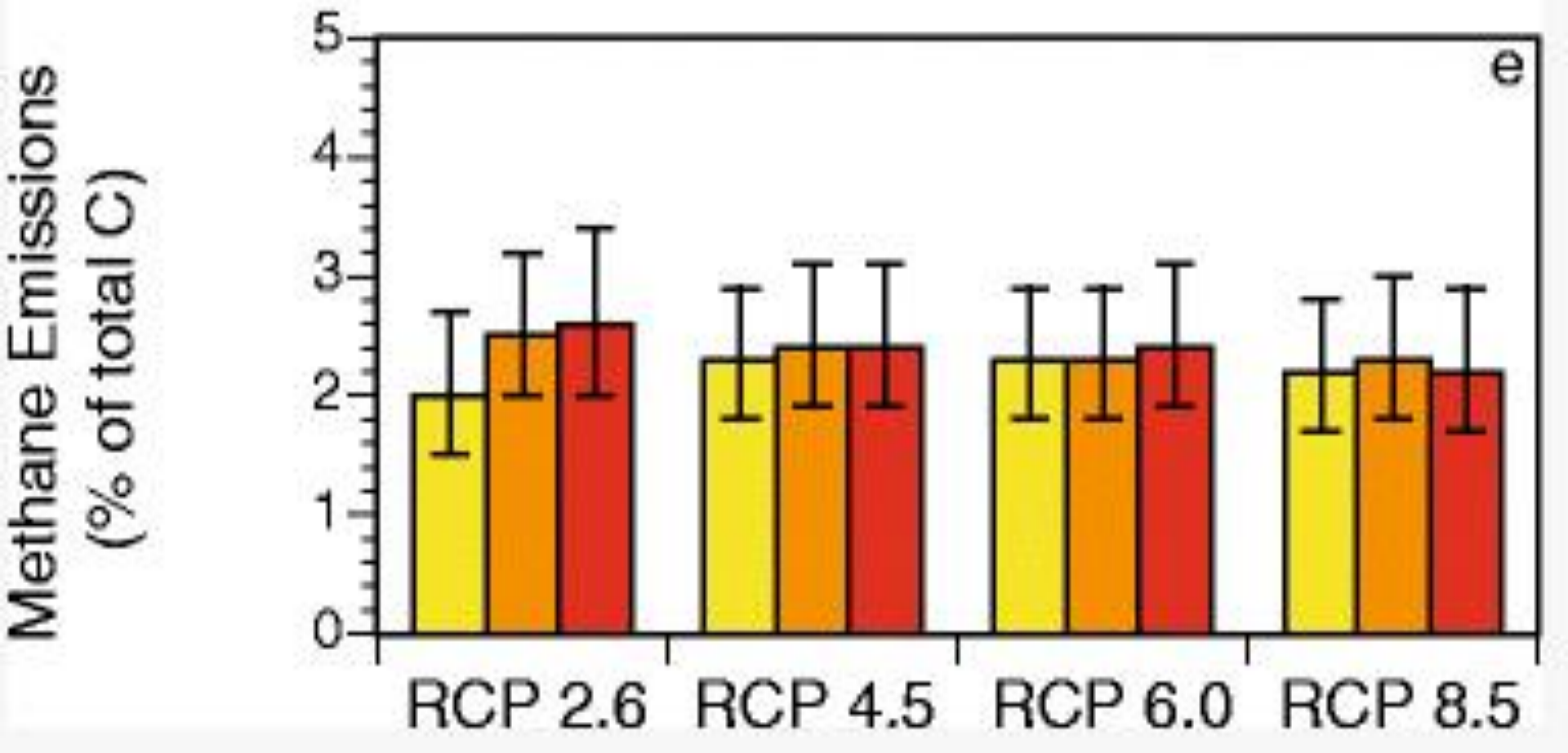


Figure 7. Global CH_4 from Dlugokencky (2016), NOAA/ESRL (http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/). End months for three indicated slopes are January 1984, May 1992, August 2006, and February 2017.

The IPCC assumed that atmospheric methane levels would, starting in 2010, decline by 37% by 2050



Schuur *et al.* 2013 , surveying dozens of permafrost experts, find a consensus that 2.3% of the permafrost's emerging carbon to be in the form of methane - regardless of human emission scenario. (bar colors are for year 2040, 2100, 2300)



This is BAD

- …because the UVic climate model (University of Victoria, BC) used by MacDougall *et al.* 2012 **does not include methane.**
- The UVic climate model, for simplicity, assumes all permafrost carbon emissions are as CO2.
- Therefore the MacDougall *et al.* study must be corrected to include methane emission when thinking of climate temperature forcing.
- **It's a significant correction – as we'll see….**

Too Rosy?

- **For context, without methane modelling**, and assuming an ECS = 3C, MacDougall *et al.* 2012 estimate about +1C of additional warming by 2300 by including only CO2 emissions from permafrost thaw.
- But even besides missing methane, they admit their UVic model is likely too rosy, because in addition to having no methane modelling…
- **…it ignores all carbon below 3.35m depth**. Other work suggests this may be relatively minor… for now… but become significant on longer time scales.

Indeed, the “active layer” is deepening rapidly with warmer temperatures, so the 0.6 factor we applied is likely too optimistic at later times

Also not included: Thermo-karst, stream and shoreline erosion

- …it only includes carbon release from active layer thaw and talik formation.
- **Not included is thermo-karst formation, stream erosion of the tundra, and shoreline erosion of tundra. New work just out in March 2017 says that including thermokarst methane alone DOUBLES the total permafrost methane emission rate (Nzotungicimpaye & Zickfeld 2017). (Added later, 2019 study shows thermokarst indeed is expanding at dramatic rates Farquharson *et al.* 2019)**
- But for our calculations, let's neglect the above additional sources.

So if 97.7% of the carbon is in the form of CO_2, but 2.3% is as methane, what does that mean for greenhouse forcing?

2.3% of tundra carbon atoms emerging as methane means 2.3%/2.75 = 0.84% by mass as methane, *vs.* CO2

- *"If just 1% of the permafrost carbon released is methane, it will have the same greenhouse impact as the other 99% that is released as carbon dioxide. Characterizing this methane to CO2 ratio is a major* ***CARVE*** *objective,"* **explains Dr. Charles Miller, P.I. of NASA's Carbon in the Arctic Vulnerability Experiment (2013).**
- **If 1% methane doubles the warming of pure CO2, then 0.84% almost doubles it**

How Would This Be Reflected in the MacDougall *et al.* 2012 CO2 Graph?

- **Here is a back-of-the-envelope estimate**… Take the CO2 evolution from Solomon *et al.* 2009 (which has no PCF and ECS~3C), and subtract it from the ~flat ECS=3.0C CO2 graph of MacDougall *et al.* 2012 (which has the PCF but still no methane)
- Then take that CO2 trend difference curve as it evolves, and multiply by 0.6 to account for the shallower active layer, and then by 1.84 to account for 0.84% (by mass) methane's CO2 equivalent, and add this back to Solomon et al.'s curve to get the CO2 equivalent warming potential. **So… doing this out loud by the numbers:**
- Solomon's graph, interpolated for 400ppm (at emissions' end) drops by 69 ppm by yr=2300 to 331 ppm. Multiplying that 69 ppm difference by 0.60 x 1.84 = 1.10 turns that 69 ppm into +76 ppm. Added to Solomon's 331 ppm gives a net rise to CO2 equivalent heating = 407 ppm by year 2300.
- It's a ballpark estimate until more careful simulations are done.

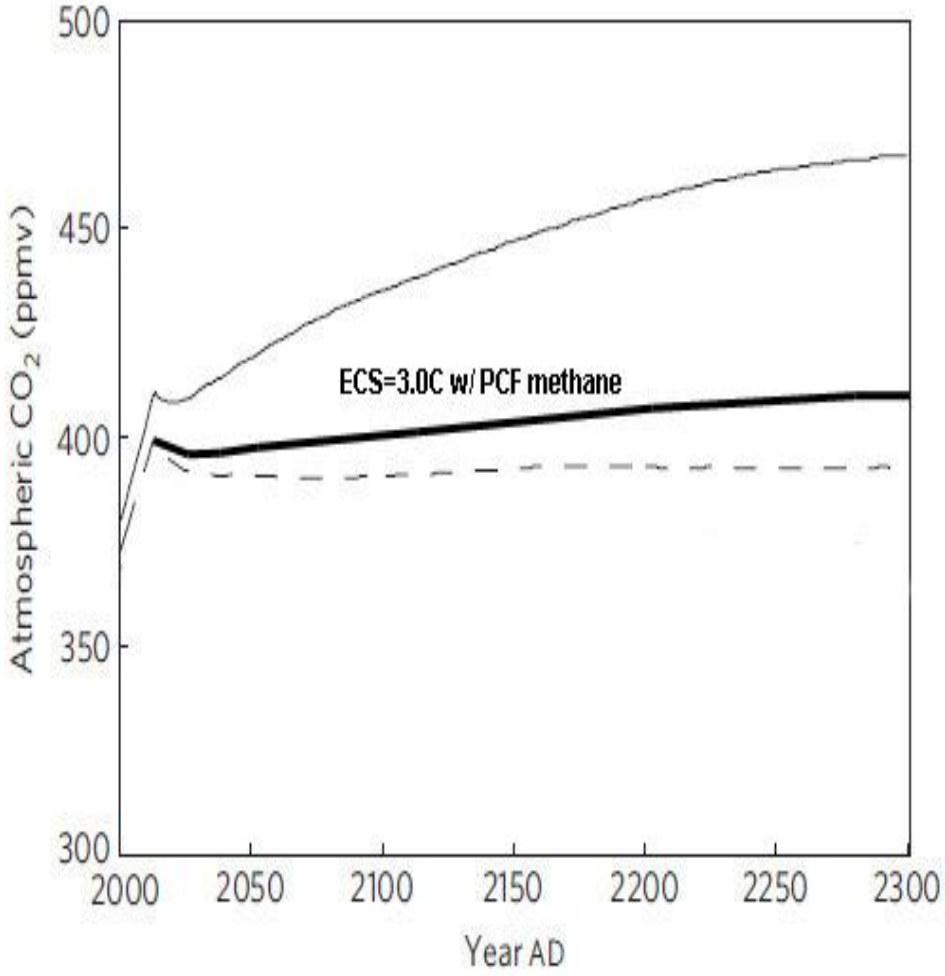


Figure 3 | Evolution of atmospheric CO_2 concentration in response to a cessation of anthropogenic CO_2 and sulphate emissions in the year 2013. The dotted line represents the response for a climate sensitivity (to a doubling of CO_2) of 2.0 °C, the dashed line a climate sensitivity of 3.0 °C and the solid line a climate sensitivity of 4.5 °C.

Here's that MacDougall *et al.* 2012 graph, with added curve after correcting for smaller active layer but including methane. Adds 17 ppm of CO2 equivalent forcing by 2300 for ECS=3.0 curve by 2300. Again, this is after turning off ALL human emissions tomorrow in 2013. We're already at 410ppm today

The sobering feature is the fact that atmospheric CO2 and temperatures continue to rise for centuries

"These correlations demonstrate a key feature of the permafrost carbon system: the long time lag between forcing and response. That is, if fossil fuel emissions are eliminated and global temperature stabilizes, permafrost soils are expected to continue to release carbon for a long time"

--A. H. MacDougall, in **MacDougall & Knutti 2016**

In 2015, Spencer *et al.* found, independently, that the CO2 release could actually be far more rapid

- Much of the Alaskan and Siberian permafrost soil is **Yedoma** permafrost, a fine-grained soil, and it releases its CO2 very rapidly to the atmosphere when thawed.
- Even, within weeks (**Spencer *et al.* 2015**)
- I'll not include that aspect in our calculation, but realize our projections may be too optimistic for this reason

Early hope was that increasing vegetation in formerly frozen soil would sequester much of the carbon in thawing permafrost.

- **Not so…** A major reason is that the thawing carbon release rate is strongly temperature-dependent, much more so than the carbon uptake by new plants.
- Permafrost thaw is, we saw, predicted to continue for all IPCC emission scenarios, even the eco-friendly ones
- **In other words, rising anthropogenic global warming causes sharply higher permafrost soil carbon release, while the amount additionally sequestered by northward migrating forests and shrubs is much smaller (Friedlingstein *et al.* 2006).**

New meta-study (Abbott *et al.* 2016) finds that permafrost melt is now irreversible and the Arctic will become a carbon SOURCE soon. Increased uptake of carbon in biomass vegetation (green) will be overwhelmed by soil carbon release (brown) to the atmosphere and ocean. It will continue for centuries after all human GHGs are assumed to end in 2100. We remain on the "business as usual"=RCP 8.5 track; (*vs*. eco-friendly RCP 2.6 which includes strong active artificial pulling and sequestration of CO2 from the atmosphere, by unknown technology).

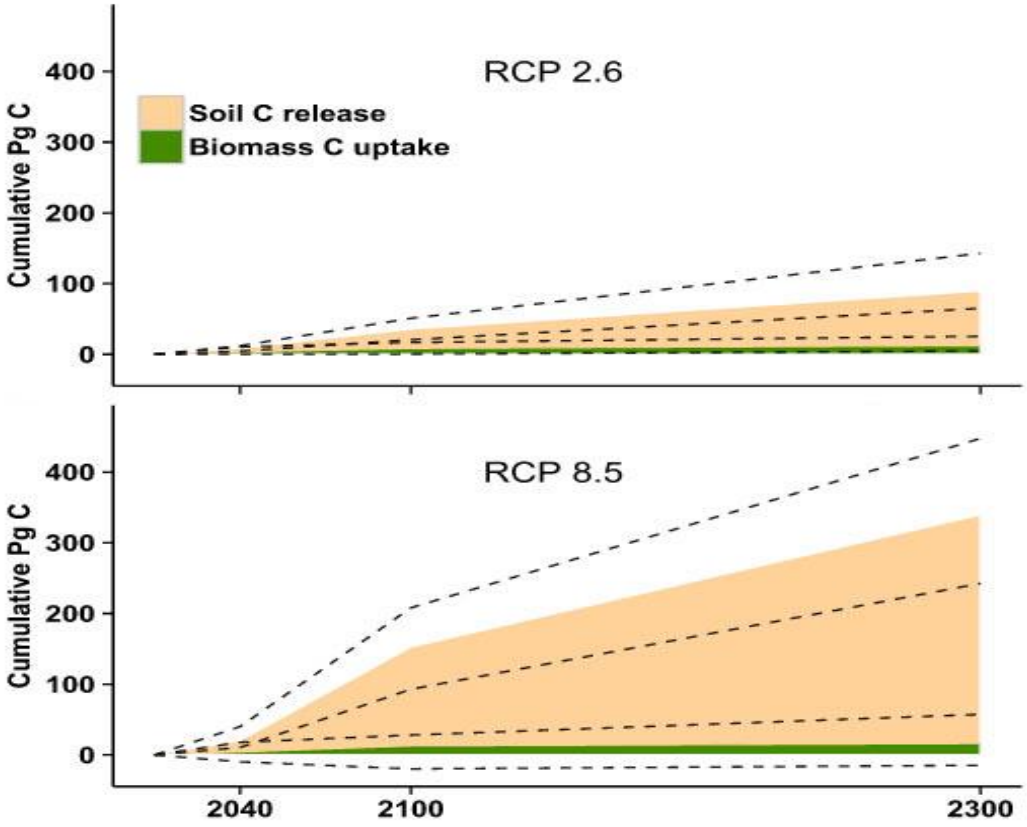
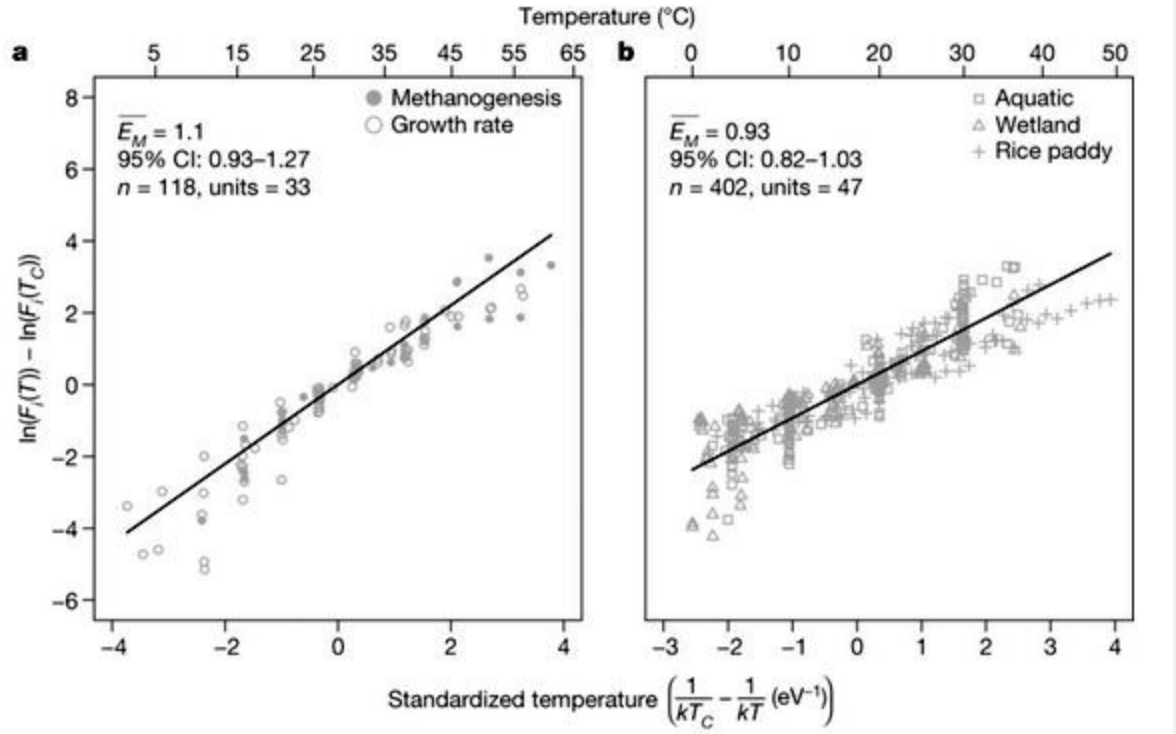


Figure 4. A comparison of soil carbon release recalculated from Schuur *et al* (2013) and non-soil biomass uptake in the permafrost region from this study for the business as usual scenario (RCP8.5) and the active reduction of human emissions scenario (RCP2.6). Polygons represent median cumulative change and dotted lines represent the interquartile range. Biomass carbon uptake is overlayed on soil carbon release to show the proportion of carbon release potentially offset by biomass. Linear rates of change were assumed between the three dates where estimates were provided.

Most methane emissions today are still from non-Permafrost. Can we at least count on these staying ~constant, as the IPCC Models assume?

- **Unfortunately, no.**
- **Yvon-Durocher *et al.* 2014 and on ResearchGate)** studied methane emission *vs*. temperature for a range of scales: microbes, small scale ecologies, and on up to global wetlands and finds strongly increasing rates with rising temperature. Their paper (discussed for the layman **here** and **here**) is titled: ***"Methane Fluxes Show Consistent Temperature Dependence across Microbial to Ecosystem Scales".*** **The effect is strong…**

IPCC Models Do Not Include: Strong positive temperature dependence of global methane emissions from wetlands



Caption

Figure 1: Temperature dependence of CH_4 production and related processes at population and community levels. Temperature dependencies for methanogen populations in culture (a) and anaerobic microbial communities from natural sediment samples (b) are separately characterized using mixed-effects models by fitting Boltzmann-Arrhenius functions with experimental-unit-level random effects on the apparent activation energy and rate at fixed...

0 Recommendations

- **Methane emission rates from natural systems go up a strong 14% per 1C temperature rise.**

That's a Powerful 44-to-1 Amplifier

- For a +4C global temperature rise such as we are likely to see, that's a 72% rise in methane emissions from wetland systems.

- In other words, a 1% rise in temp => 44% rise in methane emission rates.
- They also find that the fraction of carbon which emerges as methane *vs.* CO2, also rises with hotter climate states.
- If this is true, the 2.3% constant over all emissions scenarios we assume for the melting permafrost may be too conservative. But we'll ignore this for our calculations to come.

Not Included in IPCC Models: Arctic methane release is even stronger in the "cold season" (fall, winter, and spring) than in the summer thaw season

- Even recent post-IPCC Climate models have been assuming the Fall and Winter methane emissions in the Arctic are negligible due to freezing.
- **Zona *et al.* 2016** are the first to **measure** Fall and Winter methane emission levels across the Arctic to see if this is actually true, and find instead that methane emissions total **half or more** of all total annual methane emissions.

PNAS PNAS PNAS PNAS

Cold season emissions dominate the Arctic tundra methane budget

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Arctic terrestrial ecosystems are major global sources of methane (CH_4); hence, it is important to understand the seasonal and climatic controls on CH_4 emissions from these systems. Here, we report year-round CH_4 emissions from Alaskan Arctic tundra eddy flux sites and regional fluxes derived from aircraft data. We find that emissions during the cold season (September to May) account for ≥50% of the annual CH_4 flux, with the highest emissions from noninundated upland tundra. A major fraction of cold season emissions occur during the "zero curtain" period, when subsurface soil temperatures are poised near 0 °C. The zero curtain may persist longer than the growing season, and CH_4 emissions are enhanced when the duration is extended by a deep thawed layer as can occur with thick snow cover. Regional scale fluxes of CH_4 derived from aircraft data demonstrate the large spatial extent of late season CH_4 emissions. Scaled to the circumpolar Arctic, cold season fluxes from tundra total 12 ± 5 (95% confidence interval) Tg CH_4 y^{-1}, ~25% of global emissions from extratropical wetlands, or ~6% of total global wetland methane emissions. The dominance of late-season emissions, sensitivity to soil environmental conditions, and importance of dry tundra are not currently simulated in most global climate models. Because Arctic warming disproportionally impacts the cold season, our results suggest that higher cold-season CH_4 emissions will result from observed and predicted increases in snow thickness, active layer depth, and soil temperature, representing important positive feedbacks on climate warming.

permafrost | aircraft | fall | winter | warming

Emissions of methane (CH_4) from Arctic terrestrial ecosystems could increase dramatically in response to climate change (1–3), a potentially significant positive feedback on cli-

that extend into the fall (6, 7, 9, 10) show complex patterns of CH_4 emissions, with a number indicating high fluxes (7, 10). Winter and early spring data appear to be absent in Arctic tundra over continuous permafrost.

Beginning usually in late August or early September, the seasonally thawed active layer (i.e., ~30–50 cm, near-surface soil layer over the permafrost that thaws during the summer growing season) in the Arctic starts freezing both from the top and the bottom, moving downward from the frozen, often snow-covered soil surface and upward from the permafrost layer (Fig. 1). A significant portion of the active layer can stay unfrozen for months, with temperatures poised near 0 °C because of the large thermal mass and latent heat of fusion of water in wet soils, and for the insulating effects of snow cover and low density surface

Significance

Arctic ecosystems are major global sources of methane. We report that emissions during the cold season (September to May) contribute ≥50% of annual sources of methane from Alaskan tundra, based on fluxes obtained from eddy covariance sites and from regional fluxes calculated from aircraft data. The largest emissions were observed at the driest site (<5% inundation). Emissions of methane in the cold season are linked to the extended "zero curtain" period, where soil temperatures are poised near 0 °C, indicating that total emissions are very sensitive to soil climate and related factors, such as snow depth. The dominance of late season emissions, sensitivity to soil conditions, and importance of dry tundra are not currently simulated in most global climate models.

When buried organic matter is isolated from adequate oxygen, it makes methane. Top layer of oxygenated soil unable to oxidize methane when re-frozen, but methane production continues in unfrozen deeper layer (brown)

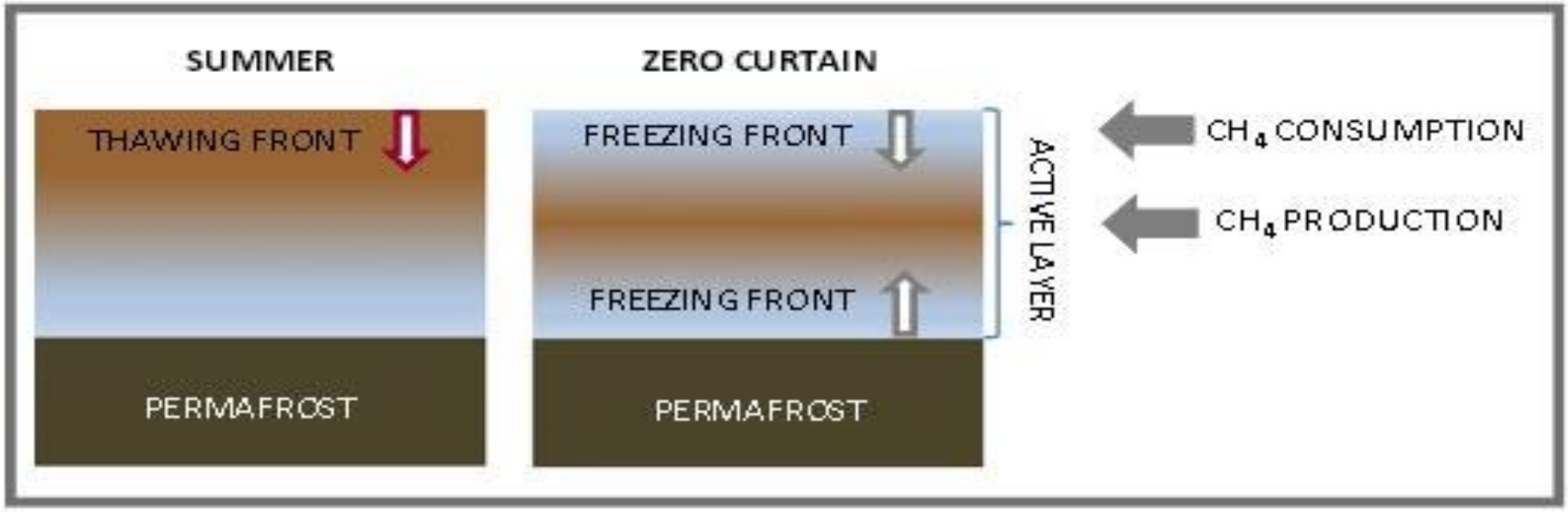


Fig. 1. Diagram of the hypothesized soil physical processes influencing CH_4 production and oxidation depending on the time of the season. We expect that during the zero curtain, the frozen near surface soil layer decreases CH_4 oxidation, resulting in substantial CH_4 emissions, even with lower CH_4 production. Light blue represents cooler soil temperatures, and light brown represents warmer soil temperatures; the arrows point in the direction of the thawing fronts in the summer and freezing front during the cold period.

So methane emissions do not end when the Arctic begins to re-freeze in September, but instead stay high through December, and at lower level all Winter and Spring. This was unexpected. <u>"Zero Curtain" isn't Zero!</u>

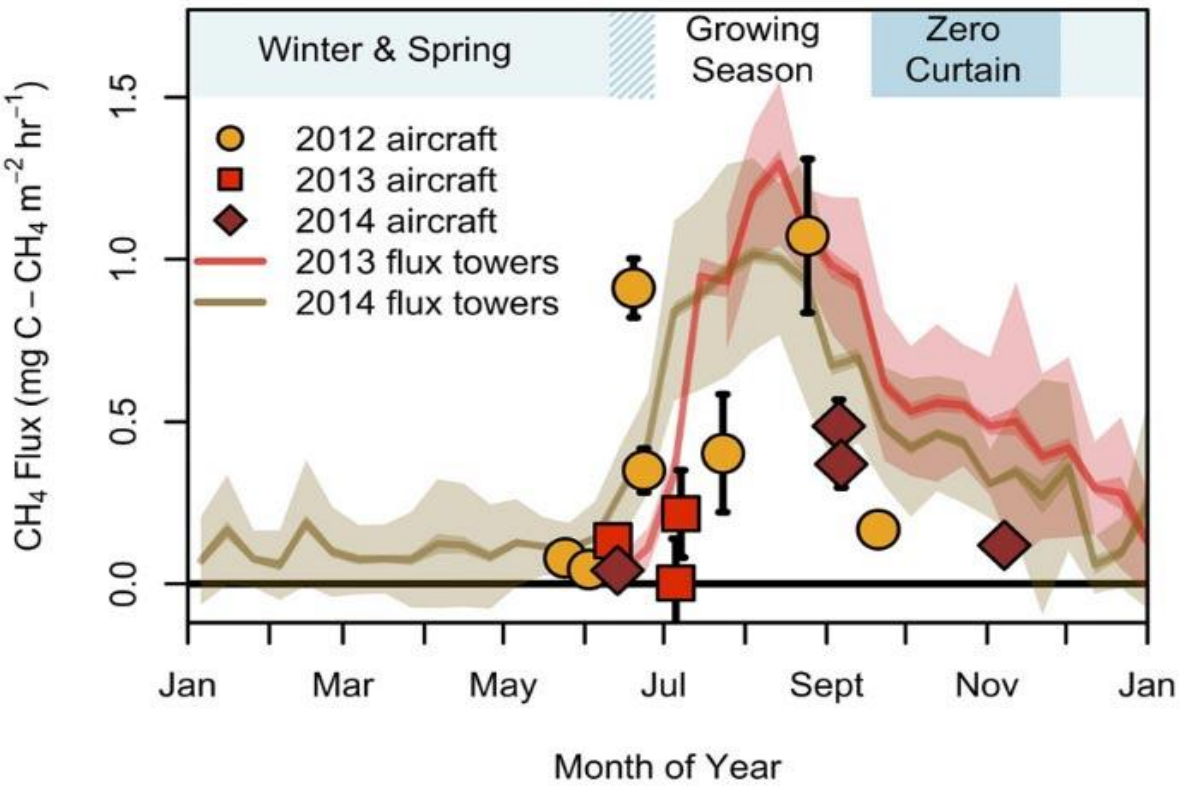


Fig. 4. Ten-day block average of the five EC flux towers over a 300-km transect across the North Slope of Alaska (shaded bands) for 2013 (red) and 2014 (brown), with the mean (solid line), 95% confidence intervals (darker shade), and SD in the CH_4 data (lightest shade). The regional fluxes of CH_4 calculated from the CARVE aircraft data for the North Slope of Alaska are shown for 2012 (yellow circles), 2013 (red squares), and 2014 (brown diamonds). The mean dates for the onset of winter, the growing season, and the zero curtain are indicated in the band on top. Regional scale fluxes of CH_4 (mg C-CH_4 m^{-2} h^{-1}) showed similar seasonal pattern to the EC flux towers across multiple years.

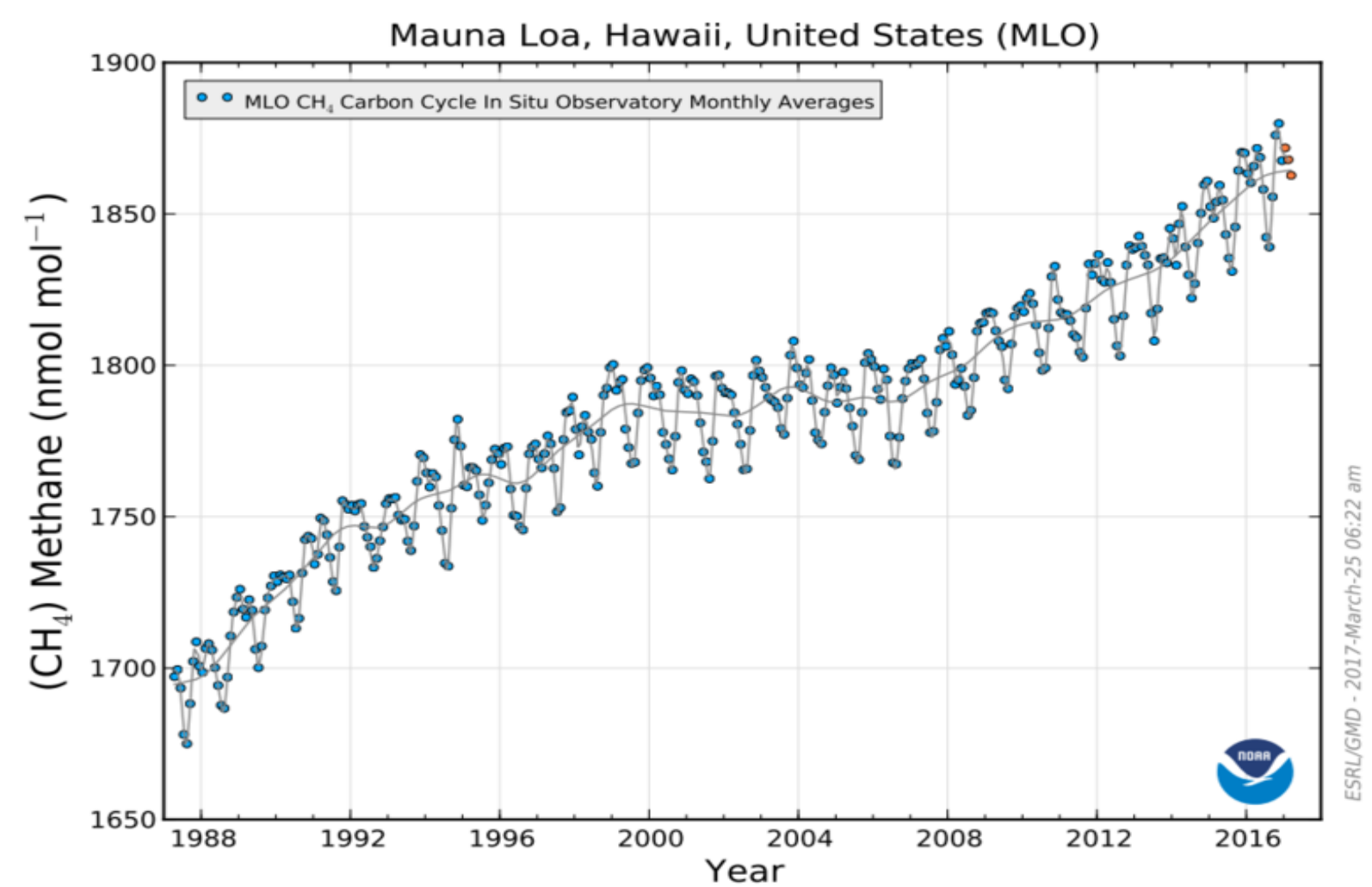
What's worrying is that this work showing doubled methane emissions from Tundra – published in 2016 – is more recent than the MacDougall and Schuur papers

- Does this mean we need to **double AGAIN** the methane emission rates we just examined?
- I'll not do that here. Even without such a doubling, we'll arrive at alarming emissions before we're done…

From the Conclusion section of Zona *et al.* 2016

- *"(We)…estimate 23±8 billion kg (**250 million tons**) CH_4 per yr from Arctic tundra, similar to these previous estimates (ref 8, 32). Our estimated CH_4 cold-season emissions as well as those from inverse analysis (27, 32) are significantly higher than that estimated by land-surface models (27, 32). This difference was thought to be linked to anthropogenic emissions, because bio-genic emissions were assumed to be negligible during the cold season (27, 32). Overall, the seasonal patterns estimated by models (27) are very different from ours and generally do not include the substantial cold season CH_4 emissions found here.* ***Our finding of large cold-season biogenic emissions from tundra reconciles the atmospheric observations and inverse model estimates without the need to invoke a large pollution influence."***
- **In other words, this indirect human source of methane appears to account for the observed re-acceleration of atmospheric methane, not direct human emissions. This is BAD: because human emissions, given proper laws, are easier to control than the Permafrost thaw, which doesn't care to obey legalities.**

Methane trending up in Mauna Loa, Hawaii monitoring site, mostly after IPCC inclusion dates. Is this mostly Arctic Permafrost CH4? Zona *et al.* finds the amounts, at least, are consistent with "yes", but other studies , and C^{13} ratios say this is far more likely microbial digestion from oxygen-deprived carbon. But, we need better Arctic data



If Arctic Methane is still a minor contributor to total methane, will it remain so?

- This is from a new 2016 study by Walter-Anthony *et al.* **described here**, where this quote is taken
- *"The new study found the rate of old carbon released during the past 60 years to be relatively small.* ***Model projections conducted by other studies expect much higher carbon release rates -- from 100 to 900 times greater -- for its release during the upcoming 90 years****. This suggests that current rates are still well below what may lay ahead in the future of a warmer Arctic."*

To Put 250 million tons/yr of methane in context…

- That's about 0.7% of the mass rate of CO2 humans emit into the atmosphere each year.
- Now, this is a RATE of continuous emission from the Arctic tundra and so that new methane continuously enters the atmosphere **fresh**
- But fresh methane has a "Global Warming Potential" of **120x stronger than CO2**, pound for pound, so the actual warming effect of this methane is roughly 120 x 0.7% = 84% that of CO2

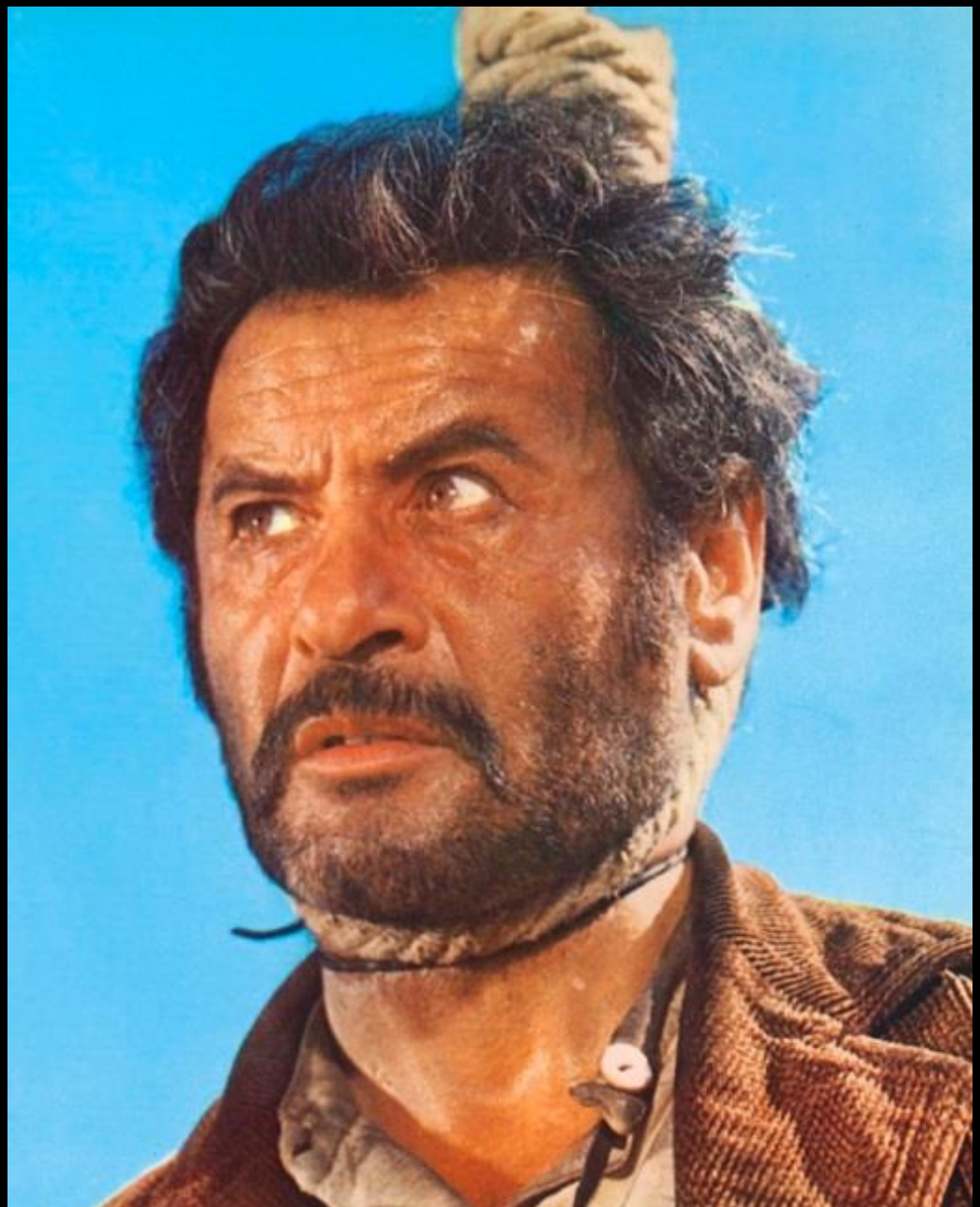
This 250 million tons/yr of methane is a near doubling of total human-caused CO2 heating forcing; a bigger number than just Arctic Permafrost CO2 from MacDougall

- In other words, **nearly DOUBLING the warming of our human-emitted 36 gigatons/yr of CO2. And if this is a rising rate, then we must include an additional rising term in the Global Warming Potential equations. Now some of this is already in IPCC methane figures, so don't over-interpret this number. Frankly, it seems to large to not have been noticed before.**
- **This Zona *et al.* finding awaits to be included in methane emissions estimates. Also, 2.3% of carbon (0.83% by mass) may get revised upward. I've seen higher estimates of 5%+. I'll neglect this here.**

Why didn't the IPCC include the non-CO2 GHG's?

- The argument was that some of these: methane and HFC's, have short half-lives in the atmosphere before they decay. So today's methane and HFC's etc don't matter since they'll decay quickly. If we stop emitting them, they go away quickly (but, we aren't stopping!) Beyond the IPCC, the ruling paradigm is to push the problem off to the next generation, THEY – hopefully - can eliminate these.
- **This responsibility-shifting maneuver has no validity, however, when much more of the increasing methane fraction is going to be supplied by melting permafrost and temperature-dependent tropical wetlands methane formation, such methane is emitted continuously, and is not subject to our legal restrictions**

And the UGLY



Is ECS Really 3C per CO2 doubling?

ECS = the global average temperature the Earth reaches after coming to equilibrium at atmospheric CO2=560 ppm (doubling of pre-industrial atmospheric CO2 level of 280 ppm)

It's a <u>rate</u> of global temperature rise per rise of atmospheric CO2.

- Is the proper ECS going forward really +3.0C? A number of new papers find… **No. It's higher.**
- A number of studies are finding ECS depends strongly on background climate state – **<u>higher</u>** <u>ECS in **warmer** climates.</u>

First, let's explain the highly questionable inclusion in the IPCC AR5 of ECS = 1.5C as a lower limit of the plausible ECS range

- **Otto *et al.* 2013** find ECS to be as low as 1.5C, but the parameters in their models have been widely criticized as unrealistic and at variance with the evidence. Nevertheless, fossil fuel interests and some government policy people refused to sign off on the IPCC AR5 unless this low ECS was included, and so it was – over the objections of the scientists.

Yet it's easy to show ECS must be much higher than 1.5C in today's world…

- At 2017's CO2 of 410 ppm, we're 46% of the way towards a doubling of pre-industrial CO2, yet global average temperature is already at +1.25C above pre-industrial as of Aug 2017, averaging over monthly variations.
- On even a linear trend, we'd be at +3.0C at the moment of CO2 doubling, and this fails to include the additional ~200 yrs of warming needed after that in order to reach equilibrium temperature at that CO2 level, adding another +1C on top of that, or more.
- ECS must be more like 4+ C, or higher, by implication.

Friedrich *et al.* (2016) studied how ECS during the past Ice Ages and interglacials appears to depend on climate state.

- First, before parsing the data with respect to background climate state, they find that ECS=3.22C as an average over all the various climate states during the well-sampled paleo atmospheric past; *i.e.* during the past Ice Ages and interglacials.
- This finding gives confidence in their basic methods, since ECS=3.22C is in excellent agreement with the PALEOSENS meta-study average, and also that of Hansen and Sato's (2012) work with the same time period (next slide)…

Hansen and Sato 2012 find that an average ECS=3.0C (black) fits Earth climate (red) going into and out of Ice Ages for the past ~million years, *i.e.* for CO2 ranges from 170-280ppm. But, they point out this ECS may be inappropriate for projections in the future since we are now quite far above the entire CO2 range during the Ice Ages

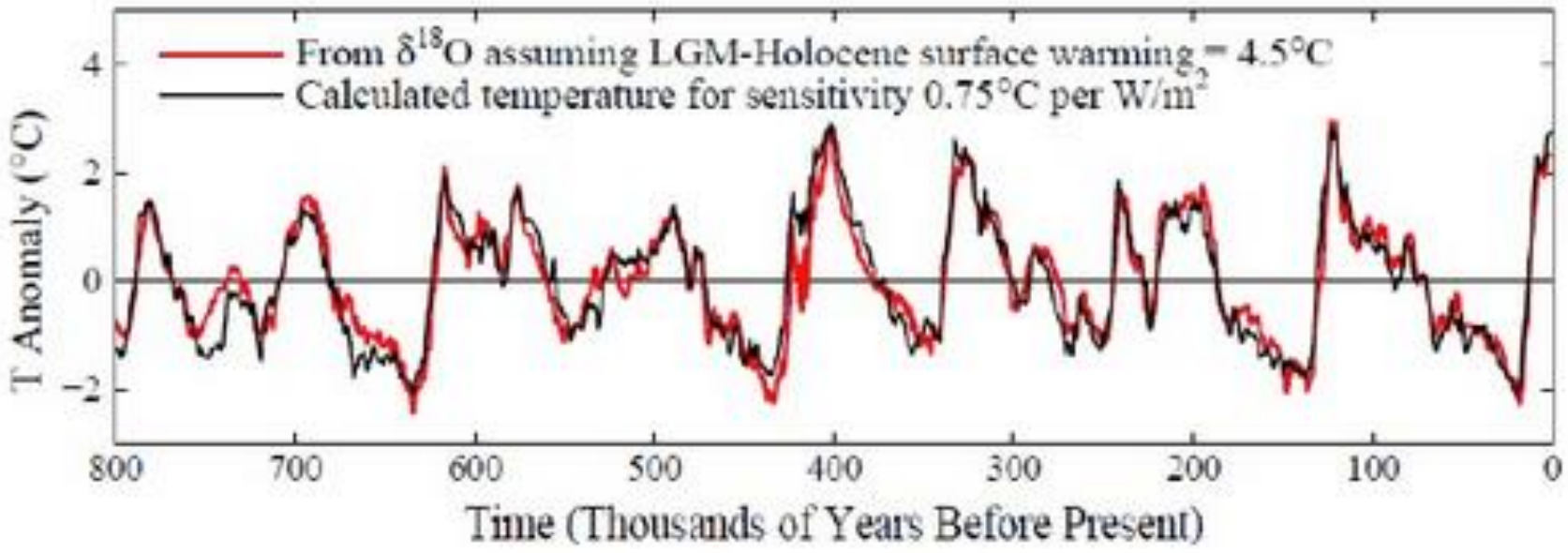
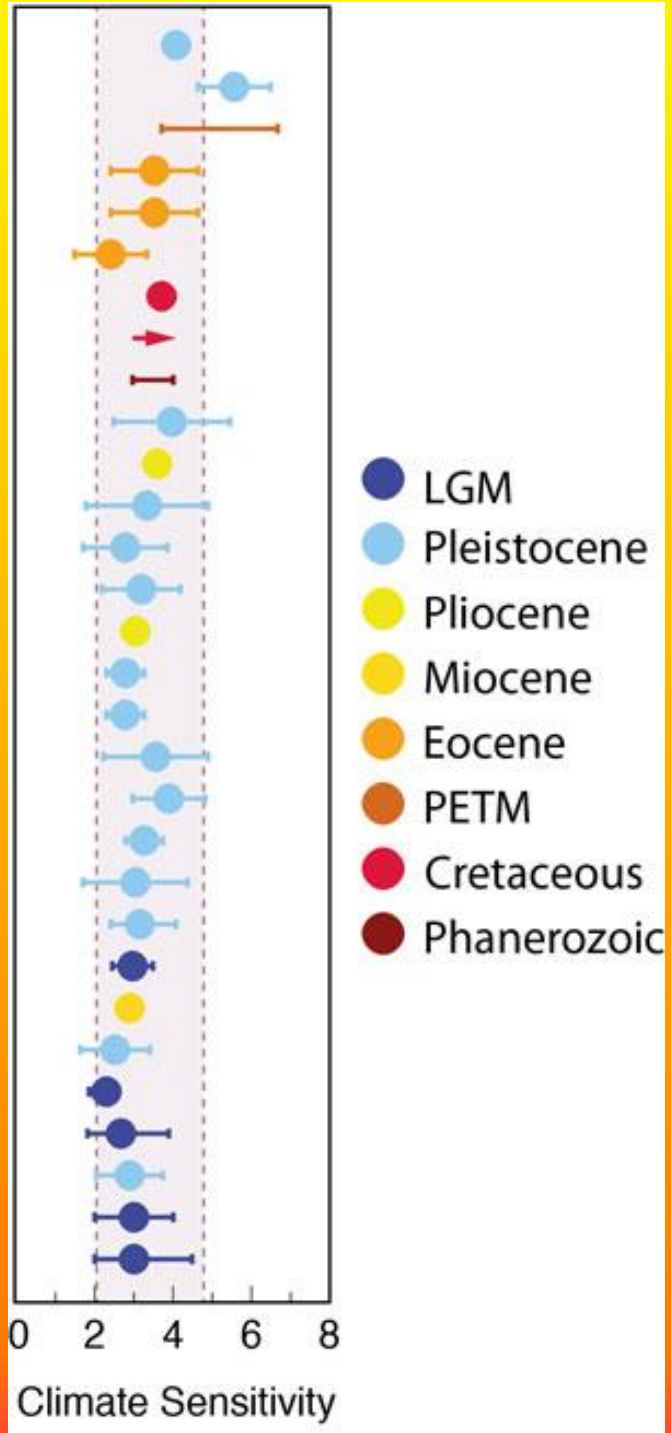


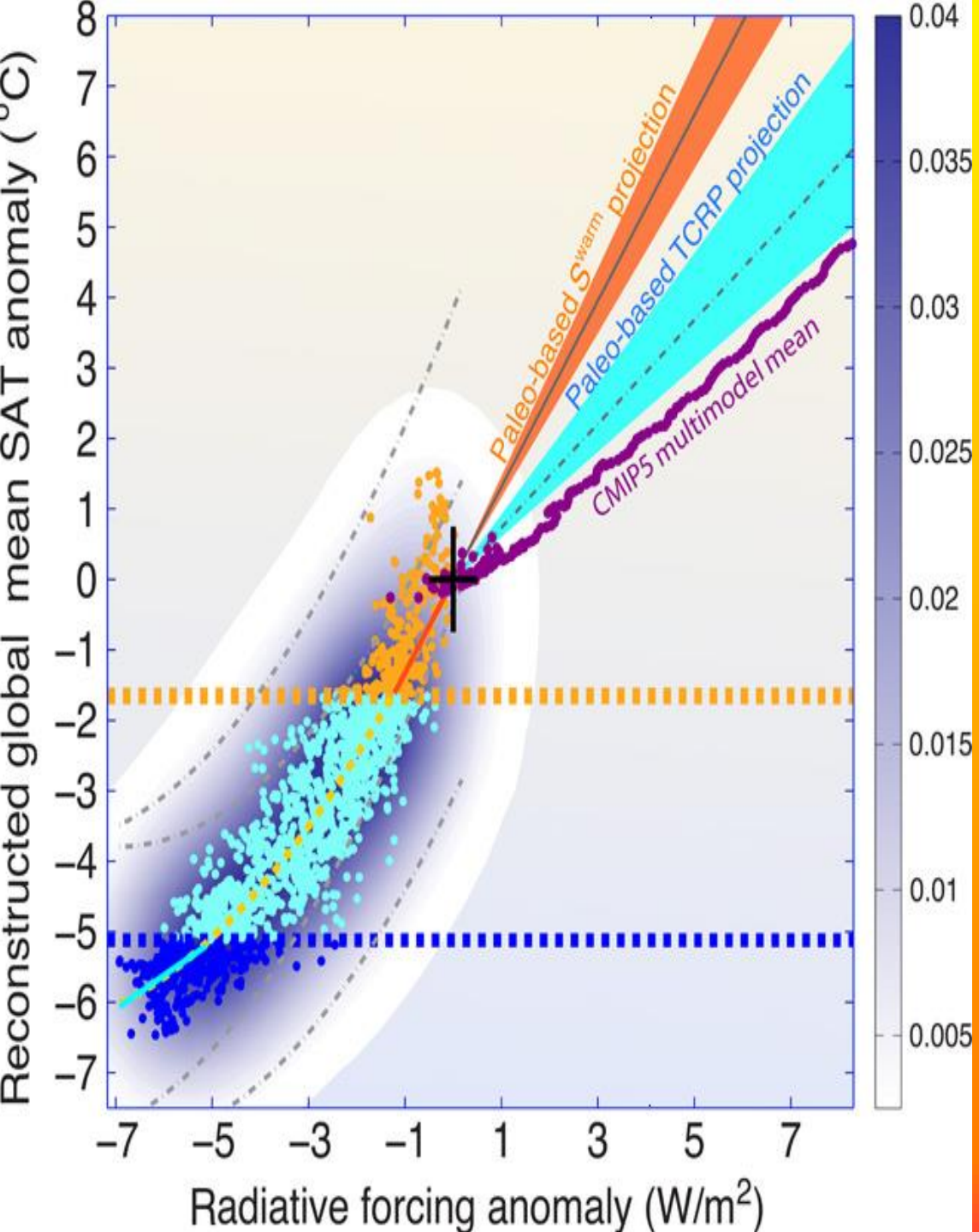
Figure 3: Black curve: calculated surface air temperature change for climate forcings HS12 and climate sensitivity 0.75°C per W/m2. Red curve: estimated global surface temperature change based on deep ocean temperatures and assumption th LGM-Holocene surface temperature change is 4.5°C. Zero point is the 800 ky mean Figure 6 from HS12.



- …And the PALEOSENS collaboration's comprehensive work which includes times without ice core data such as we have for the past ~million years.
- **ECS == Final global avg temperature change after doubling CO2 from 280 to 560 ppm, after all "fast" feedbacks have stabilized**
- **ECS Ranges from +2C to +5C temperature rise, averaged over the many different climate states studied**

Friedrich *et al.* (2016) then combine the paleo data with climate modelling to show that ECS is higher at higher background global temperatures

- Meaning; climate indeed has positive feedbacks which amplify the warming direction non-linearly.
- During glacial periods ECS is a low 1.78C
- **But during the warm interglacials, ECS=4.88C**
- **Even this alarmingly high ECS may be an underestimate, because CO2 was at most 280 ppm during those past interglacials. Yet today it is 410 ppm and rising.**



Friedrich *et al.* 2016 Fig 3. Dots are paleo data. A straight slanting trend would correspond to a constant ECS; i.e. same slope at both low and high temps. But instead, we see a strong upward curvature; says **higher ECS applies at higher temperatures**. The orange band assumes **ECS=4.88C** holds today and for the future. But even this may be too low, since the orange straight line slope projection looks shallower (lower ECS) than the highest orange paleo data slope indicates, and we're already far above the 280ppm CO2 of all of this data: So as we enter a new regime of rapidly disappearing polar caps ECS could well be even higher than 5C.

This implies that amplifying non-GHG feedbacks (albedo and clouds?) are more powerful than the standard models assumed (indeed, IPCC models ignore many feedbacks, including clouds)

- This conclusion is supported with the work of **Fasullo *et al.* (2012)**, who finds that **it is the most "alarming" climate models which do the best job of predicting what we have already seen**.
- See an **interview with Fasullo on this work here**.
- **Brient *et al.* 2016 agree**, finding ECS=4.0C and weakening low clouds (which cool climate) with higher temperatures

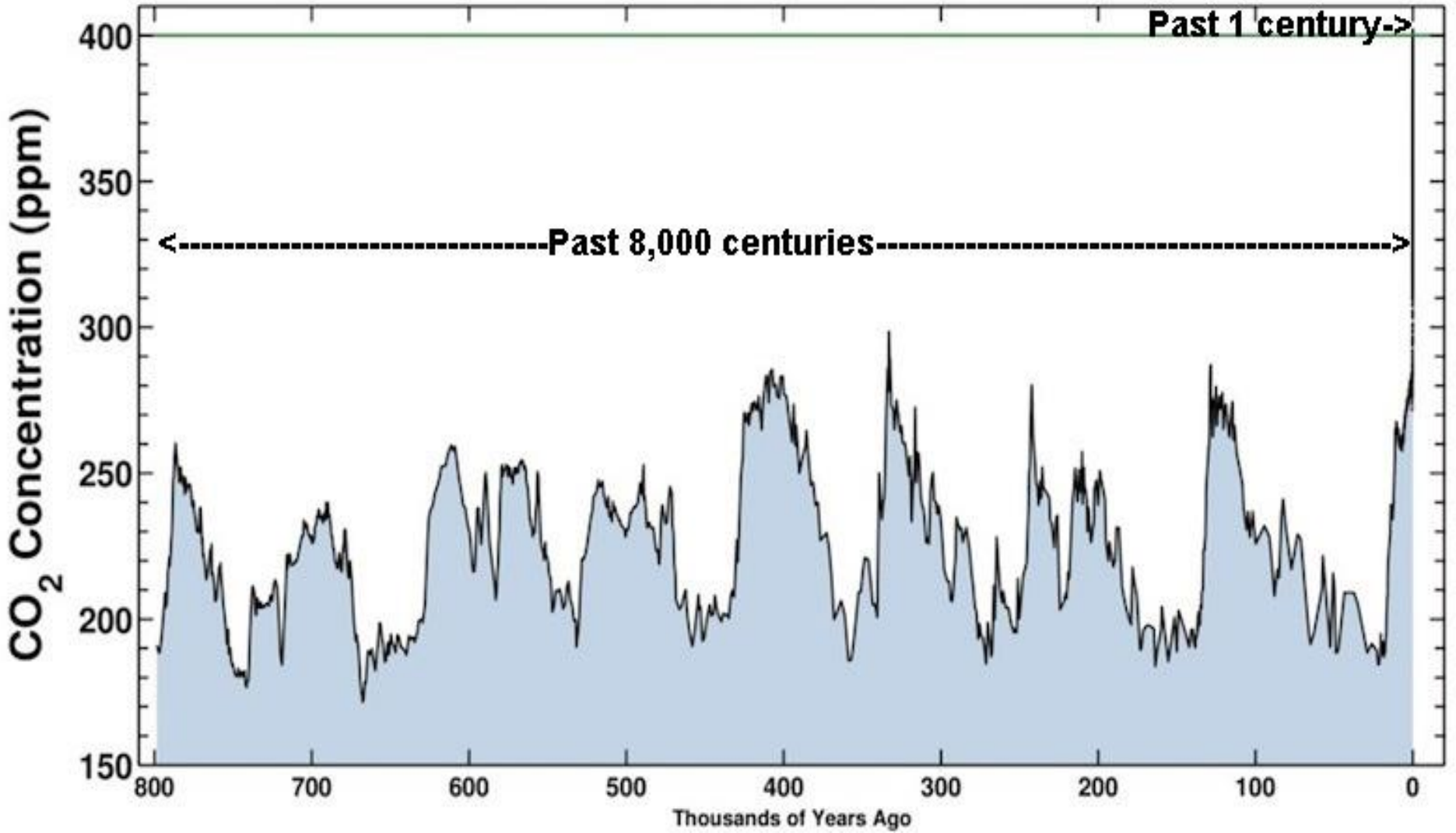
What I find impressive in the Friedrich *et al.* work is…

- … that when analyzing the entire data set as a whole, **they get the same value for ECS as the existing best work in this field: ECS=3.22C as an average over all climate states.**
- This strongly suggests there is no underlying mistaken physics or methodology relative to prior studies.
- And no underlying bias to find a high ECS. On this, note that Friedrich is a relatively young scientist at a time in his career when doing poorly motivated sensationalized work would be most damaging to his future career. It is unfortunately true that it's when emeritus professors are at the END of their careers and perhaps yearn for another at-bat for a chance at glory, that there can be temptation to do junk science in hopes to prove everyone else is wrong (I'm thinking of a certain disgraced retired professor at M.I.T.).

Are even these warm interglacial periods reliable to predict our future? After all, these had atmospheric CO2 at only 280 ppm. Today we're at 410 ppm and rising at new record rates of 3 ppm per year

- The Friedrich *et al.* 2016 curve appears to be even steeper than ECS=+4.88C at the high end at 280ppm CO2, and we're far above the high end of any interglacial atmospheric CO2 level
- Is there additional support for higher ECS at higher temperatures? **Yes. Millennium and longer time scale "slow" feedbacks raise this to ECS=~+6 C**. **Hansen *et al.* 2008**
- **The temperature response to a rapid GHG pulse reaches 60% of its eventual level after 1 century, but takes 2,000 years to reach final equilibrium (Hansen *et al.* 2016 fig 4)**

Today, we're 410 ppm - far above those CO2 data points from the ice cores – rapidly forcing a new climate state



Here's a powerful reason why future projections of climate may follow a stronger ECS than in the paleo record

- In modelling paleo data, CO2 is shuttled between the ocean, permafrost, and the atmosphere according to the CO2 solubility pump (*e.g.* **Heydt and Ashwin 2016**), and this is appropriate going into/out of Ice Ages w/o humans. But today's CO2 rise is **not** shuttling these oscillating sources in an approximately zero-sum way.
- **We're instead taking new long-sequestered carbon from the Carboniferous Era and ADDING millions of years worth of it to the ocean / atmosphere system in a geological instant.**

Classic Assumption that ECS=Constant? Yes – But only for simplified Climate Models that include only CO2 and the Water Vapor Feedback to predict climate

- ECS due ONLY to CO2 and the Water Vapor Feedback IS Close to Constant… (band saturation in CO2 absorption causes this)
- **But the real world is different than this simplified idealization…**

Let's Count Some of the Reasons…

Non-GHG heating feedbacks

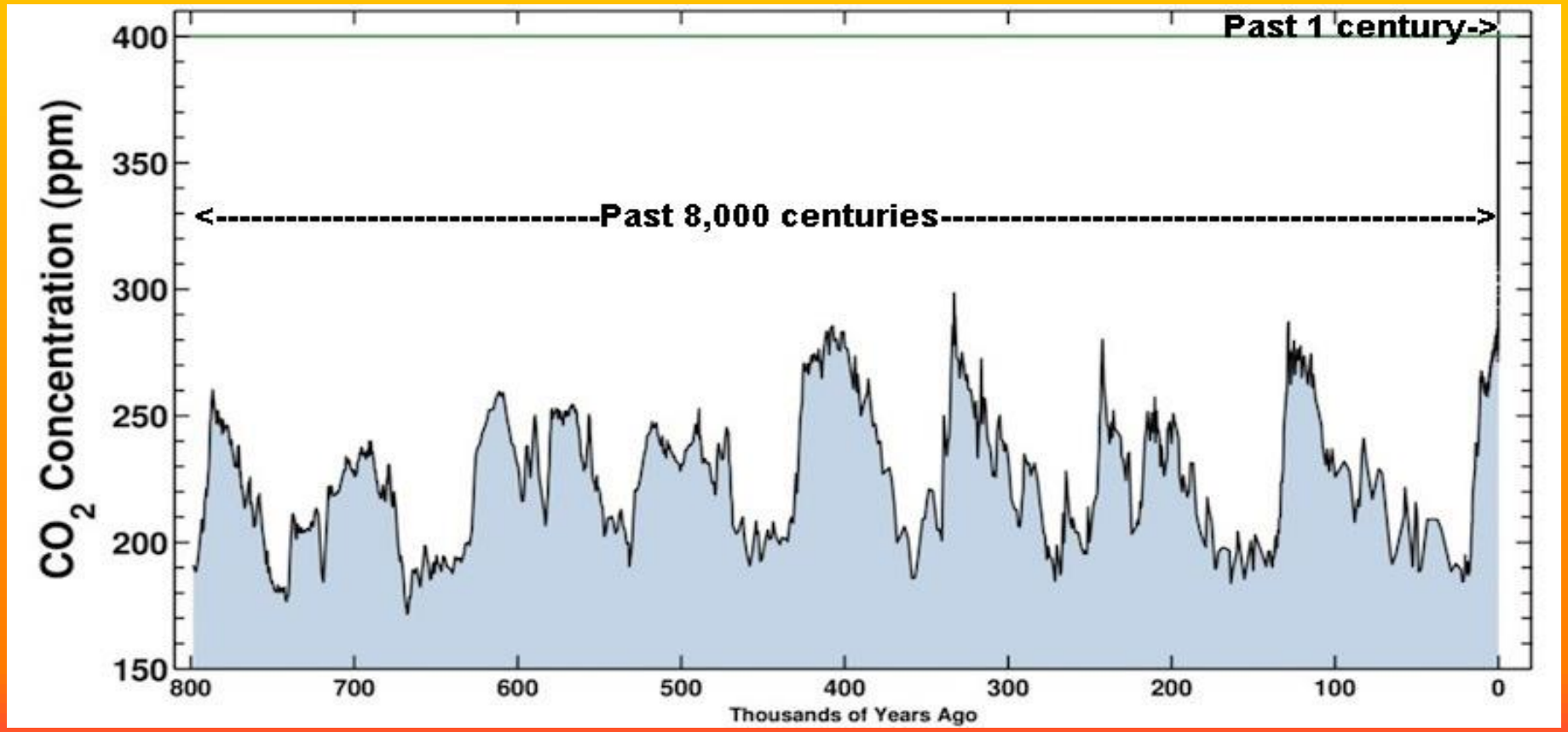
- - Rapid loss of reflective Arctic ice – the albedo feedback – much faster than IPCC models
- - Reduced low cloud (e.g. Sherwood *et al*.) and increased cirrus cloud are both warming forcings to climate. Missing from IPCC modelling

GHG-related but in perhaps non-standard ways

- - Desiccation of and impairment of carbon-sequestering soil microbes who can't adapt to such rapid environmental change, desert band moving poleward.
- - Methane % rise rate is much faster than CO2 % rise rates –
- -Industrial non-CO2 GHG's rising e.g. HFCs, NOx
- -Deforestation
- - Ocean acidification harming calcareous marine species' ability to pull CO2 out of solution and thereby aid ocean absorption of atmospheric CO2

…these are not included in pure CO2-driven climate sensitivity and amplify the forcing, leading to higher ECS at hotter climate states, especially when reached rapidly.

Note on the CO2 paleo graph that it is typical for transitions out of Ice Ages into warm Interglacials such as we're in now, to be much more rapid than the descent into Ice Ages (and today's rise is vastly faster still). Warming into Interglacials should reasonably be expected to correspond to higher ECS than the avarage



Indeed, there are now many new studies showing significantly higher ECS applies at hotter climate states, and so will very likely apply for our future (von der Heydt *et al.* 2016)

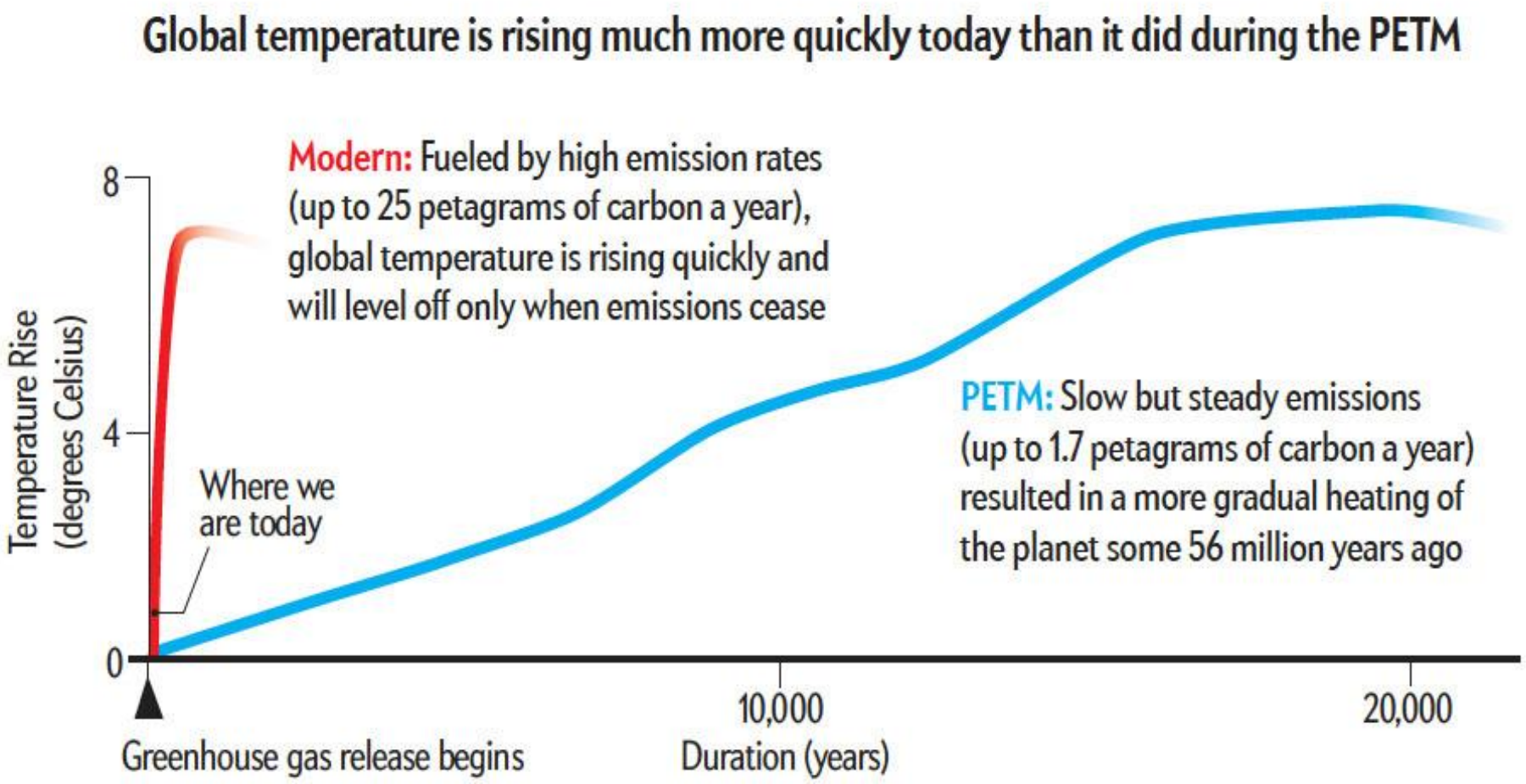
Kohler *et al.* 2015, using different data and methods, similarly and independently find a higher ECS at higher CO2 and temperature levels.

- Roughly 45% larger ECS during the interglacial warm periods than during the glacial cool periods, although they don't translate their numbers into an ECS corresponding to a CO2 doubling and so direct comparison is difficult. However, note that…
- …45% above ECS=3.22C is 4.6C, in good agreement with MacDougall *et al.*

Shaffer *et al.* 2016 agree

- They studied the PETM (**Paleocene-Eocene Thermal Maximum**), a geologically brief spike in CO2 and temperatures, using new methods.
- **They find ECS = 4.5C (+-1.1)** just before the PETM excursion, and **ECS=5.1C (+-1.4)** into the PETM and conclude **ECS rises with increasing temperature**, and this remains true even at the hotter temperatures already existing in the late Paleocene with little or no ice on Earth

Yet; we today are forcing temperature 100 times faster than the extinction-inducing Paleocene/Eocene Thermal Maximum



Different studies, different methods, but within each study (*e.g.* Caballero, Kohler, Shaffer) the trend is higher *ECS at hotter climate* von der Heydt *et al.* 2016 - here as S *vs.* deltaT (see Pfister and Stocker 2017) for the connection

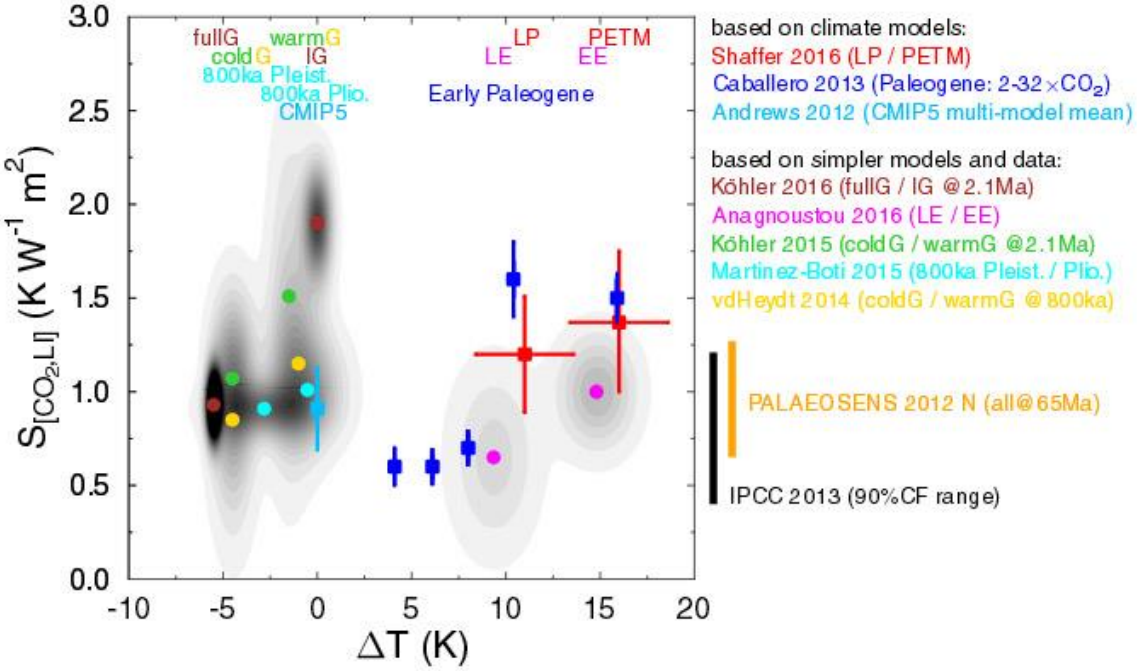


Fig. 1 Published paleo-based values of $S_{[CO_2,LI]}$ (specific equilibrium climate sensitivity parameter caused by CO_2 radiative forcing and corrected by variations in land-ice (LI) feedbacks) indicating its state dependence. Only studies published after the PALAEOSENS review paper [21] are considered. For comparison, the state-independent values from PALAEOSENS, and from the IPCC report [3], and the CMIP5 multi-model mean for present day [41] are also shown. All values of $S_{[CO_2,LI]}$ were given as mean (*or most likely*) $\pm 1\sigma$, apart from IPCC, which is the 90 % confidence (CF) range. Climate background states are given by ΔT from pre-industrial and are marked as estimated ranges (or $\pm 2\sigma$). In [42], further corrections for other slow feedbacks have been calculated, which has been ignored here, leading to different values of ΔT than published. To increase the clarity of the figure, the data-based results are visualised by *colour-coded circles* (mean values), while their uncertainties are combined in a cumulative probability density distribution (*grey shading*) assuming normal distributed values. Results based on climate models are shown by *colour-coded squares* (mean) including their uncertainties (*bars*). *G* glacial, *IG* interglacial, *LE* late Eocene, *EE* early Eocene, *LP* pre-PETM/late Paleocene, *PETM* Paleocene-Eocene thermal maximum. Reference numbers of the given citations: IPCC 2013 [3], PALAEOSENS 2012 [21], Andrews 2012 [41], Caballero 2013 [43] vdHeydt 2014 [20], Martinez-Boti 2015 [44] Köhler 2015 [32], Anagnoustou 2016 [42], Köhler 2016 [45], and Shaffer 2016 [46]

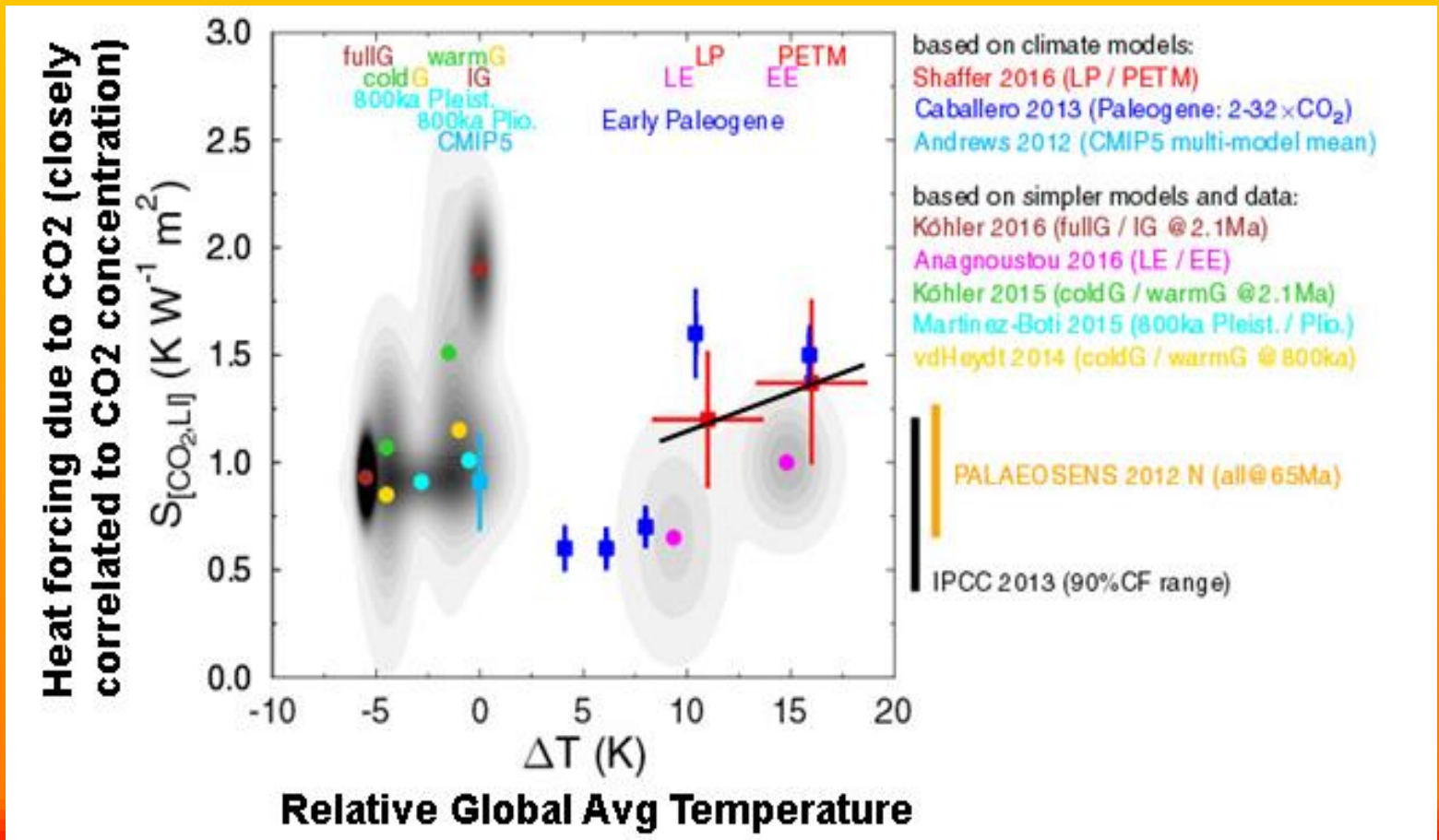
To clarify that message in this complicated von der Heydt *et al.* graph…

- Let's look at each of the studies and note that they all came AFTER the IPCC AR5 cutoff.
- Each study analyzed enough data at many different epochs using a variety of climate models and paleo data to determine the climate forcing.
- In order to make a fair apples-to-apples comparison and take the variable of different methods out of what we see, we should look at how the points trend within each individual study.
- Higher climate sensitivity to FORCING (y-axis) corresponds to more rapid temperature rise per unit time, and therefore over the characteristic time constant of the climate system, would correspond to a higher temperature RISE due to that forcing when equilibrium is reached. In other words – **to HIGHER Equilibrium Climate Sensitivity ECS in hotter climate states**

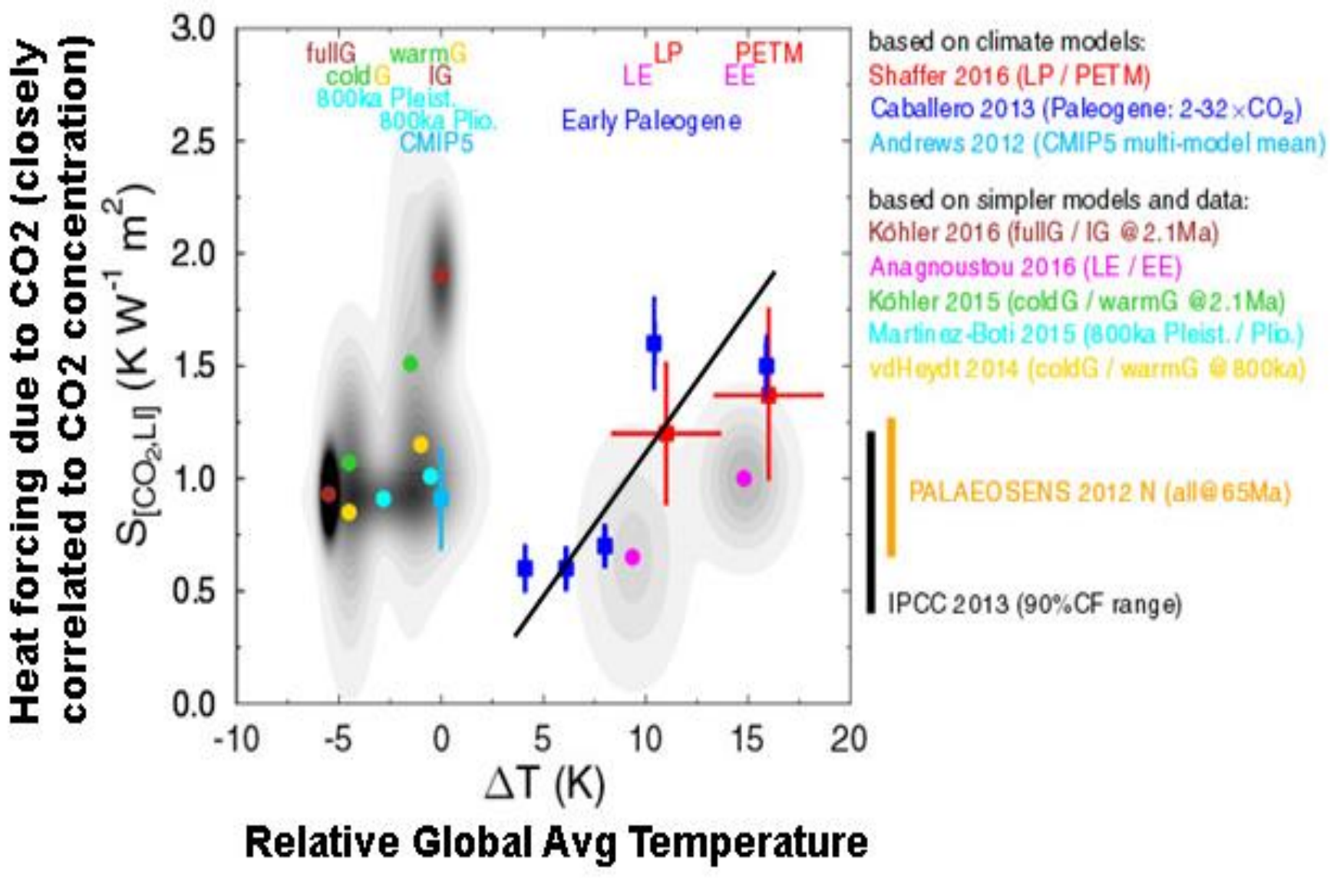
So How Do these Many Studies Say ECS is Varying with Underlying Climate State?

- The Y-axis is closely related to atmospheric levels CO2, of course. Higher CO2 = stronger forcing level
- If climate forcing (Y-axis) were constant independent of climate state (*i.e.* global average temperature, which is the X-axis), then this would say that ECS is flat as well, *i.e.* a constant.
- **A trend fit line sloping upward says higher FORCING, implying HIGHER ECS (y-axis) at HOTTER Climate States (x-axis)**

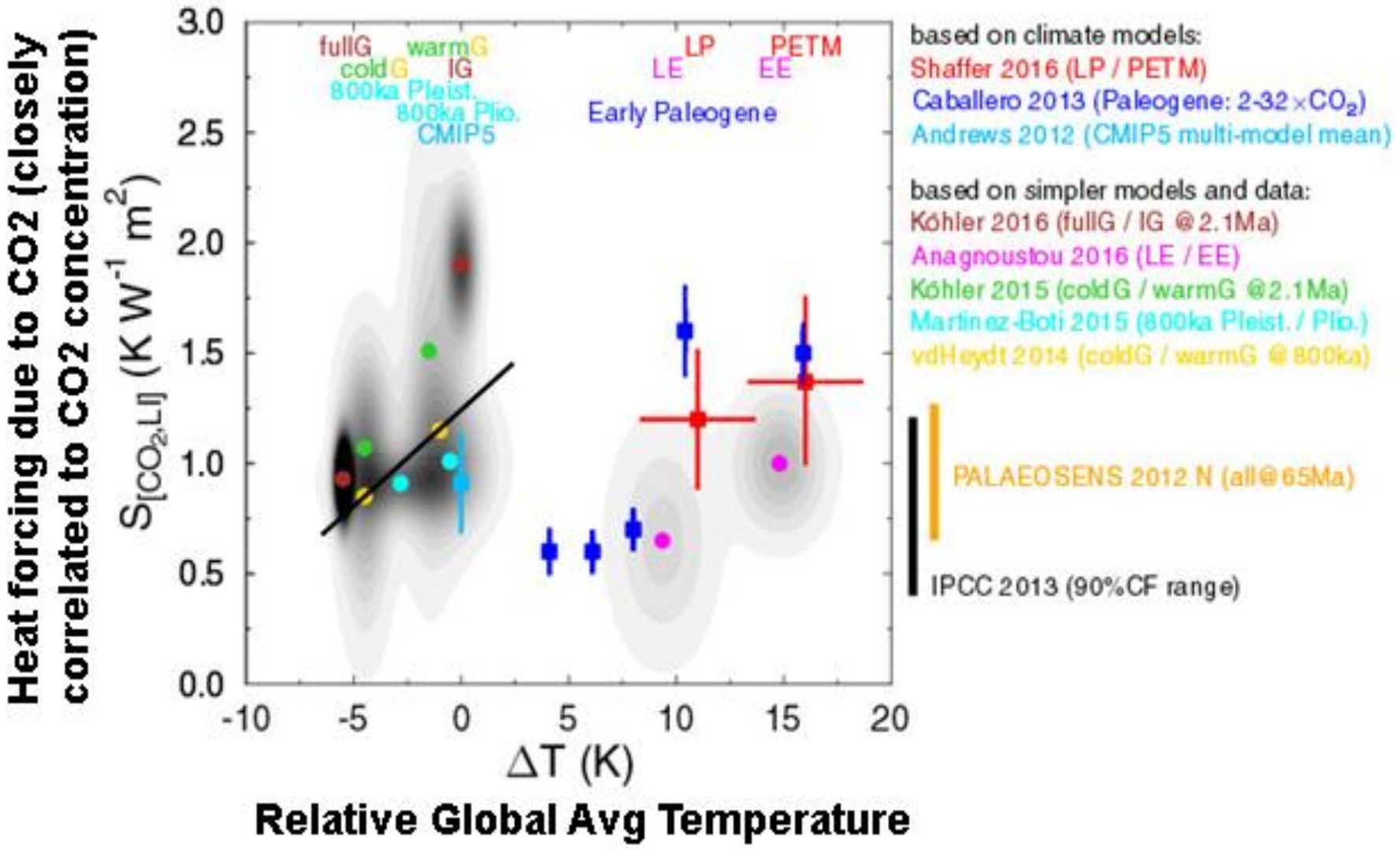
Shaffer *et al.* 2016 (red dots), looking at the Late Paleocene (LP) compared to the Paleocene/Eocene Thermal Maximum (PETM): **Warmer climate=Higher ECS**



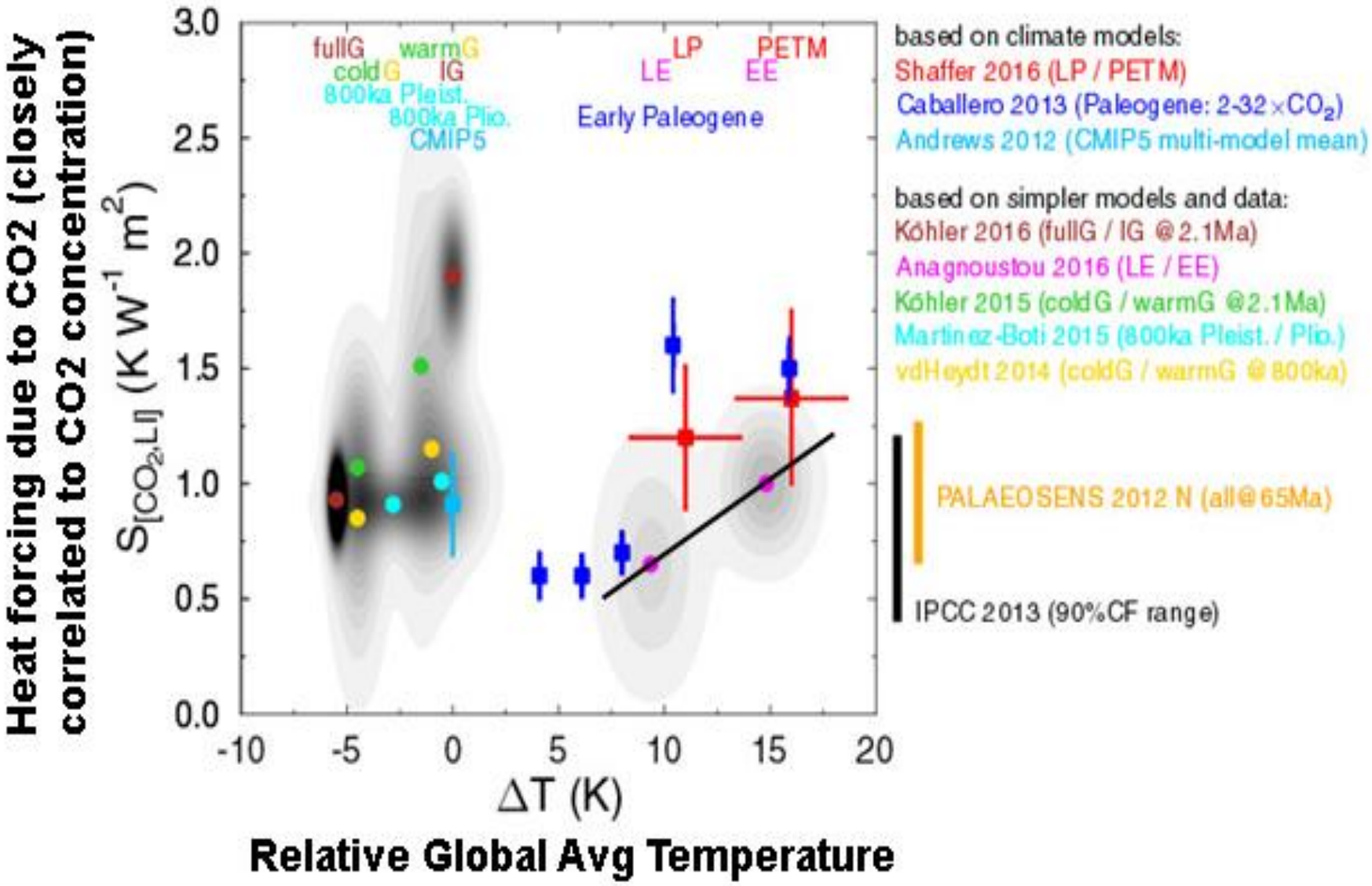
Caballero 2013 (blue): **Warmer=Higher ECS**



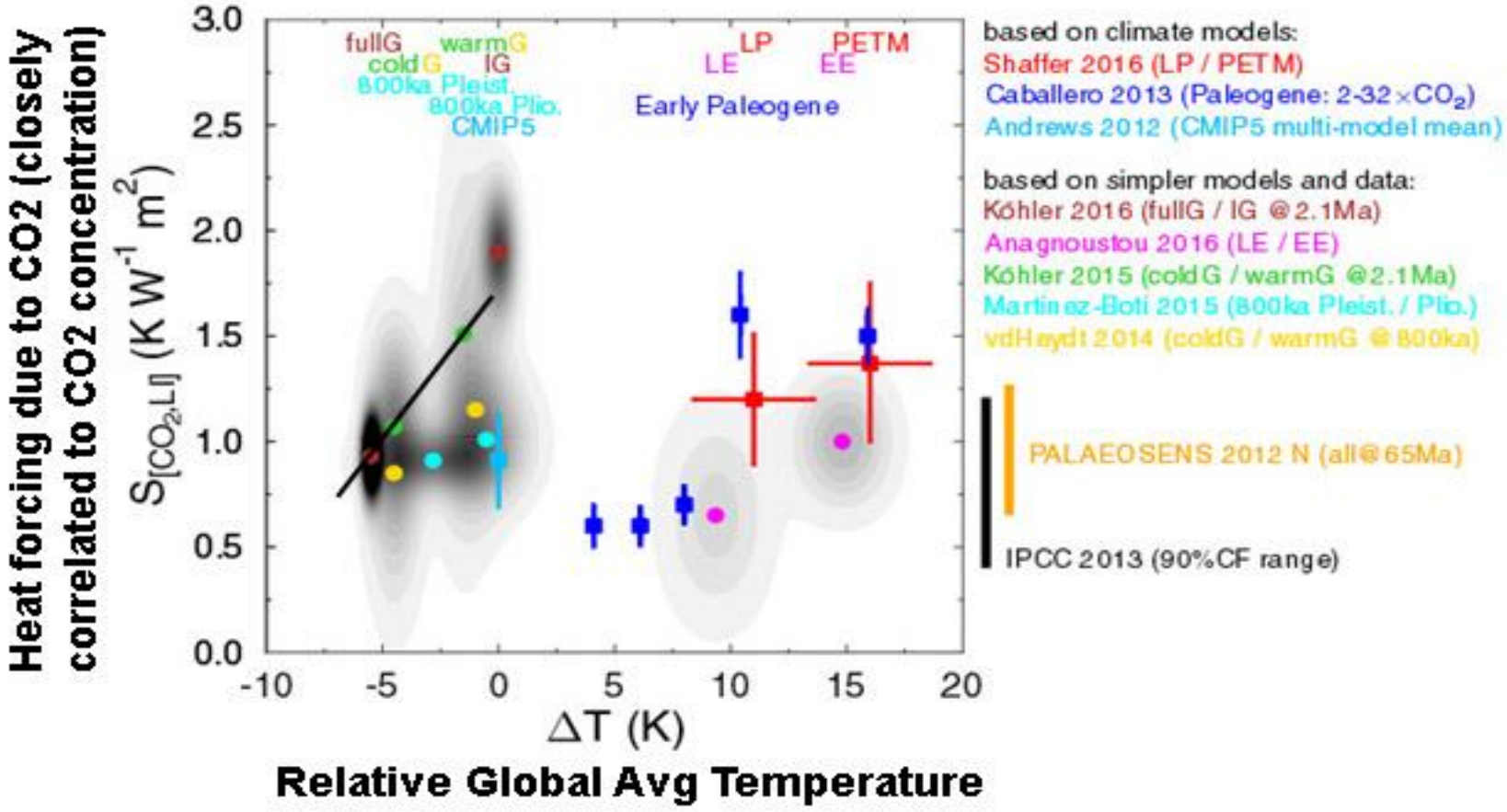
Andrews 2012 (yellow), using CMIP5 computer models: **Warmer = Higher ECS**



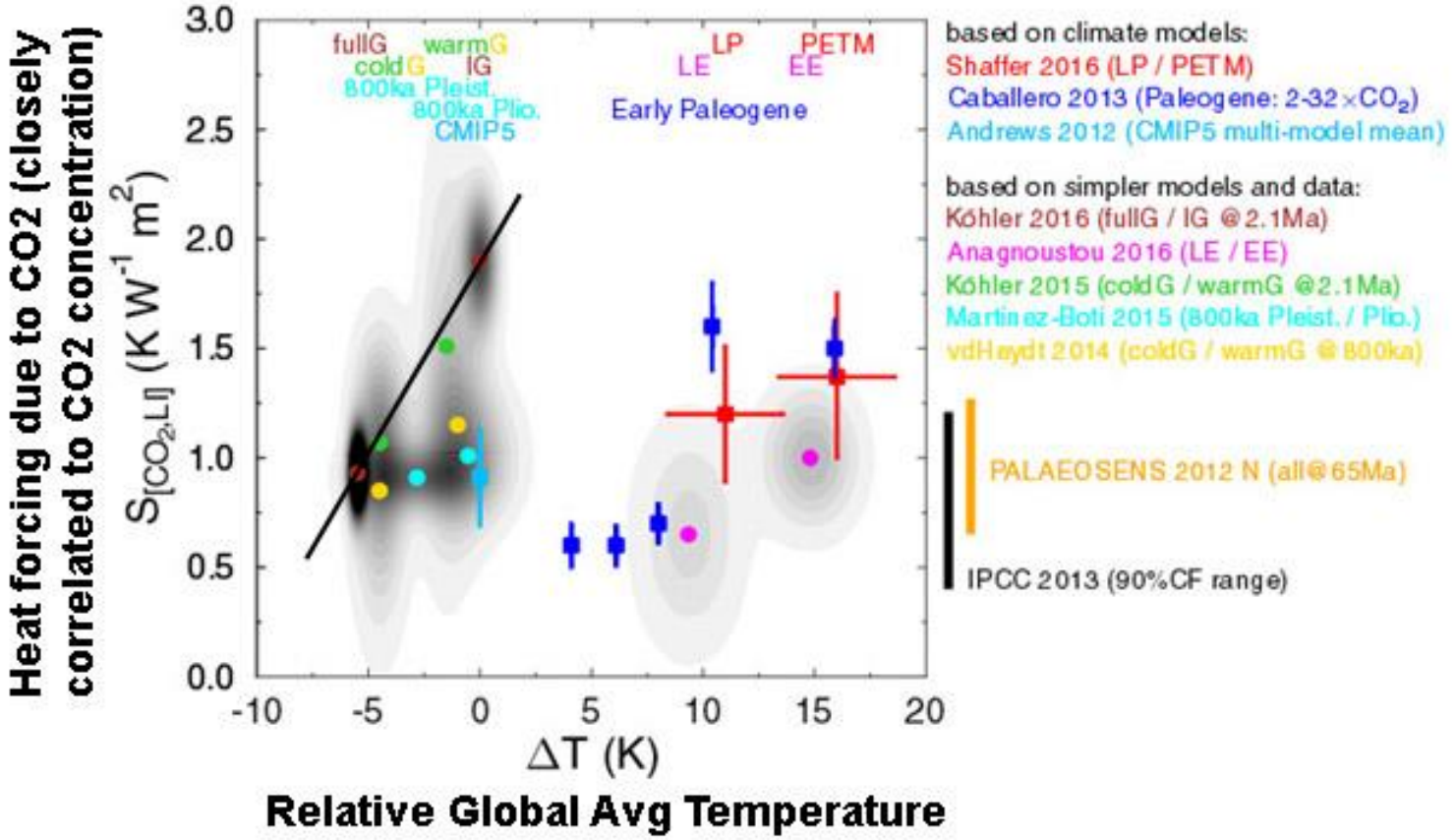
Anagnostou *et al.* 2016 (purple), in the Cenozoic period: **Warmer = Higher ECS**



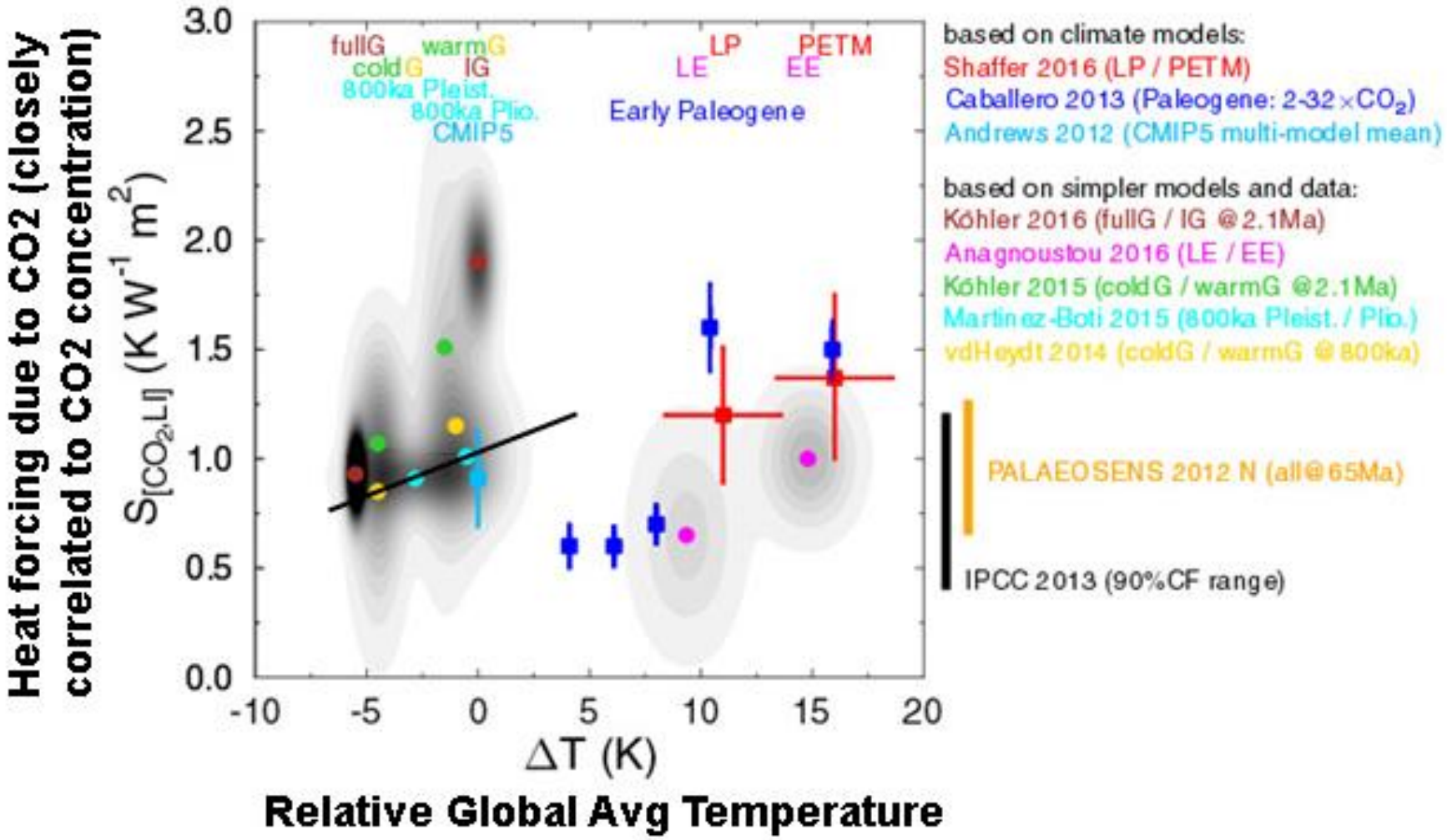
Köhler *et al.* 2015 (green), using just cold glacial *vs*. warm interglacial at 2 million years ago: **Warmer=Higher ECS**



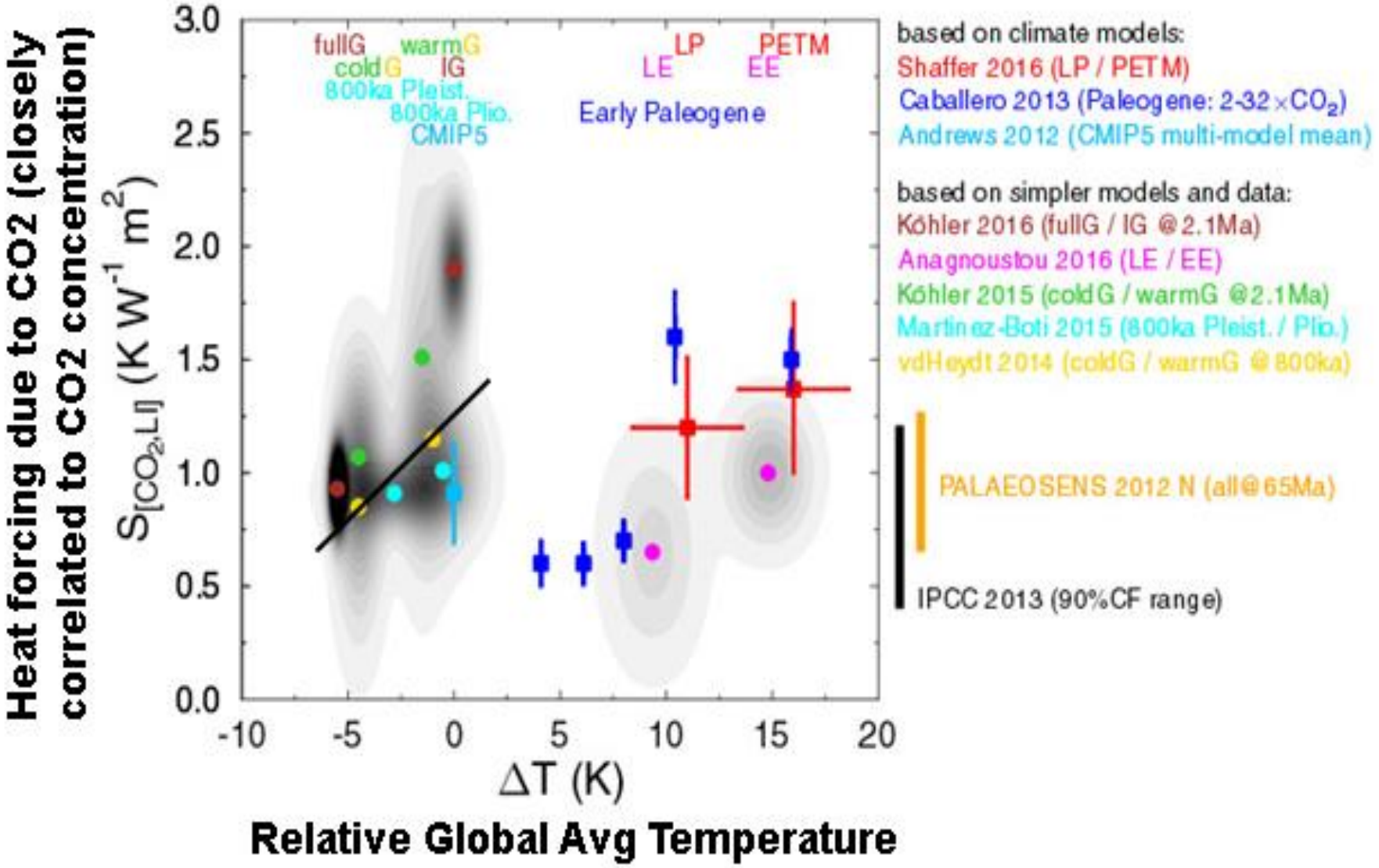
Kohler *et al.* 2016 (brown-gray clouds) using all glacial/interglacial data 2.1 million years ago: **Warmer = Higher ECS**



Martinez-Boti *et al.* 2015 (light blue), comparing the Pleistocene and Pliocene climate sensitivity: **Warmer=Higher ECS**



von der Heydt *et al.* (2014), yellow, 800,000 years ago: **Warmer=Higher ECS**



The two most recent of all these studies, and which have had the benefit of putting the others in context…

- …is that of Friedrich *et al.* 2016, about which we've already discussed…
- And that of Kohler *et al.* 2016, which gives an excellent mathematical and conceptual analysis of ECS *vs* climate state, and concludes that, expressed as ECS, the correct value is "at the upper end of the range shown in the PALEOSENS meta-study", which did not consider climate state dependence in formulating their values.
- And the upper end of the PALEOSENS meta-study (slide 121) agrees with that of Friedrich et al 2016: Namely, **ECS=4.8C** as the best guess that applies for our current state today and the near future.

The Most Powerful State-Dependent Cause for higher ECS Today?

- The Arctic Ocean's ice had been, until the 21st century, a massive thick floating reflective cap ~10m thick or more which had only thinned some in summer and only exposed dark ocean for a thin band at the continental shorelines.
- All during the 20th century that ice was thinning, but yet still doing its reflective job, which doesn't care whether its 10m thick or 1m thick.
- But now, it's so thin it's breaking up, raising the surface area exposed to warm air and warm water, and moving south out of the Arctic Ocean. Wind fetch is increasing an order of magnitude, raising wave heights which further break up the ice
- And now, nearly all the permanent thick ice is gone, and only seasonal thin ice remains, with vast areas now dark and exposed to the summer sun – a powerful change in Earth's heat balance which is at this moment happening much more rapidly than CO2 (the ultimate cause) itself is rising.

What Does This Imply for our Future?

- Let's go back again and look at the MacDougall *et al.* Figure 3 showing the evolution of atmospheric CO2 assuming ALL HUMAN EMISSIONS END IMMEDIATELY, but we include the **Permafrost Carbon Feedback**'s CO2 and methane emissions
- And now add the new understandings…and ponder an ECS which is +5C, not the +3.0C as had been assumed earlier…

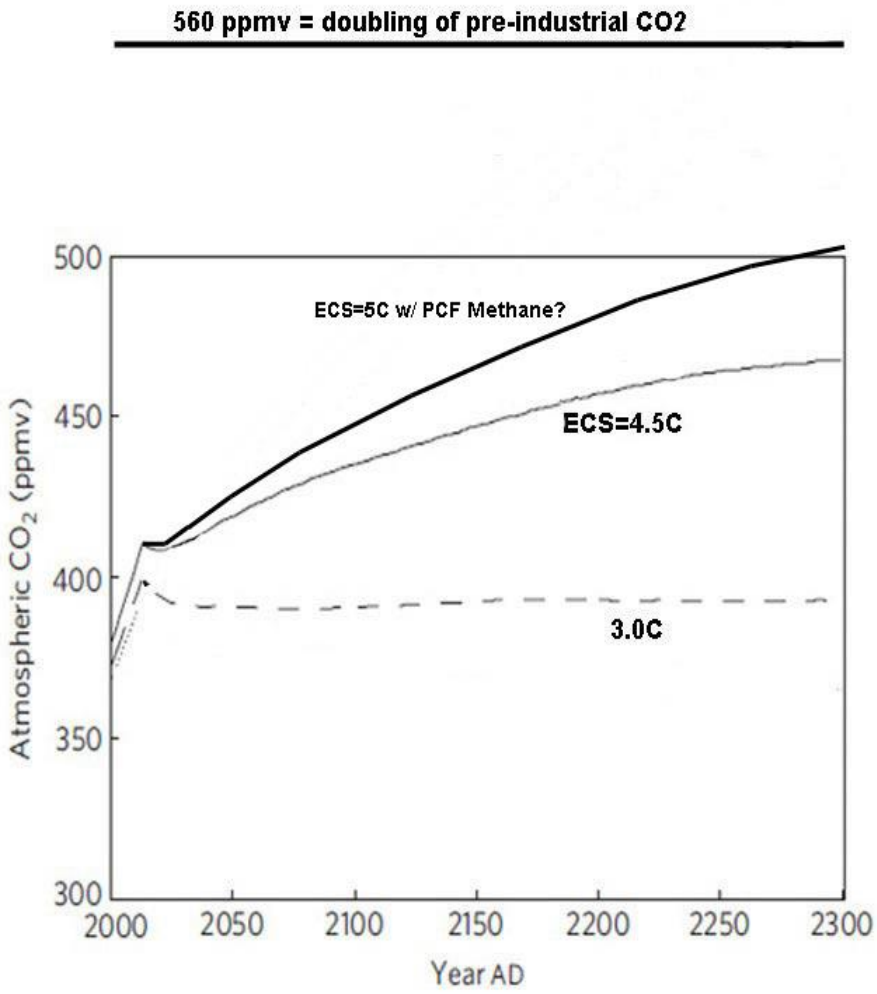


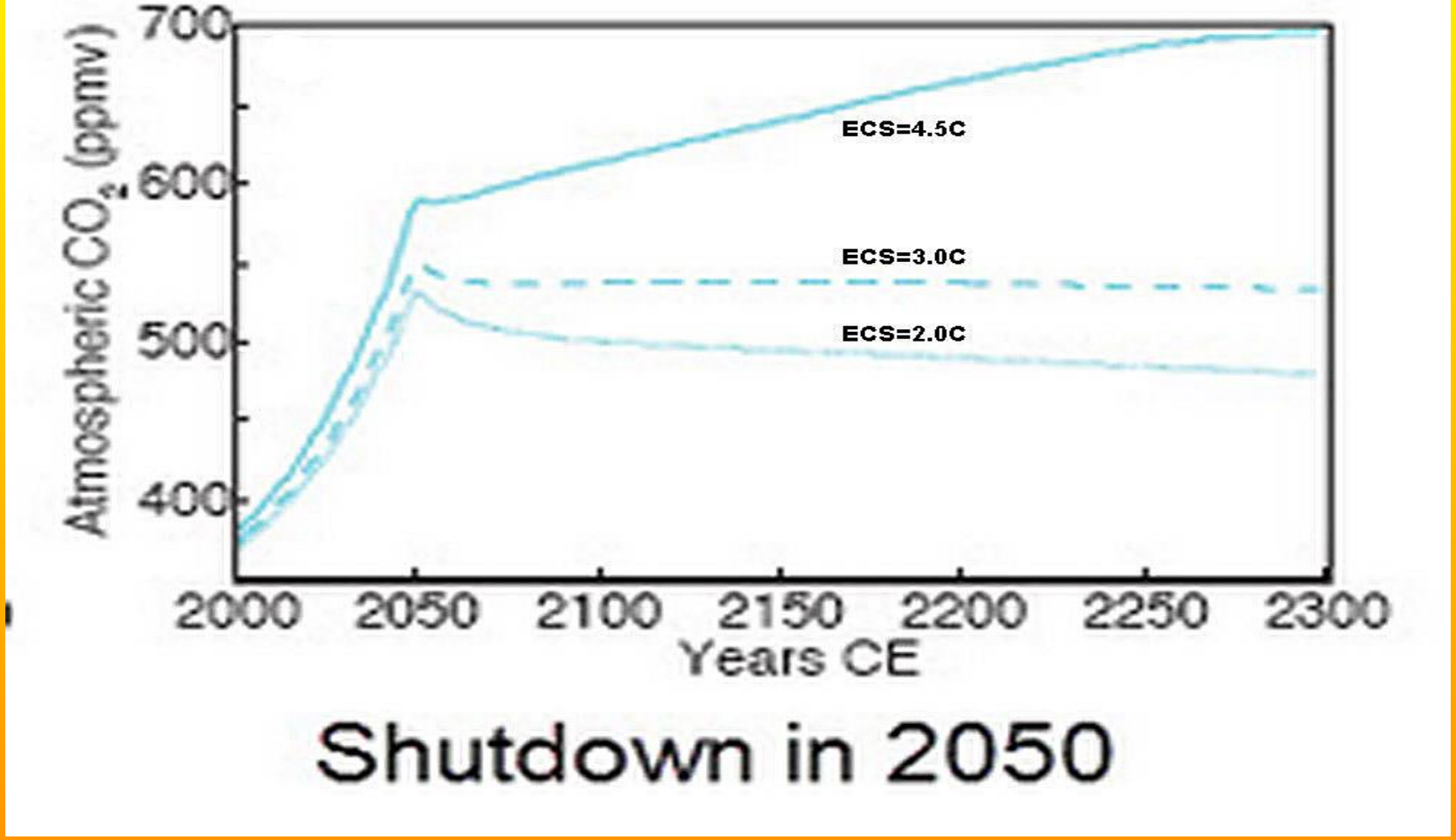
Figure 3 | Evolution of atmospheric CO_2 concentration in response to a cessation of anthropogenic CO_2 and sulphate emissions in the year 2013. The dotted line represents the response for a climate sensitivity (to a doubling of CO_2) of 2.0 °C, the dashed line a climate sensitivity of 3.0 °C and the solid line a climate sensitivity of 4.5 °C.

Here's the MacDougall *et al.* (2012) graph. Since Solomon *et al.* (2009) didn't assume ECS=5.0C, we can't quite do the same methane addition like we did earlier. But it's clear the ECS=5C w/methane curve will be far above the ECS=3.0C w/methane curve.

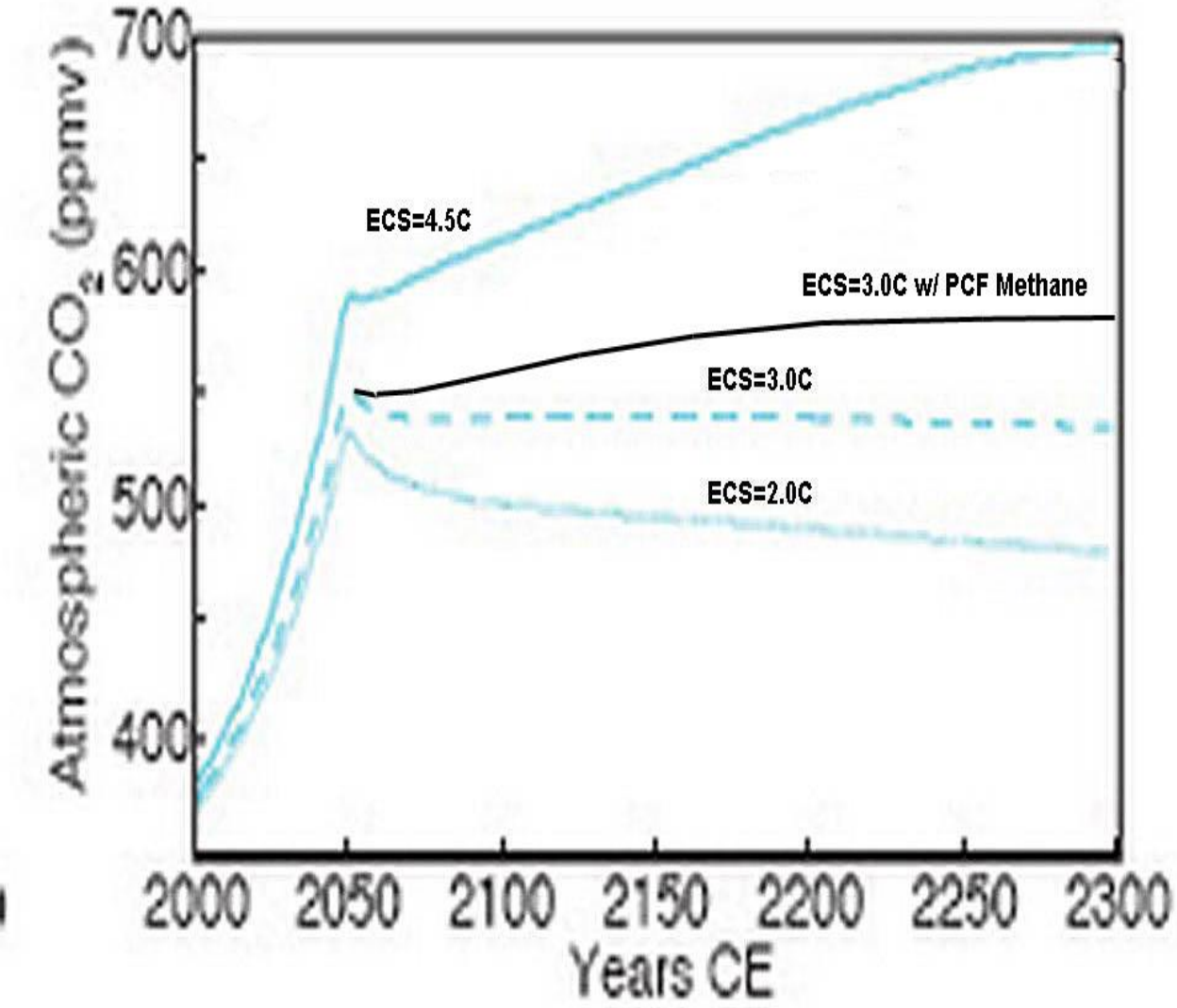
Here, I've taken the 3C vs 4.5C MacDougall curves and how the 3C curve changes by including methane, and conservatively estimated a curve for ECS=5C w/ PCF methane.

Again, for emphasis, this is after turning off ALL human emissions in 2013, and neglecting the thermokarst methane, which may double the total permafrost methane emissions, mechanical erosion on coasts and streams, and any carbon below 3.5m depth

And finally, what if we DIDN'T shut off carbon-based Civilization in 2013? (we didn't). What then?



Here's the MacDougall CO2 curves but again w/o Arctic (or temperature - dependent tropical) methane, nor revised active layer depth. **CO2 Much Worse:** Assumed "business as usual" then **complete human emissions shut down in 2050. The ECS=3.0C case CO2 at shutdown is almost at 2x Pre-Industrial = 560 ppm. Now - add PCF Methane…**

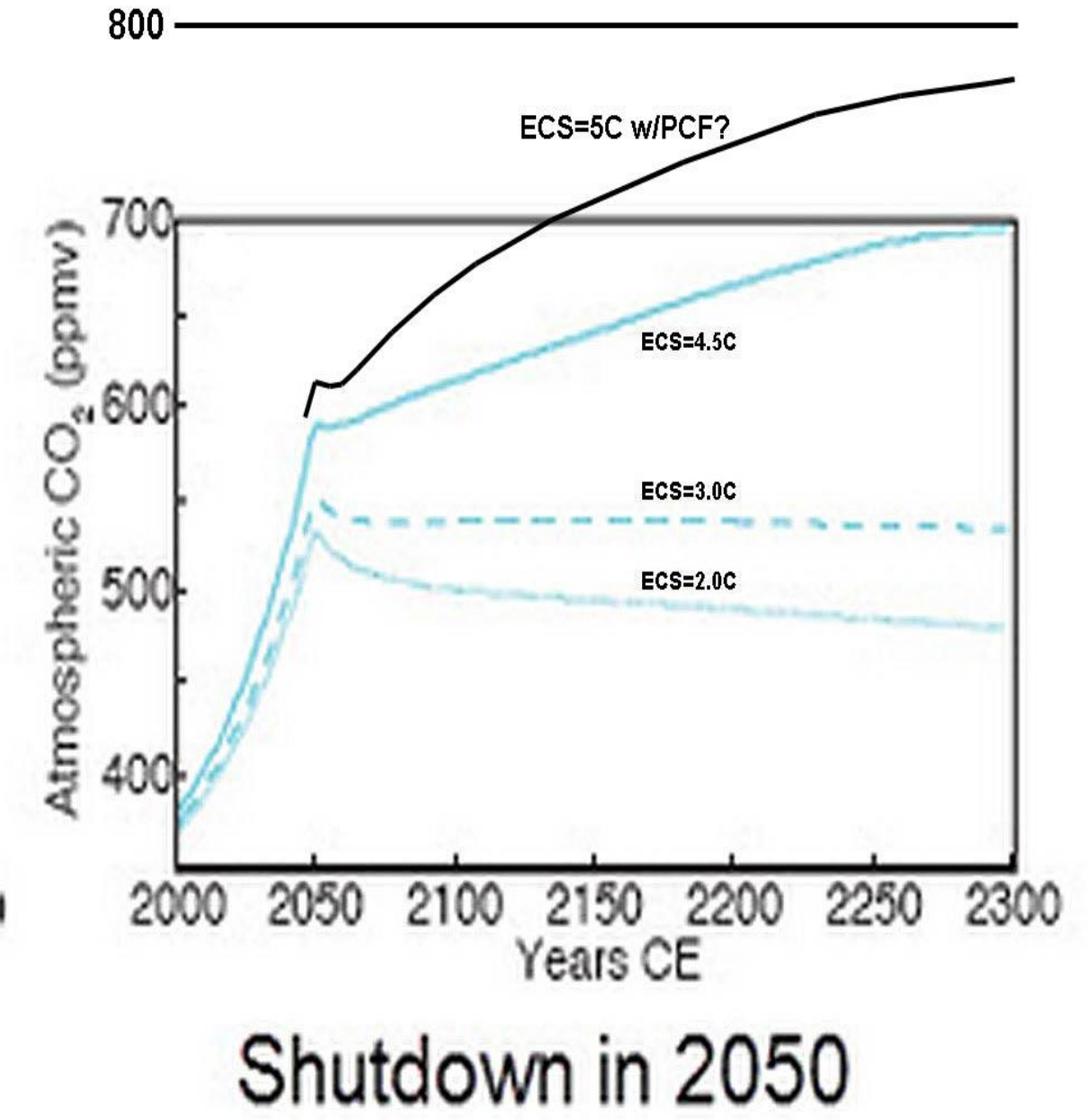


Shutdown in 2050

Here, adding in an estimated PCF methane curve as we did before; using the Solomon *et al.* 2009 curve, this time for CO2=550 ppm at shut down, revising active layer depth, and doing our same estimation technique to get CO2 equiv. global warming potential from 2.3% methane

To Summarize the Logic…

- 580 ppm is a bit more than 2x pre-industrial, and so corresponds to a global temperature rise of about 3.1C of committed change.
- This is after continuing "business as usual" and then total shutdown of all human-generated GHG's in 2050 and assuming ECS=3C.
- These effects are just from triggered permafrost CO2 and methane alone (but missing thermo-karst methane, coastal/stream permafrost erosion), and if the quoted research sources are approximately correct.
- As the highly respected and award-winning site "SkepticalScience"'s **summary** of the work says… ***"Unfortunately, there are several good reasons to consider the outlook in MacDougall et al. as rosy; as the authors themselves make clear."***

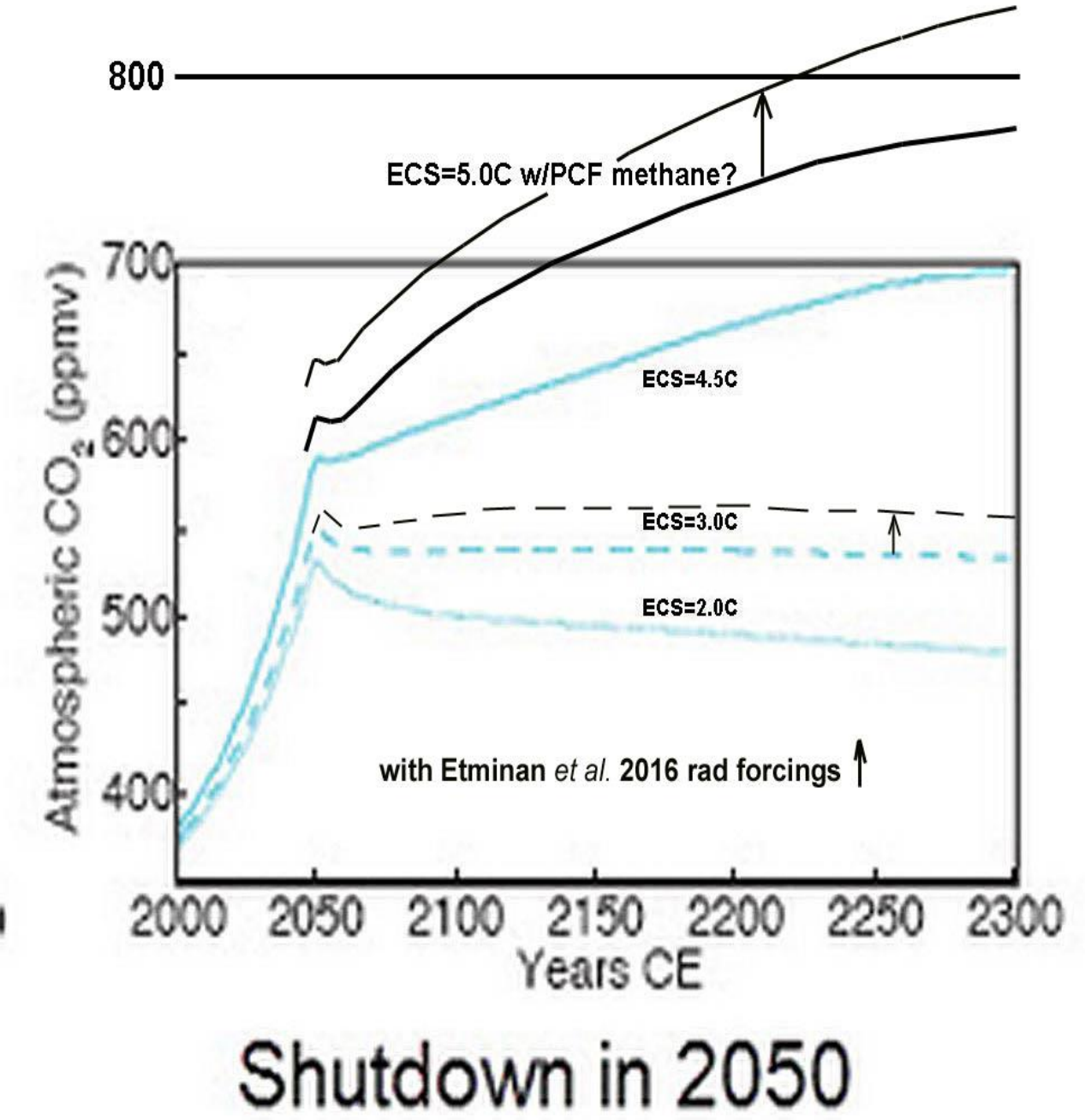


Shutdown in 2050

But if indeed ECS=5C going forward, as these recent papers suggest, then including permafrost methane drives atmospheric CO2 close to 770 ppm. corresponding to a global temperature rise of ~6.9C. And worse if we don't <u>end all human GHG emissions in just 32 years</u>

But wait – New research shows it is worse still. Etminan *et al.* 2016 recalculated the radiative forcings of methane and N_2O

- The included new data on short-wavelength band absorptions not included in the prior calculations, including those used in the IPCC synthesis.
- They showed that both GHG's have radiative forcing to climate that is about 23% higher than previously thought.
- How would this affect those last curves?...



Shutdown in 2050

I've merely added 23% conservatively onto the ECS=3C and ECS=5C curves, neglecting nonlinear amplifying. Now, atmospheric CO2 is driven to 830 ppm and rising, by 2300. Temperatures would rise to likely +8C and beyond. All, without any human CO2 emissions starting 20 yrs from now.

"Incompatible with an Organized Society"

- Yet, as Prof. Kevin Anderson summarizes, even just … "***a +4 degrees C future is incompatible with an organized global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems, and has a high probability of not being stable***." (meaning, it continues hotter).
- Think this is doomsday poppycock? Nobel physicist and former Secretary of Energy under Obama – Steven Chu – entirely independently, finds it **highly likely** that we'll exceed 550-600ppm CO2 equivalent
- **The course we're on is sheer madness**.

At that point, fine-tuning the details would likely be moot

- … since societal breakdown would almost certainly be underway, with large loss of life, and the remaining population could not function in any way recognizable today. It would be transforming to a different planet. Trying to do high tech science and engineering would likely not be possible as the structure of civilization is most intimately required for such work.

Other physics would likely have added further trouble

- Soil carbon would likely be net outgassing as well, ocean CO2 absorption would be strongly negatively affected by the widespread death of aragonite species from both ocean heat, stagnant anoxic conditions, AMOC shutdown, and rising acidity.

Another hydrogen sulfide-induced mass extinction?

- Dr. Peter Ward worries that global ocean thermo-haline circulation (THC) shutdown could initiate another hydrogen sulfide-induced mass extinction, as has happened several times in Earth's past when massive volcanism produced large CO2 outgassing. It might make the current mass extinction due to human predation look tame. On the re-assuring side, THC shutdown happened in a previous interglacial w/o this disaster.

Could it be Even UGLIER?

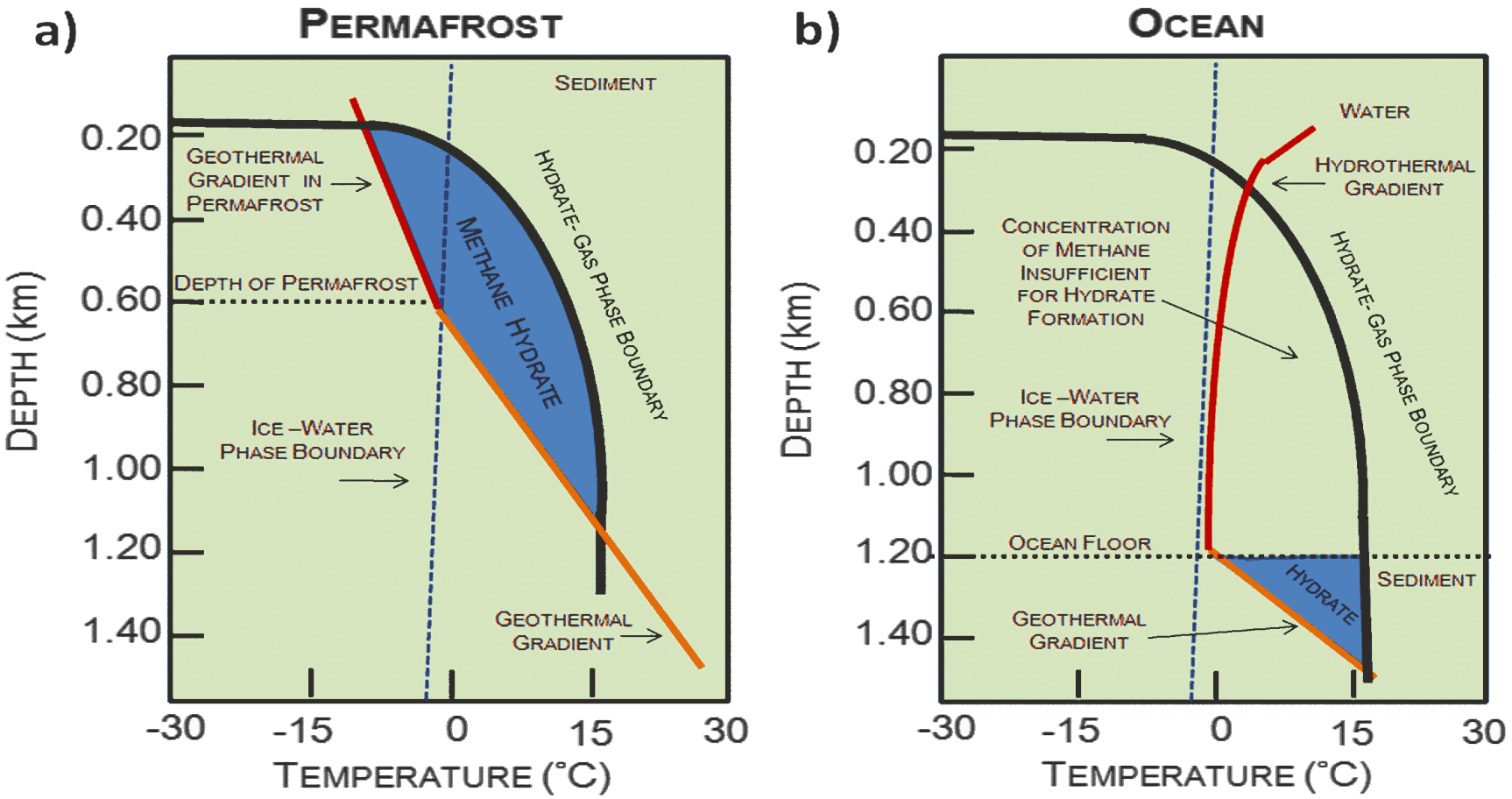
The Methane Apocalypse!!?

Are we in danger of massive methane hydrate deposits de-stabilizing in the Arctic and releasing gigaton-sized amounts of methane all at once?

- This was a much-publicized worry after discovery of methane seepage in the Siberian Arctic Ocean offshore in 2010.
- But climatologist David Archer, a couple of years back, pointed out that in the Arctic Ocean Basin, methane hydrates would only be stable in recent millennia and could therefore only be expected to exist today at depths of about 380m and lower (depending on ocean floor depth), which is ~280m below the shallow ocean floor of the Siberian continental shelf.

380m Depth is Safe. Right?

- **Yes - Probably!**
- The Siberian Sea is only ~50m deep, so ocean heating will reach the bottom. In most of the ocean, 90m is about the depth that is mixed by storms in winter, much shallower in other seasons.
- **But, it's about 300m below the sediments, and heat transfer through sediments can only happen by conduction which is extremely slow.**
- It would be many centuries before our global warming could penetrate to those depths



Methane hydrates cannot exist above 380m depth in the Arctic continental shelf, and the Arctic Ocean continental shelf is only 50~100m deep, requiring the hydrates to be buried under ~300m of sediments, which are quite difficult and slow for heat to penetrate. Making a "methane apocalypse" very unlikely. Remember, methane must come out in huge volumes and ALL AT ONCE for its large global warming potential to be realized. Otherwise, it oxidizes to CO2 in a few decades.

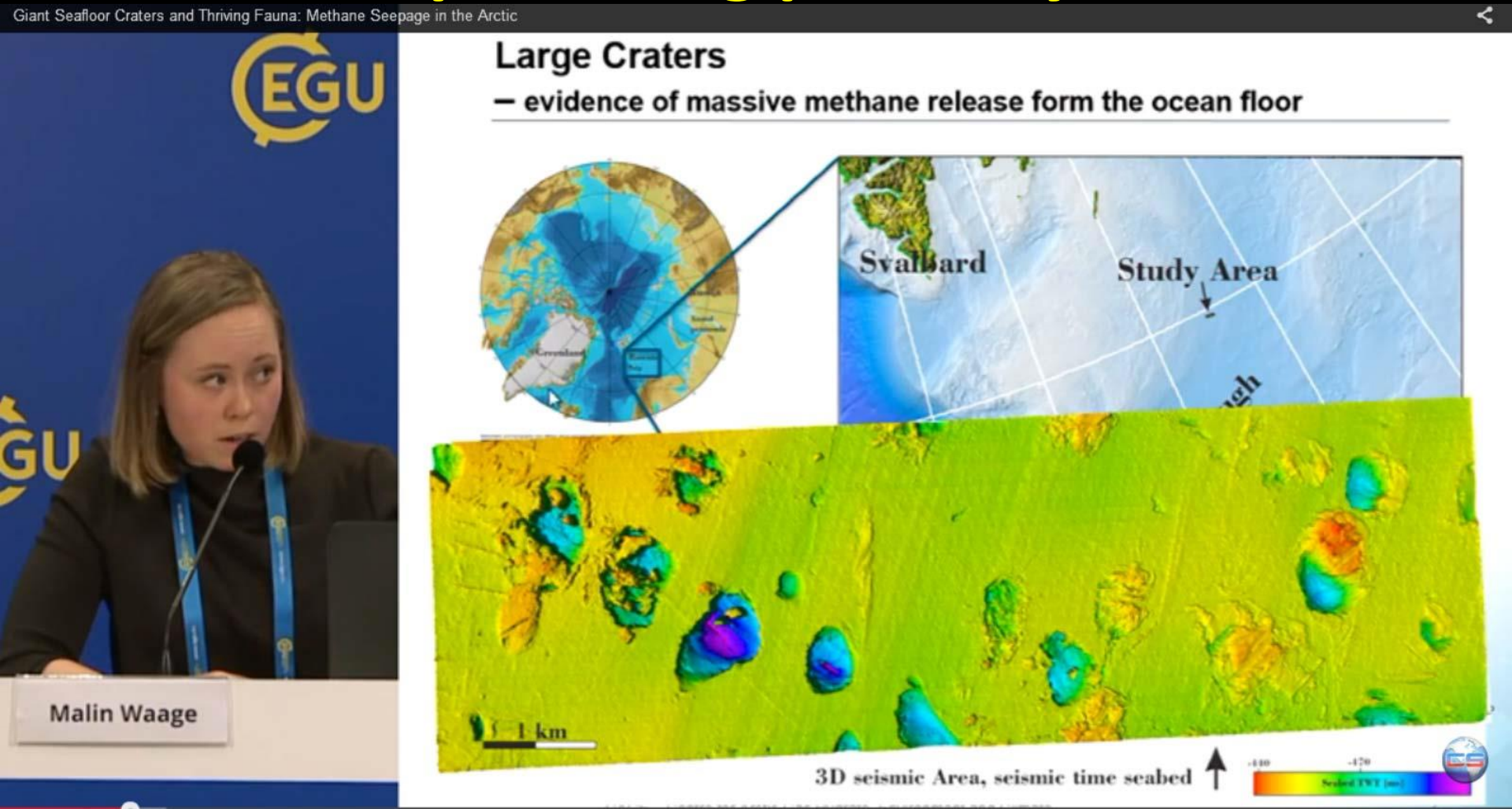
But there IS Evidence for "Abrupt Climate Change" in Paleo Data

- It is fairly widespread in Greenland ice cores (see Richard **Alley (2000)**)
- These abrupt climate changes are associated with rapid changes in CO2 and methane, but their ultimate causes are still controversial.
- Is the recent re-acceleration in methane due to destabilized methane hydrates?
- **No**, says many recent studies – the shifting C^{13}/C^{12} ratio is too low to be from methane hydrates (see *e.g.* **Nisbet *et al.* 2016, sec 4.1.1**) and is more consistent with production by current tropical microbes munching on oxygen-deprived vegetation, and cattle, rather than hydrates or from millions of years old fossil fuel.

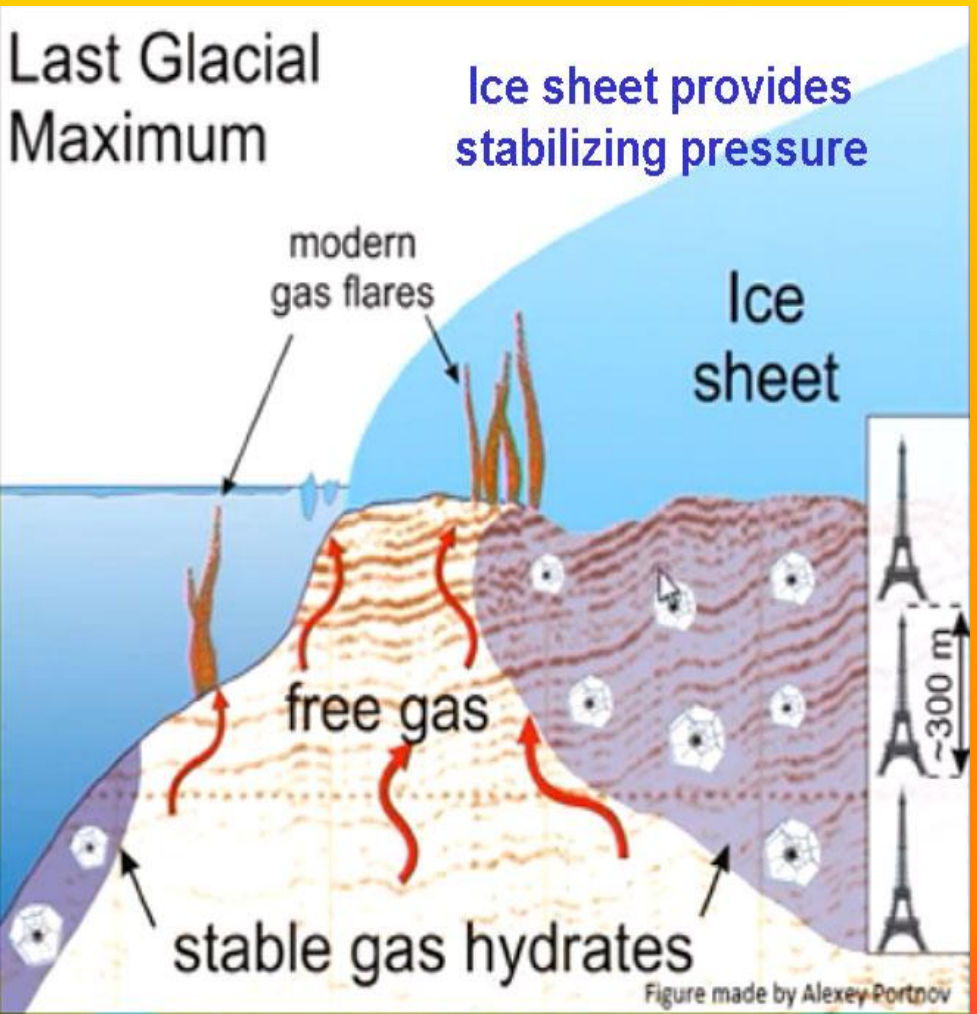
In 2016, new work is adding just a bit more worry to this story, however…

- Waage *et al.* 2016, at a talk, show new seismic imaging showing methane pingos and craters at ~320m depth in the deeper Arctic Ocean trench floor off Svaalbard, in a small area, in bedrock. Similar features off New Zealand, due to methane.
- Craters are up to 1 km in diameter, with hydrate gas likely underneath according to reflection signals. **However, these explosions were 20,000 yrs ago at the end of the last Ice Age, when overlying Scandanavian ice sheet pressure was removed.**
- They're still leaking at a low level today.
- But 320m is deep enough that it will be a long time before significant global warming ocean heat will penetrate there. Centuries? Probably, but not clear since we have no actual real-world data yet on how a de-iced Arctic Ocean heat transfer will behave. Fluid/thermo theory still says it'll be slow. **Not the absurd 9 years till Human Extinction claimed by Guy McPherson**

Ocean floor craters and pingos (mounds) are still leaking methane. Area is faulted as well, providing pathways in rock



Last Ice Age's Ice Sheet easily could provide enough pressure to stabilize hydrates at even very shallow depths



- Some people worry: Ice Age Ice Sheet pressure relieved but permafrost remains, providing a cap to prevent outgassing from otherwise insufficiently pressurized unstable hydrates?
- But, this apocalypse scenario still seems very unlikely. Even if the study area had a thick ice sheet (it did not), and if these hydrates relieved of pressure could blow km-sized craters in bedrock, they should have already blown out more fragile permafrost ice capping long ago – pressure left 20,000 yrs ago.

Here's the reasoning why the "Methane Apocalypse" is unlikely

- Where it existed, a ~mile-thick Ice Age ice sheet provides VASTLY more of a stabilizing environment, and hence vastly more of a **de**-stabilizing environment when it melts at the end of the last Ice Age 20,000 years ago – than does the 1C or 2C temperature rise which may be reaching the sub-sea permafrost layer over coming decades and centuries.
- We should expect rising methane from the ocean floor, but not dramatically rising and not in gigaton bursts as some a decade ago had feared.
- Large bursts of methane hydrate phase transitions would have already happened, as indeed we see evidence for in **the craters seen off the sea floor of Svaalbard, but those are dated 20,000 years ago – not today.**

Also, unlike North America - the vast Siberian Sea Continental Shelf did not have a thick, heavy Ice Age ice sheet

- So the ability of such an ice sheet to pressure-stabilize methane hydrates was missing. We therefore would not expect hydrates except at depths far below the sediments.
- The Siberian Sea no doubt contains much recently created methane in its sediments (Shahkova *et al*), We should expect continued slow leakage from previously frozen carbon during the last Ice Age, which will likely increase… but the rapid 10 yr oxidation time scale for methane will likely save us from any rapid “apocalypse”. More like a thousand paper cuts delivered one at a time.

Answers? No, mostly still Questions… but The scientific mood seems to be one of optimism (albeit slightly worried), that the "Methane Apocalypse" is still a very low probability scenario

- All the more reason for additional study.
- CAGE **"Center for Arctic Gas Hydrate, Environment, and Climate"** is on the job, and thankfully beyond the gunsights of the U.S. Congress and U.S. President's War on Science.
- Cheers for Norwegian Science!

More UGLY: Polar Ice Cap Melt and the Global Ocean Circulation:

IPCC Models Did Not Include: Surface melt of Greenland, causing cold, low density, low salinity sea surface waters (Hansen *et al.* 2016)

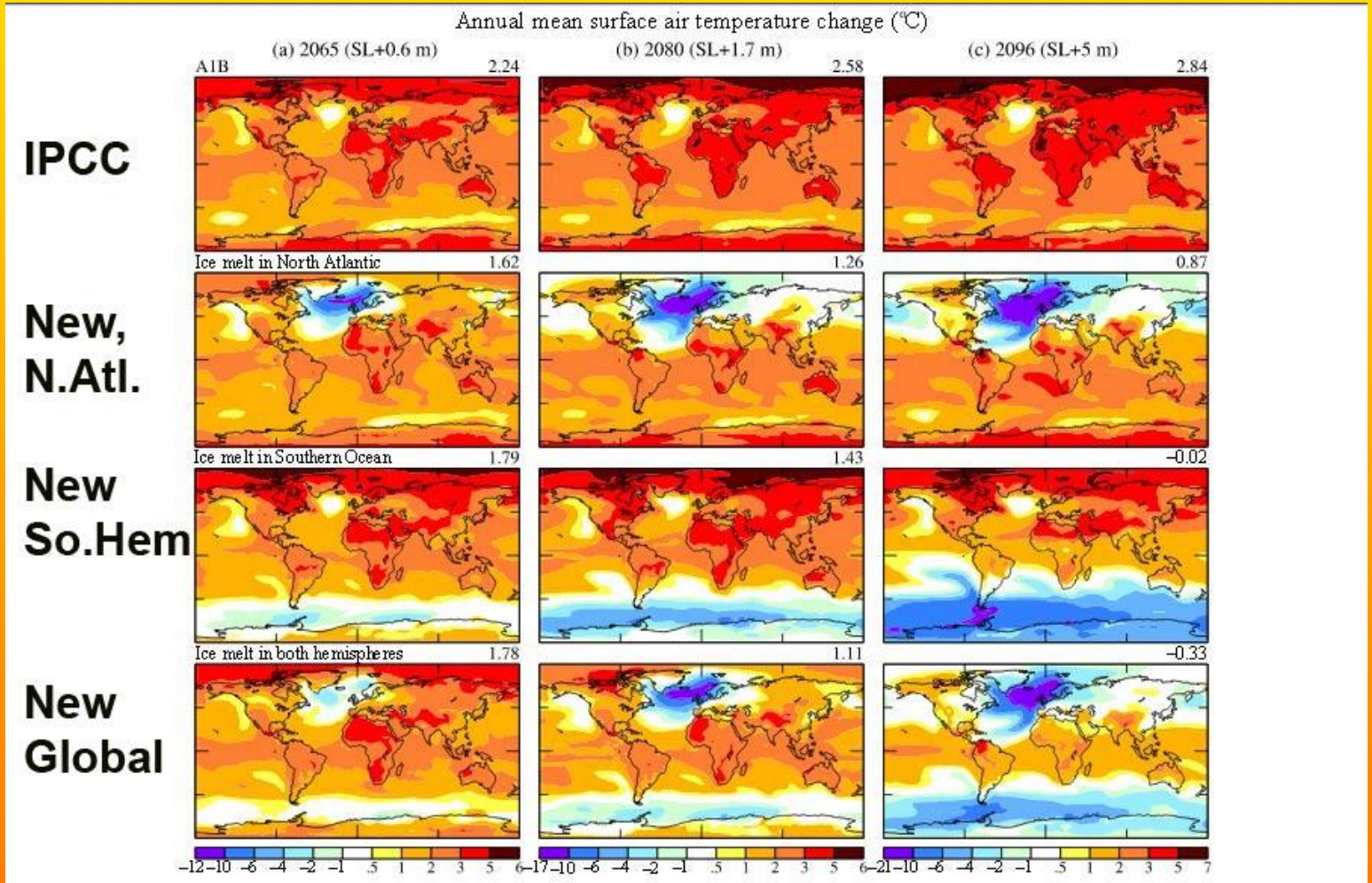


Figure 6. Surface air temperature (°C) relative to 1880–1920 in **(a)** 2065, **(b)** 2080, and **(c)** 2096. Top row is IPCC scenario A1B. Ice melt with 10-year doubling is added in other scenarios.

Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous

James Hansen[1], Makiko Sato[1], Paul Hearty[2], Reto Ruedy[3,4], Maxwell Kelley[3,4], Valerie Masson-Delmotte[5], Gary Russell[4], George Tselioudis[4], Junji Cao[6], Eric Rignot[7,8], Isabella Velicogna[7,8], Blair Tormey[9], Bailey Donovan[10], Evgeniya Kandiano[11], Karina von Schuckmann[12], Pushker Kharecha[1,4], Allegra N. Legrande[4], Michael Bauer[4,13], and Kwok-Wai Lo[3,4]

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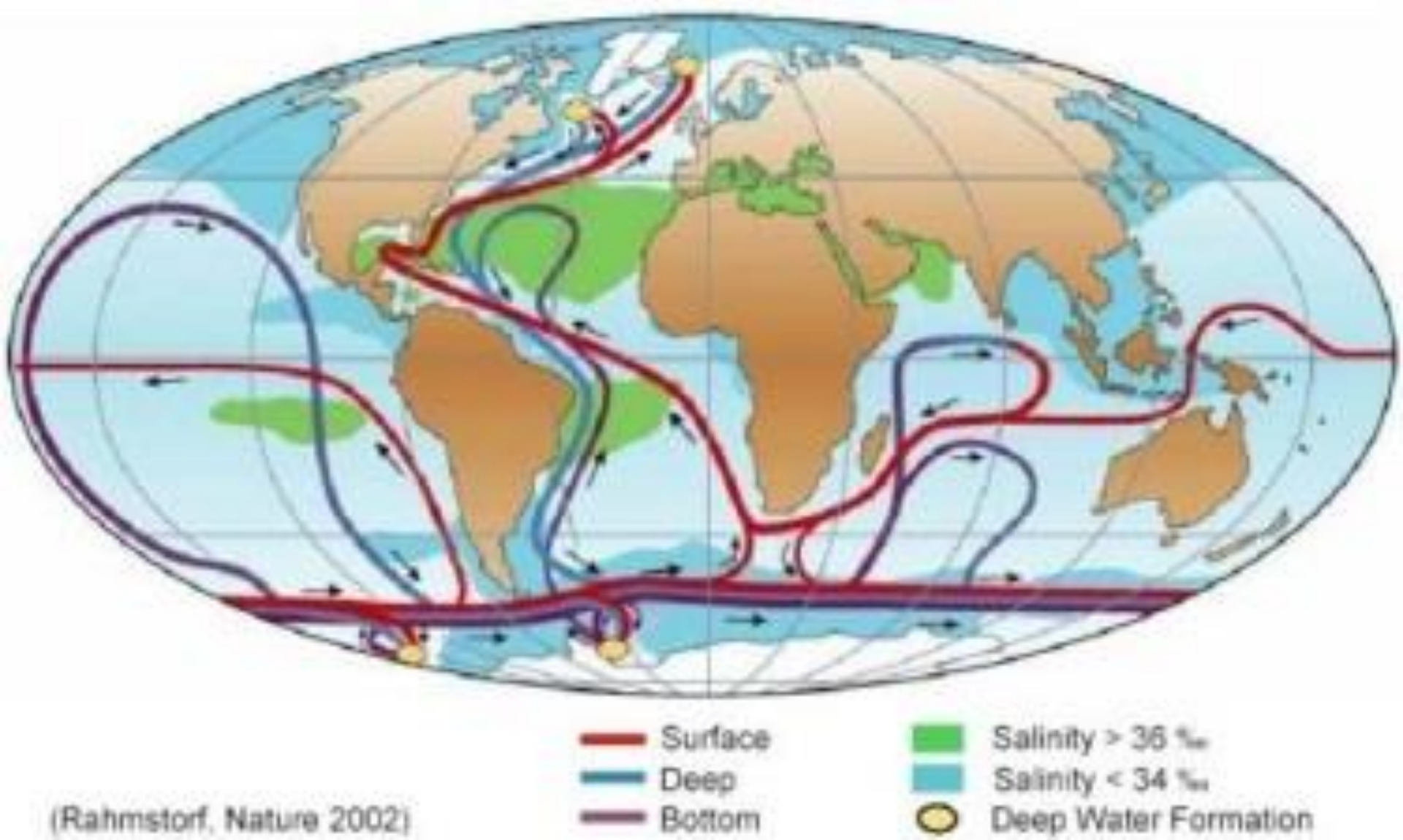
The Good and the Bad

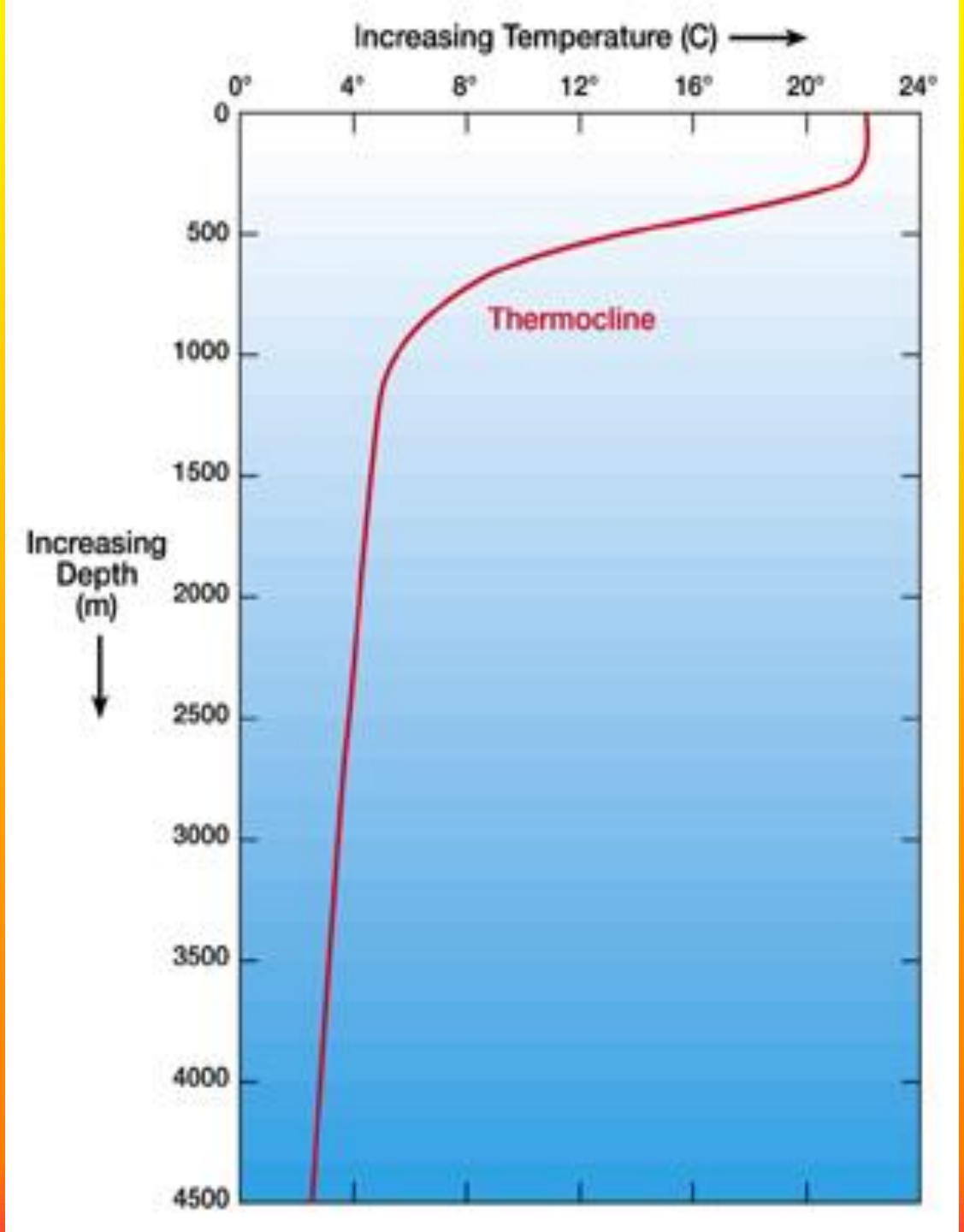
- The “good” news is that this rapid melt absorbs significant global warming heat into the latent heat of converting ice to liquid, lowering global temperature rise rates temporarily
- **The bad news is…**
- -- it worsens our heat imbalance by 2 W/m² (more than triple what it is now) by lowering our ability to radiate energy to space, and once the ice is largely gone, temperatures will skyrocket
- -- multi-meter sea level rise this century, flooding most of the great cities of civilization
- --SuperStorms of a magnitude which, in Hansen’s words, **“All Hell will break loose”**
- **--Worst of all: Shut down of the ocean thermohaline circulation, leading to massive heating and cooling around the globe, and radically altered rainfall patterns which would devastate most countries’ existing population and agricultural infrastructure.**
- **Let’s take a look…**

Consequences

- The cold freshwater low density meltwater cap prevents the warmer saline waters underneath from cooling and densifying and dropping through the thermocline to the bottom. This is essential to keep the global ocean circulation in motion.
- **This is likely to shut down the Atlantic Meridional Overturning Circulation (AMOC**) if it continues.
- Indeed, this happened at the height of the last interglacial warm period – the Eemian Interglacial.
- This would radically change global weather patterns, rainfall, and temperatures.
- Yet our weather patterns have determined the siting of our entire civilization; farming, cities… everything.
- **If the AMOC shuts down, James Hansen points out it's essentially permanent. It would take centuries for it to re-start even if conditions improved**

The Global Ocean Circulation: Surface current dives through the thermocline in 2 places off Greenland, and 2 more off Antarctica , forming bottom water currents (yellow dots)





Tropical ocean: The warm mixed layer on top, then a steeply falling temperature regime – **the Thermocline** – and the deeper ocean is only a few degrees above freezing.

In polar waters, the mixed layer can be cool enough and dense enough to eliminate the thermocline and waters will sink.

Look again at where the surface waters now dive down through the thermocline to form the bottom water current: Exactly at the places we predict accelerated formation of low-density cold fresh water from nearby ice melt: Off Greenland, and the Antarctic Peninsula

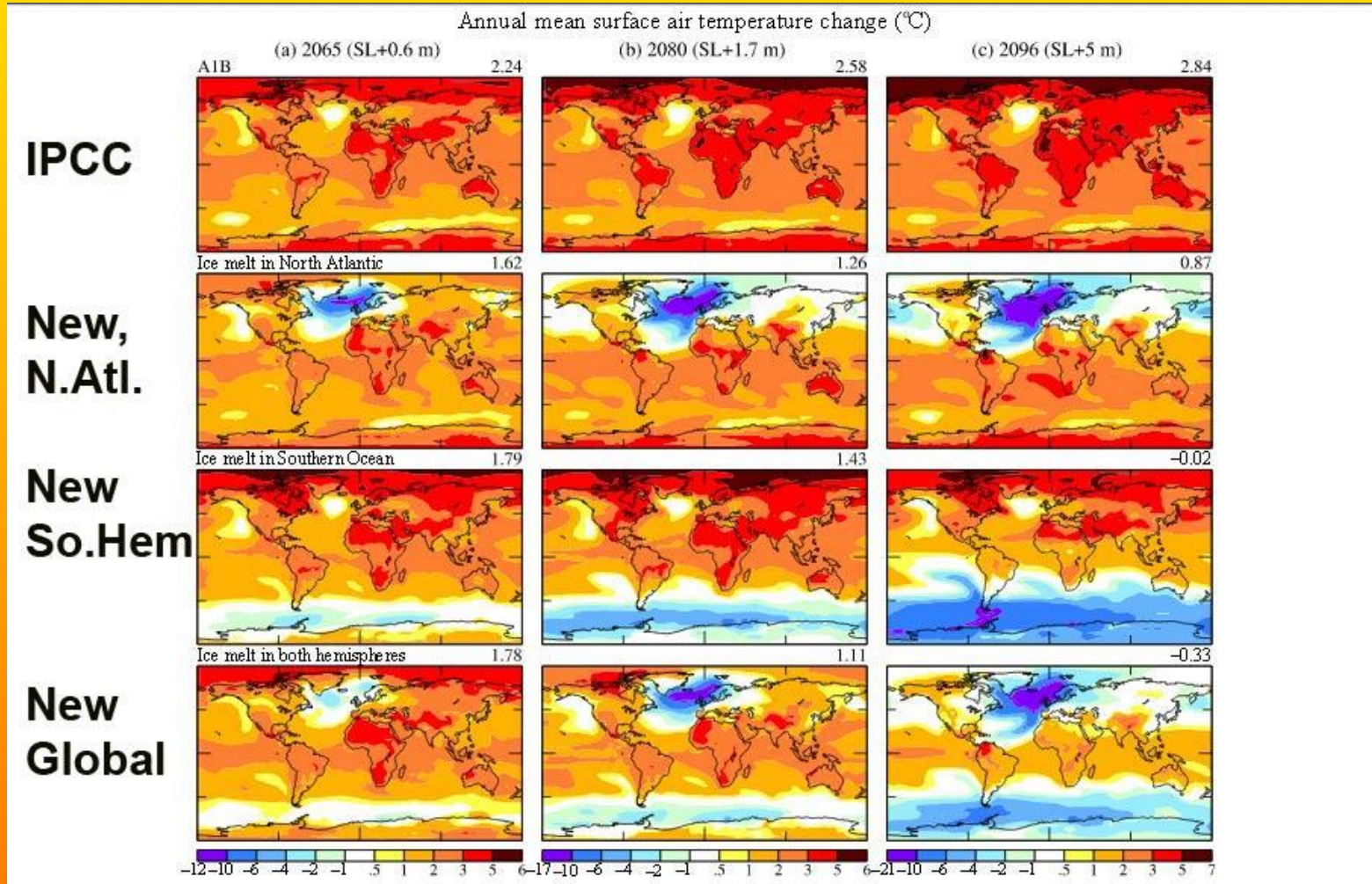


Figure 6. Surface air temperature (°C) relative to 1880–1920 in **(a)** 2065, **(b)** 2080, and **(c)** 2096. Top row is IPCC scenario A1B. Ice melt with 10-year doubling is added in other scenarios.

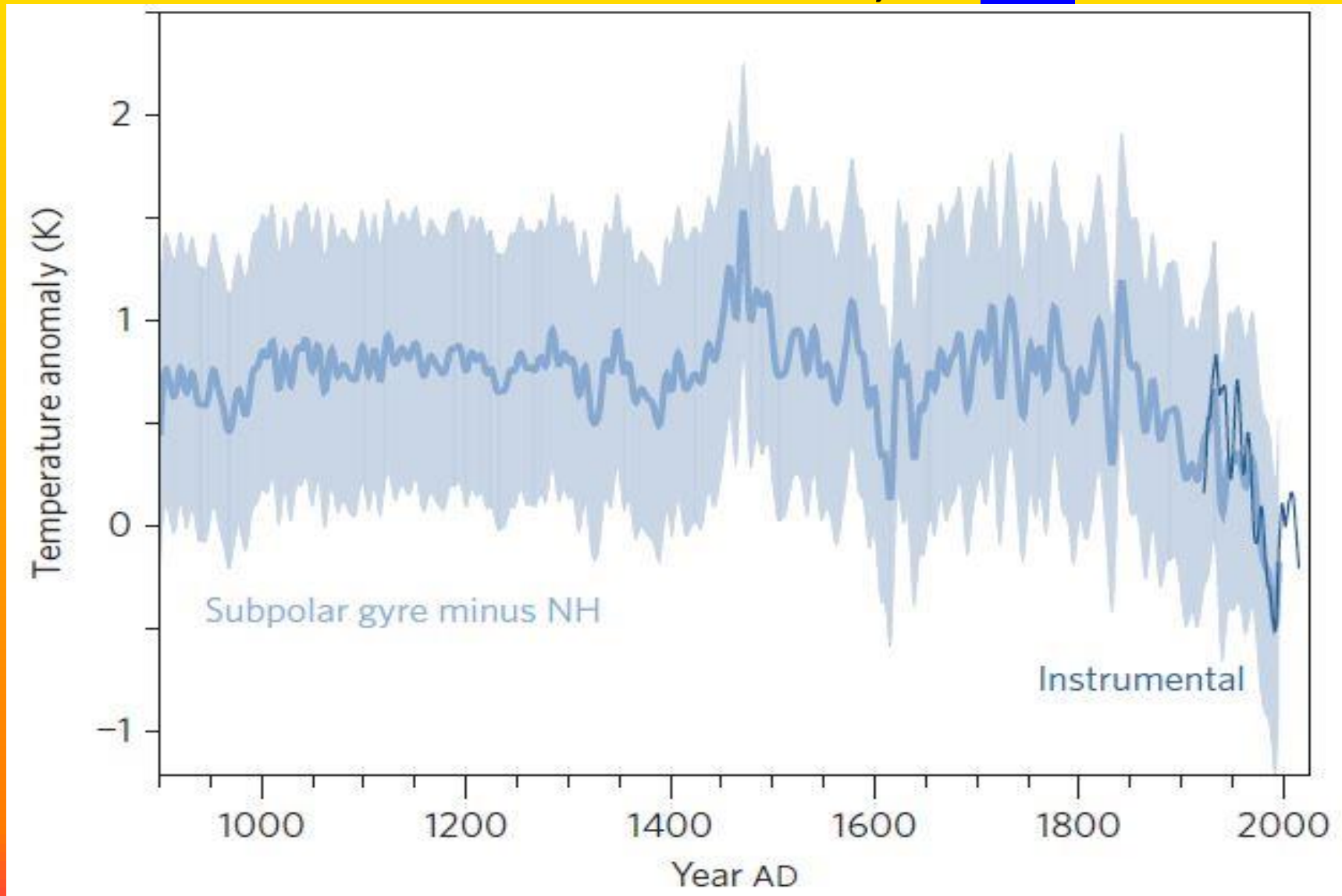
Hansen *et al.* 2016: +2C Global Warming Implications Summary (see my Presentation last summer as well)

- *1. "Cooling of the Southern Ocean, especially in the Western Hemisphere*
- *2. "Slowing of the Southern Ocean overturning circulation, warming of the ice shelves, and growing ice sheet mass loss"*
- *3. "Slowdown and eventual shutdown of the Atlantic overturning circulation with cooling of the North Atlantic region"*
- *4. "Increasingly powerful storms"*
- *5. "Non-linearly growing sea level rise, reaching several meters over a timescale of 50–150 years."*

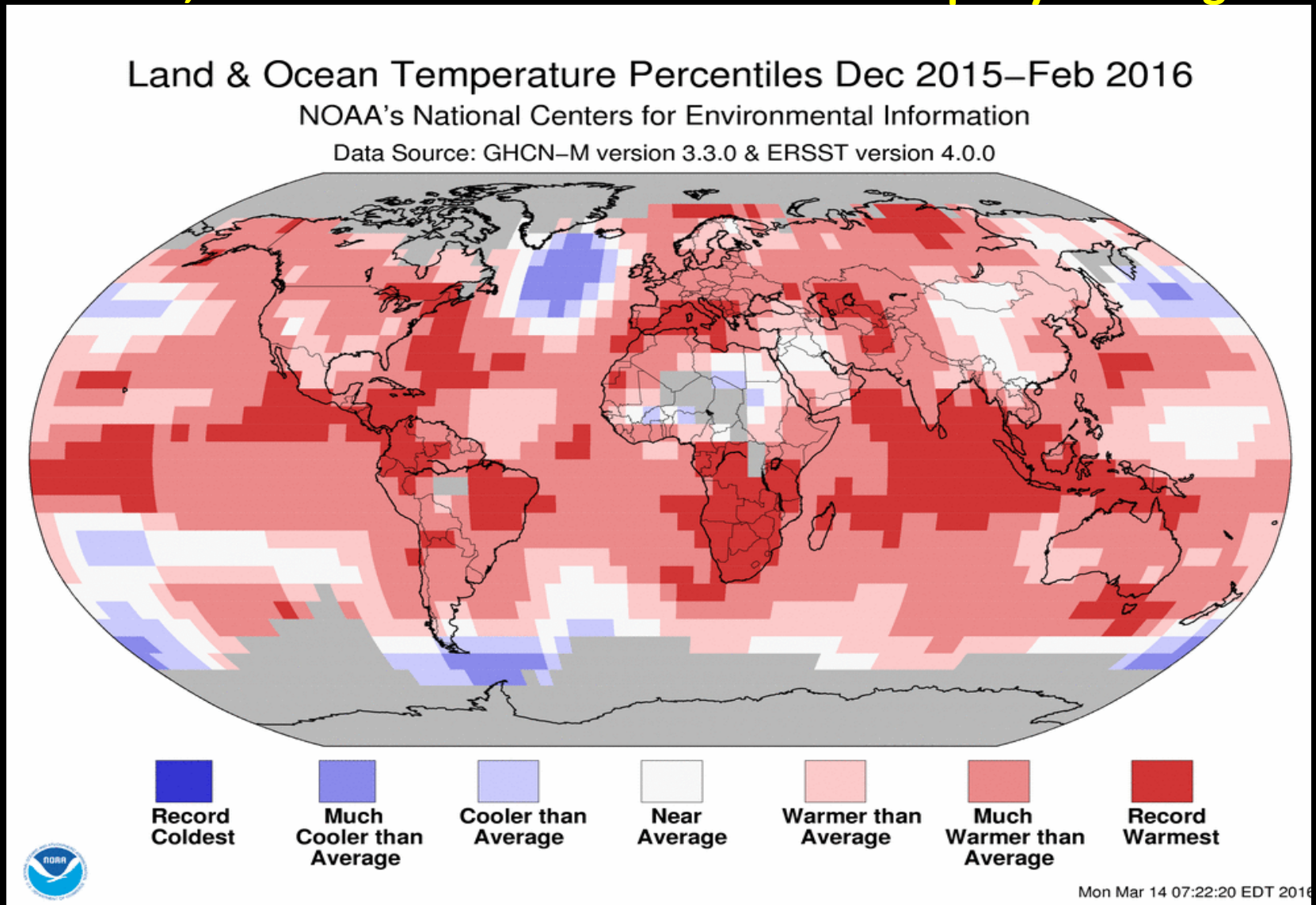
Could the Global Ocean Circulation Really Shut Down?

- **Yes.** The IPCC AR4 thought it would weaken but not halt this century, but new observations (below) is suggesting a more rapid decline than their models expected. Yet again, IPCC under-estimation is evident.
- It's concerning that the current greenhouse forcing is far more rapid than any prior Milankovich climate forcing, including the Eemian interglacial, yet **the Eemian Period – the immediately previous interglacial warm period - did see global ocean circulation shut down,** initiated with global temperatures at those we have just now reached.
- **Indeed, the Atlantic Meridional Overturning Circulation (AMOC), which is the only portion of the global currents on which we now have good data, has already weakened…**

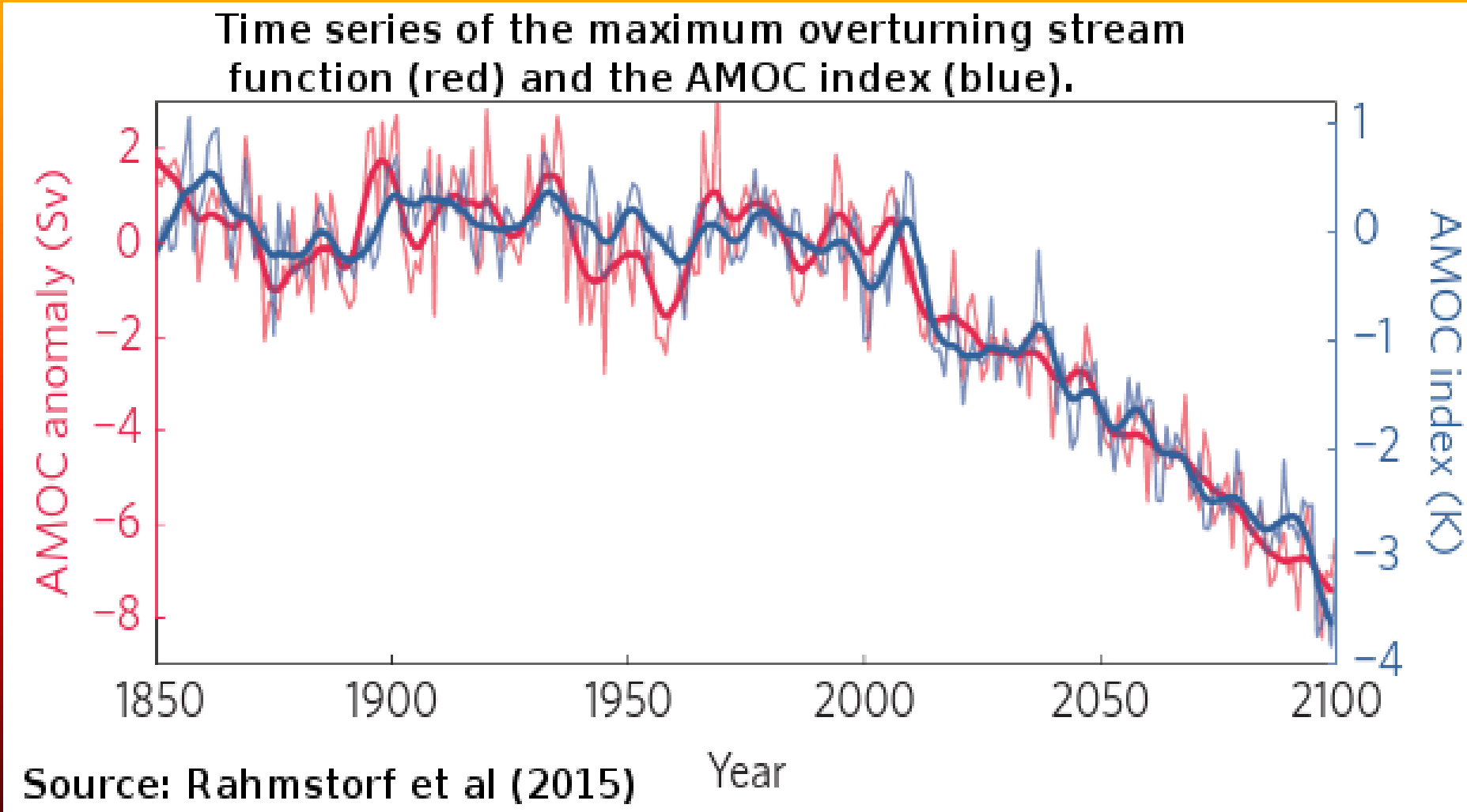
Past 1200 years of the temperature difference between the subpolar North Atlantic and the entire northern hemisphere, which can be interpreted as an indicator of the strength of the Atlantic circulation. From Rahmstorf *et al.* 2014, see [here]



“It’s Happening”, much sooner than expected… Note the cold patch (blue) below Greenland, due to Greenland meltwater. Another at the Southern Ocean’s deepwater formation points off the Antarctic Peninsula, where the Larsen Ice Shelves are rapidly disintegrating



The strength of the AMOC is indeed declining, and predicted to continue declining (Rahmstorf *et al.* 2015)

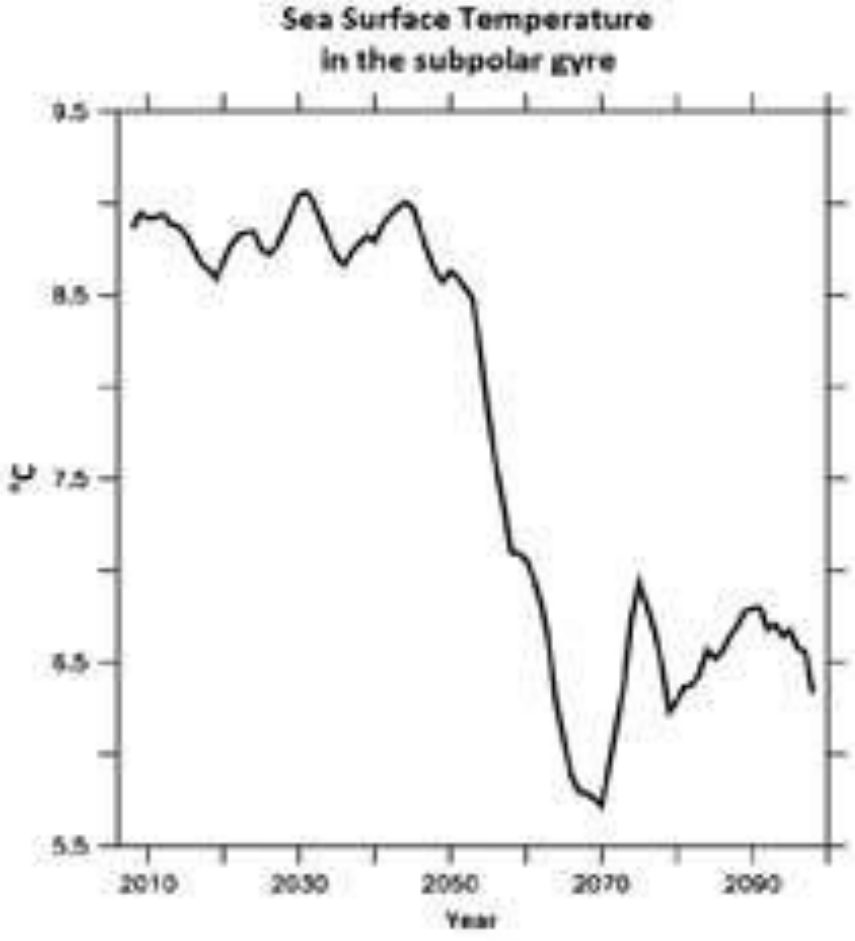


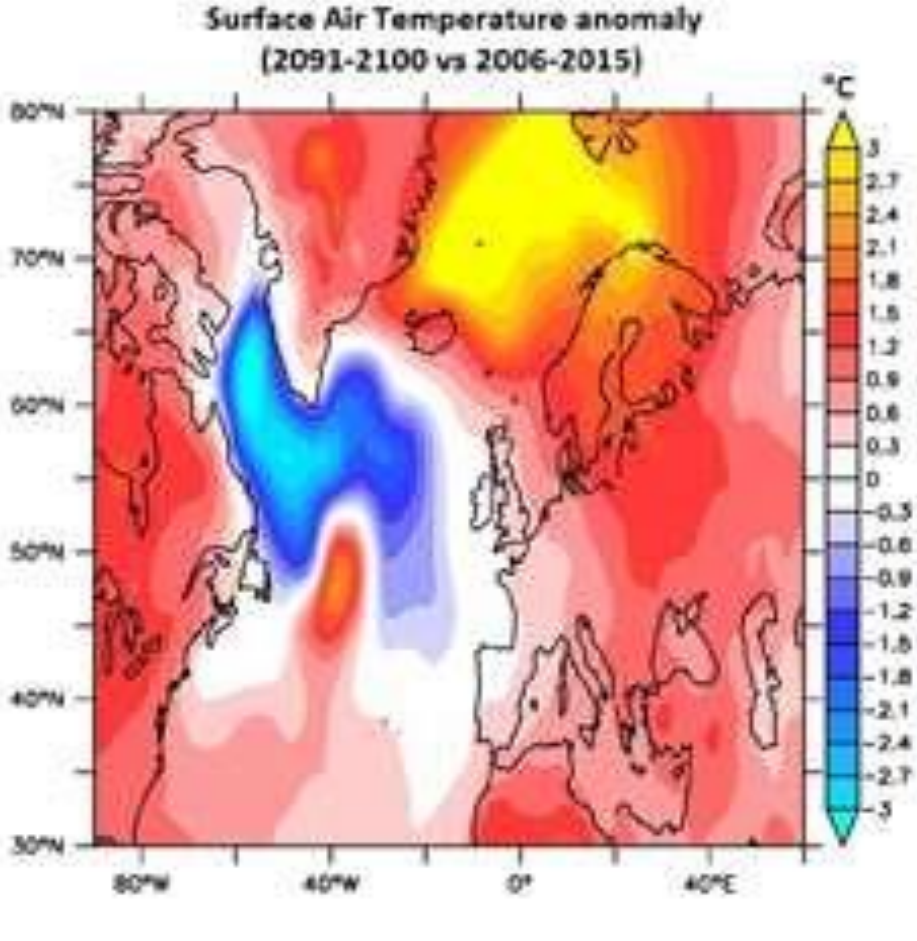
Source: Rahmstorf et al (2015)

Hot off the Press as this PowerPoint Talk is Being Readied for YouTube…

- Remember **"The Day after Tomorrow"** and the breathless *"Well… I THINK IT'S HAPPENING!"?*
- A new paper finds that rapid AMOC slowdown due to a convective failure of the North Atlantic Subpolar Gyre (SPG) is much more likely than IPCC AR5 had thought, when CMIP5 models best able to reproduce actual observed stratification are examined in more detail. (Sgubin *et al.* 2017) (*Nature* paper) (related video summary)
- Half of their most realistic models lead to AMOC shutdown and very large climate change **in as little as 1 decade** (see next slide…).
- The authors **note**… ***"contrary to a potential AMOC disruption, no assessment has been made of the possibility of a local SPG convection collapse in the latest IPCC AR5 report"***

Rapid Drop in North Atlantic Sea Surface Temperature caused by failure of the sub polar gyre due to impenetrable stratification. Estimated 45% odds this Century





Cold Stagnant Water in North + Hot Stagnant Water in Tropics = Large Scale STEEP Temperature Gradient = Super Storms

- It is temperature GRADIENTS – the steepness by which temperature drops from one place to another – which powers winds, and it is winds which power storms and waves
- **An era of Super Storms is the theoretical prediction…**
- **And the observational confirmation in paleo data – Hansen *et al. 2016* find that during the Eemian Period, temperatures similar to today induced ice melt and sea level rise several meters higher than today. And - Super Storms…**

The hotter tropical waters strongly amplify convective storms, further amplified by the stronger temperature gradient between colder offshore Greenland and the hotter equator. Result: Storm-tossed 1,000+ ton boulders

Fig. 1. Two boulders (#1 and #2 of Hearty, 1997) on coastal ridge of North Eleuthera Island, Bahamas. Scale: person in both photos = 1.6 m. Estimated weight of largest boulder (#1, on left) is ~ 2300 tons.

Enormous boulders tossed onto an older Pleistocene landscape (Hearty, 1997; Hearty et al., 1998; Hearty and Neumann, 2001) provide a metric of powerful waves at the end of stage 5e. Giant displaced boulders (Fig. 1) were deposited in north Eleuthera, Bahamas near chevron ridges and runup deposits (Hearty, 1997).

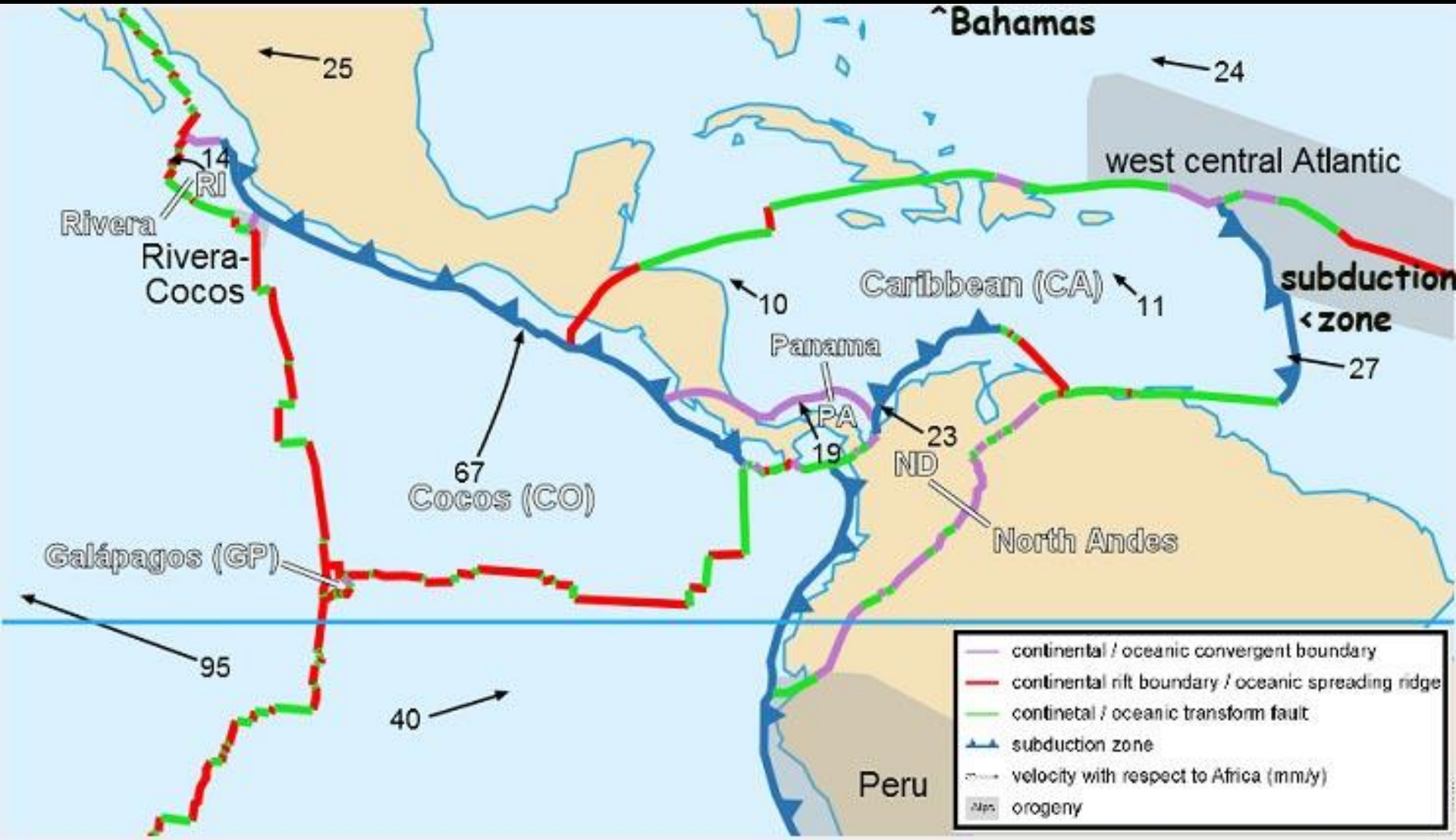
Hansen *et al.* detail evidence supporting these are boulders, tossed up to current locations, not erosion remnants

- **1.** They rest on younger Pleistocene landscape aged at MIS 5e, yet composed of limestone sand of MIS 9 or MIS 11 age (older). That's the reverse of what the landscape stratigraphy would predict, but in line with having been tossed up from deeper, lower, older off-shore strata.
- **2.** Land snail fossils beneath boulders correlate to younger MIS 5e (Eemian, the last interglacial), not older boulder age
- **3.** Amino acid raceimization confirm the age differences of boulders and substrate
- **4.** Bedding plane angles are far different between boulders and boulder/substrate, arguing against being erosion remnants *in situ*

Could The Boulders Be Erosional Remnants? Tsunami Deposited?

- Could they have fallen from higher elevation by erosion?
- Not likely; the largest of the boulders are found even ~on the ridge line of the highest ridge of the Island, and are older
- Tsunami's make little sense. Their parallel pattern says the energy source could not be nearby. **PBS Nova** had a show promoting fear of a tsunami generated by landslide from the Canary Islands, but evidence in undersea deposits there show no such landslide in the Eemian or the indeed the past few million years.

The nearest subduction zone of any kind is a short and weak zone SE of Cuba, SE of Bahamas – the wrong direction to explain the chevron deposits. And any events due to the subduction zone north of Colombia would be shielded from the Bahamas by Cuba and Haiti



What's the evidence they were tossed up by mega-storms?

- Run-up deposits **50 ft high,** across much of the Bahamas, and characteristic **"chevron" patterns ~3 kilometers long**, (compare to those you see today on sea shores, a few feet long and maybe a few inches high or less)
- Stratigraphy slanting which is ~impossible to produce by rain processes, and…
- All aimed directly away from deep water (southwest), with no relation to the varying coastal inlets and peninsulas, and…
- All parallel *vs.* oriented from a point source as would be expected from a massive slope-failure-origin caused tsunami originating in the Bahamas

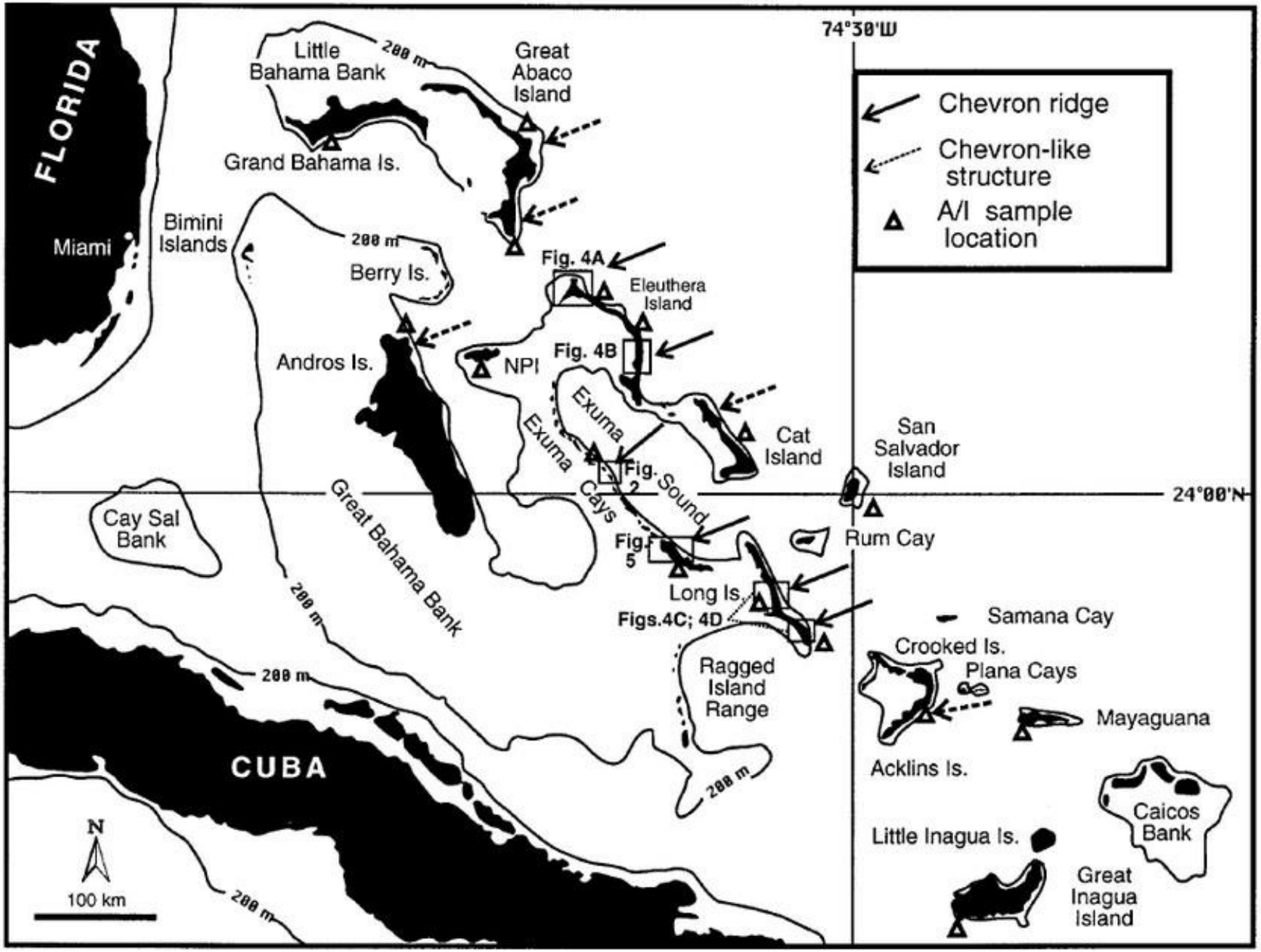


FIG. 3. Map showing location and approximate orientation (arrows) of chevron landforms and amino acid samples (Table 2).

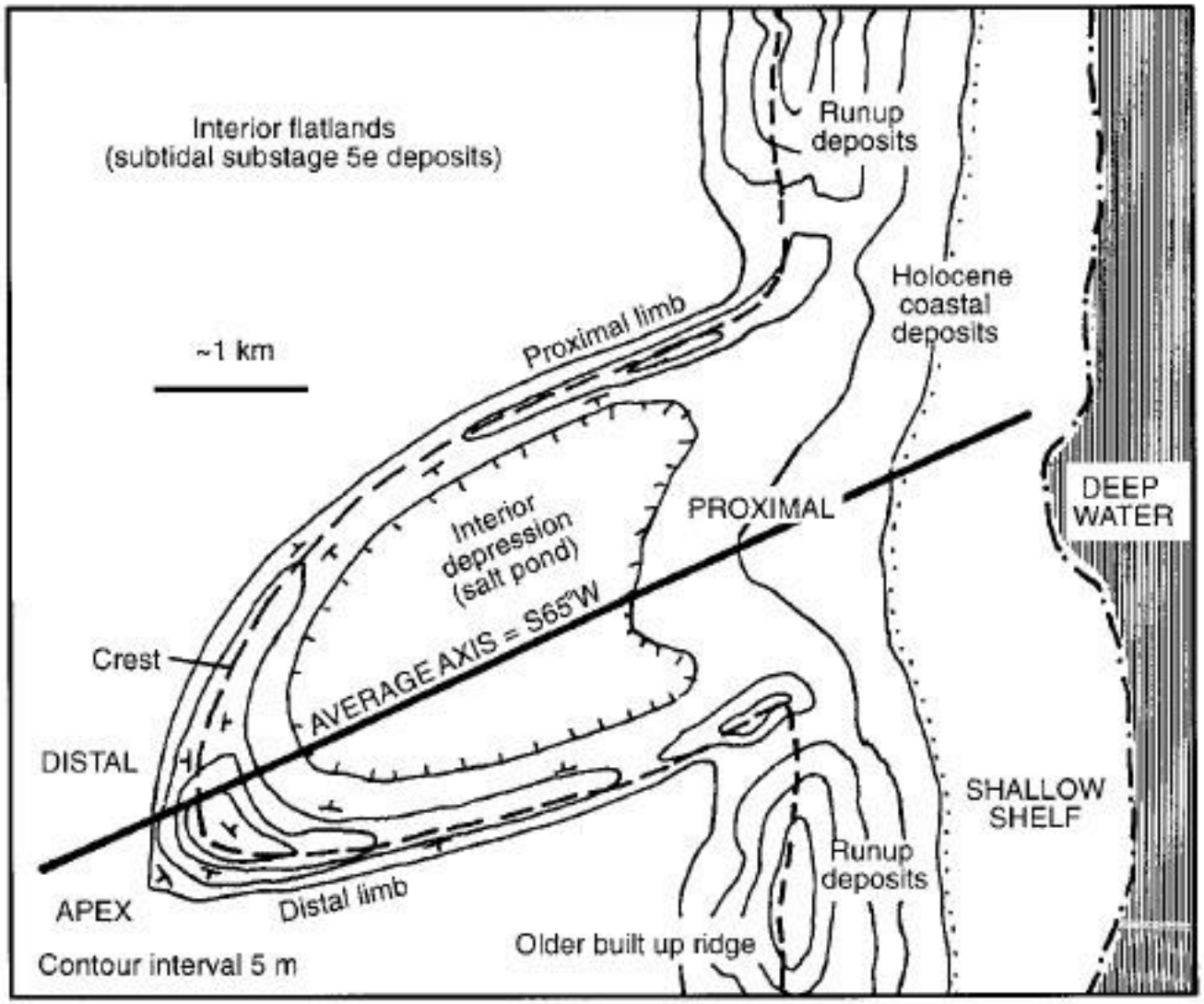


FIG. 1. Schematic map of chevron beach ridge.

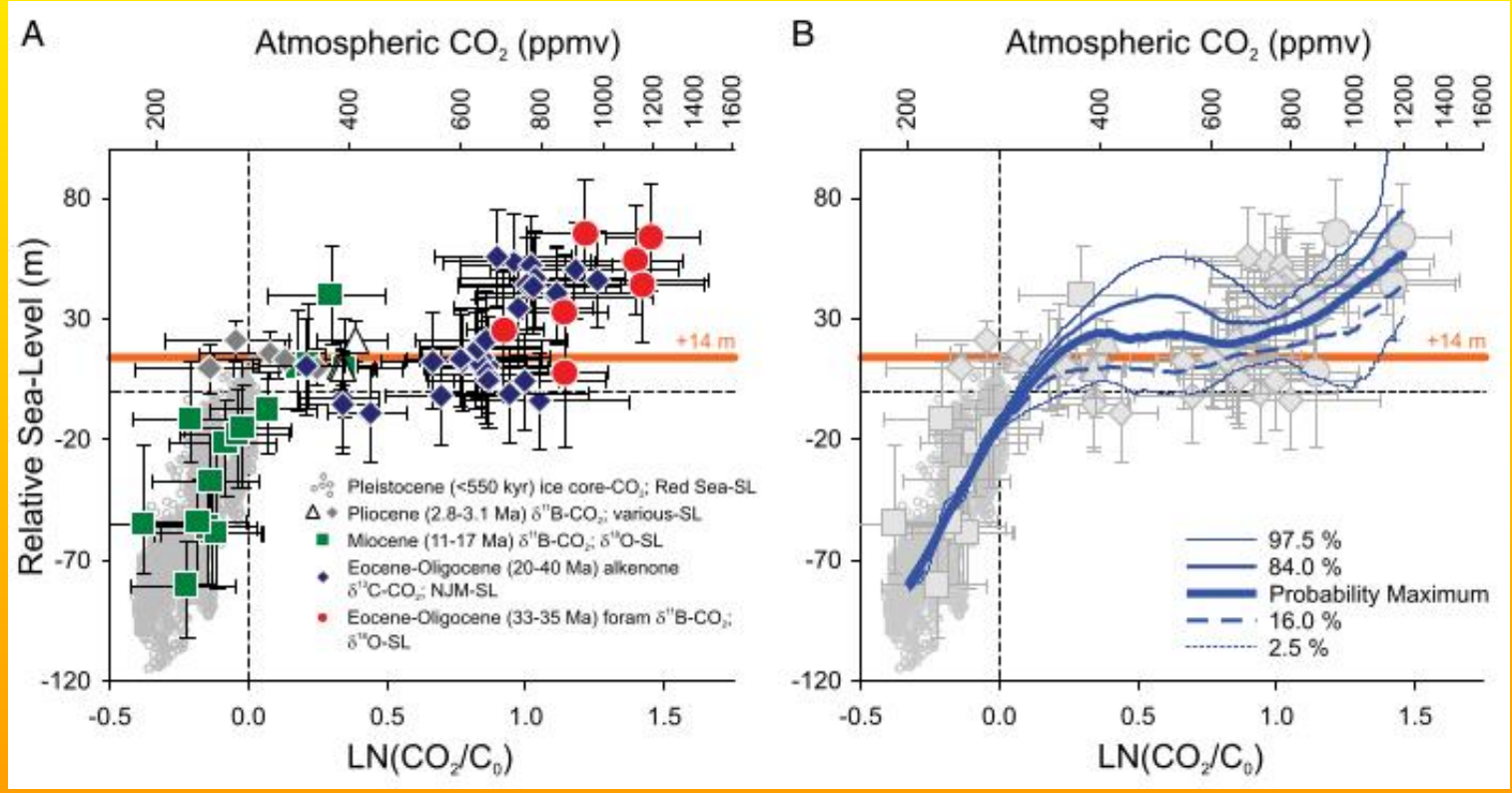
Imagine the size of waves capable of creating chevron deposits 50 ft high and 2 miles long when washing back to sea

If the AMOC Shuts Down and SuperStorms Arrive?

Finding such boulders on the highest ridge lines in the Bahamas suggests that the smaller islands of the Caribbean Sea would be wiped clean during such storms, and miles of low coastal area on the larger islands as well

Coastal areas in the Atlantic, and perhaps many places in the world, would be uninhabitable

Sea Level Rise for ~500-600 ppm CO2?



- From paleo data of past periods, Foster and Rohling 2012. Since methane was no doubt part of past emissions as well, should not use the CO2 equiv's we've been estimating, but CO2 itself, which is still in the 500-600ppm range depending on human emissions, being optimistic. Suggests about 20m or **66 ft of sea level rise**; enough to destroy most coastal cities worldwide and vast areas of flat farmland in California, Florida, the East coast, Asia, and around the world… It would take several centuries to fully reach that.

Sea level rise is worst in North America, as the loss of ice cap gravity allows the water presently pulled up against the Antarctic Ice Cap to relax away. Results of loss of West Antarctica shown below.

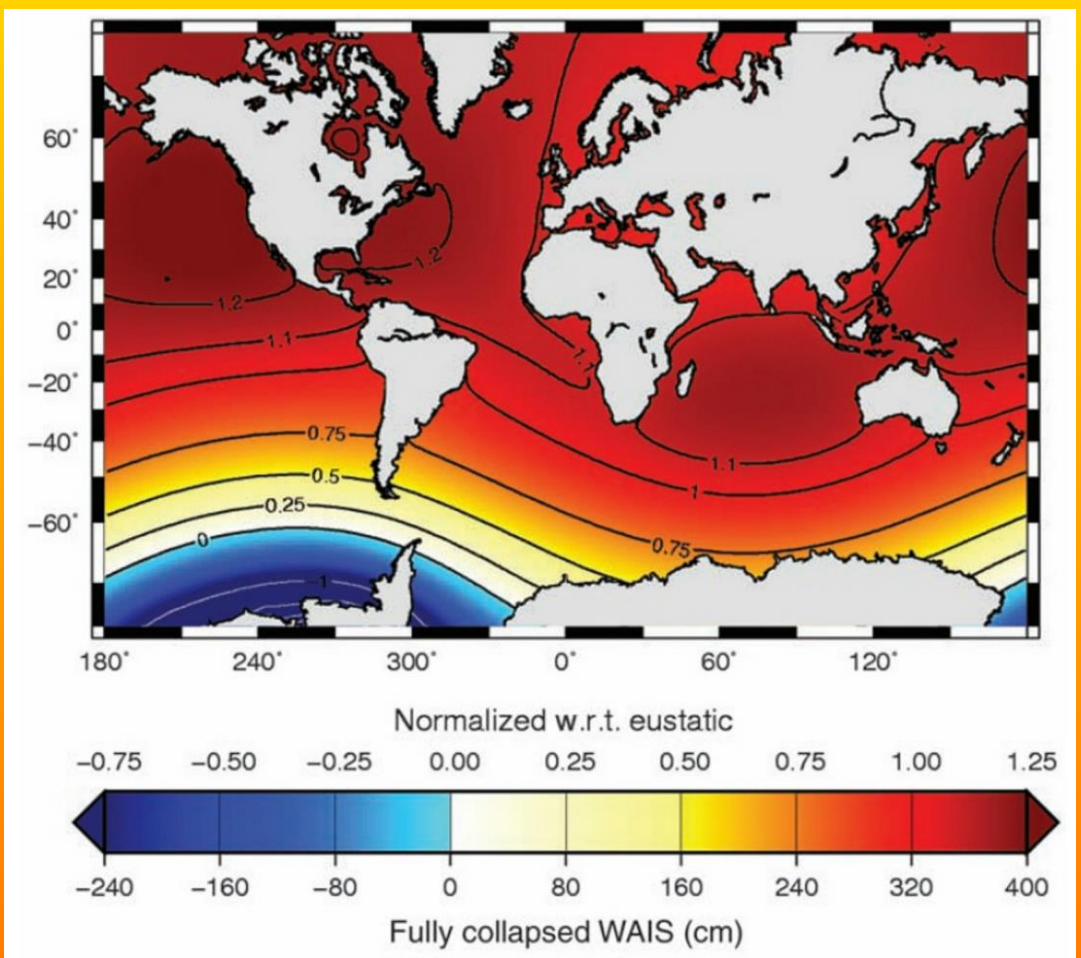
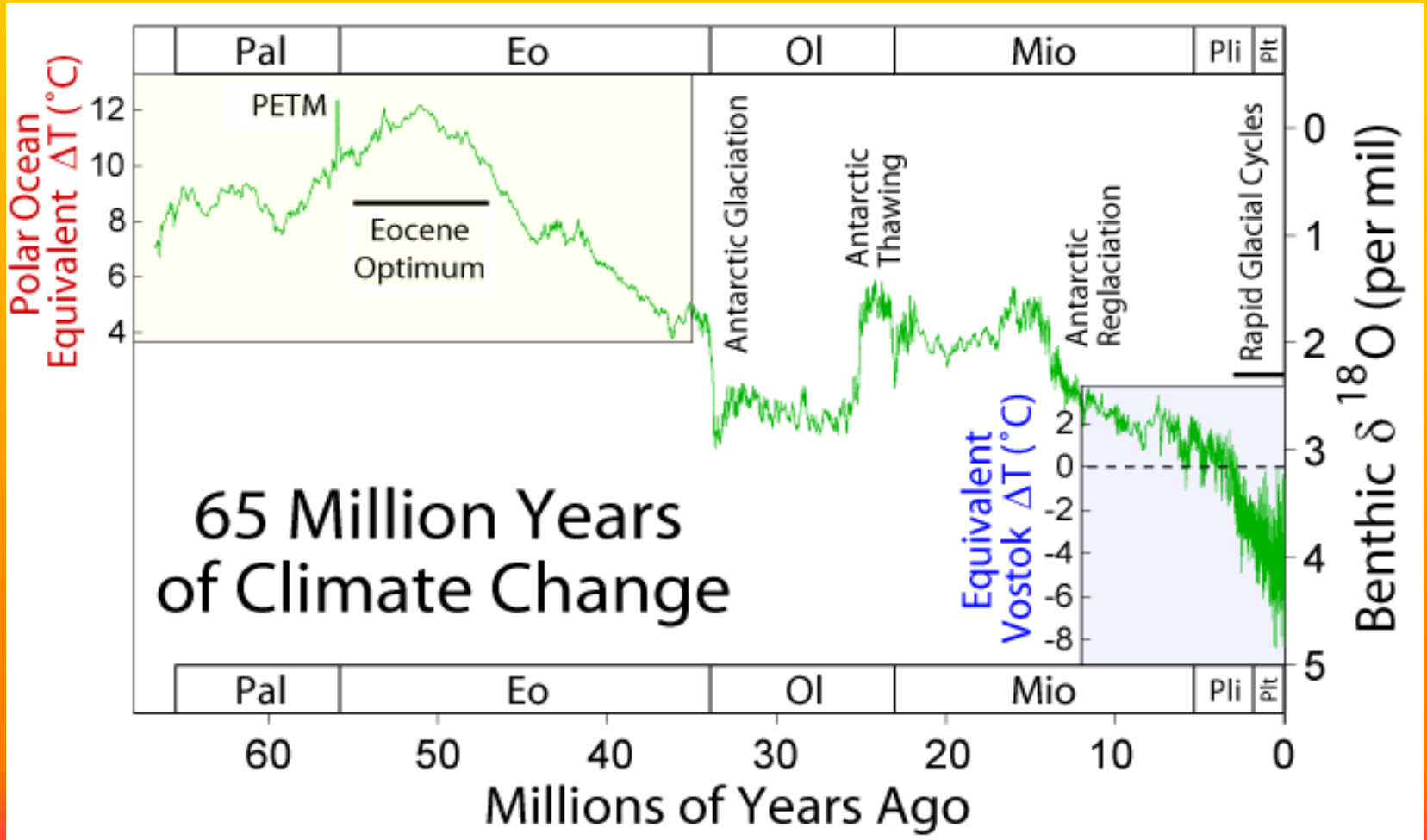
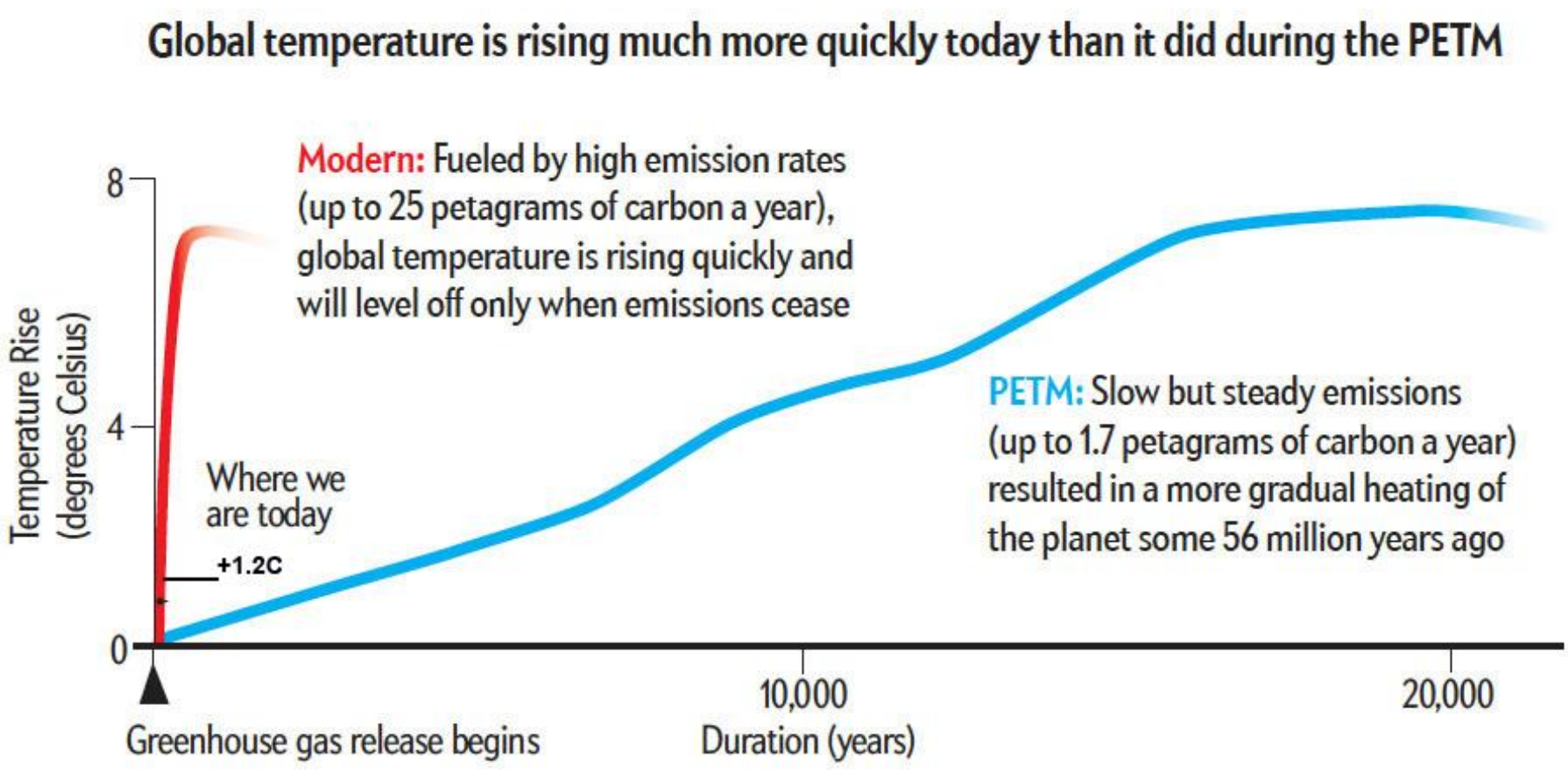


Fig. 3. Regional SLR after instantaneous removal of ice from the ROI, including the effects of self-gravitation, elastic rebound of the lithosphere, and Earth rotation perturbations but excluding the effects of ocean circulation (*29*) and other sources of ocean mass. w.r.t., with respect to.

Climate denialists like to dismiss climate change with *"Hey. Climate has ALWAYS changed. It's no big deal."* Now look at the PETM: the Paleocene-Eocene Thermal Maximum - an extinction-level event with CO2 rise and +2.5C polar ocean temperature rise, 56 million years ago. Looks rapid, right? Don't be fooled by the trick of looking at tens of MILLIONS of years all on the same graph! Because…



…Our human-caused global temperature rise rate today is 100 Times faster than the "rapid" PETM, due to our extreme radiative forcing, emitting 100x more CO2 per year than nature does (volcanoes)

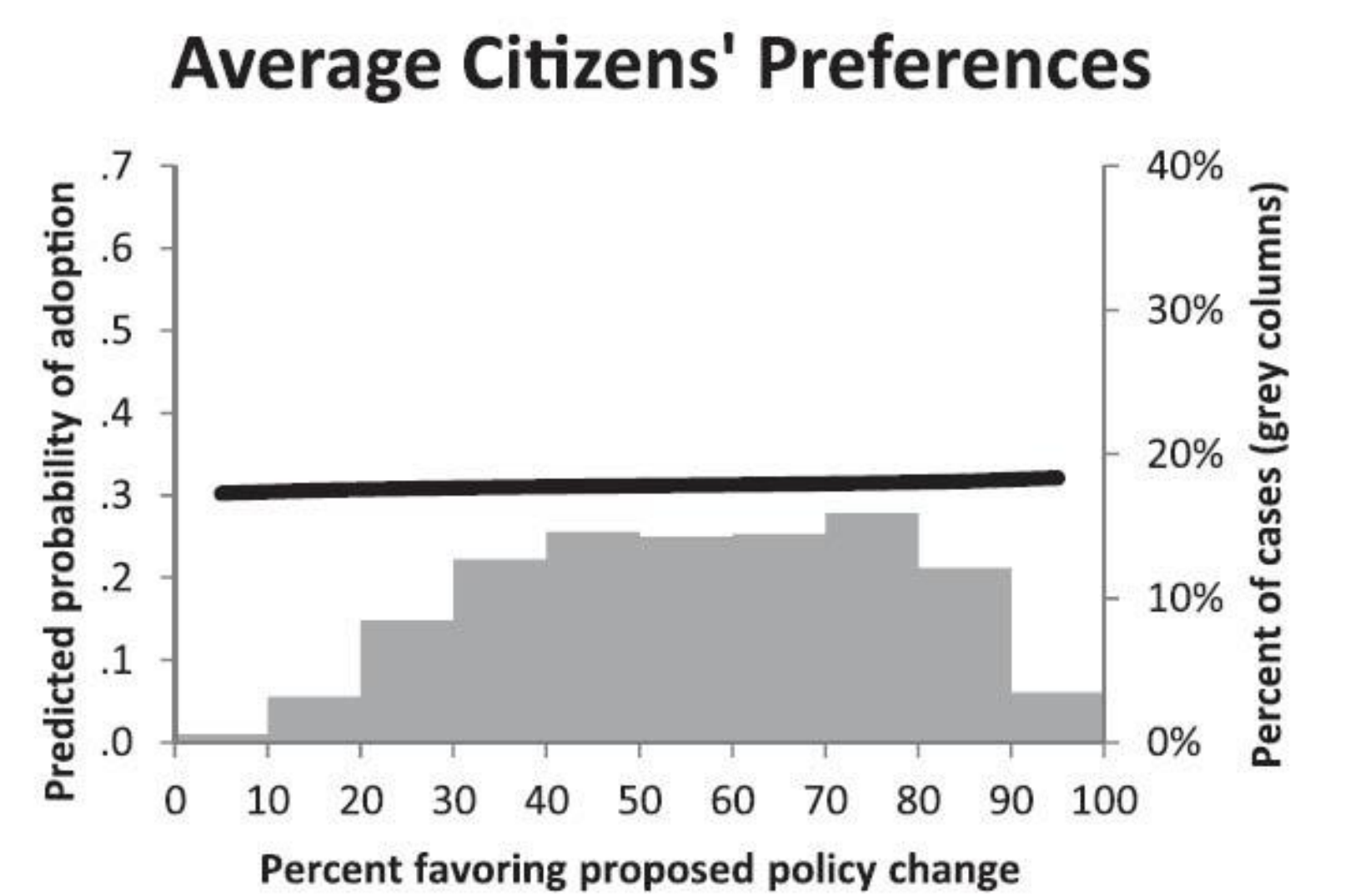


Our Leadership: Psychopaths and their Psychopathologies

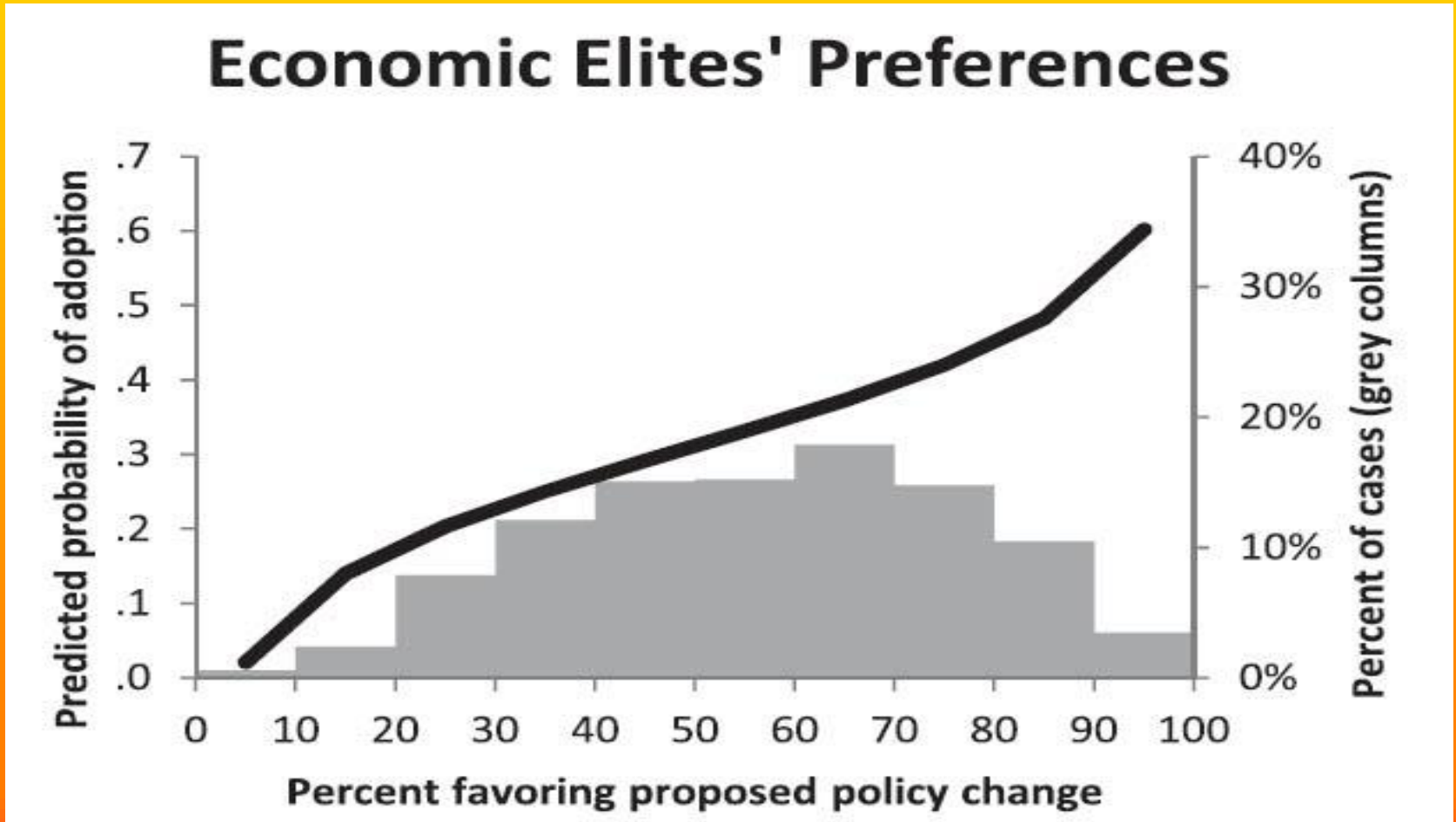
Psychopaths in Corporate CEO Boardrooms?

- Indeed, **this study** (Brooks *et al.* 2016, to be published in ***The European Journal of Psychology***) finds fully 21% of Corporate CEO's fit the diagnosis as **psychopaths.**
- **This is the same fraction as found in prisons.**
- **In the general population, the rate is only 1%**
- Lead author and forensic psychologist Nathan Brooks notes: *"For psychopaths, it [corporate success] is a game, and they don't mind if they violate morals. It is about getting where they want in the company and having dominance over others."*

So, little wonder there is absolutely ZERO correlation between what legislation is desired by average citizens, and what actually gets adopted (Gilens and Page 2014)

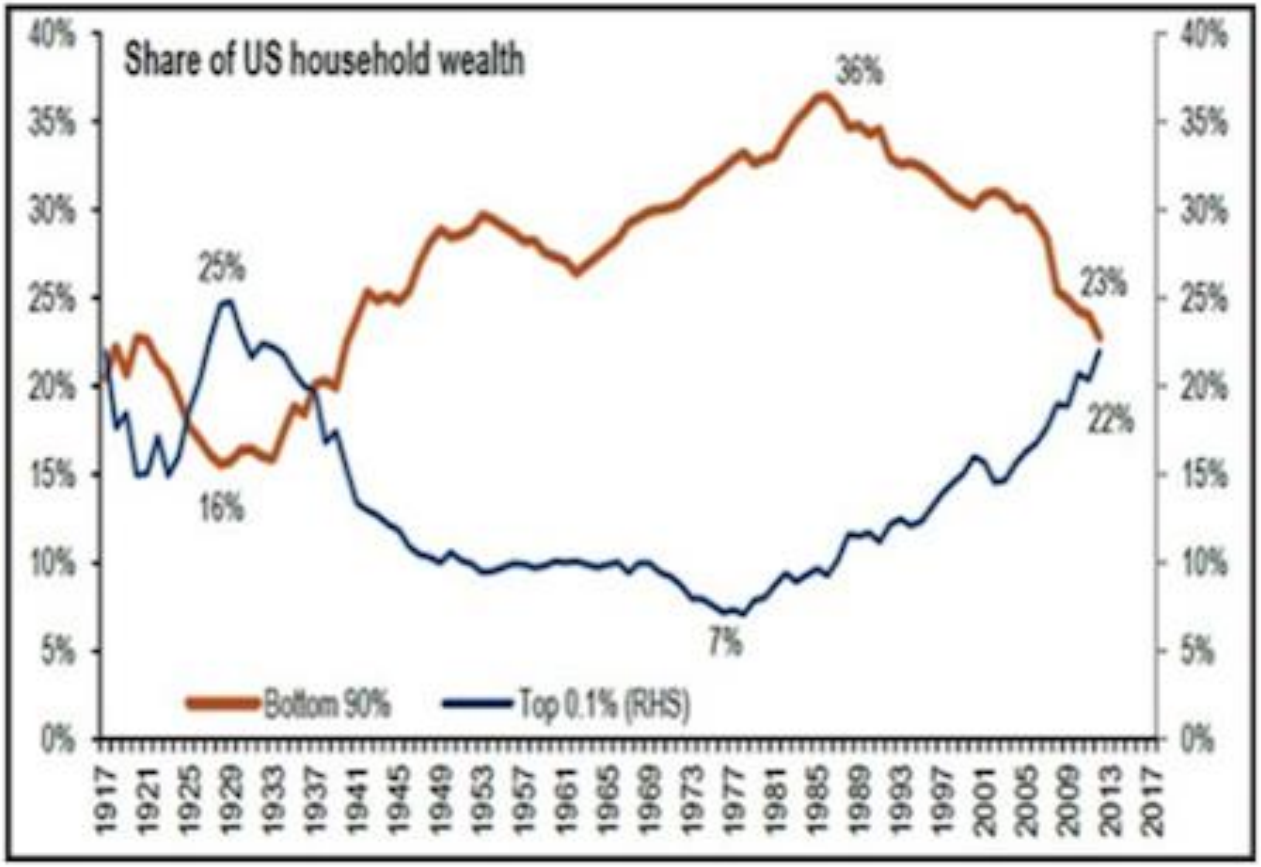


…And near-perfect correlation between what legislation the Economic Elites want and what gets adopted. True over 20 years of both Republican and Democratic Executive, Legislative, and Supreme Courts. This is a deep systemic dysfunction. Will be in my next talk, not today's



Since Ronald Reagan, there has been a massive “transfer of wealth” from the bottom 90% to the top 0.1%, along with the political power that wealth buys

Figure 2 **Distribution of Wealth in the US, 1917–2015**

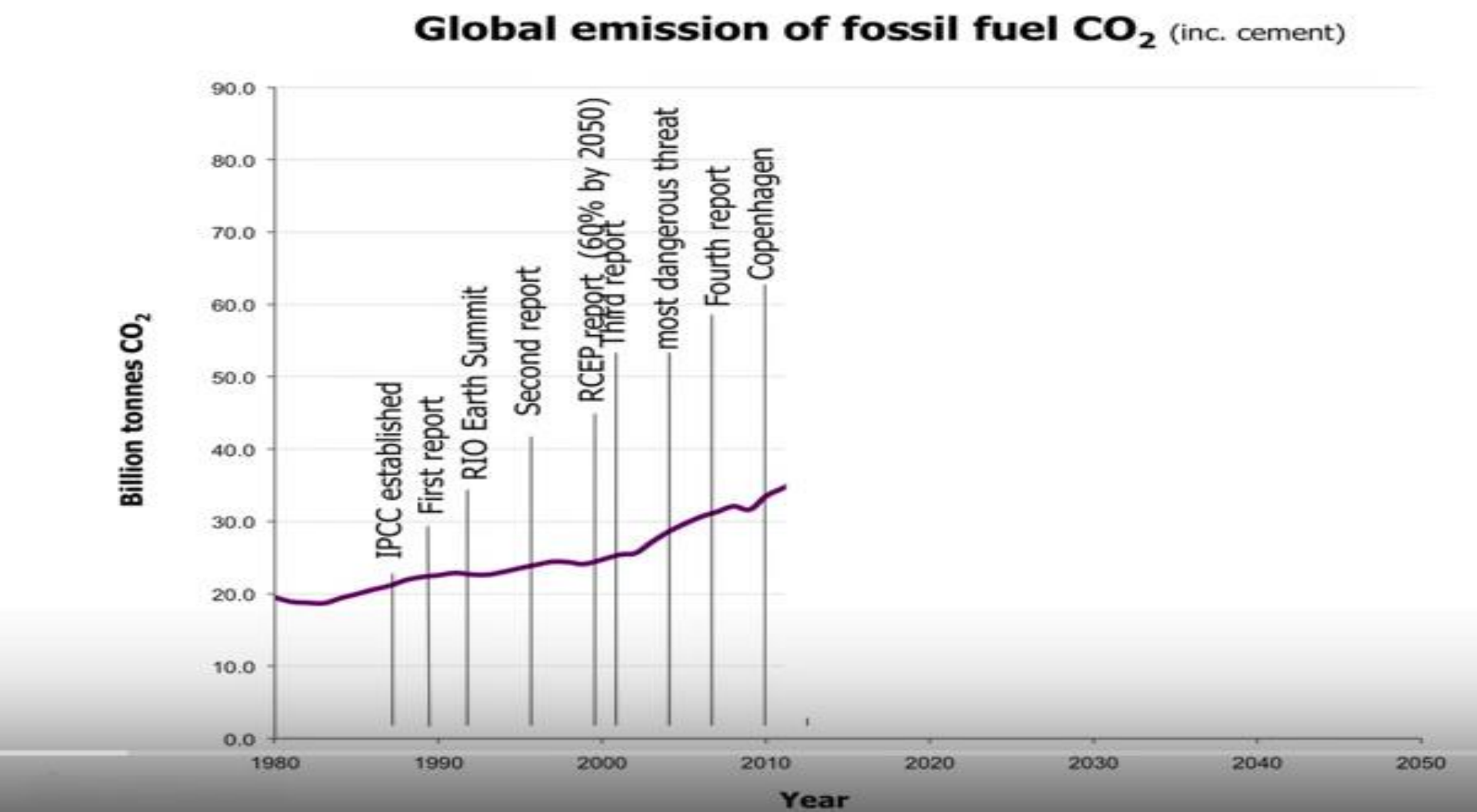


Source: BofA Merrill Lynch, Emmanuel Saez & Gabriel Zucman

Climate Action Implications?

- Too many people are still living in the ‘90’s, when we thought that increasing energy efficiency and voluntary adoption of renewables could solve the problem. We’ve done ~nothing, for over 20 years, except accelerate CO2 emissions, and string along those who continue to hope for better.
- In the words of Leonardo diCaprio in **“Before the Flood”**. ***“It seemed like a positive thing at the time, you know?” he says. “Changing your lightbulb. But it’s pretty clear that we’re way beyond that point now. Things have taken a massive turn for the worse.”***

Total Policy Failure: CO2 Annual Emission RATES Are Rising Relentlessly, despite IPCC Climate Summits. But there's a reason – You can't have a growing economy w/o growing CO2 emissions today, and the Economic Elites (Gilens/Page 2014) INSIST on growth. Without growth, Wall Street plummets. Wall St. (who installs our politicians who then employ policy people) finds this absolutely UNACCEPTABLE. Many Greens do too, it seems



It will be a separate Presentation of mine later, on critically assessing climate action strategies

- **I'll present a new framework for judging strategies**
- I'll go beyond the promotionals and look critically at the safety, efficacy, and workability of the proposals you'll see out there
- I'll put them in the human context – the **Thermodynamics of Civilization itself** - and the psychopathologies of people in both the personal and institutional context.
- These aspects too, alas, will show how much more difficult is our task than is appreciated by most. **But what's most badly needed if we're to make real progress – is REALISM, not false bravado.**

Thermodynamics: Civilization vs. Physical World

- Inanimate objects have no power to challenge the laws of thermodynamics, and they must follow those laws perfectly, every time.
- But civilization is composed of human beings, who CAN, if they choose, do the hard thing, do the uncomfortable and inconvenient thing – and voluntarily push back from the table of consumption. They can voluntarily use their institutions of enforcement to compel an end to population growth, to economic expansion and consumption…
- Do we have the will? So far I see no evidence of it.
- **Will we? You decide. I challenge you to challenge your institutions' leadership and PROVE THIS SCENARIO WRONG. But it won't happen with happy-talk, earnest letters to your congressman, and the like. It won't happen with a continued underestimating of the nature of the forces – natural and human - taking us down.**


Sorry!
The lifestyle you
ordered is currently
out of stock

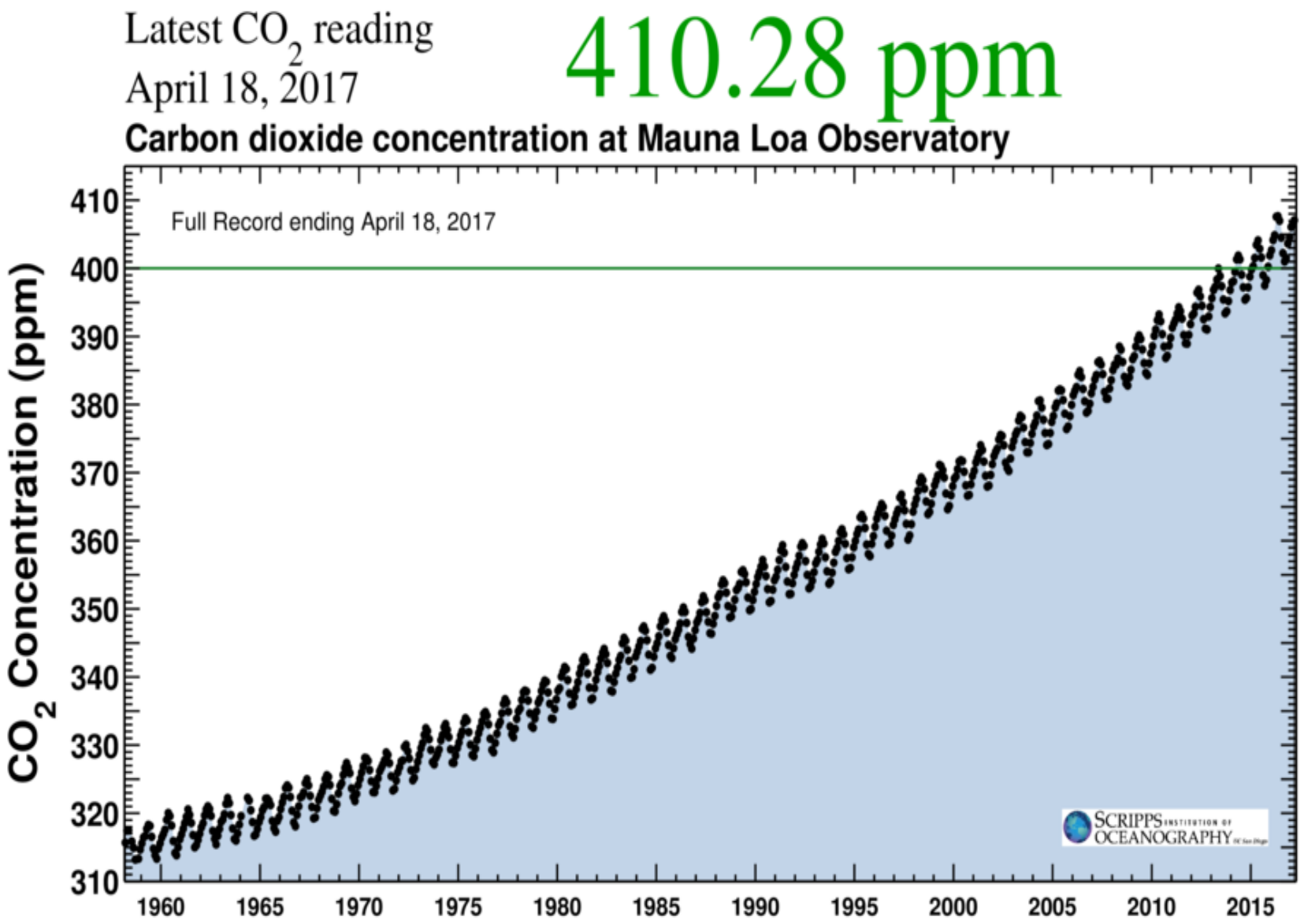
But Rick – what about the GOOD News! We May Be hitting Peak Emissions!

- Global economic growth rates of 2-3% but emission rates level for 3 years!
- Really?
- **Pop quiz time!**
- **First – if emission rates are level, should this mean that atmospheric CO2 should remain level too?**

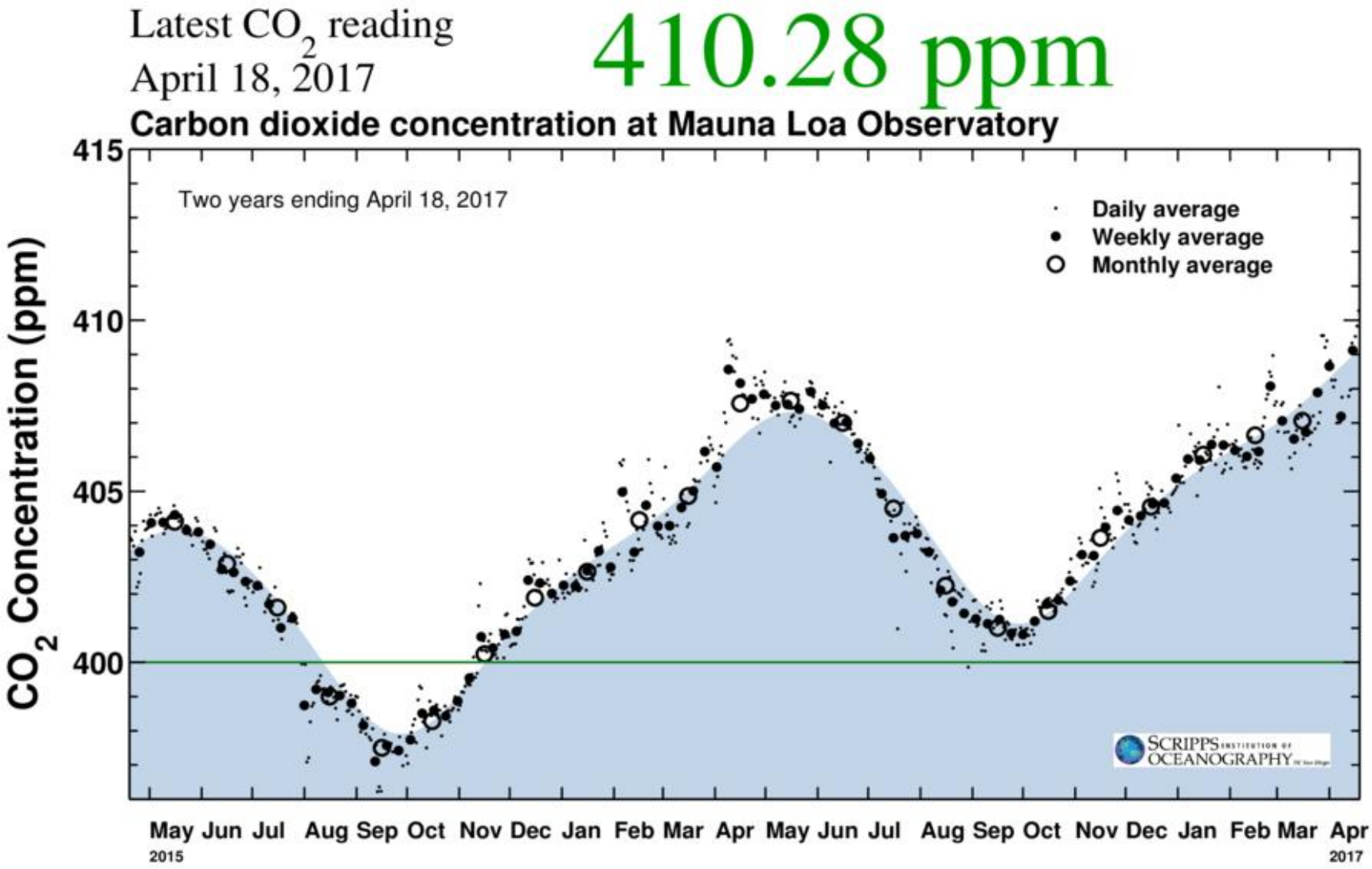
Answer: No

- **Do the math…**
- Level emissions rate means that Atmospheric CO2 should continue to rise at a constant straight sloping line UPWARD. (the integral of a constant is a sloping straight line)
- Is that what we see? **NO**. I **wish** it were only a constant slope upward… Instead, CO2 levels have risen over the past 2 years at the **highest year-over-year rate ever**, now at 3 parts-per-million per year

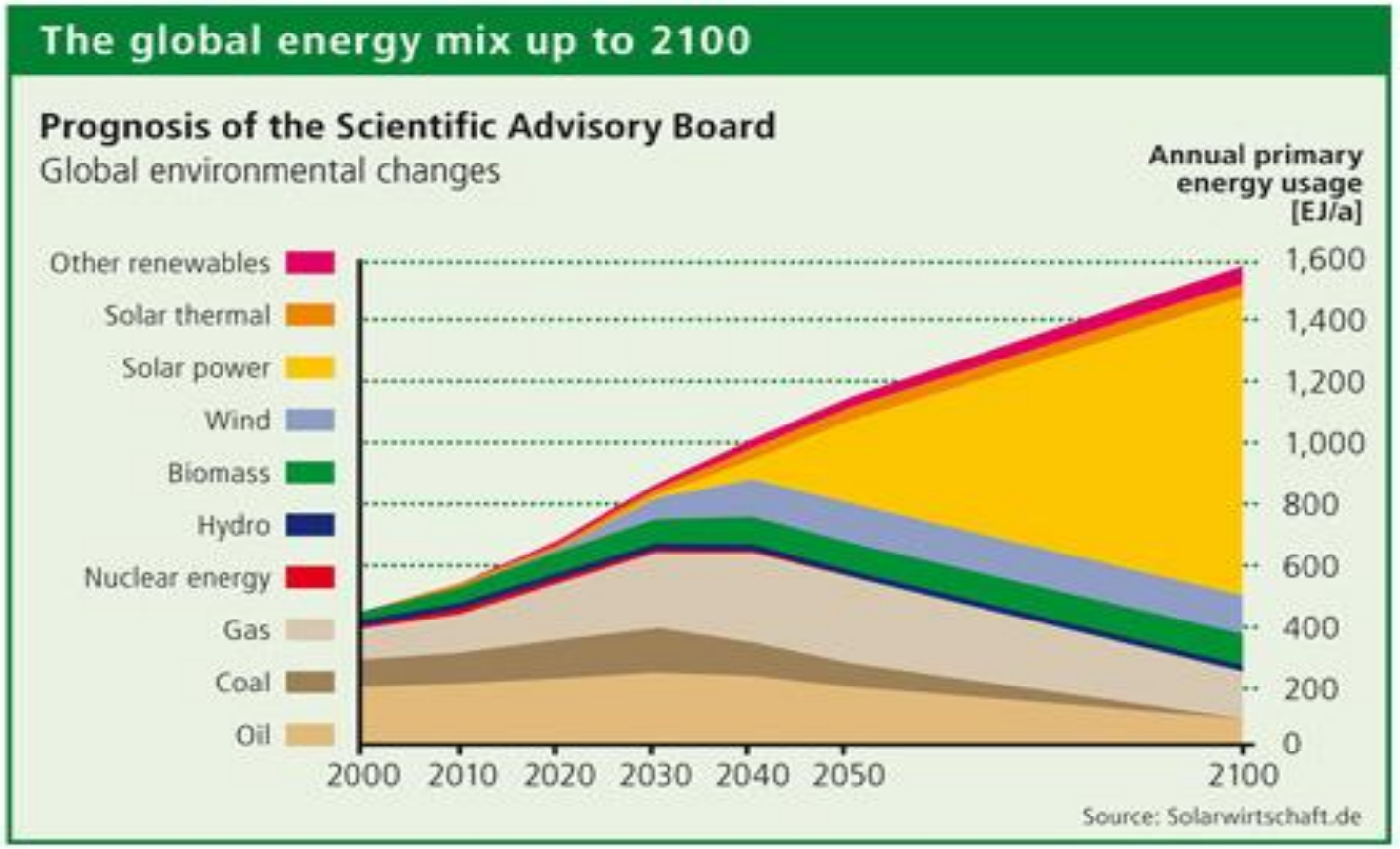
Real World: CO2 Continues to Accelerate



Nature does not lie. Atmospheric CO2 acceleration means – The total global annual emissions rate must in fact be continuing to go UP, despite false claims



While Solar is expected to dominate global energy production by 2100, note that even this solar energy organization's scientific advisory board's analysis finds that global fossil fuel energy will continue to rise until peaking by 2040, and even staying higher than today right up till 2060. Well-built fossil fuel power plants don't get decommissioned just to save the planet, after all… not if they produce u$eful energy.



Source: http://www.solarwirtschaft.de

There have been Many Promises

- …promises of change, of revolutionary technologies that will transform our energy system.
- Believe them when you see them.
- There are political and financial interests to placate the People, to forestall revolt and societal instability.
- Recently I have read that China is planning on banning all gasoline and diesel cars by 2040. That would be big. But that may assume unlimited supplies of lithium or some other materials for making electric vehicles cheap and just as affordable as old gasoline cars.
- It's more believable that those old gasoline cars will continue to operate as long as possible, if not by the rich, then by the poorest among us in countries elsewhere than China and the West.
- It's more believable that existing oil and gas supplies WILL be exploited. Better to get $omething rather than nothing. We don't tend to leave "stranded assets.

This is a Key Point Almost Universally Ignored in Presentations

- We as members of a global society will ONLY do what is **personally economically advantageous**
- We will NOT decommission perfectly well-functioning new fossil fuel power plants, such as have emerged by the thousands in Asia. We instead will wait until they are uneconomical to operate. That may well be many decades.
- Yes, NEW power plants are increasingly solar and wind (but above 20% penetration, they become much more expensive in today's grid, so that's a current ceiling it seems) – but what's immediately necessary is to shut down, **today,** perfectly well-functioning fossil fuel burning facilities, and this we refuse to do.
- The rest, is all "theater", as they say.

To Close: Dealing with this is Hard

- 8 years ago, I was happily beginning work on a project with UCSC astronomers, using Kitt Peak National Observatory to search for transits, finding new planets around other stars.
- Then I was confronted, quite close to home, by the urgent need to switch my focus to **Climate Change**, to create **Astro 7 "Planetary Climate Science",** and to tell the straight truth of what the peer-reviewed science really says to Cabrillo College students and to all who have ears and a sincere intention to listen.
- But my trust has been deeply challenged – in people I once had respect for, in institutions, in the very fabric of civilization itself.
- As the eminent energy analyst and polymath Dr. Nate Hagens told me last year… ***"you have to be careful. This stuff is toxic"***
- **I confess I struggle with this. Every. Single. Day.**
- **I think of the innocents; of now and the future…**

<u>They</u> will bear the true cost of our self-absorption and our short-sighted refusal to face Reality

I'm Haunted by the words of the late Peter Matthiessen

- …author of **The Snow Leopard** – my favorite book and a constant companion on my frequent sojourns to the wilderness. This book renews me with what inner beauty is, and natural beauty as well…

- ***"Our Native Americans are said to consider the effects on the next 7 generations of their people before undertaking an action which will affect their lands… and we don't even consider one."***

– Peter Matthiessen

While there's more to be said about post-IPCC climate science…

- *e.g.* cloud feedbacks are increasingly looking to amplify global warming – these too, not included in IPCC models…
- …But we're out of time
- **It's time for your questions**