THE ECONOMICS OF CLIMATE DAMAGE: A CRITIQUE OF WILLIAM NORDHAUS AND NEO-CLASSICAL ECONOMICS IN LIGHT OF 21ST CENTURY CLIMATE SCIENCE

PART 2

RICHARD NOLTHENIUS

CABRILLO COLLEGE, AND UC SANTA CRUZ EARTH FUTURES INSTITUTE

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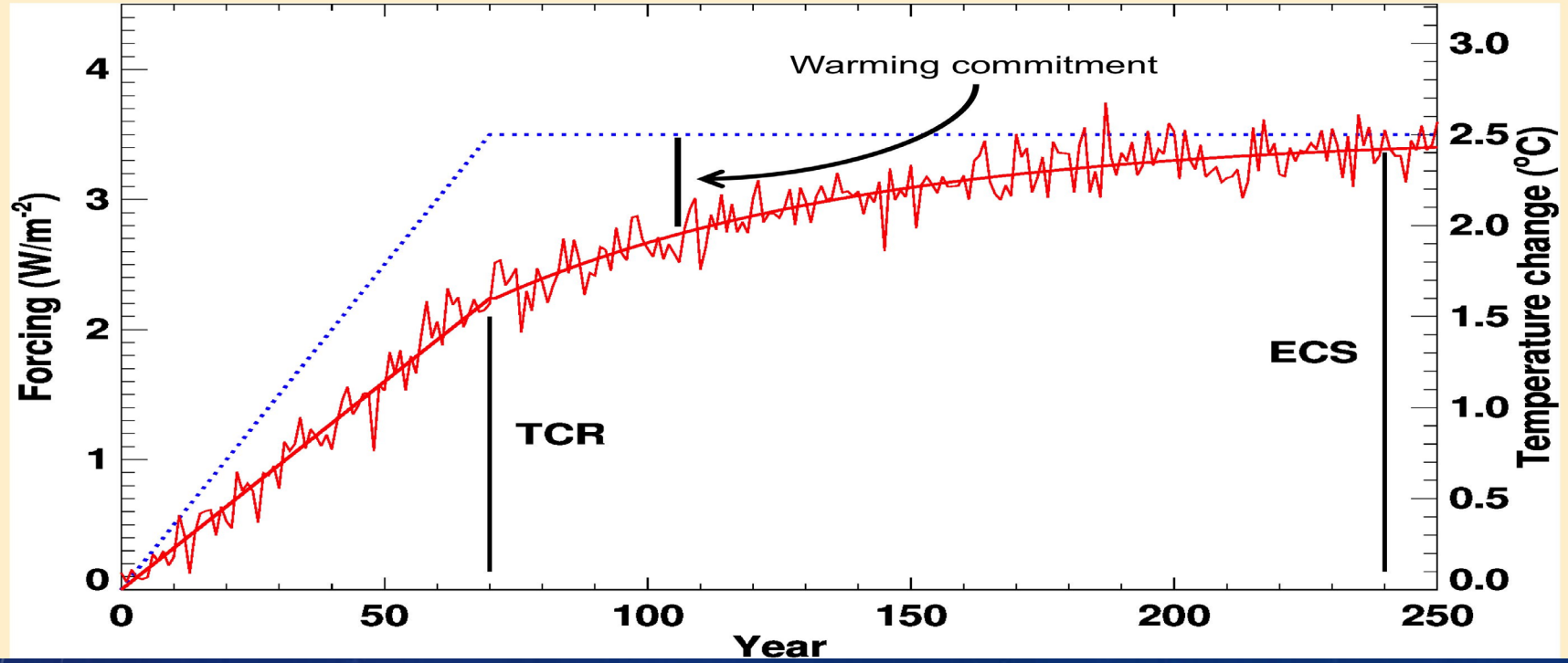
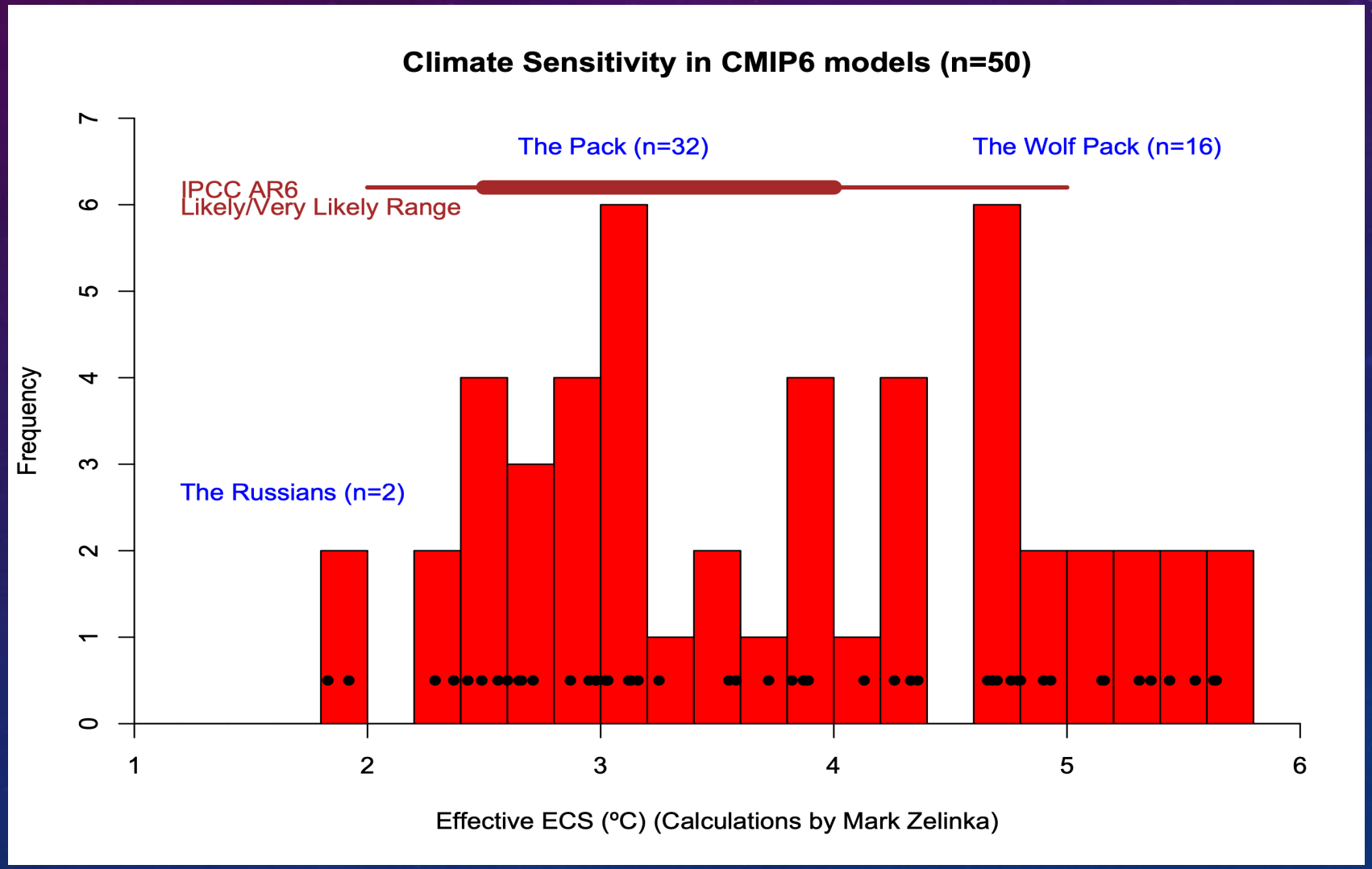
QUICK REMINDER FROM PART 1 ON **EQUILIBRIUM CLIMATE SENSITIVITY**, ARGUING **ECS** COULD WELL BE +4 TO +5C FOR THE PURPOSE OF PREDICTING OUR FUTURE IN ECONOMISTS' "INTEGRATED ASSESSMENT MODELS" (IAMs). EXAMPLE BELOW, ASSUME ECS=2.5C JUST TO ILLUSTRATE ECS CONCEPTS.

Transient Climate Response (TCR)
Equilibrium Climate Sensitivity (ECS)



COUPLED MODEL INTERCOMPARISON PROJECT (CMIP): LARGE SCALE MODELS ARE A KEY PART OF THE IPCC WG1 (THE SCIENCE) DOCUMENT. WHILE ECS STILL OCCUPIES A LARGE RANGE IN CMIP6…



…WE ARGUED HERE THAT 20TH CENTURY **ECS** IS, IN TOO MANY MODELS, AN UNDERESTIMATE. WHY?

- Only the Earth itself includes ALL the proper physics, and paleo data (*e.g.* Friedrich *et al.* 2016, von der Heydt 2016 review) shows ECS during past interglacials was ~+4.9C; High. Yet this was when CO2 was only 280ppm.
- We're at 420 ppm today, and ECS is highly "state-dependent", being **higher in hotter climates** von der Heydt 2016 review**,** as well as there now being additional man-made non-CO2 GHG's today.
- The Earth has ~never warmed at the rate we're doing today, so ECS can change more quickly than usually assumed. It should not be assumed constant, even if computationally convenient to assume so.

FURTHER ARGUMENTS FOR ECS = 4 – 5C FOR OUR FUTURE PROJECTIONS

- **Progressive Loss of Low Clouds.** Low clouds are a coolant to climate. Rate of current loss is not yet well determined, but the physics of how these clouds form and are damaged by high CO2 is understood.
- **Will we see increasing cirrus (high) clouds** from the predicted more frequent and stronger convective storms? (data still sparse)? Cirrus clouds are a climate heater.
- **Accelerating methane and N_2O emissions** (see later slides today).
- **Underestimated powerful cooling from pollution-seeded clouds having higher reflectivity**, meaning ECS needs to be higher in order to compensate and still match observed heating.

AND MORE…

- **We've Underestimated the amount of heat deposited into the ocean (Durack *et al.* 2014)**, now that better ocean data (*e.g.* ARGO floats) is making clear.
- Where did that heat come from?
- Prime suspect is loss of marine low clouds; meaning that we need higher ECS to remain consistent…

…HIGHER ECS THAN WE HAVE BEEN ASSUMING

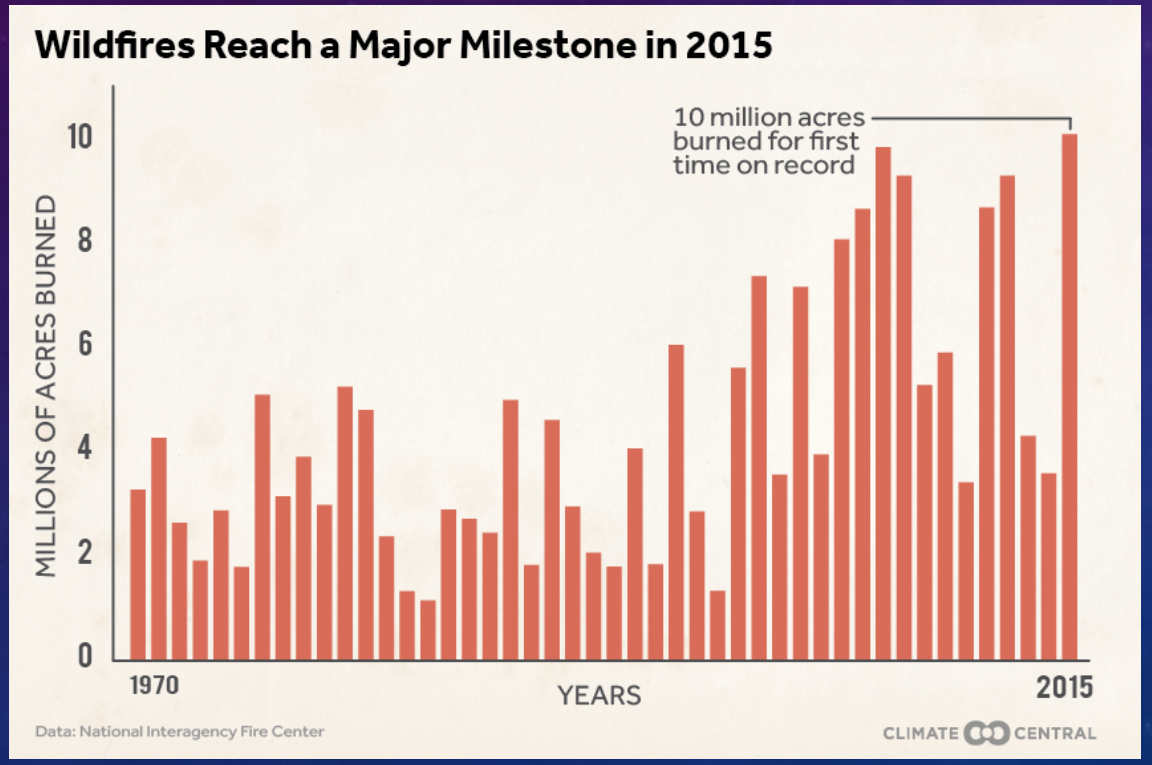
- IPCC policy people pressure scientists, through the 100% consensus rule, for lower ECS in publications. An example is the insistence on the inclusion of an ECS=1.5C (Otto *et al.* 2013) in the official IPCC AR5 report range, over the objections of most of the scientists, who continue to argue this was too low.
- Policy/econ people are using remaining uncertainty and high cost of addressing climate change as their justifications.
- Journal papers and logic in prior slides is increasingly tilting instead towards 4 – 5 C for the relevant ECS for modelling future 21st century and beyond.

REALIZE WHICH ECS IS THE MOST RELEVANT…

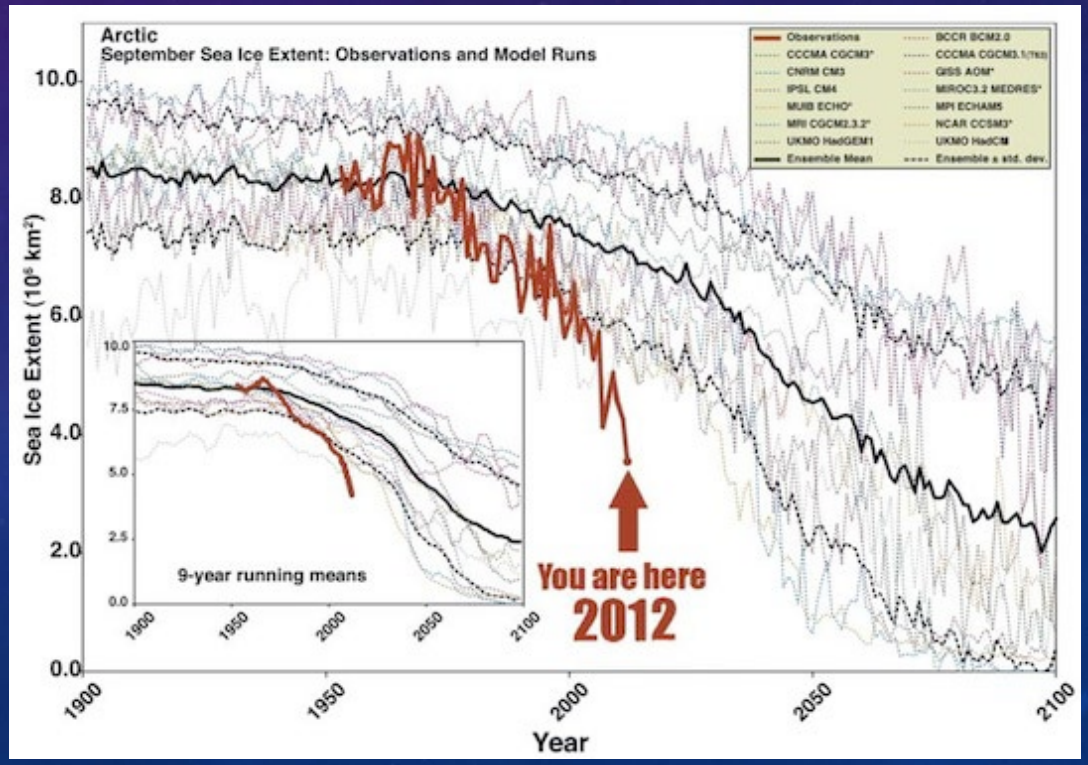
- The term ECS is not used in a uniform way in the literature, unfortunately (Gavin Schmidt 2013).
- There are formal theoretical bases to estimate ECS, and then there are real-world bases. The former tend to be lower than the latter, after it was realized the 20th century had a short term "cosmic variance" realization of sensitivity unusually lower than average due to non-CO2 related natural variations (e.g. ENSO oscillation, volcanics...)
- The ECS that is most relevant is the ECS that applies to our future on the *real* world. The ECS that should be used in **Integrated Assessment Models (IAM's;** used by economists for their simplicity and ease of use): How will temperatures and climate change as CO2 concentrations change, in our actual future world? That is our goal.
- That is the ECS that I, as well as many researchers, are striving for, and communicate.
- Pay particular attention to Paleo data – it is the Earth itself talking to us. Modelling is useful, but climate models are still inadequate to include all the effects happening – and new effects and feedbacks not proportional to CO2 concentrations are still now being discovered and quantified.

EXAMPLE: THE ALBEDO FEEDBACK – HOW REFLECTIVE IS THE EARTH. A SHARP RISE IN THIS FEEDBACK BEGINNING IN ~1998. THIS IS A HEATING SOURCE WHICH IS NOT DIRECTLY CO2, AND THEREFORE AFFECTS THE DETERMINATION OF ECS.

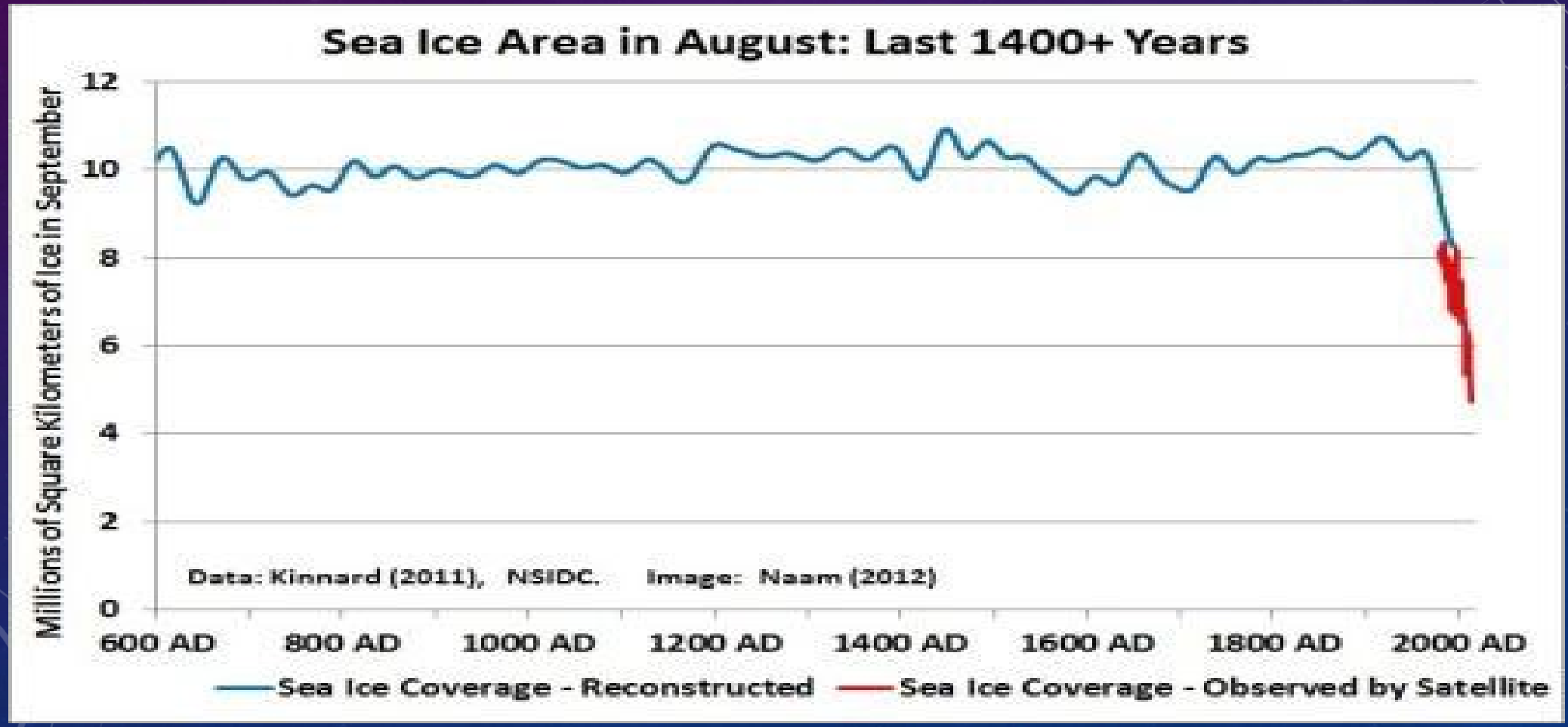
Darkening ice sheets from rapidly rising wildfires across the Tundra and northern forests. Minimal until post-2000



Arctic Ocean ice cover. Early IPCC models assumed it would remain until ~2100. Now we see, perhaps 2030?



SUMMER SEA ICE, WHEN THE SUN IS SHINING AND WE NEED REFLECTIVE ICE THE MOST… DROPPING RAPIDLY NOW. **ECS DETERMINED FROM EVEN RECENT PAST, AND RECENT PAST CENTURIES, WILL BE LOWER THAN TODAY, AND THE FUTURE.**



INDEED, WE'RE ALREADY AT +1.48C ABOVE PRE-INDUSTRIAL IF YOU USE THE BETTER MOTIVATED DETERMINATION OF THE TRUE "PRE-INDUSTRIAL BASELINE" FROM MICHAEL MANN'S TEAM (SCHURER, MANN *et al.* 2017, **THEIR FIGURE S1 BELOW**), RATHER THAN THE CONVENTIONAL 1880-1910 AVERAGE

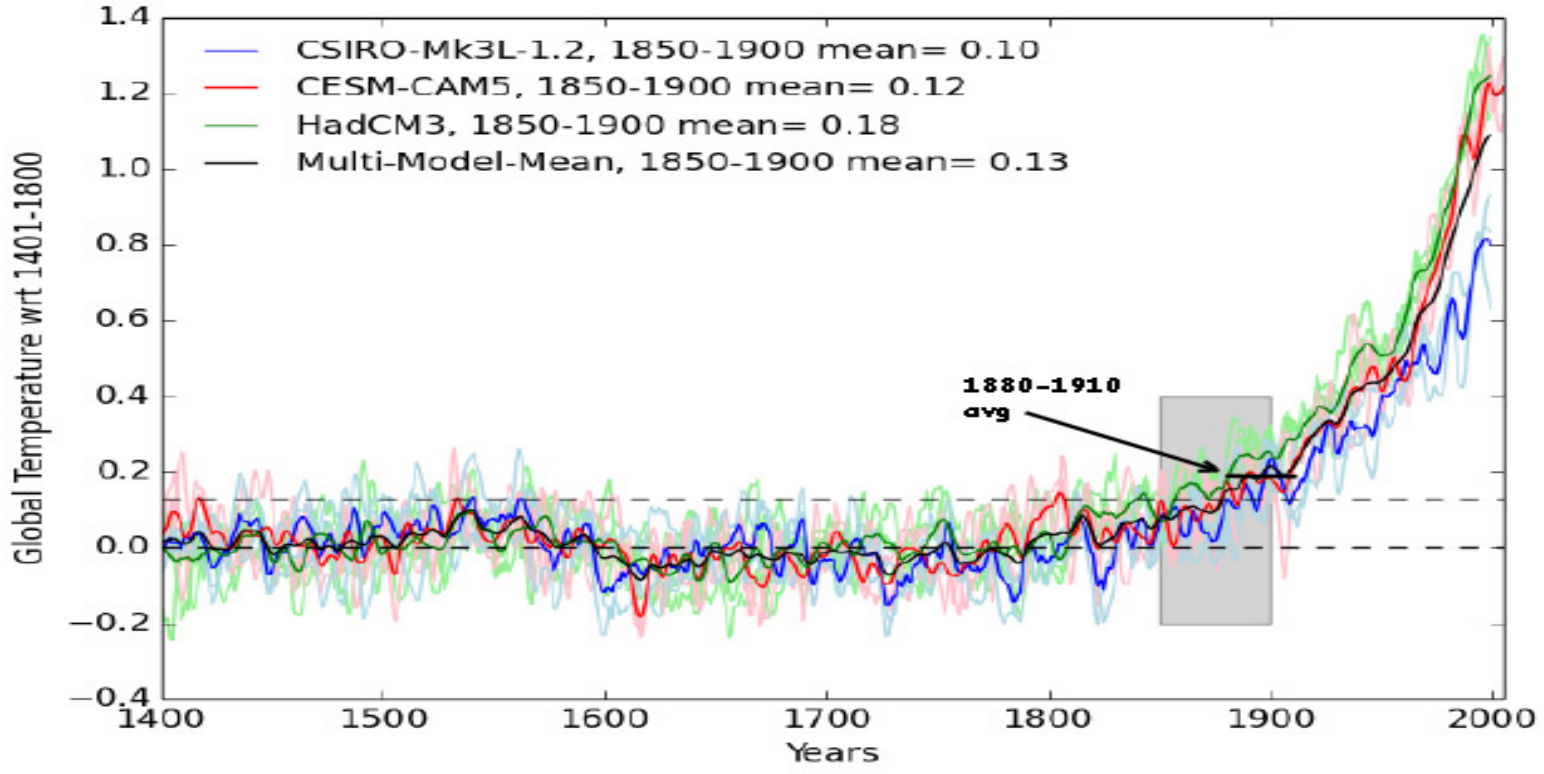


Fig S1- Temperature response to Greenhouse Gas forcing Global mean temperature for three models, smoothed by a 5-year running mean, details given in table S1. Bold coloured lines model means, light coloured lines individual ensemble members. Black line multi-model mean. 1851-1900 highlighted by grey box. Mean for this period shown in legend for the different models and multi-model mean for this period is highlighted by a horizontal dashed line.

IRREVERSIBLE ICE SHEET LOSS

- The Antarctic Ice Sheet is at risk of irreversible loss.
- Garbe *et al.* (2020 in Nature) show that at +2C West Antarctica begins collapse (except, it has already begun), and at +6-9C even East Antarctica collapses
- **And with strong hysteresis: Returning to pre-industrial temperatures will not bring it back.**
- Why? The dark albedo and altitude feedbacks mean a much **colder** Earth is required to re-start re-icing.

Article | Published: 23 September 2020

The hysteresis of the Antarctic Ice Sheet

Julius Garbe, Torsten Albrecht, Anders Levermann, Jonathan F. Donges & Ricarda Winkelmann

Nature **585**, 538–544 (2020) | Cite this article

13k Accesses | **44** Citations | **1852** Altmetric | Metrics

Abstract

More than half of Earth's freshwater resources are held by the Antarctic Ice Sheet, which thus represents by far the largest potential source for global sea-level rise under future warming conditions[1]. Its long-term stability determines the fate of our coastal cities and cultural heritage. Feedbacks between ice, atmosphere, ocean, and the solid Earth give rise to potential nonlinearities in its response to temperature changes. So far, we are lacking a comprehensive stability analysis of the Antarctic Ice Sheet for different amounts of global warming. Here we show that the Antarctic Ice Sheet exhibits a multitude of temperature thresholds beyond which ice loss is irreversible. Consistent with palaeodata[2] we find, using the Parallel Ice Sheet Model[3,4,5], that at global warming levels around 2 degrees Celsius above pre-industrial levels, West Antarctica is committed to long-term partial collapse owing to the marine ice-sheet instability. Between 6 and 9 degrees of warming above pre-industrial levels, the loss of more than 70 per cent of the present-day ice volume is triggered, mainly caused by the surface elevation feedback. At more than 10 degrees of warming above pre-industrial levels, Antarctica is committed to become virtually ice-free. The ice sheet's temperature sensitivity is 1.3 metres of sea-level equivalent per degree of warming up to 2 degrees above pre-industrial levels, almost doubling to 2.4 metres per degree of warming between 2 and 6 degrees and increasing to about 10 metres per degree of warming between 6 and 9 degrees. Each of these thresholds gives rise to hysteresis behaviour: that is, the currently observed ice-sheet configuration is not regained even if temperatures are reversed to present-day levels. In particular, the West Antarctic Ice Sheet does not regrow to its modern extent until temperatures are at least one degree Celsius lower than pre-industrial levels. Our results show that if the Paris Agreement is not met, Antarctica's long-term sea-level contribution will dramatically increase and exceed that of all other sources.

CONFIRMATION: GREENLAND/ANTARCTIC MELT TIPPING POINT IS HERE

- **Pattyn *et al*. (2018)** and discussed **here** finds that the tipping points for both the Antarctic (West Antarctic) and Greenland ice sheets is between +1.5C and +2C.
- These temperatures are unavoidable at this point. There's too much existing climate forcing, forcing levels that are only rising, not falling.
- **Greenland will contribute 25 ft of sea level rise, and West Antarctica 12 ft. East Antarctica melt would raise the total to over 220 ft but requires higher temperatures.**

WEST ANTARCTIC ICE SHEET COLLAPSE: MUCH FASTER THAN OLD CLIMATE MODELS

- **Glaciologists had puzzled over why their climate models failed to hind-cast the strong sea level rise during the Pliocene, at temperatures very similar to today**.
- For one; discovery marine-terminating glaciers cannot support cliffs higher than 300 ft without collapsing, helps resolve this (Alley *et al*.)
- They now (2017) predict the West Antarctic collapse could be triggered over **decades**, not centuries, and predict 6+ ft of global sea level rise (more, in the U.S.) by 2100 on our current path (for the layman, **here**).
- **Nordhaus assumed many centuries for this.**

OCEAN OXYGEN LEVELS DROPPING 2-3X FASTER THAN SIMPLE MODELS PREDICTED; FASTER EVEN THAN SOPHISTICATED BIO-INCLUSIVE MODELS PREDICTED

- *"Depletion of dissolved oxygen in our oceans, which can cause dead zones, is occurring much faster than expected, a new study finds. And by combining oxygen loss with ever-worsening ocean warming and acidification, humans are re-creating the conditions that led to the worst-ever extinction, which **killed over 90 percent of marine life** 252 million years ago." (Scientific American **May 2017**)*
- *"2015 study **found** there is no techno-fix to prevent a catastrophic collapse of ocean life for centuries, if not millennia, if we continue current CO2 emissions trends through 2050. If we don't start slashing carbon pollution, then, as co-author John Schellenhuber put it, '**we will not be able to preserve ocean life as we know it.'**"*
- ***Dead zones lead to hydrogen sulfide production, implicated in several of the Earth's 5 great Mass Extinctions.***

(LEFT) ACCUMULATED INDUSTRIAL-AGE FORCINGS. BUT NON-CO2 FORCINGS ARE GROWING PROPORTIONALLY FASTER (RIGHT). NOTE POWERFUL ANTHROPOGENIC AEROSOL-INDUCED COOLING. ENDING FOSSIL FUEL BURNING MEANS LOSING MUCH OF THIS COOLING.

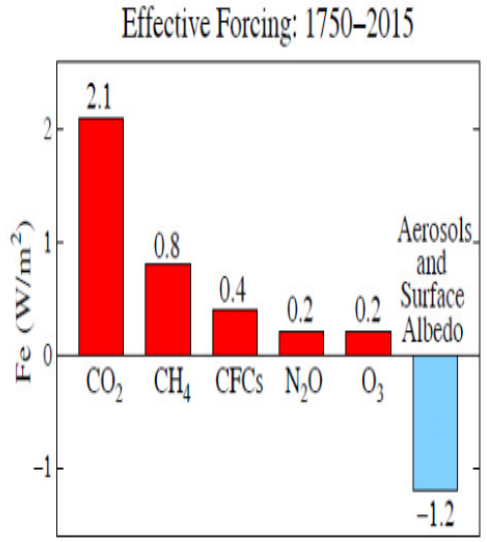
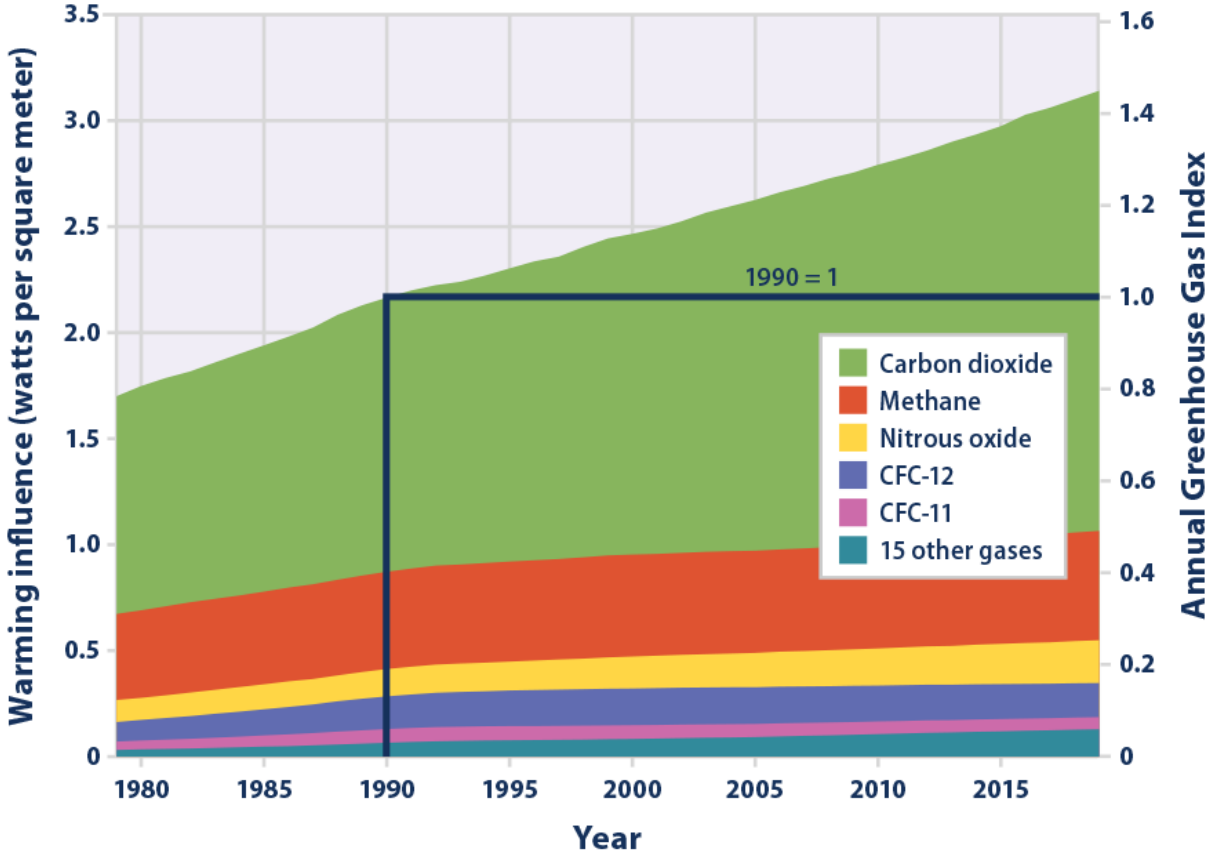


Fig. 4. Estimated effective climate forcings (update of Hansen et al 2005 through 2015). Forcings are based on actual changes of each gas, except CH_4-induced changes of O_3 and stratospheric H_2O are included in the CH_4 forcing. Oscillatory and intermittent natural forcings (solar irradiance and volcanoes) are excluded. CFCs include not only chlorofluorocarbons, but all Montreal Protocol Trace Gases (MPTGs) and Other Trace Gases (OTGs).



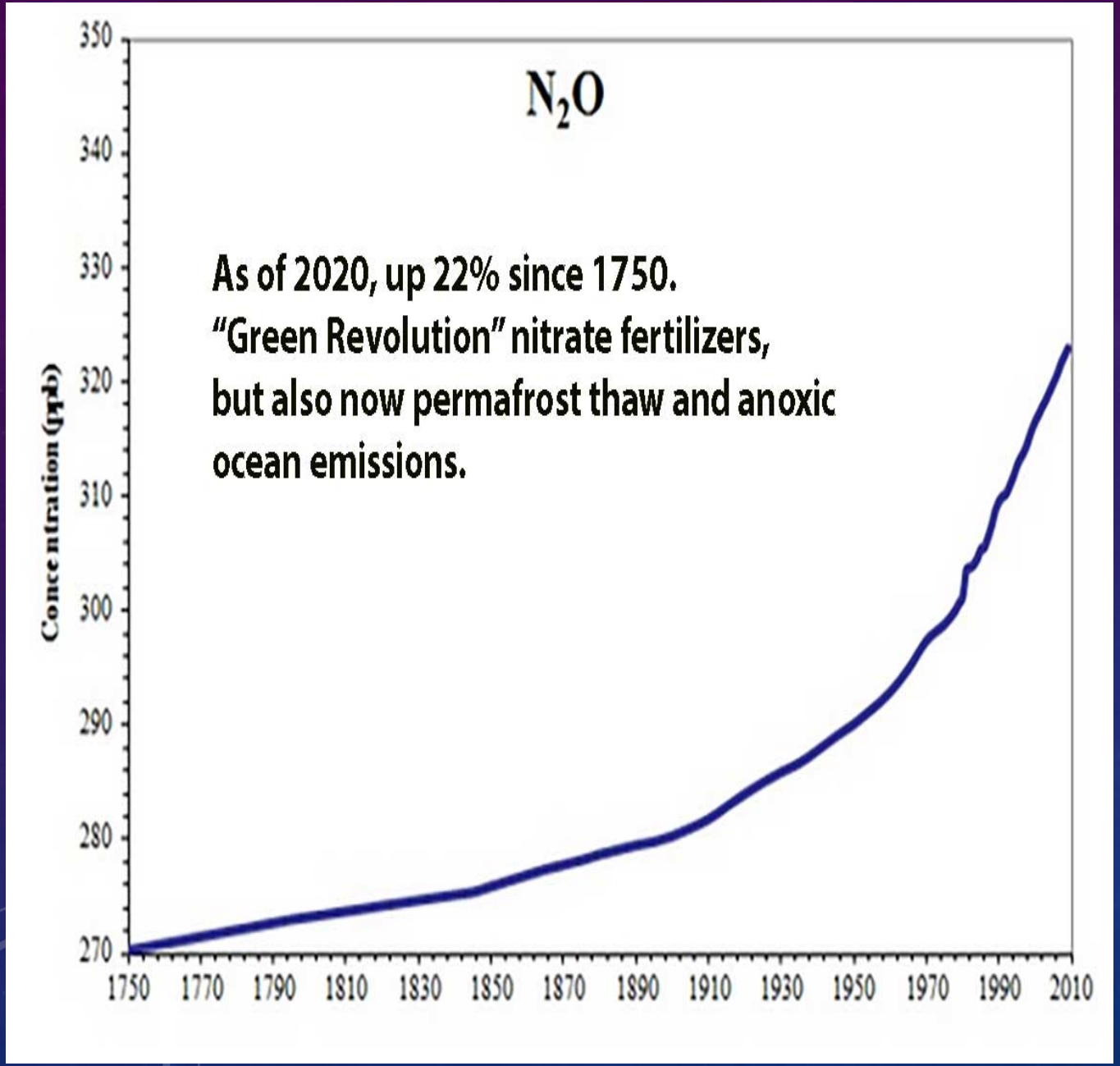
WE STRIVE TO END COAL, FOR OUR HEALTH… ALAS, THE REPORTS OF THE DEATH OF **COAL** ARE GREATLY EXAGGERATED. COAL IS ON THE RISE, POST-COVID. A FAUSTIAN BARGAIN BETWEEN LOWER TEMPERATURES, OR ELSE WORSE HEALTH AND RISING CO2.

CO2 emissions from coal rise to all-time high

Coal accounted for over 40% of the overall growth in global CO_2 emissions in 2021. Coal emissions now stand at an all-time high of 15.3 Gt, surpassing their previous peak (seen in 2014) by almost 200 Mt. CO_2 emissions from natural gas also rebounded well above 2019 levels to 7.5 Gt, as demand increased in all sectors. At 10.7 Gt, emissions from oil remained significantly below pre-pandemic levels because of the limited recovery in global transport activity in 2021.

N_2O EMISSIONS: UNDERESTIMATED BY IPCC…

- **Thompson *et al.* 2019** find N_2O emissions are nearly double that assumed by the IPCC,
- And permafrost emissions are up 200-500% higher than thought, based on earlier much more limited sampling (**Wilkerson *et al.* 2019**).



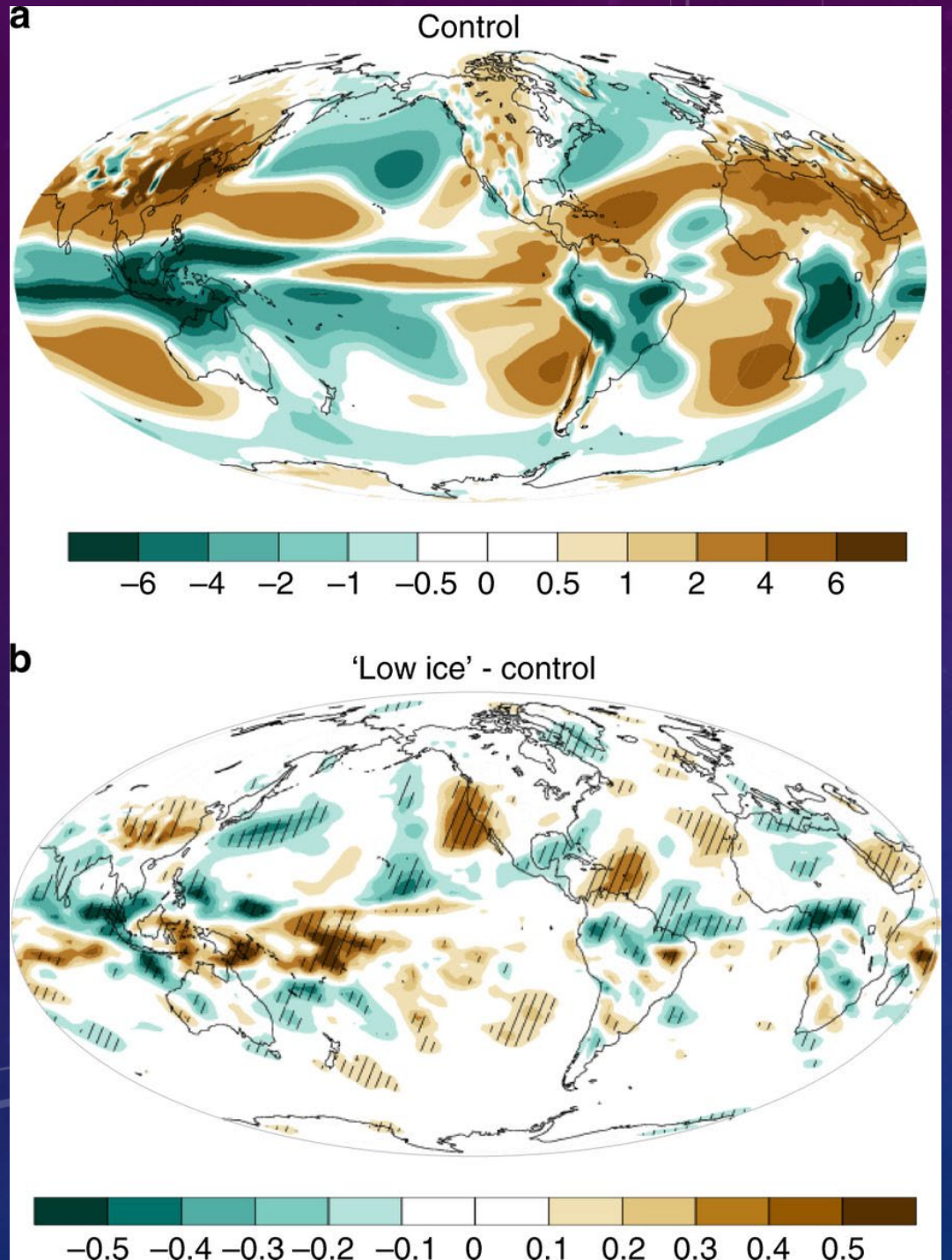
N_2O IS THE 3RD MOST POWERFUL GREENHOUSE GAS, AFTER CO_2 AND METHANE.

ANTHROPOGENIC, CAUSED BY BOTH DIRECT (AGRICULTURE) AND INDIRECT (ANOXIC OCEANS, WARMING PERMAFROST) PROCESSES.

IT'S NOW THE MOST POWERFUL OZONE DESTROYER AS WELL.

OCEANS EMISSIONS TOO: GROWING ANOXIC OCEANS ACCELERATE N_2O EMISSIONS, **FAR HIGHER THAN IPCC ESTIMATED** (BABBIN *et al.* 2015)

- *"Babbin's measurements demonstrate that production of N_2O in just these three small regions* ***could equal the total worldwide marine production*** *that had been estimated in climate models, including the most recent International Panel on Climate Change report (AR5): some 4 million metric tons of N_2O per year." (article source).*
- (from abstract): *"Because of incomplete denitrification, N_2O cycling rates are* ***an order of magnitude higher than predicted by current models*** *in suboxic regions, and the spatial distribution suggests strong dependence on both organic carbon and dissolved oxygen concentrations. Furthermore, N_2O turnover is 20 times higher than the net atmospheric efflux.* ***The rapid rate of this cycling coupled to an expected expansion of suboxic ocean waters implies future increases in N_2O emissions."***



PRECIPITATION: THE LOSS OF THE ARCTIC OCEAN ICE CAP WORSENS GLOBAL PRECIPITATION WHERE PEOPLE LIVE (MID LATITUDES).

TOP; ASSUMED GLOBAL WARMING BUT NO ARCTIC OCEAN (AO) THAW.
BOTTOM: SAME BUT INCLUDES AO THAW.

STRONGER DROUGHT IS IN BROWN. **THE WORST-HIT CONTINENTAL LAND IS CALIFORNIA** (BOTTOM)

RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES | FREE ACCESS

Resilience and reactivity of global food security

Samir Suweis, Joel A. Carr, Amos Maritan, +1, and Paolo D'Odorico Authors Info & Affiliations

May 11, 2015 | 112(22)6902-6907 | https://doi.org/10.1073/pnas.1507366112

THIS ARTICLE HAS A CORRECTION +

243 123

Significance

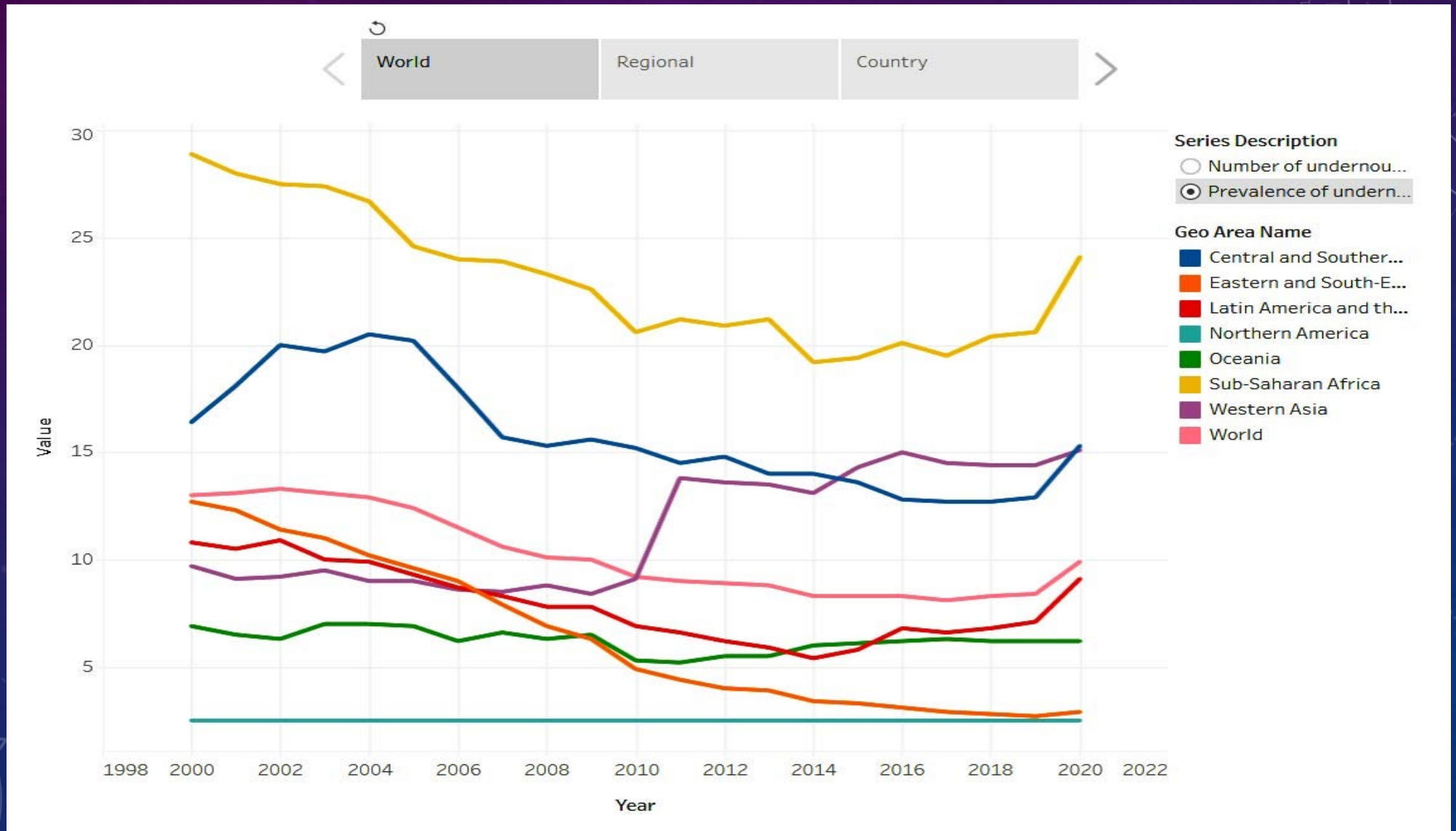
The past few decades have seen an intensification of international food trade and the increase in the number of countries that depend on food imports. As an effect of the associated globalization of food, local shocks in food production, combined with the adoption of new national or regional energy and trade policies, have recently led to global food crises. Here we develop a framework to investigate the coupled global food–population dynamics, and evaluate the effect of international trade on global food security. We find that, as the dependency on trade increases, the global food system is losing resilience and is becoming increasingly unstable and susceptible to conditions of crisis.

THE RISING COMPLEXITY OF NON-LINEAR DYNAMICAL SYSTEMS: NOT MODELLED BY NEOCLASSICAL ECONOMISTS.

PURSUING THE LAST FEW CENTS OF PROFIT MARGIN WITH ENERGY-INTENSIVE GLOBAL TRADE IN A DE-GLOBALIZING WORLD – **RESULTS IN INCREASING INSTABILITY.**

2015 STUDY **PREDICTS FALLING FOOD RESILIENCE**. INDEED – COMING TRUE IN 2022…

THE AGRICULTURAL "GREEN REVOLUTION": UNSTABLE AND FAILING. BEGINNING IN 2015 – SHARPLY RISING RATES OF GLOBAL PREVALENCE OF UNDERNOURISHED PEOPLE



AGRICULTURE IN CALIFORNIA – WILL BE IN STEEP DECLINE: **POLEWARD MIGRATION OF THE DESERTS**

- Physics Nobel Steven Chu in 2009: "We're looking at a scenario where there is no more agriculture in California". Snowpack in the Sierras could drop by 90%, ground water disappearing, saline intrusion into one of the richest agricultural lands in the world.
- Why? The expanding Hadley Cell of the tropics combined with the shrinking weakening polar cell, is shifting the desert band northward at 3x of the rate of our past climate models. Drought is our future.

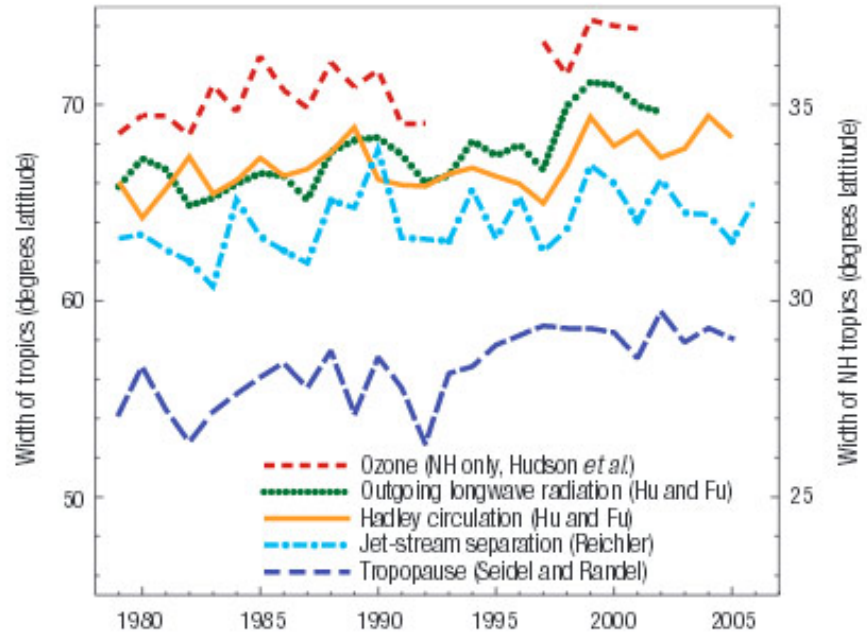
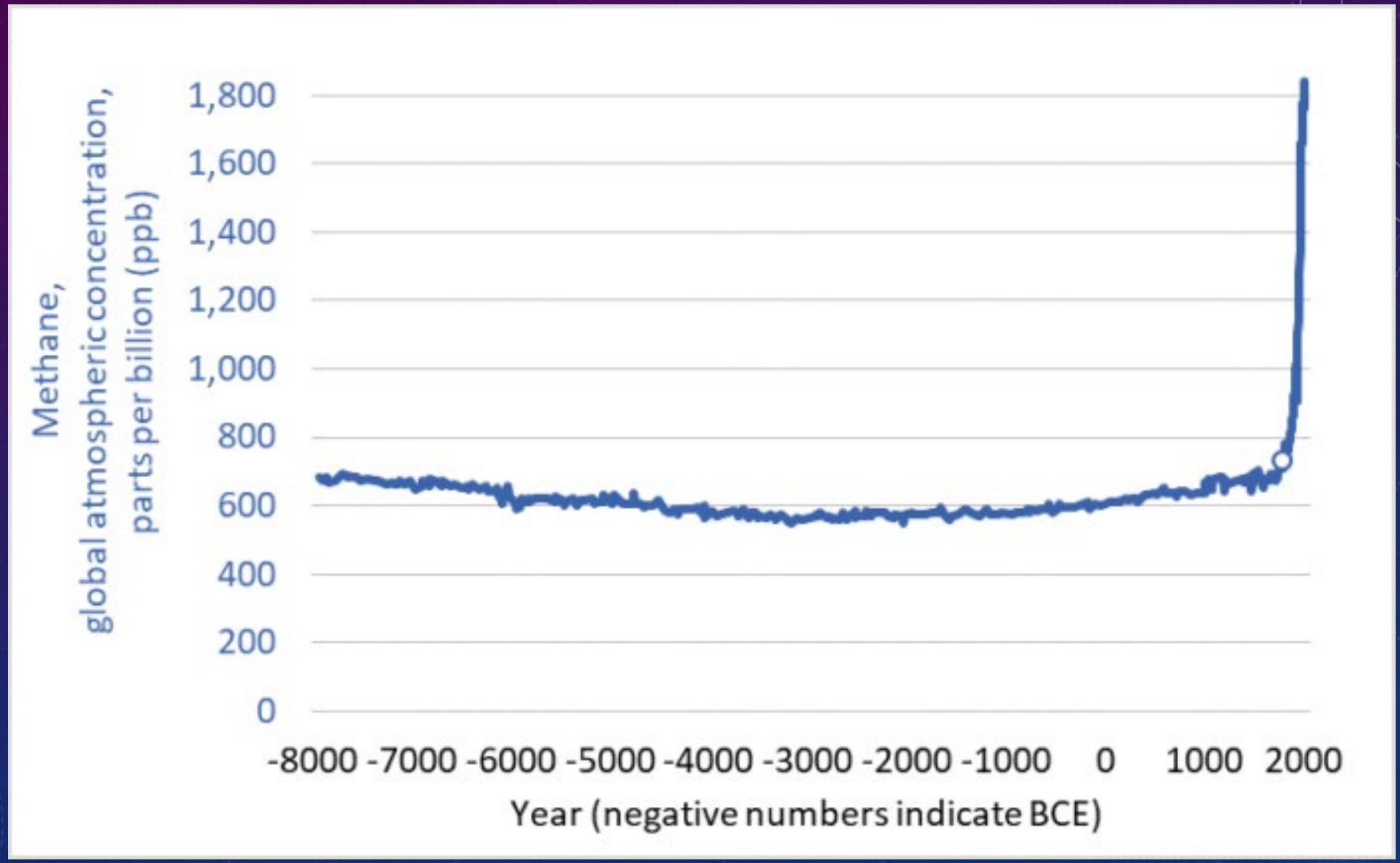
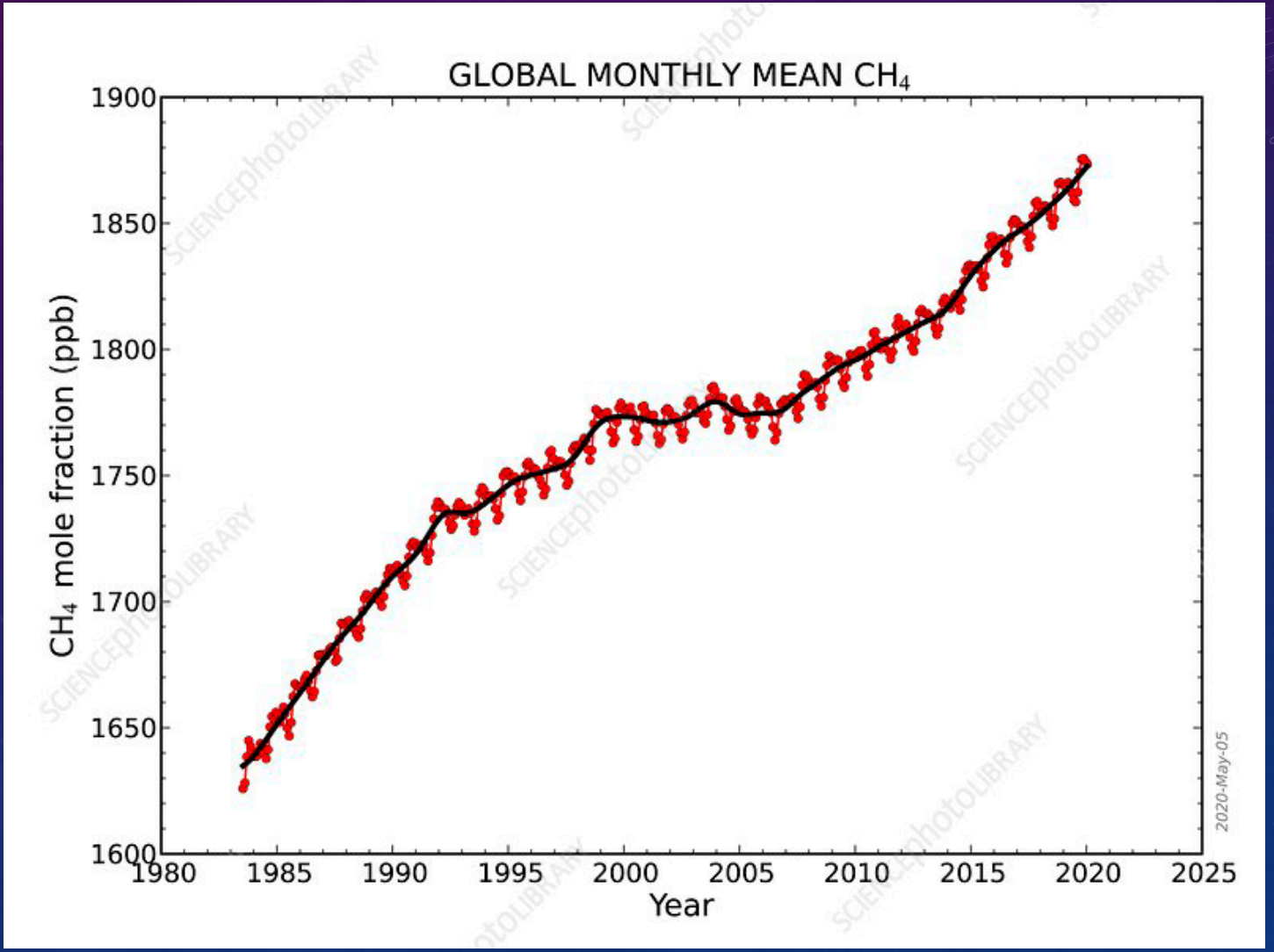


Figure 2 Changes in several estimates of the width of the tropical belt since 1979. These include: the width of the Hadley circulation, based on both outgoing longwave radiation and horizontal winds stream function[10]; the separation of the Northern and Southern Hemisphere subtropical jet-stream cores; the width of the region of frequent high tropopause levels[8]; and the width of the region with tropical column ozone levels (Northern Hemisphere only, right axis, ref. 6). Although each shows an increase since 1979, the rates vary from 2.0 to 4.8 degrees latitude per 25 years, with an even larger range when considering the entire spread of trend estimates in each individual study.

ATMOSPHERIC METHANE DURING THE HOLOCENE, AND INTO THE ANTHROPOCENE



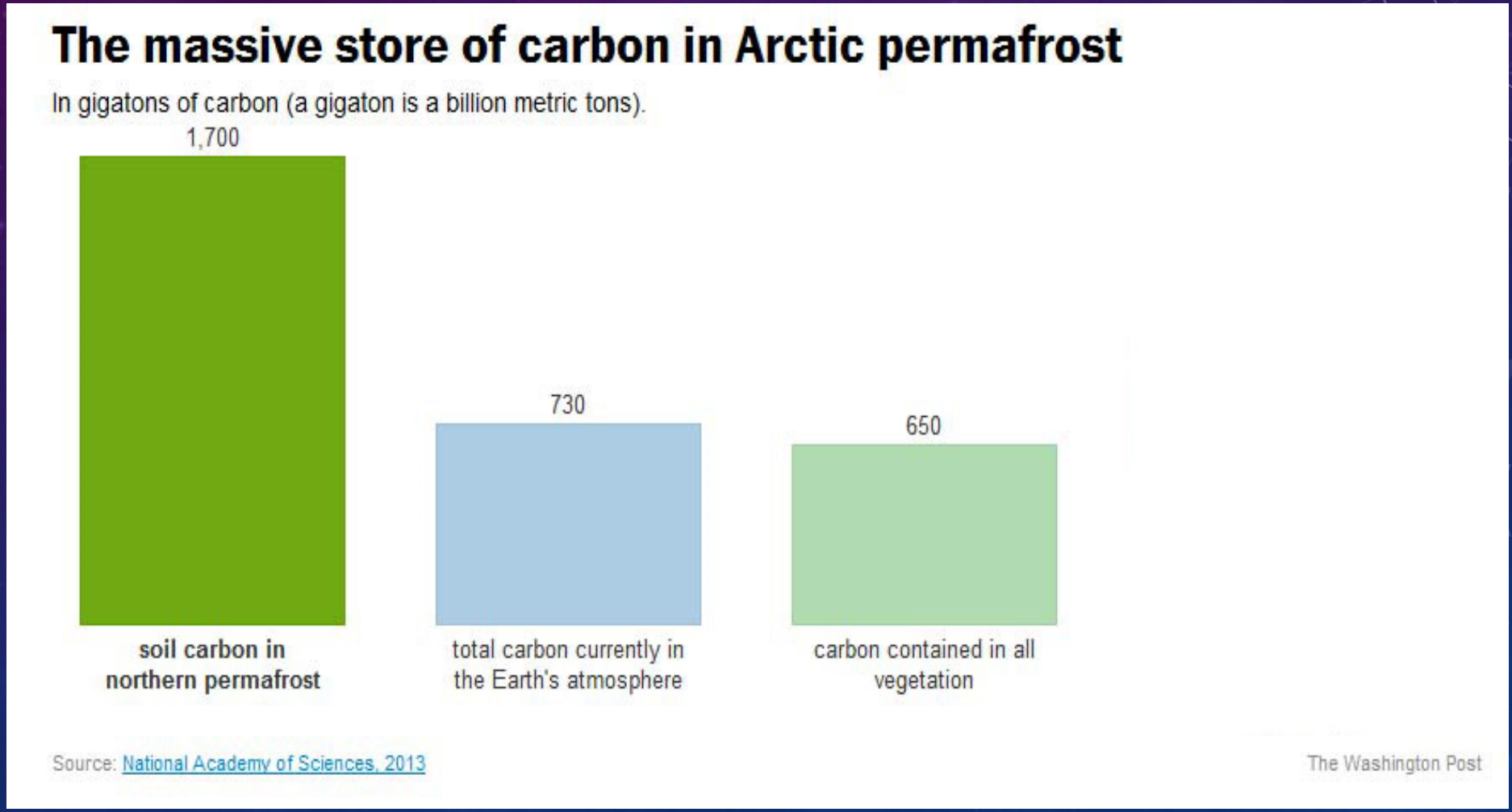
METHANE LEVELS UP 16% IN JUST THE LAST 40 YEARS, AND RE-ACCELERATING DURING THE PAST 15 YEARS. THIS, DESPITE ITS SHORT ~10 YEAR HALF LIFE DUE TO OH- REACTIONS (AND TOO, WE WORRY OH- WILL BE CONSUMED BY RISING METHANE FASTER THAN IT CAN REGENERATE. SIMPLE INTEGRATED ASSESSMENT MODELS IGNORE THIS.



CARBON RELEASE FROM THE PERMAFROST AND THE PERMAFROST CARBON FEEDBACK (PCF).

- Ignored by Nordhaus.
- And, while some climate models are including the PCF in recent years, NONE of these models were selected by the UN controllers for inclusion in any IPCC Assessment Reports (!).
- All IPCC models required inclusion of a specified rising GDP per capita, and ignore any real world growth-induced climate damages (!)

JUST THE TOP 3M OF THE NORTHERN HEMISPHERE PERMAFROST HAS MORE THAN DOUBLE THE CARBON CONTENT OF THE ENTIRE ATMOSPHERE. RELEASING JUST 0.6% PER YEAR OF THIS CARBON, EQUALS ALL DIRECT HUMAN CARBON EMISSIONS. REMEMBER THIS, FOR PART 3 TO COME AND LATEST RESEARCH…



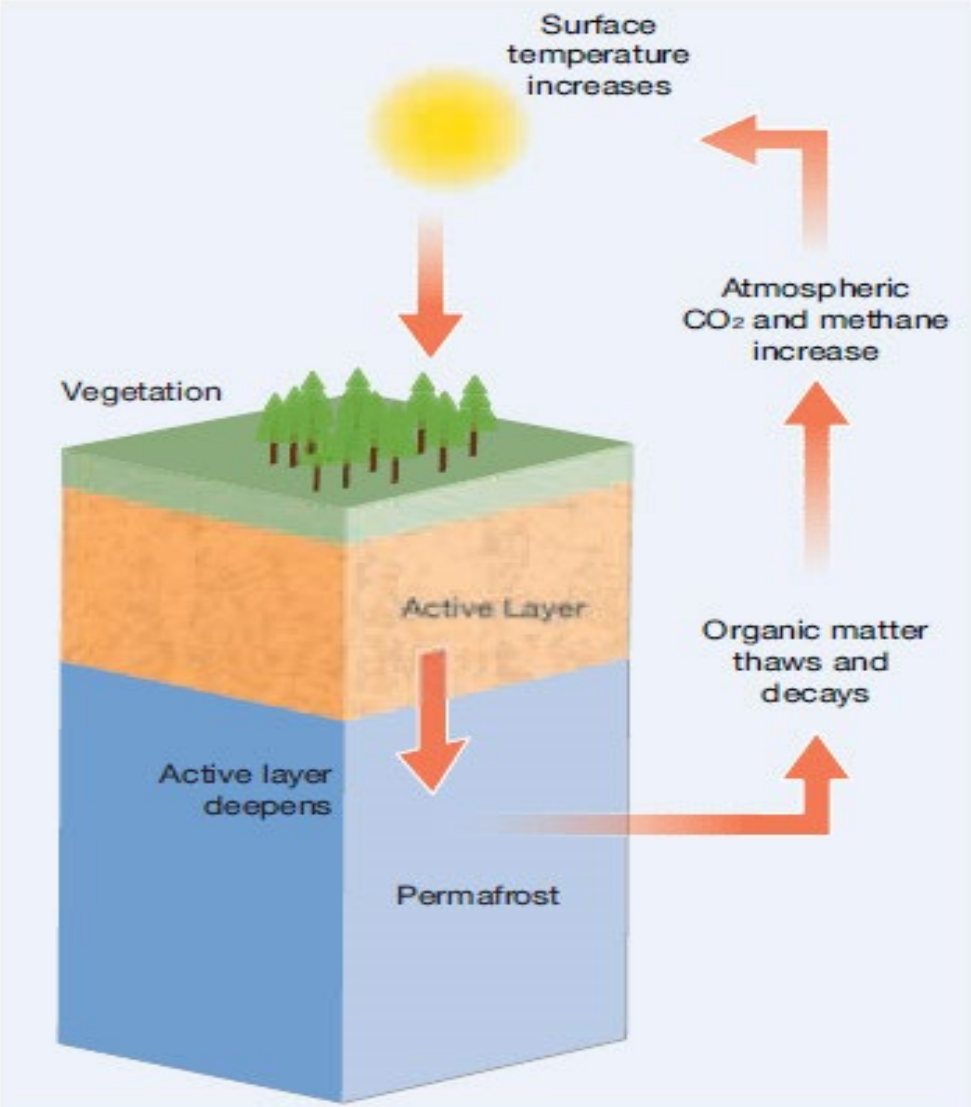
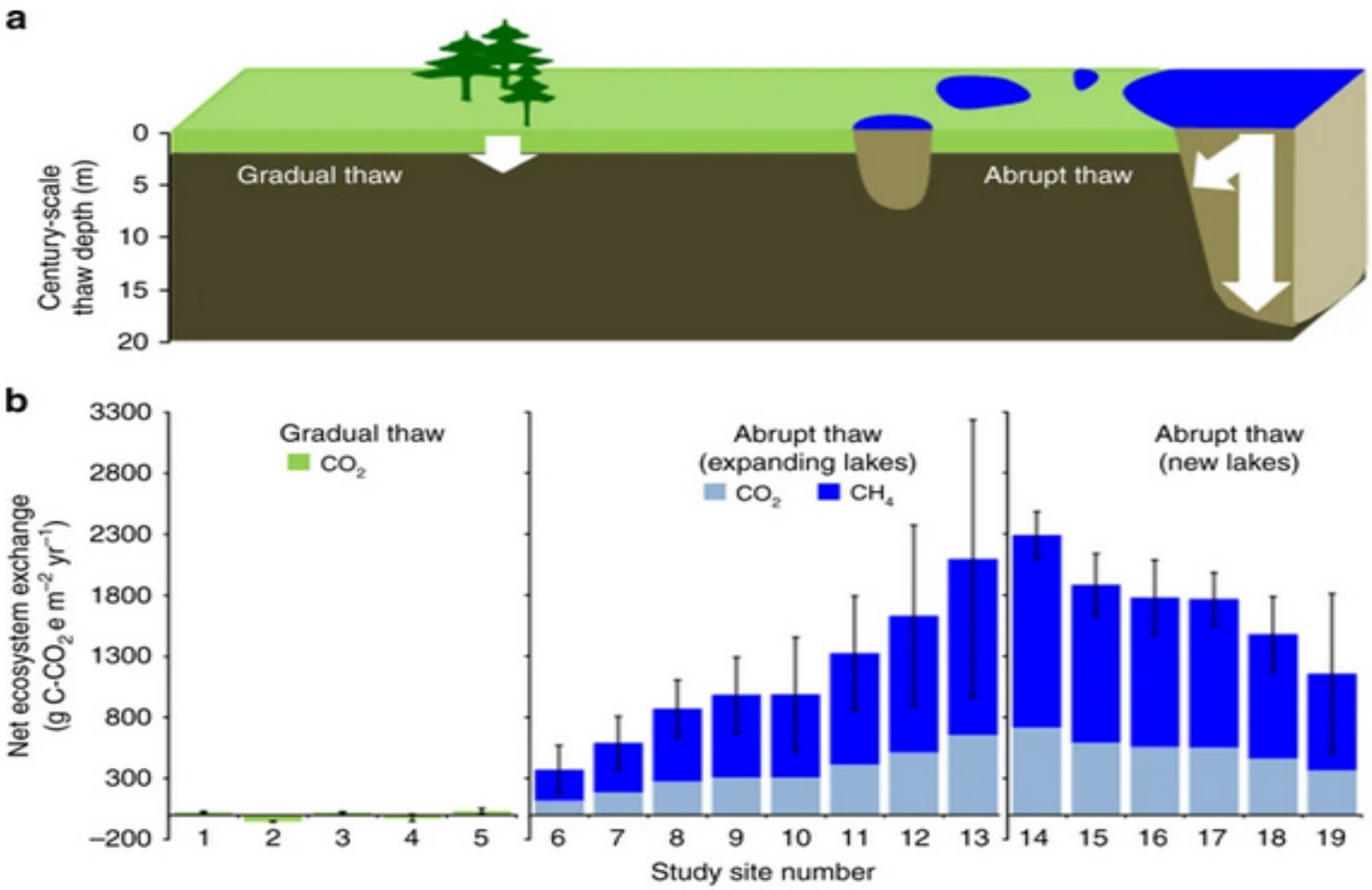


Figure 21: The permafrost carbon feedback is an amplification of surface warming due to the thaw of organic material currently frozen in permafrost, which will then decay and release CO_2 and methane into the atmosphere.

THE PERMAFROST CARBON FEEDBACK IS IRREVERSIBLE ON HUMAN TIME SCALES

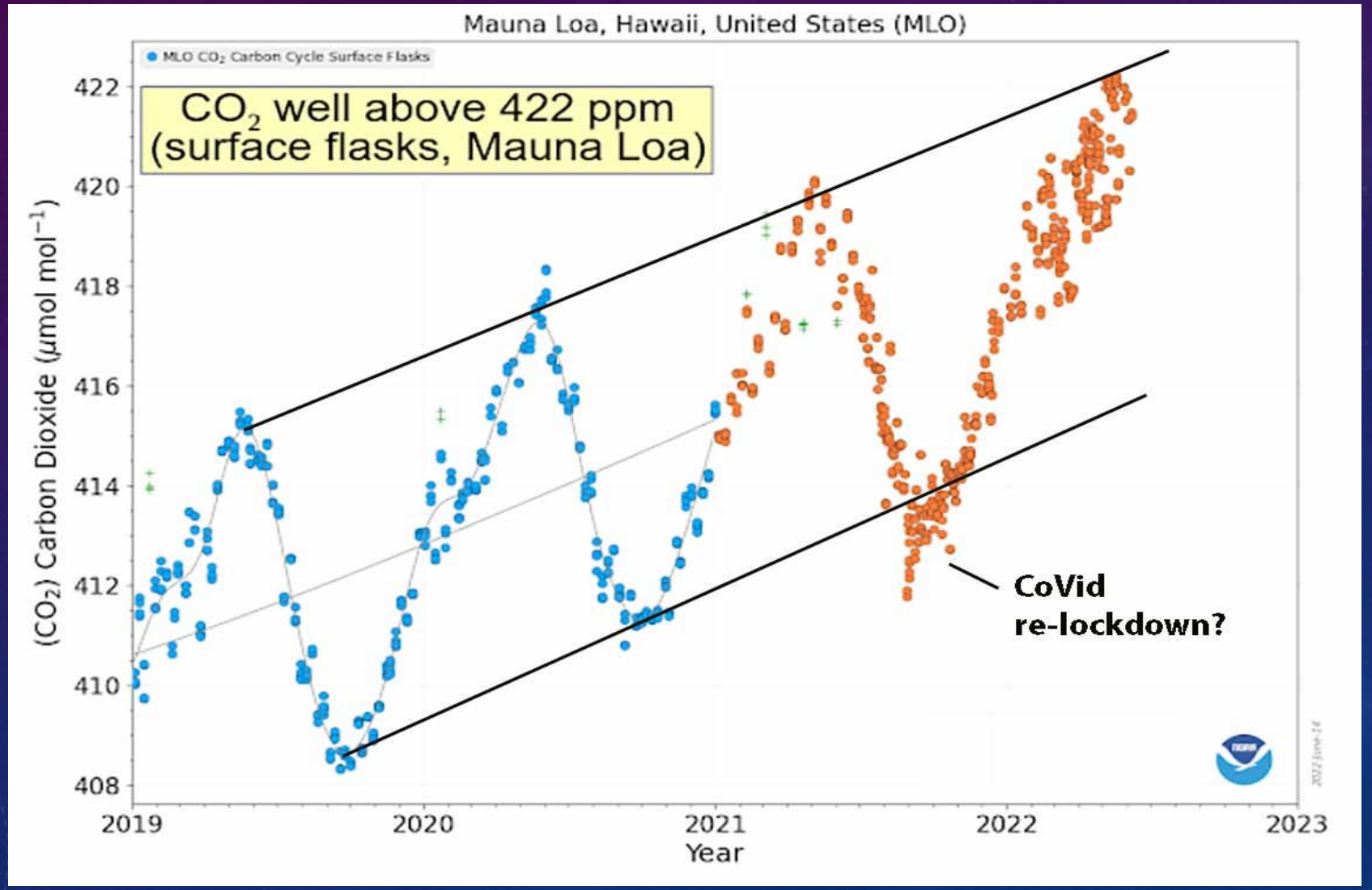
- With less near-surface permafrost, the burial mechanism described above slows down or stops, so there is no way to convert the atmospheric CO2 into organic matter and freeze it back into the permafrost.
- **The effect of permafrost carbon feedback on climate has not been included in the IPCC Assessment 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 also do not include the permafrost carbon feedback. **Consequently, the IPCC Fifth Assessment Report also does not include the potential effects of the permafrost loss. While some estimates are in the new AR6, the modelling studies selected did not include the PCF.**



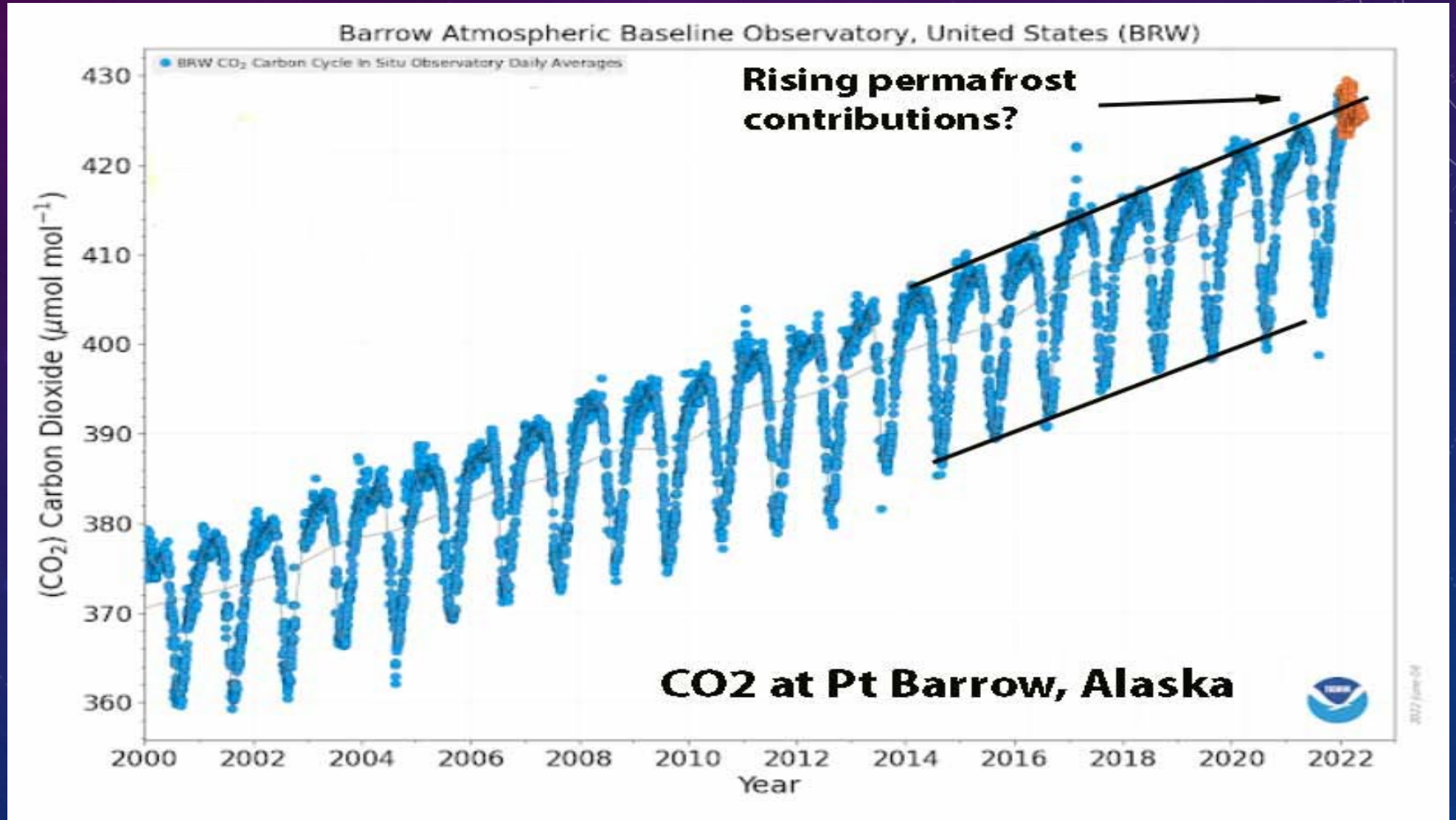
Conduction is very slow, resulting in very gradual thaw and very low rates of CO2e emission (green). By contrast, the thaw of ice on ground results in "thermokarst" lakes, which drives taliks, fluid heat transport, and "abrupt" (their words) CO2e release. Because the organic carbon is isolated from oxygen by being underwater, it instead emerges mostly - in climate forcing terms - as methane (dark blue).

EVEN FORECAST STUDIES WHICH DO INCLUDE PERMAFROST THAW (THE IPCC AR5 AND AR6 DID NOT) HAVE SIGNIFICANTLY UNDERESTIMATED EMISSION RATES. WALTER-ANTHONY *et al.* 2019 FIND DRAMATICALLY HIGHER CO2e EMISSION RATES (LOWER GRAPH) WHEN THERMOKARST LAKES AND THEIR METHANE ARE INCLUDED.

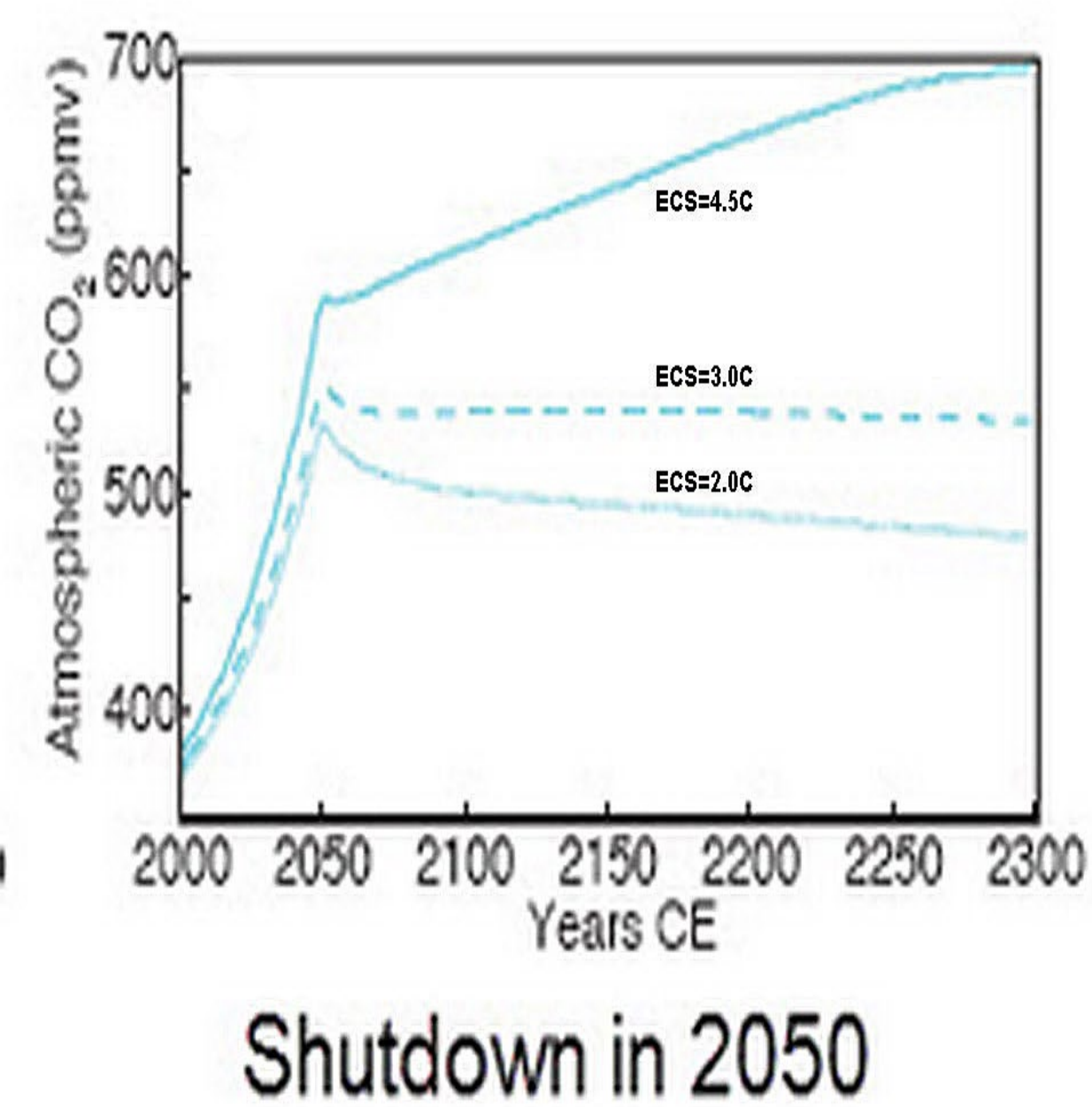
CO2 AT MAUNA LOA, EVIDENCE OF COVID ECONOMIC SLOWDOWN IN CO2? BUT MAY ‘22 SEASONAL PEAK MORE THAN MADE UP FOR TEMPORARY DROP. 422 PPM PEAK.



BUT AT BARROW ALASKA IN THE PERMAFROST, CO2 LEVELS ARE HIGHER. AND, HINT OF AN EXCESS PEAK IN ‘21 – ’22 NOT PRESENT IN LOWER LATITUDES. RISING **PERMAFROST THAW ADDING A HIGHER FRACTION?**



THERMOKARST THAW PONDS – ISOLATE THAWED CARBON FROM ATMOSPHERIC OXYGEN, THUS ENCOURAGING METHANE EMITTING MICROBES. METHANE PRODUCTION STRONGER THAN FIRST THOUGHT (WALTER-ANTHONY *et al.* 2019)

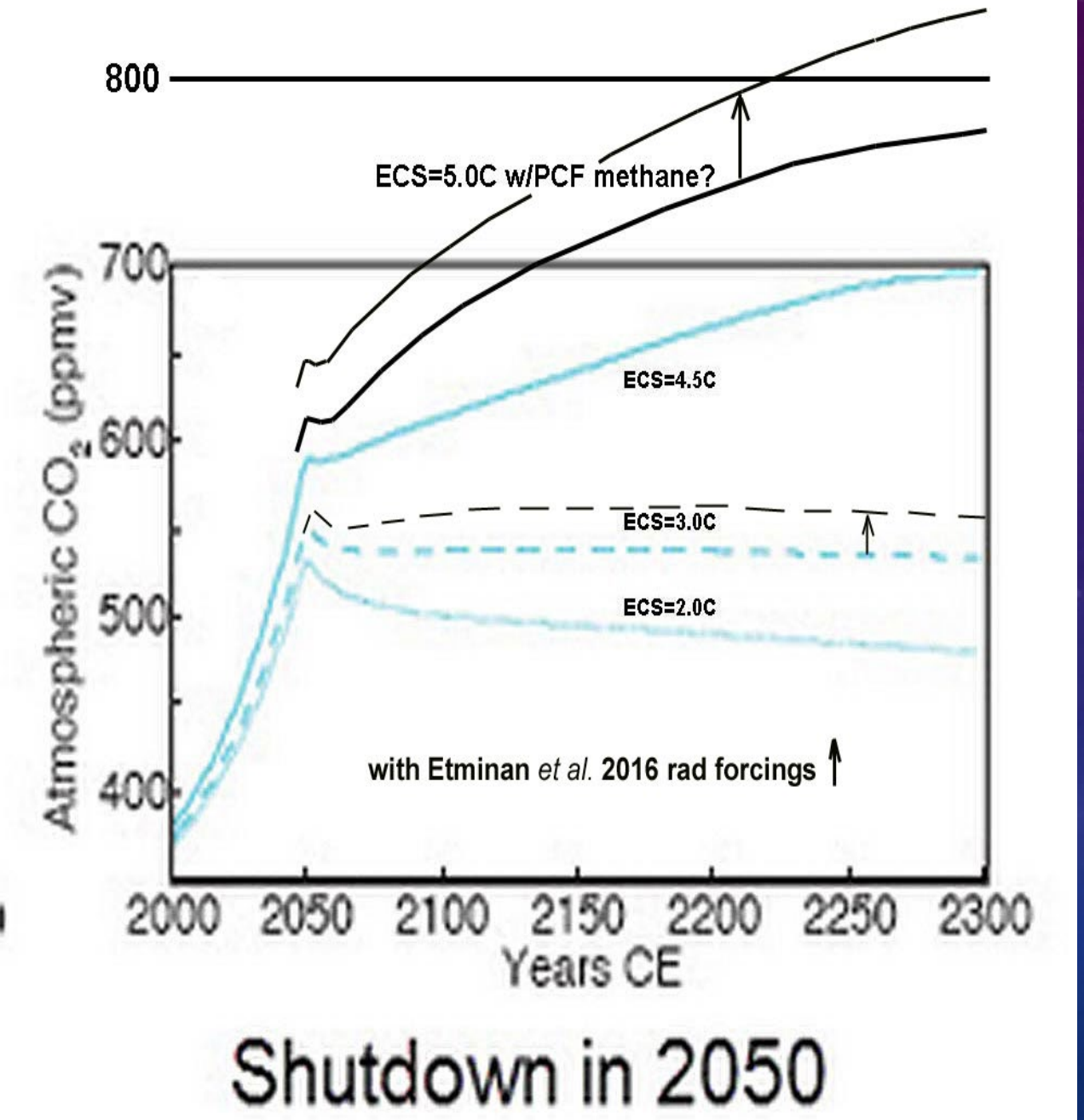


MACDOUGALL (2012) MODELLED ATMOSPHERIC CO2 CONCENTRATION AND INCLUDED PERMAFROST THAW CARBON, USING THE UNIV. VICTORIA CLIMATE MODEL WITH THE LABELLED ASSUMED ECS VALUES.

ASSUMED "BUSINESS AS USUAL" TILL 2050 THEN INSTANT COMPLETE END OF ALL FOSSIL FUEL BURNING.

THE U. VIC. EARTH SYSTEM MODEL HAS NO METHANE MODULE, ONLY CO2. METHANE MUST BE ADDED "BY HAND" HERE…

NOTE THAT CO2 CONTINUES TO RISE EVEN WITHOUT HUMAN CO2 BURNING, IF ECS IS GREATER THAN 3.1C



Shutdown in 2050

HOW MUCH ADDITIONAL GLOBAL WARMING POTENTIAL (GWP) DOES PERMAFROST METHANE PRODUCE? LOWER BLACK CURVE IS MY ESTIMATED CO2e = METHANE+CO2 USING PRE-2016 GHG FORCINGS (SEE NEXT SLIDE).

UPPER BLACK CURVE ADDS ~23% FROM ETMINAN *et al.* 2016 , FINDING GWP FORCING FOR CO_2, CH_4, N_2O ~23% HIGHER THAN IPCC ASSUMED.

Atmospheric CO2e IS NOW DRIVEN TO 840 PPM AND BEYOND, BY 2300.

CORRESPONDING ECS=5C INFERRED TEMPERATURES WOULD RISE BY ROUGHLY 5C X ((840-280)/280ppm= +10C

ALL, WITHOUT ANY HUMAN FOSSIL FUEL USE AFTER 2050. COULD IT BE THIS BAD? PERMAFROST DATA AND MODELLING STILL HAS SIGNIFICANT UNCERTAINTIES.

TO SUMMARIZE MY ESTIMATION TECHNIQUE FOR THE BLACK CURVES (PREVIOUS SLIDE) (IT'S HERE FOR COMPLETENESS)

- The blue curves are MacDougall *et al. 2012,* while the black curves are mine.
- I looked at the **difference** between the Solomon *et al.* 2009 post shut-down curve for 550 ppm and the MacDougall curve for 550 ppm shutdown in 2050. I took the difference as being the PCF additional atmospheric CO2e contribution over time, after 2050.
- I increased the soil conductivity by 1/0.6 given the revised thinner active layer (Macdougall and Knutti 2016).
- Then I took the resulting **difference** and multiplied it by 1.84 to account for the CO2e of MacDougall's neglected methane, which implies comprises 45% of permafrost climate forcing initially but decaying over time. But SGWP for methane is 60% of initial over 70 year horizon.
- Since 1.84 x 0.6 =~1, then the delta from Solomon *et al. 2009* to MacDougall is roughly correct, although my black curves should nominally be a perhaps higher near term and lower far term.
- I did this for ECS=3C which is what both Solomon and MacDougall assumed. Then I scaled up this difference for MacDougall's ECS=4.5C and for ECS=5C to match the proportionally higher curves for these ECS's in MacDougall *et al.*
- *Still, this is only a very back-of-the-envelope estimate. Needs a proper climate model and better data.*

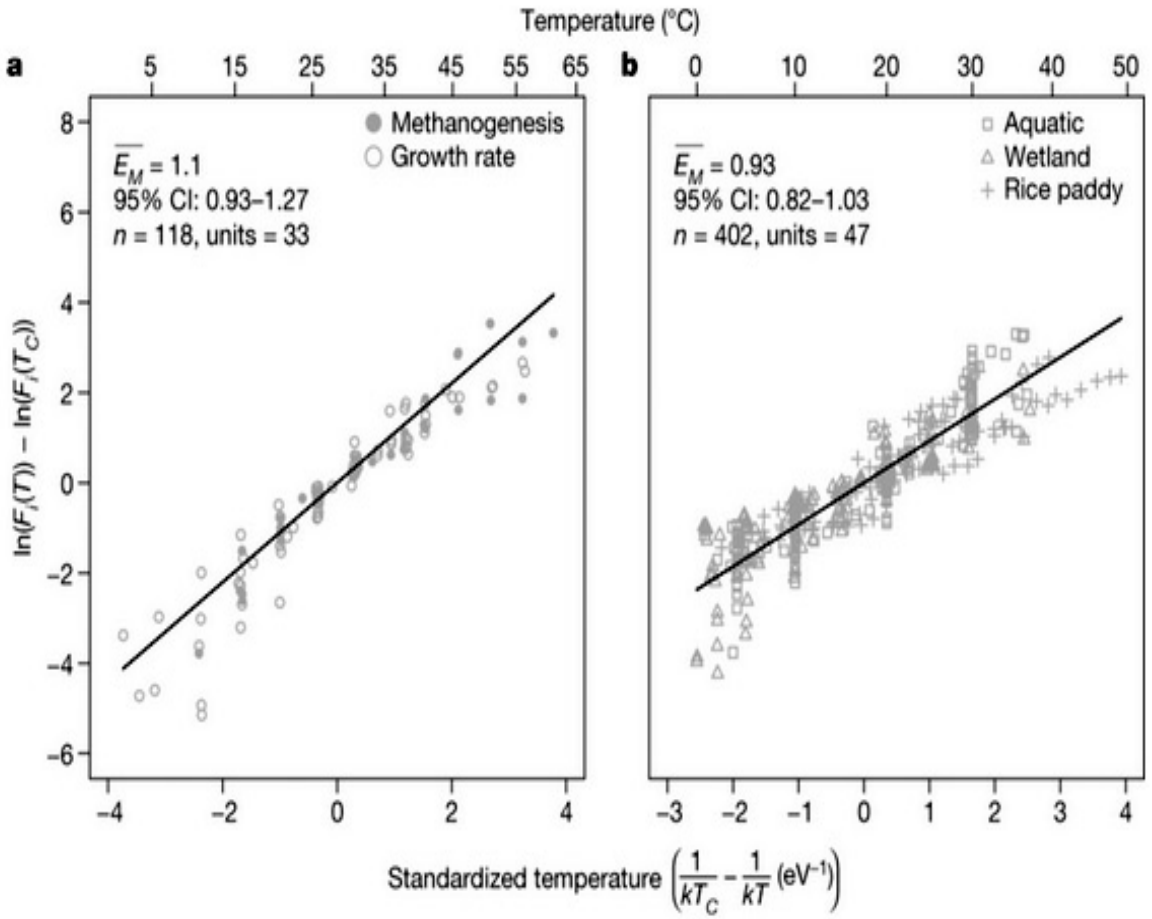
NEW CAVEATS TO MACDOUGALL'S WORK AND THE ESTIMATED EXTRAPOLATIONS…

- Katy Walter-Anthony's work also finds that the methane emissions, while worse than previously thought, max out sooner (a century or two), and thermokarst lakes then should clear, admit sunlight, and become carbon sinks as photosynthesis rises and methane producers decline.
- **Suggests these curves would likely peak higher and sooner, within a century or so and then decline, rather than the gradual rise shown.**
- This is a very active area of research and numbers are uncertain as the physics and the Arctic landscape are both complex. We hope these curves are, for once, too pessimistic.

ALAS, KATY WALTER-ANTHONY *et al.* (2018) SAYS EVEN THIS IS LIKELY TOO OPTIMISTIC

- Her team **finds that contrary to current** models in which methane contributes only ~25% of permafrost thaw climate forcing (75% from CO2), instead methane will actually provide **~300%** vs. CO2
- Thermo-karst lake methane then comprises ~75% of all permafrost climate forcing.
- My black curves, as described, only estimate at 45% for methane's contribution

YVON-DUROCHER *et al.* 2014 FIND A 44:1 AMPLIFICATION OF METHANE EMISSION RATES WITH TEMPERATURE ACROSS ALL ECOSYSTEMS; LARGE AND SMALL. A +1C RISE WILL RAISE METHANE EMISSION RATES 15%.

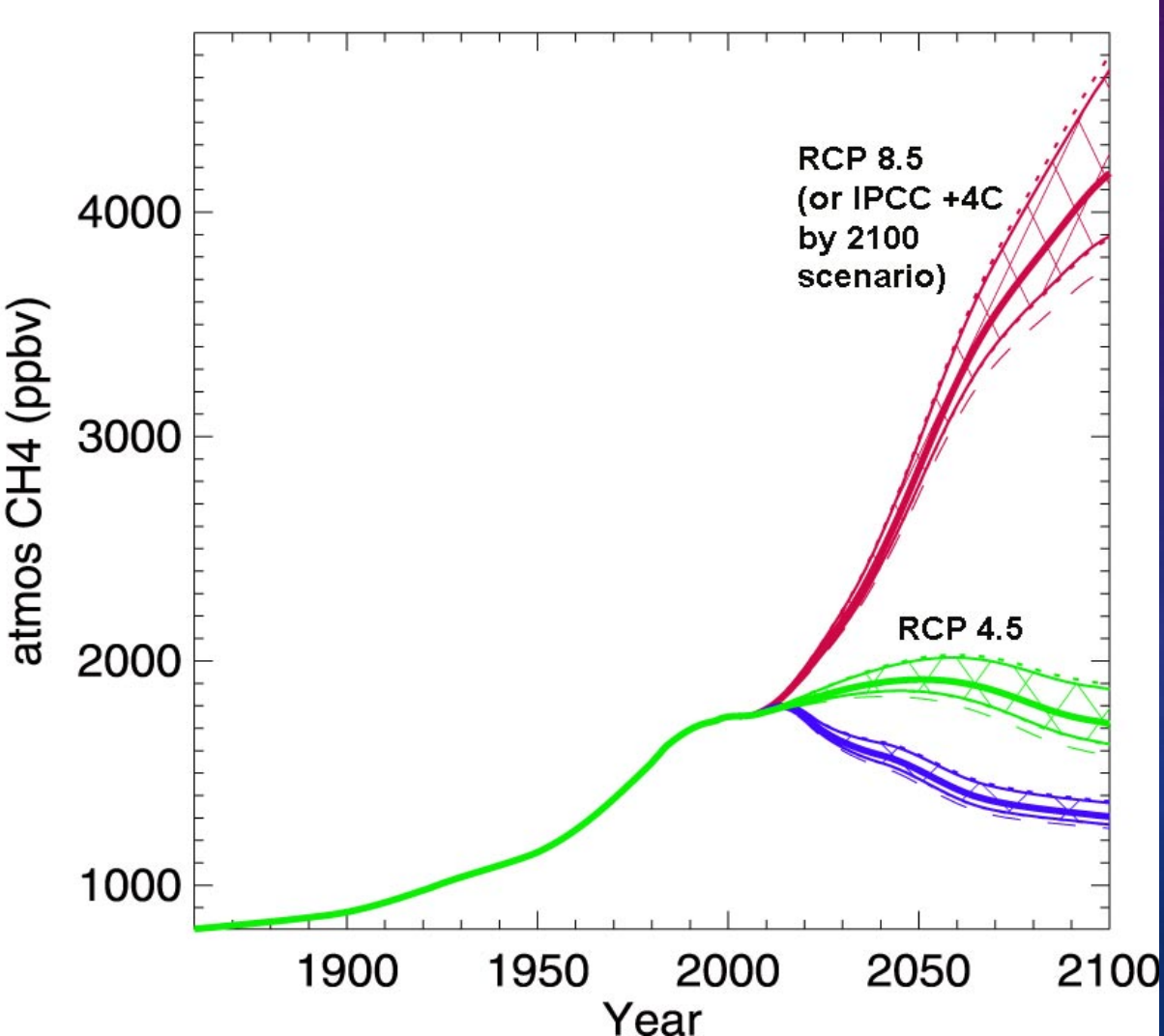


Caption

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 EMISSIONS FROM COMPLEX NATURAL SYSTEMS STILL REMAIN DIFFICULT TO PREDICT WITH THE DESIRED PRECISION. BUT HERE'S THE LATEST NON-ARCTIC ESTIMATES…

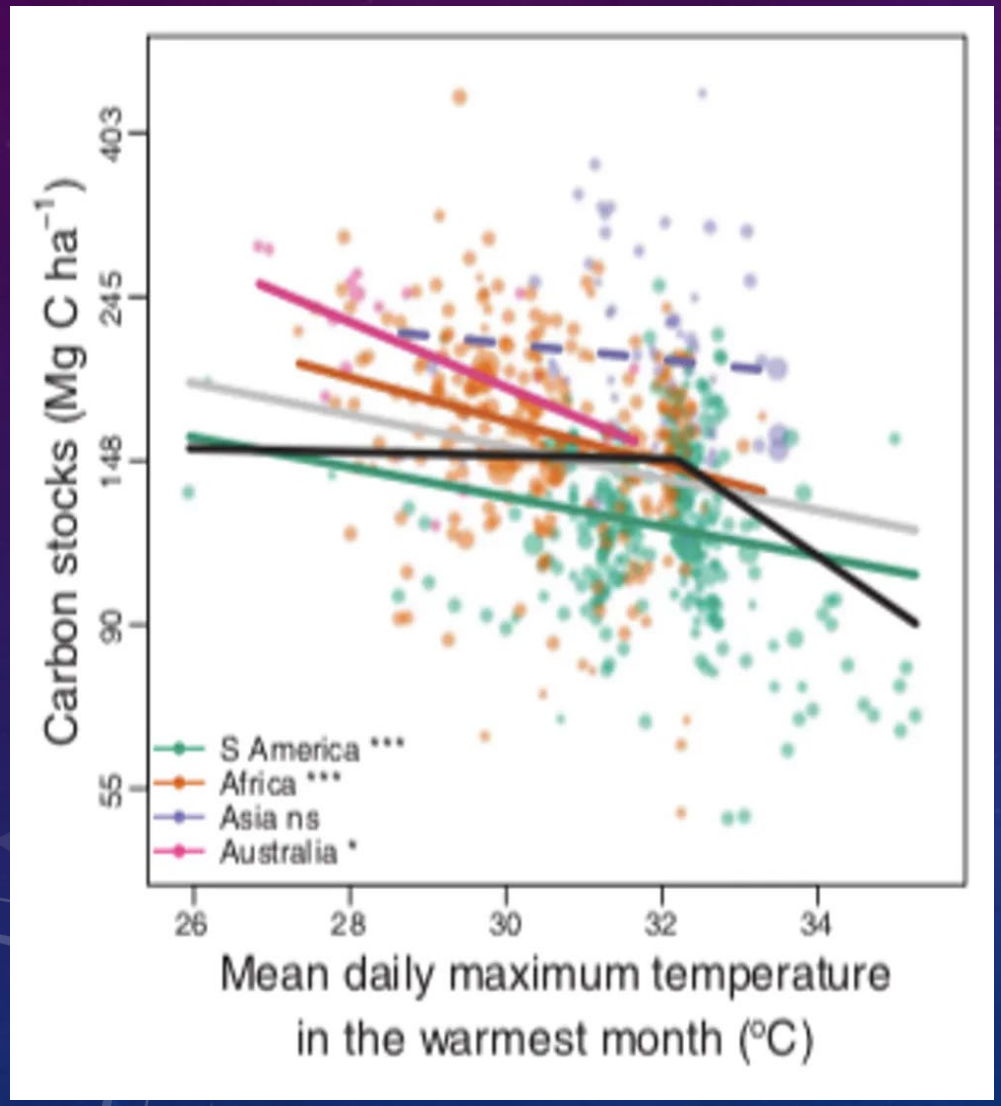


Gedny *et al.* (2019) find, on the temperature trajectory RCP 8.5 (nominally +4C by 2100 in the IPCC), that methane atmospheric concentrations rise strongly from even just non-polar wetlands, rising to over 4,000 ppb from today's 1850 ppb.

PERMAFROST CARBON FEEDBACK SUMMARY

- Natural carbon sinks in the permafrost weaken or reverse
- CMIP6 Earth System Models (ESM's) lack important climate feedbacks, including permafrost GHG feedbacks
- Permafrost thaws by series of local tipping points, not a single global point
- Abrupt Thaw; creates PF local tipping points which greatly increase total warming
- Overshoot warming will trigger irreversible permafrost thaw that drives additional warming for centuries, even after temperatures stabilize
- Permafrost neglected in IPCC reduces their remaining 2C carbon budget by 50% (other climate work indicates we actually have no carbon budget for 1.5C. It's too late.)
- Global warming might still be reversible by removing atmospheric CO2, but many feedbacks will persist for centuries to thousands of years, imposing a burden on all future generations to continue removal.

A NEW TIPPING POINT IS DISCOVERED IN DATA; AT AVG SUMMER TEMPERATURE T=90F (32C) IN TROPICAL FORESTS' WARMEST MONTHS



- Sullivan *et al.* 2020 (behind paywall but discussed here) find that at this temperature, tropical rainforests transition to a state of **steep carbon loss**, as tree growth is stunted and decay amplifies (black curve)
- **They point out that this corresponds to a global temperature rise of only +2C, which, as we saw, is virtually impossible to avoid at this point.**

THE AMAZON RAINFOREST TIPPING POINT TO SAVANNA, IS HAPPENING NOW; FAR AHEAD OF PREDICTIONS.

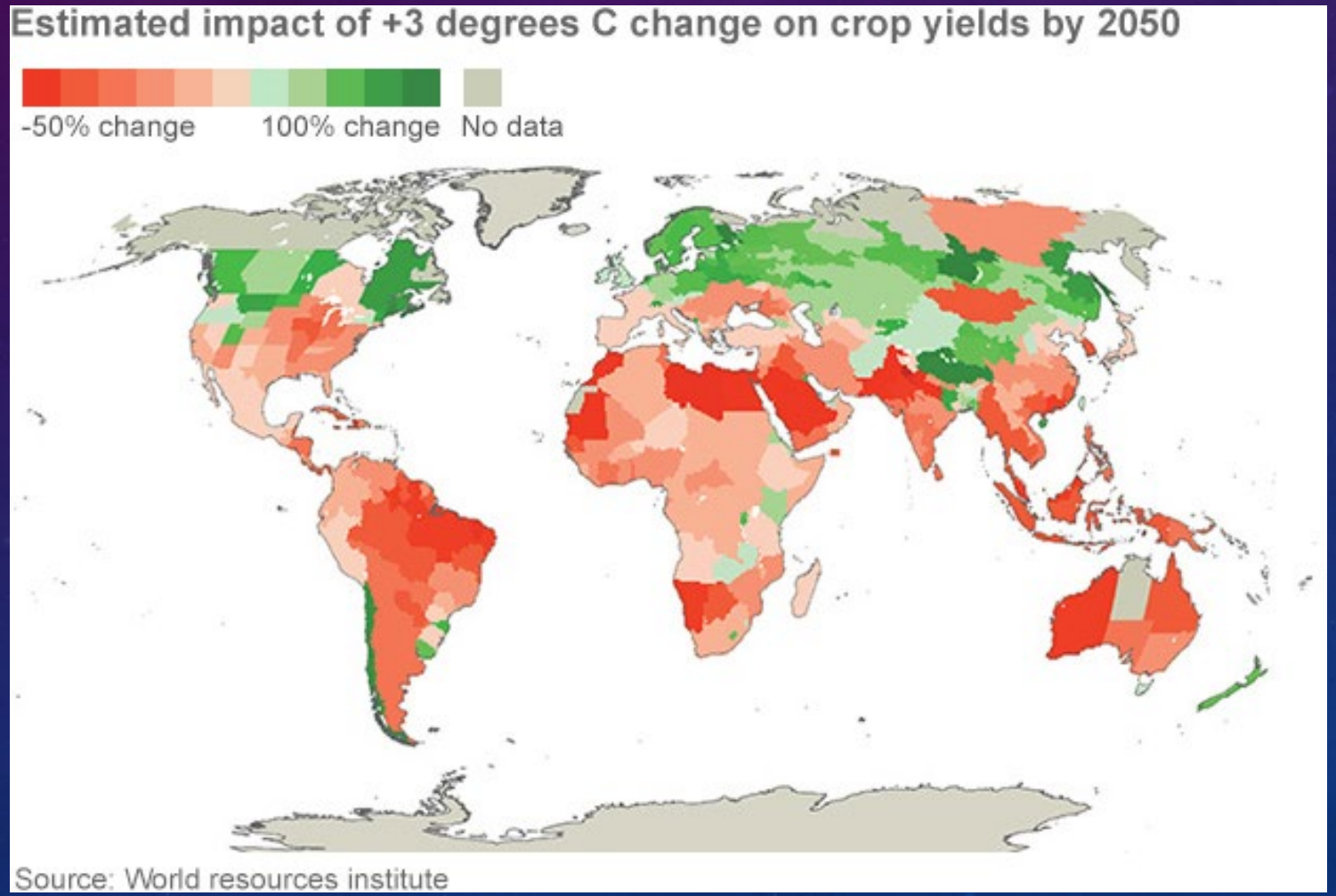
THE AMAZON IS ALREADY A NET CARBON SOURCE, NO LONGER A CARBON SINK.

AGAIN, FAR AHEAD OF PREDICTIONS FROM MODELS.

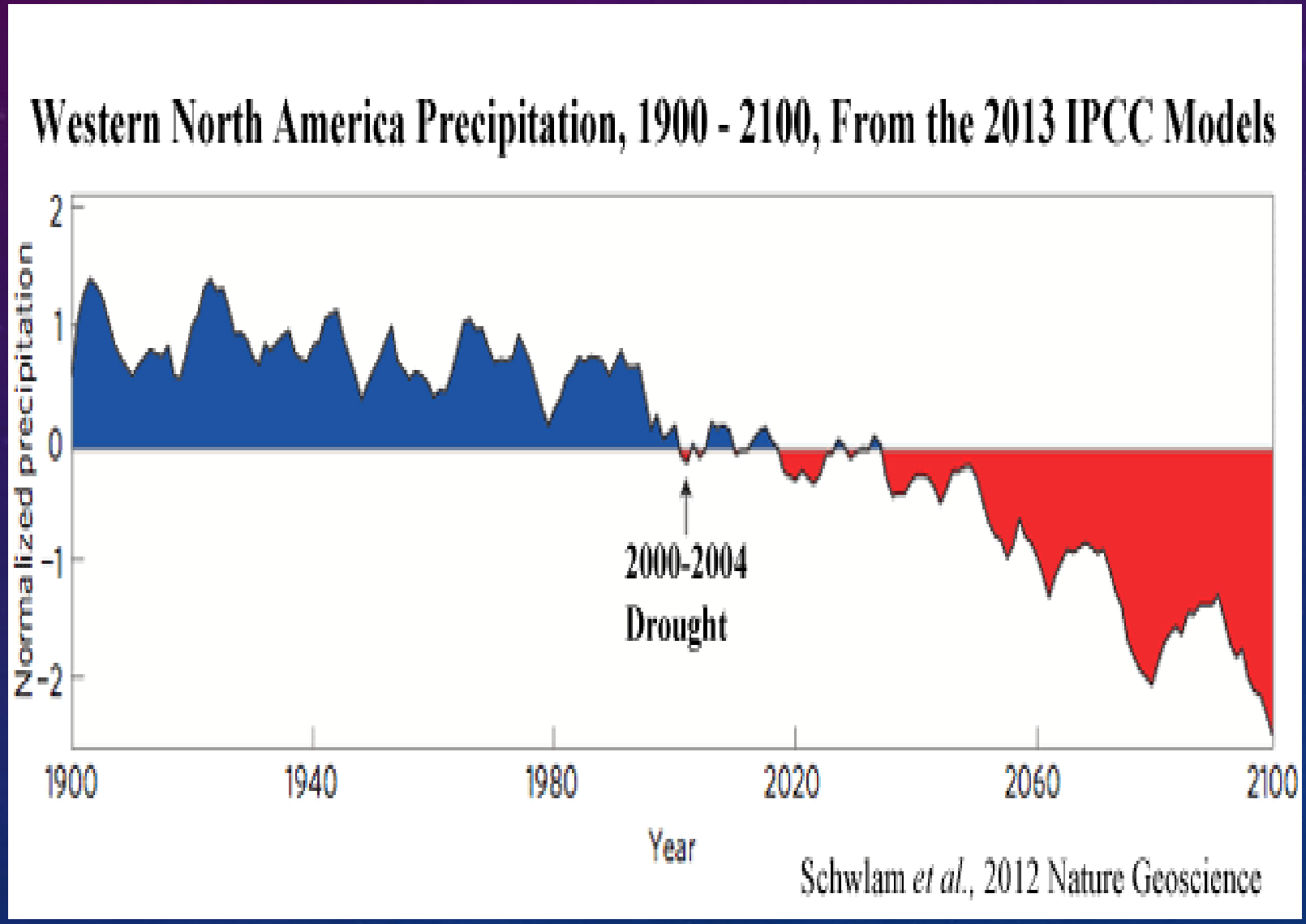
"THE AMAZON IS (NOW) A CARBON SOURCE. NO DOUBT,"...

- *...Luciana Gatti, a researcher at Brazil's National Institute for Space Research who led the study, said in an interview with environmental news site Mongabay.*
- *"By now we can say that the budget for the Amazon is 0.3 billion tons of carbon per year [released] into the atmosphere. It's a horrible message." (source)*

EVEN JUST +3C TEMPS MEAN MOST OF EARTH HAS POORER (RED) CROP YIELDS, UP TO 50% LOSS. THE WORST EFFECTS ARE IN THE MOST POPULATED AREAS. NOTE THE DEVASTATING EFFECTS ON THE ARAB COUNTRIES. THEN PONDER THEIR RAPID POPULATION RISE, THEIR VIOLENT POLITICAL INSTABILITY, AND IMAGINE THE SYRIAN TRAGEDY OF THIS PAST DECADE MULTIPLIED BY ORDERS OF MAGNITUDE.



IPCC PREDICTIONS OF SUMMER PRECIP – WESTERN U.S. DROUGHTS ARE ONLY JUST GETTING STARTED. SCHWALM *et al.* 2012.



CARNEGIE INSTITUTE'S KEN CALDIERA, USING CLIMATE MODELLING IN A "BUSINESS AS USUAL" (RCP 8.5) SCENARIO…

- …finds that by year 2100, the climate of the Santa Cruz/San Jose area will be that of the dry desert and chaparral at the latitude of San Diego.
- And that Seattle's climate will warm and dry to become that of present day Santa Cruz - San Jose. (**Petri and Caldiera 2014 in Nature**)
- **This spells the end of California's redwood forests.**

MY “ASTRO 28 :FIELD ASTRONOMY” COURSE STUDENTS, AT GIANT SEQUOIA NATIONAL MONUMENT’S “TRAIL OF 100 GIANTS” IN 2004

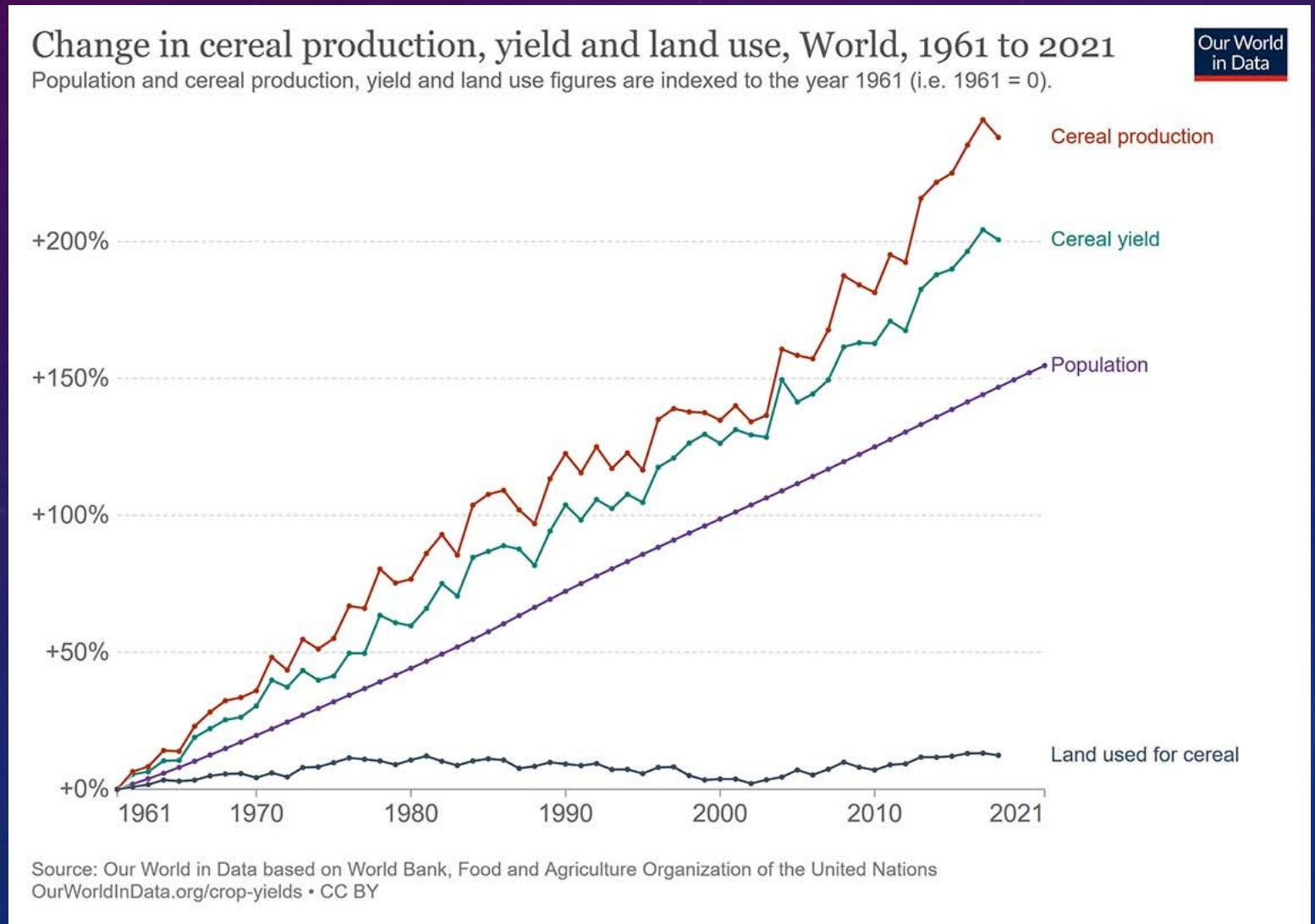
QUESTION: DID NATURE GIVE THESE BEAUTIFUL TREES TO WHOMEVER AGGREGATED THE MONEY TO…

- Erect a fence and toll booth to satisfy their rent-seeking behavior?
- Or worse, to chop them down and convert them to cash for faster investment growth?
- Or did Nature give these magnificent trees to all humanity, and all life on Earth?

THIS SAME ~2,000 YEAR OLD TREE - IN 2016. VICTIM OF THE 21ST CENTURY DROUGHT – WORST IN AT LEAST 1200 YEARS. FALLEN AND DEAD. YOUNG SEQUOIAS; DEAD AS WELL (AT RIGHT). PRESIDENT TRUMP HOPES TO OPEN MOST OF THE MONUMENT TO LOGGING, WHICH THIS ARTICLE, IN A GESTURE OF STARTLING UNDERSTATEMENT, CALLS "COUNTER-INTUITIVE". I WONDER WHAT NEO-CLASSICAL AND OTHER CONVENTIONAL ECONOMISTS FEEL AT SUCH SIGHTS? I WONDER WHAT THEIR CHILDREN FEEL?

WHAT WILL BE THE FATE OF THESE BEAUTIFUL TREES? WILL THEY BE CLEAR CUT BEFORE THEY ARE FULLY DEAD?

SO FAR… YIELDS OF STAPLE CROPS HAVE KEPT AHEAD OF RISING POPULATION, THANKS TO THE HIGHLY ENERGY CONSUMPTIVE HABER-BOSCH PROCESS CONVERTING NITROGEN INTO FERTILIZER (AND GHG'S)



BUT AS TEMPERATURES RISE… CAN WE "GMO" CLIMATE-TOUGHER STAPLE CROPS?

- We've had some success engineering more drought-tolerant plants.
- **But biology is extremely temperature dependent, and despite 30 years of major efforts, there has been NO success at breeding heat-tolerant staple crops (1:04:50 into this talk by atmospheric scientist Dr. David Battisti in 2016**).
- And elevated CO2, far from being "good for plants", is robbing food crops of vital nutrients (**Myers *et al*. 2014)**

KEY TAKE-AWAYS…

- Legally enforced controls (assuming that we can even choose such a politically charged path) can only affect direct human emissions, but the increasing indirect human-caused emissions discussed here, even if they are feedbacks, act with such a large lag and such large hysteresis (see later), that they may not respond to even draconian actions.
- Standard econometric models that neoclassical economists such as Nordhaus pledge allegiance to, assume temperature equilibrium, optimized human absolute control, and full-knowledge'd acting from supposedly rational self-interest (max short-term profits for self). This is just false. The economy is never in equilibrium, and rationality is a misnomer and rarely seen. And it CERTAINLY isn't how climate operates.
  - **"We risk leaving our children with a situation which is beyond their control"** – James Hansen

TO BE CONTINUED… MUCH MORE TO SAY…

- …finishing the most relevant modern climate science which has not been appreciated in economic models to date
- …ethical flaws in existing economic modelling
- These will be in the final Part 3 of this series.

- Then… later…
- On policy ideas
- And, on framing solution thoughts within the Thermodynamics of Civilization and how it limits realistic options