Ice Melt, Sea Level Rise, and SuperStorms

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A Condensed Digest of the Paper of Hansen, Sato, *et al.* 2016, and…

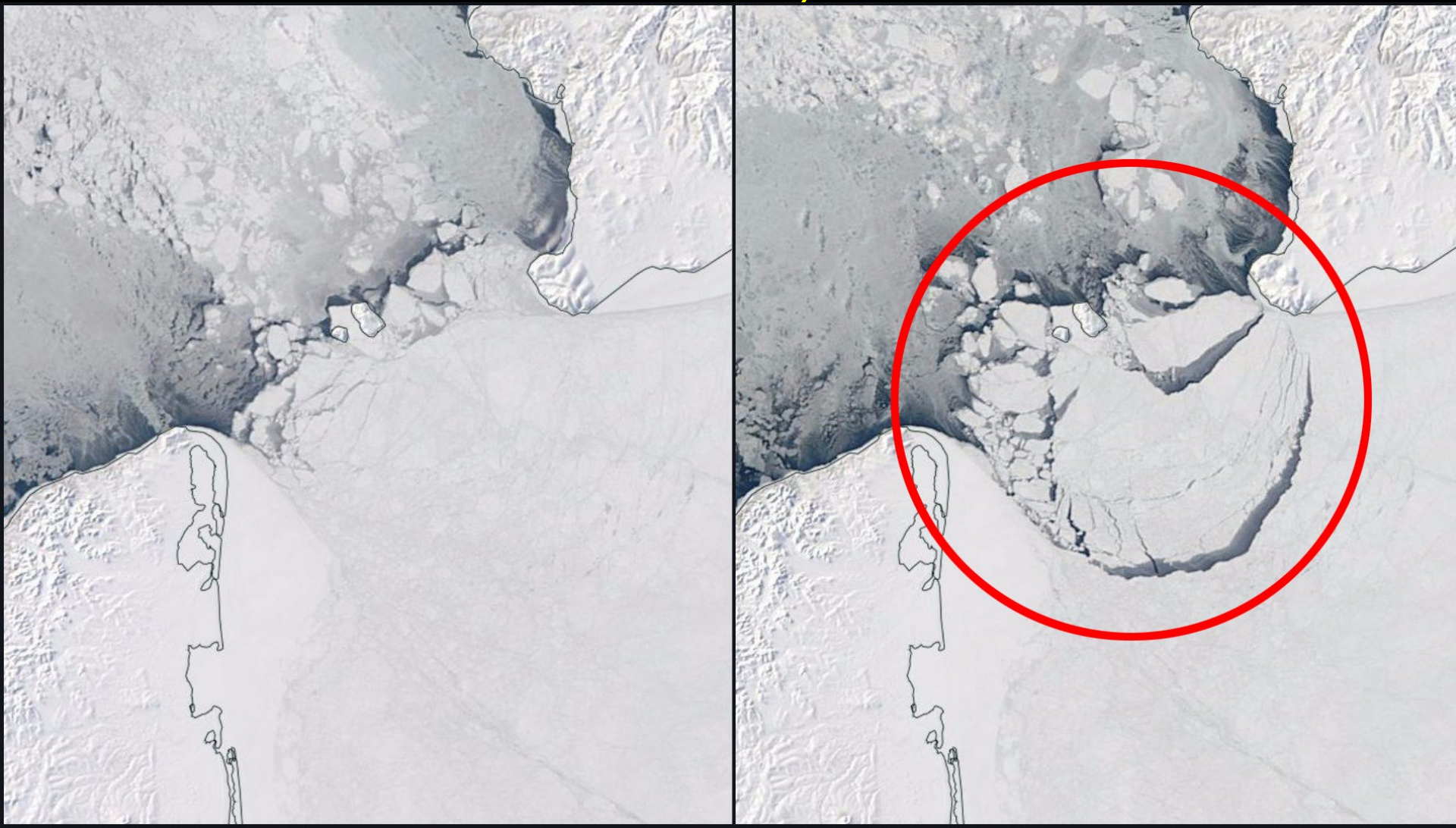
and What are the Economic and Physics Constraints on our Options to Deal with Climate Change ?

A Note about this Presentation

- It's designed to appeal to a broad, intelligent, and largely non-scientific audience.
- I've focused on good science, but it also has some gallows humor to leaven the proceedings, and point out some outrageous claims as an example.
- It also has a sprinkling of moral outrage – this subject is more than arcane academic material with little relevance to civilization's future and life itself. It is as far from it as is possible to imagine. For some scientists, this is a jarring distance from their cultural paradigm. Especially astronomers (like me!). Get used to it; it's our future.
- We'll all have to get used to talking both with meticulous accuracy and fidelity to evidence and rationality, and also the stark human meaning of it all, or else we'll continue to be ignored.
- I'm not here to put anyone to sleep till the bell rings! Strap in for the ride…

"We Ignore James Hansen at our peril"

- Professor Michael Mann, Lead IPCC Scientist



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

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Here's the Paper Itself…

- The **full 52 page paper**, in .pdf form
- And here is Dr. James Hansen giving a 15 minute **video summary of the paper**

- **I will explain Hansen's conclusions and the physical reasoning to support his conclusions, and weave in supporting evidence from other studies**

Methods

- CMIP climate model runs (CMIP= “Coupled Model Intercomparison Project)
- And…Ocean modelling
- Together with … paleo data from past interglacial periods,
- Together with … the modern observed changes, and rates of change of ice sheets and climate over the past 100 years where data is more precise

+2C Global Warming Implications Summary

- ***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."***
- ***<u>Why?... Here briefly are some key reasons….</u>***

1. Surface mixing of the ocean is too efficient in the earlier models

- This transports heat too efficiently out of the surface ocean into the deeper ocean, and causes a slower climate response by ~10-20 years compared to observational data.

2. Ice sheet dynamics are not included in IPCC models.

- Not included in IPCC models: Transport of floating ice out of Arctic on both sides of Greenland
- *In Situ* mechanisms which accelerate ice breakup, including calving dynamics, moulins, drainage to glacier/basement interface causing softening, increased glacier speed
- Observed ice loss rate is rising exponentially; doubling every 10 years, vastly faster than IPCC models

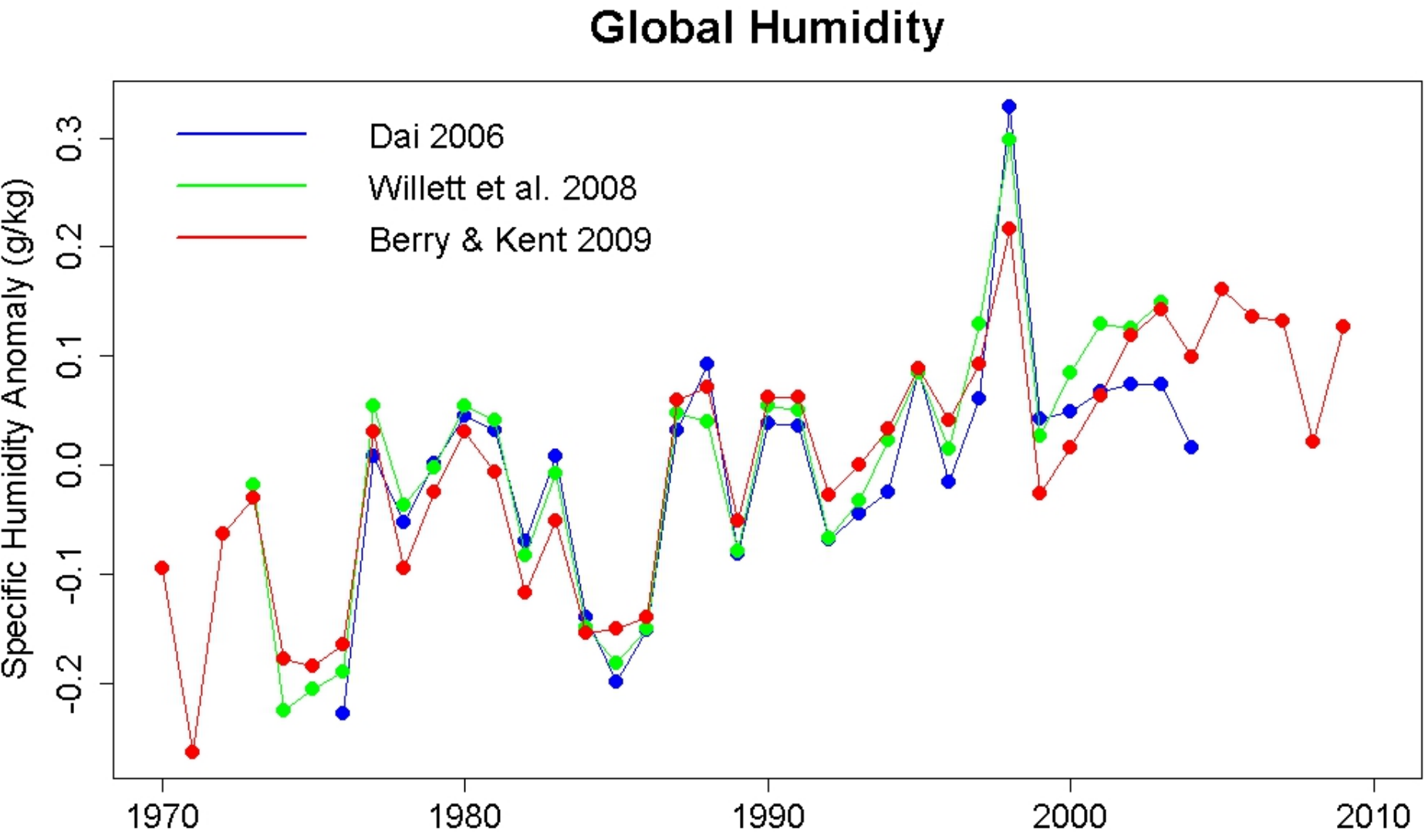
3. The predicted large melt off Greenland and Antarctica COOLS the surface of the ocean with low density fresh water

- This lowers Earth surface temperatures *vs.* no melt. Great, right? **NO.**
- **This <u>lowers</u> Earth's ability to cool itself**
- **This WORSENS Earth's heat imbalance. The heat instead is trapped beneath the ocean surface where it can't escape, but still is close to the surface and thus RAISES the melting of the ice shelves from beneath, worsening sea level rise**
- **You haven't let the heat radiate away to space, which is the only real solution.**
- **Before discussing the resulting sea level rise, we discuss the more dramatic and previously unexpected implications**

Implications: Weather Intensity Changes

- **Warmer Sea Surface Temperatures Mean…**
- more evaporation
- stronger vertical air temperature gradient driving convection
- This is one cause which drives stronger storms
- **Warmer Air Temperatures Mean…**
- --- Air can hold more water vapor, so rain is less frequent.
- **7% higher saturation humidity per 1 degree C of temperature rise, predicted by the Clausius-Clapeyron equation, and confirmed by decades of observation (e.g. Held and Soden 2006).**

Indeed, Global humidity **is** rising, doubling the warming due to CO2 alone, and aiding stronger storms



Warm Air Holds More Water Vapor

- However, when saturation of the air does take place, the rarer resulting rains will be more forceful because of the higher amounts of water
- Floods significantly more common, as higher air temps mean more precip falls as rain now instead of snow, which runs off rapidly rather than being stored for weeks or months as snow in the mountains.

- **We are transitioning from a time of more frequent, gentle rains which allow soaking of the soil and plant roots, to a time of rarer rains on parched dry land with less healthy plants, and soil, and severe erosion caused by stronger deluges when and where rain does occur**

Extreme Precip Events Were Expected to Increase at the Same Rate, 7%, as Water Vapor, per Degree Celsius

- This was the conclusion of Pall *et al.* 2006
- But climate models post-dicted that the increase would be greater, 8.3% per degree Celsius over land areas with weather stations since 1901…
- In fact, though… actual observations since 1901 show an even greater increase, of 10% per degree Celsius of global temperature rise (**Asadieh and Krakauer 2015**)

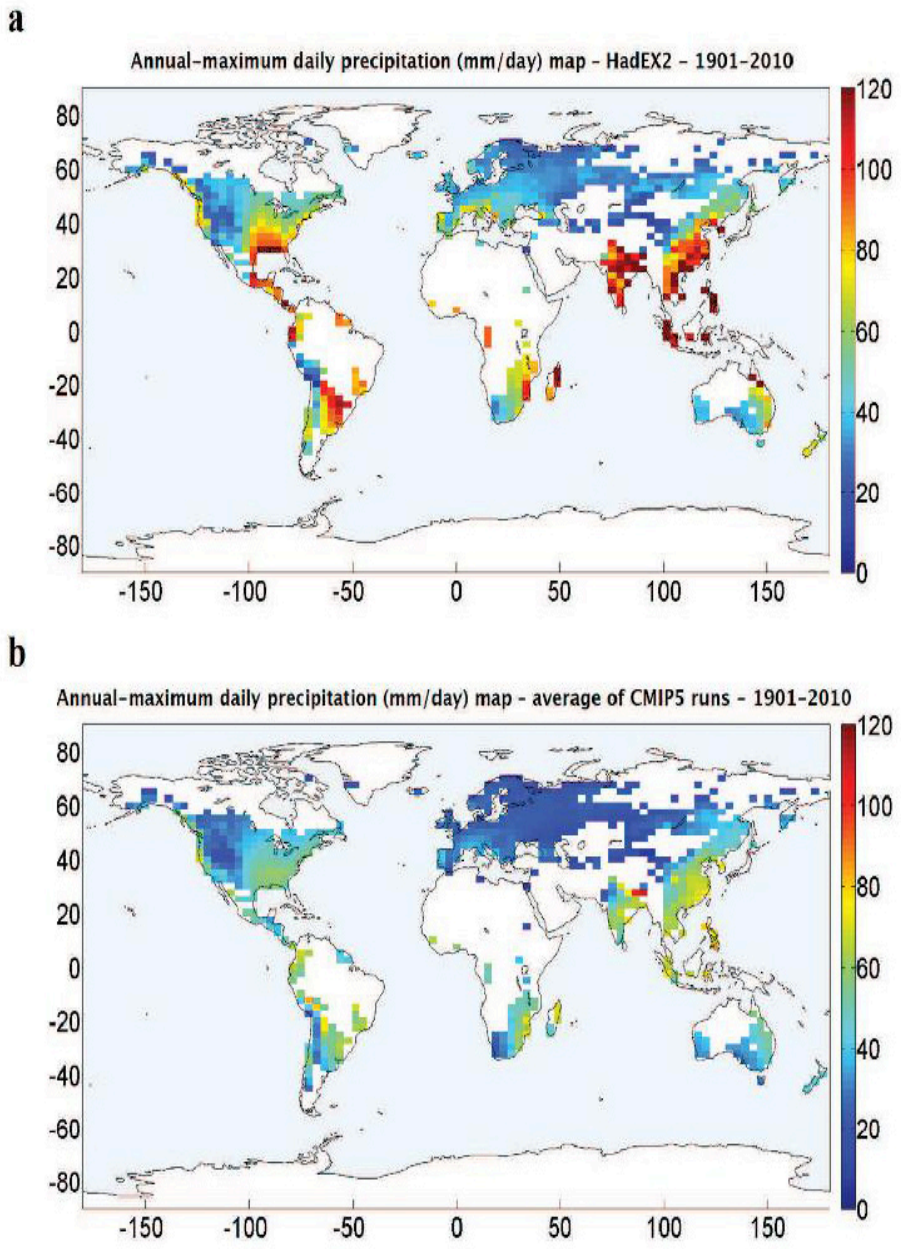
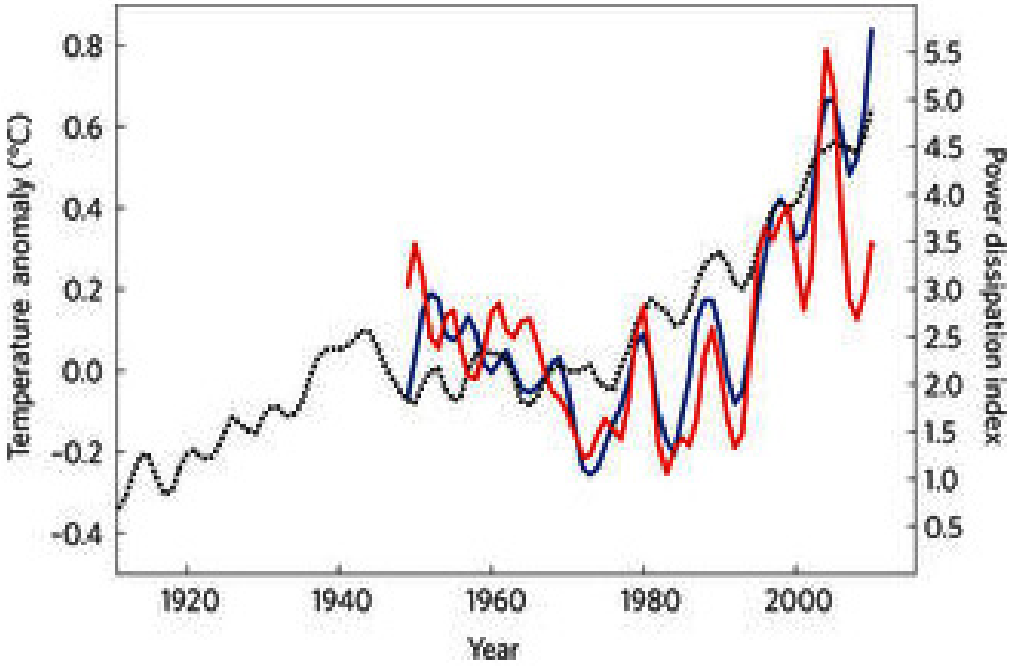


Figure 3. HadEX2 observational data versus CMIP5 averaged results of global extreme precipitation in 1901–2010 – annual-maximum daily precipitation map (mm day^{-1}) for **(a)** HadEX2 and **(b)** the average of CMIP5 model runs.

We are already seeing more extreme deluges than even those climate models predicted. HadEX2 (top) is a century's data, *vs.* CMIP5 climate model runs (bottom) post-diction average, from Asadieh and Krakauer 2015

From Coumous and Rahmstorff (2012) : Higher ocean surface temperatures go with stronger tropical storms for the future

Figure 3: Power dissipation index for North Atlantic tropical storms linked to tropical sea surface temperature in the main development region for Atlantic hurricanes.



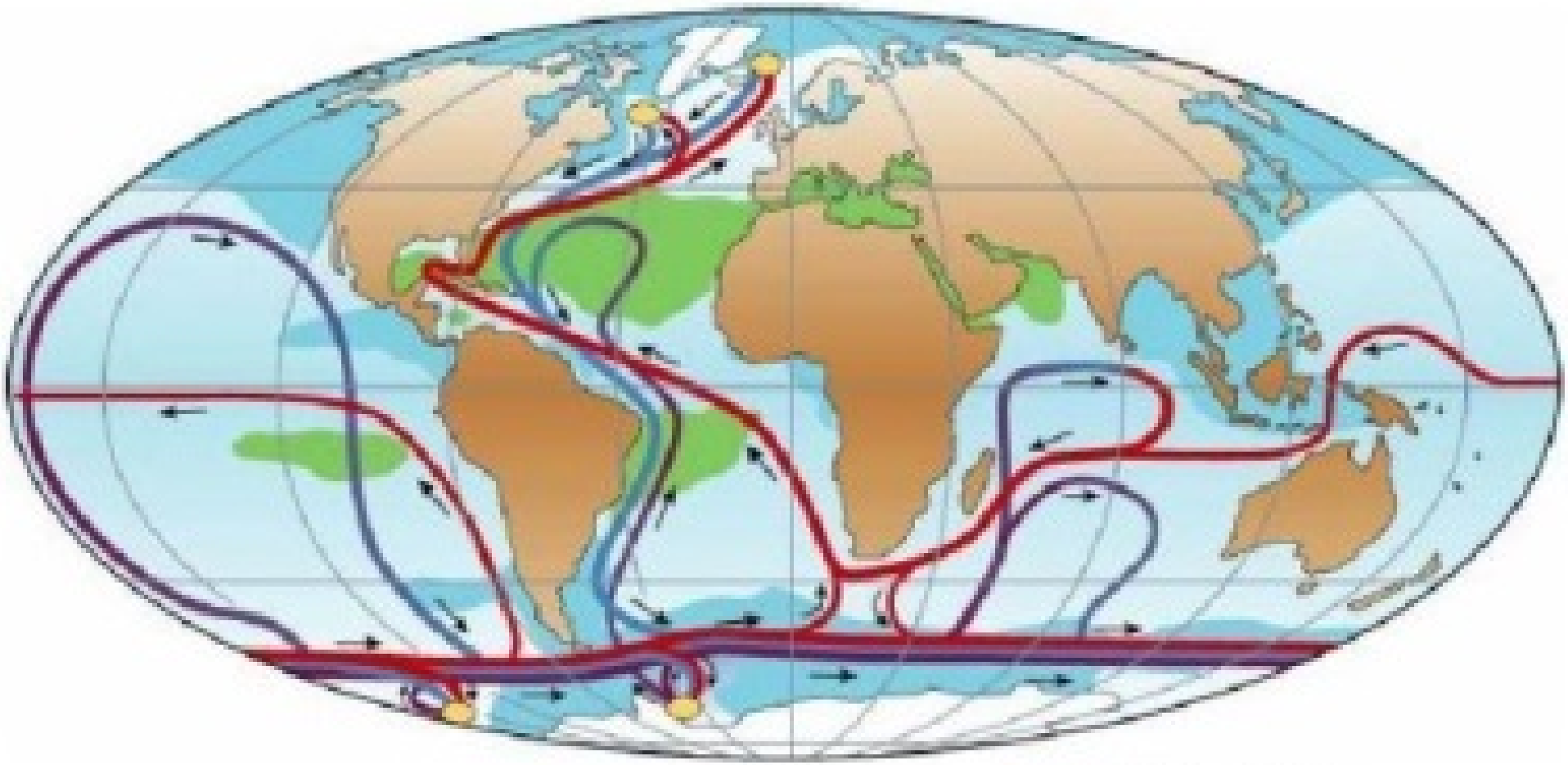
Red line denotes North Atlantic tropical storms; blue line denotes tropical Atlantic sea surface temperature. For comparison, the evolution of Northern Hemisphere mean temperature from NASA Goddard Institute for Space Studies is also shown...

What about Tornados? These are over Land;

We're not sure if there will be more, or stronger.

But, here is not where we want to go

Global Ocean Surface and Deep Currents



(Rahmstorf, Nature 2002)

How Ice Melt Can Shut Down The Global Ocean Circulation

- **AMOC = Atlantic Meridional Overturning Circulation;** a wonky description of the current which absorbs tropical heat, carries it by the Gulf Stream north, where it cools, gets saltier, denser, and falls to the bottom of the ocean, then heads south to rise again near the equator and get re-heated.
- Atlantic most important than Pacific in the northern hemisphere because it has access to cold on either side of frozen Greenland, cooling the surface waters enough (given they're salty) to punch down through the thermocline to reach the bottom of the ocean

AMOC Shutdown

- Hansen shows that the advanced stages of polar melt **can shut down the global thermohaline circulation**, as too much surface cold fresh water prevents water from breaking through the thermocline as it currently does at two places near Greenland, and two places near Antarctica. Why? **Fresh water is LESS dense than salt water!**
- This shuts off the transport of warm water to the sub polar areas, cooling their surface, while strongly heating stagnant surface tropical waters, driving storms of surprising intensity
- This happened during the Eemian interglacial 120,000 years ago, as we'll show from Hansen *et al's* paper.
- **This situation can drive…**

Superstorms

The Hansen *et al.* 2016 Study of Future Climate Predicts a New Era of Superstorms

- Paleo data indicates remarkably powerful storms driven by the **amplified temperature gradient in the Atlantic** if the AMOC shuts down.
- The developing "cold patch" off Greenland, where the AMOC descends, is, in the collective authors' judgment, the beginning of this gradient (see later slides).
- Sharp temperature gradient from hotter equatorial waters to cold Greenland meltwater. Heat engines are how mechanical work is generated from temperature differences.
- **Strong gradient -> strong "work" (storms)**

Prediction: Ice Sheet Melt -> Cold Freshwater Pools Sitting on Surface Waters (low density), Off Greenland and Antarctica. Without ice dynamics, IPCC models fail to predict (top row) the cold (purple) surface fresh water that results from amplified Greenland melt

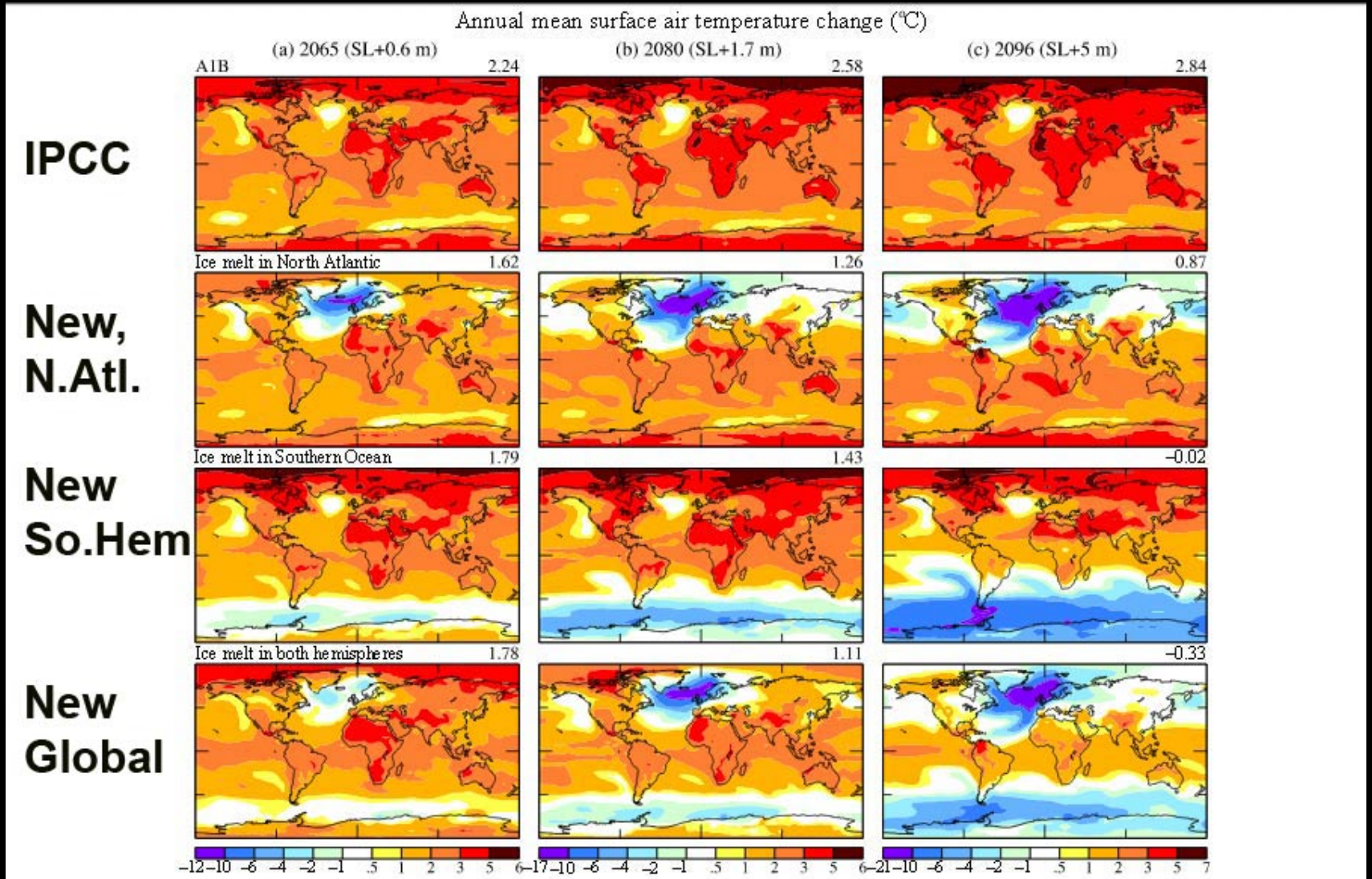
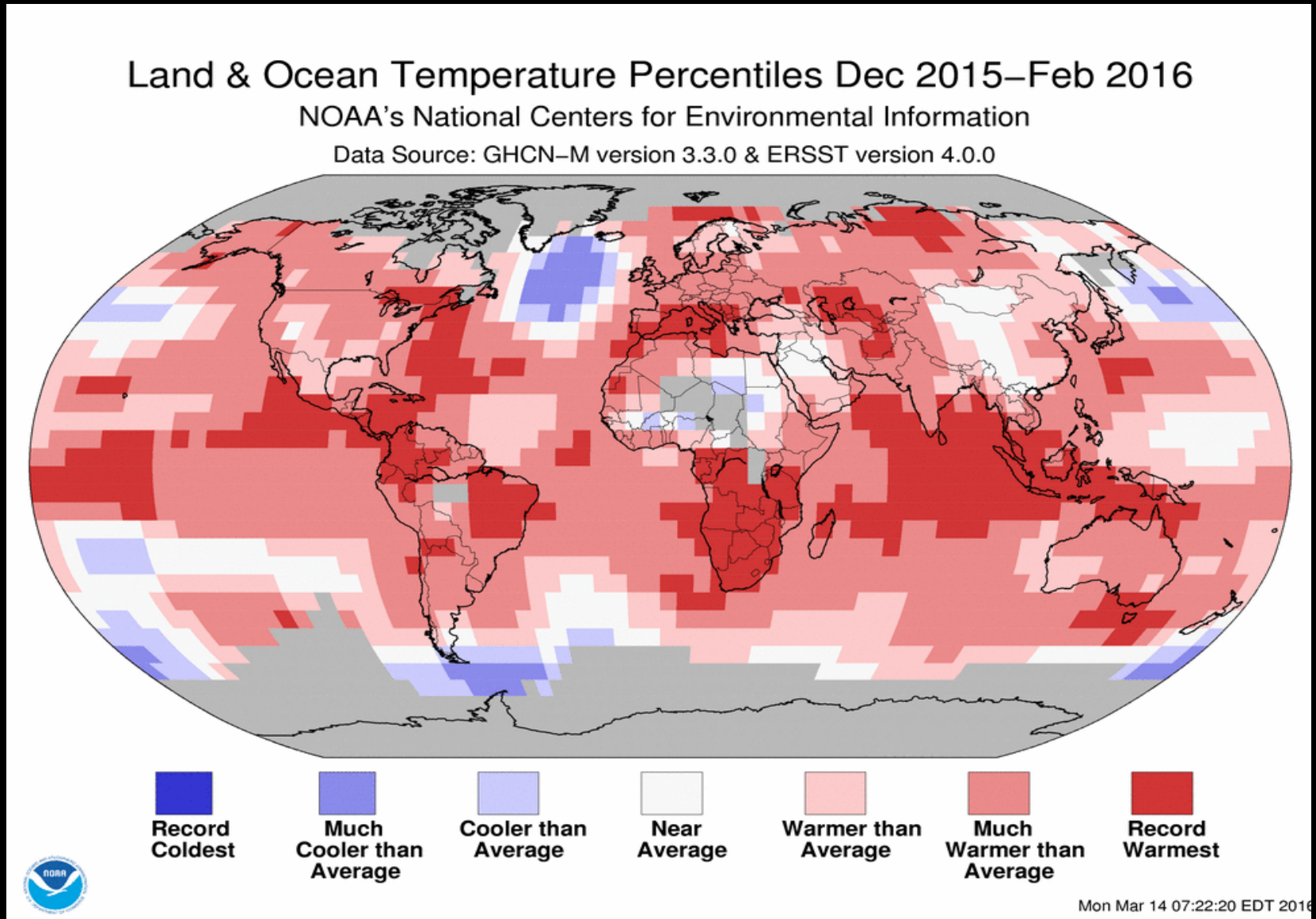


Figure 6. Surface air temperature (°C) relative to 1880–1920 in **(a)** 2065, **(b)** 2080, and **(c)** 2096. Top row is IPCC scenario A1B. Ice melt with 10-year doubling is added in other scenarios.

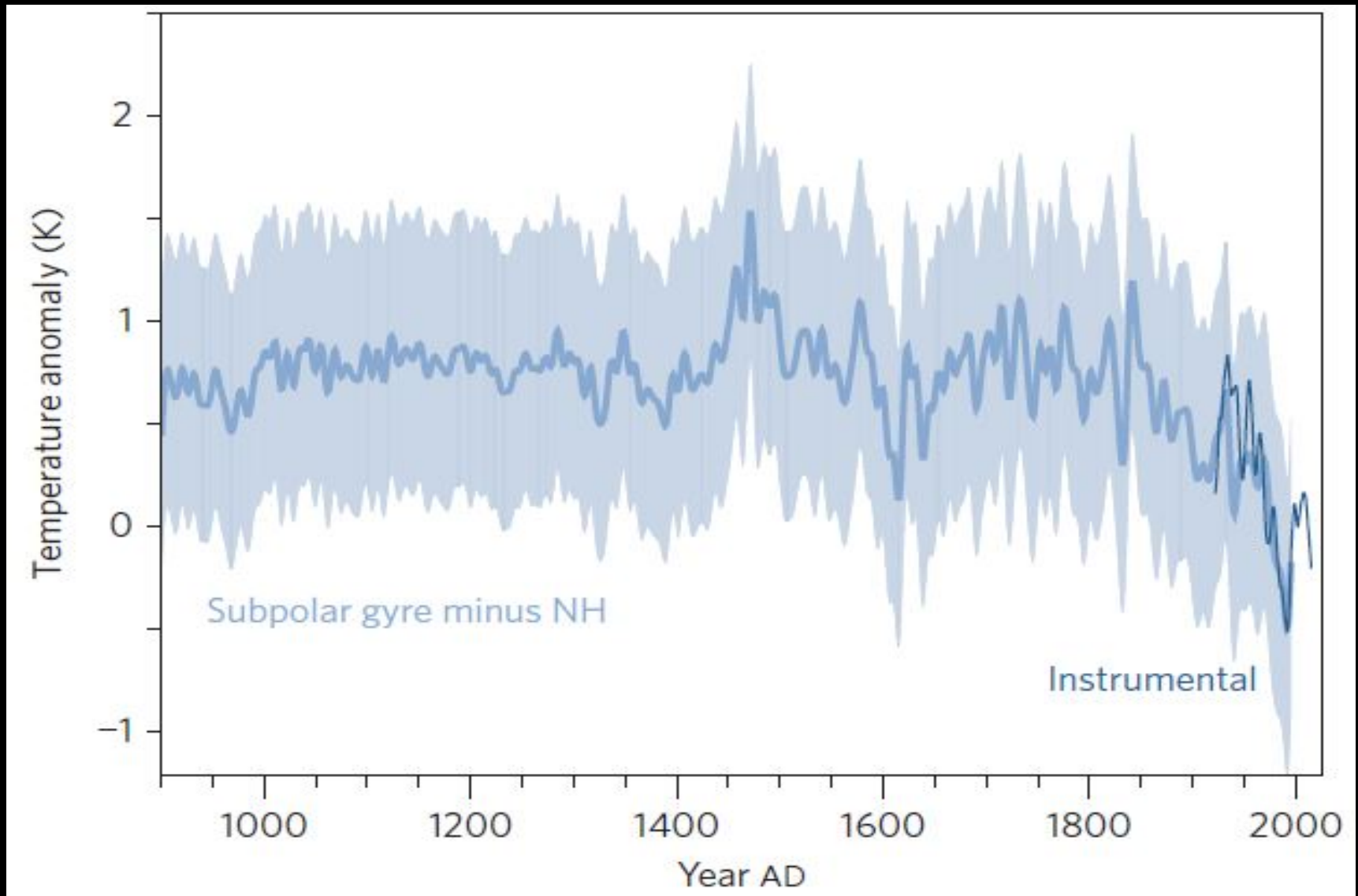
Could the Global Ocean Circulation Really Shut Down?

- **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 more rapid (by "a factor of a million" - Prof. Michael Mann) than any prior climate forcing, including the Eemian interglacial, yet the Eemian Period **did** see global ocean circulation shut down, initiated with global temperatures barely above those we have now.
- **Indeed, the Atlantic Meridional Overturning Circulation (AMOC), which is the only portion of the global currents on which we now have good data as of 2015, has already weakened…**

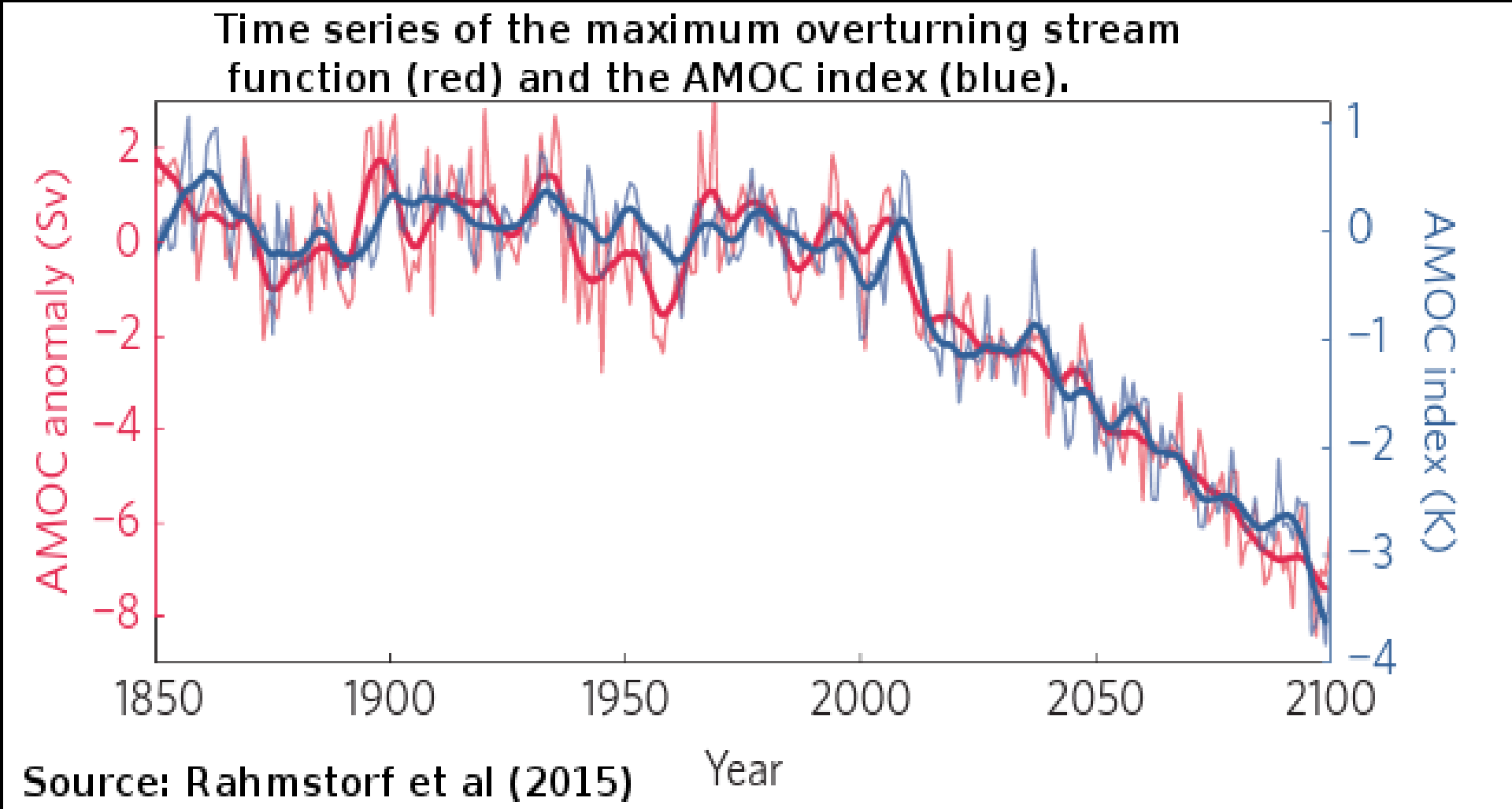
Observed Data Now Show: The Process Has Begun, Much Sooner than Expected... Note the cold patch (blue) below Greenland, due to Greenland meltwater



Past 1200 years time series 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



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



Source: Rahmstorf et al (2015)

The hotter tropical waters strongly amplify convective storms, further amplified by the stronger temperature gradient between cold offshore Greenland and the hot equator. Storm-tossed thousand ton boulders – Evidence?

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).

Evidence Detailed in Support these Are Boulders, Moved to Current Location, 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)
- 2. Land snails beneath boulders correlate to MIS 5e (Eemian, the last interglacial), not boulder
- 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?
- No, the largest of the boulders are found even on the top of the ridge of the Island
- What's the evidence they were tossed up by mega-storms?
- Run-up deposits **50ft 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) with stratigraphy impossible to produce by rain processes (next slide), and all aimed towards 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

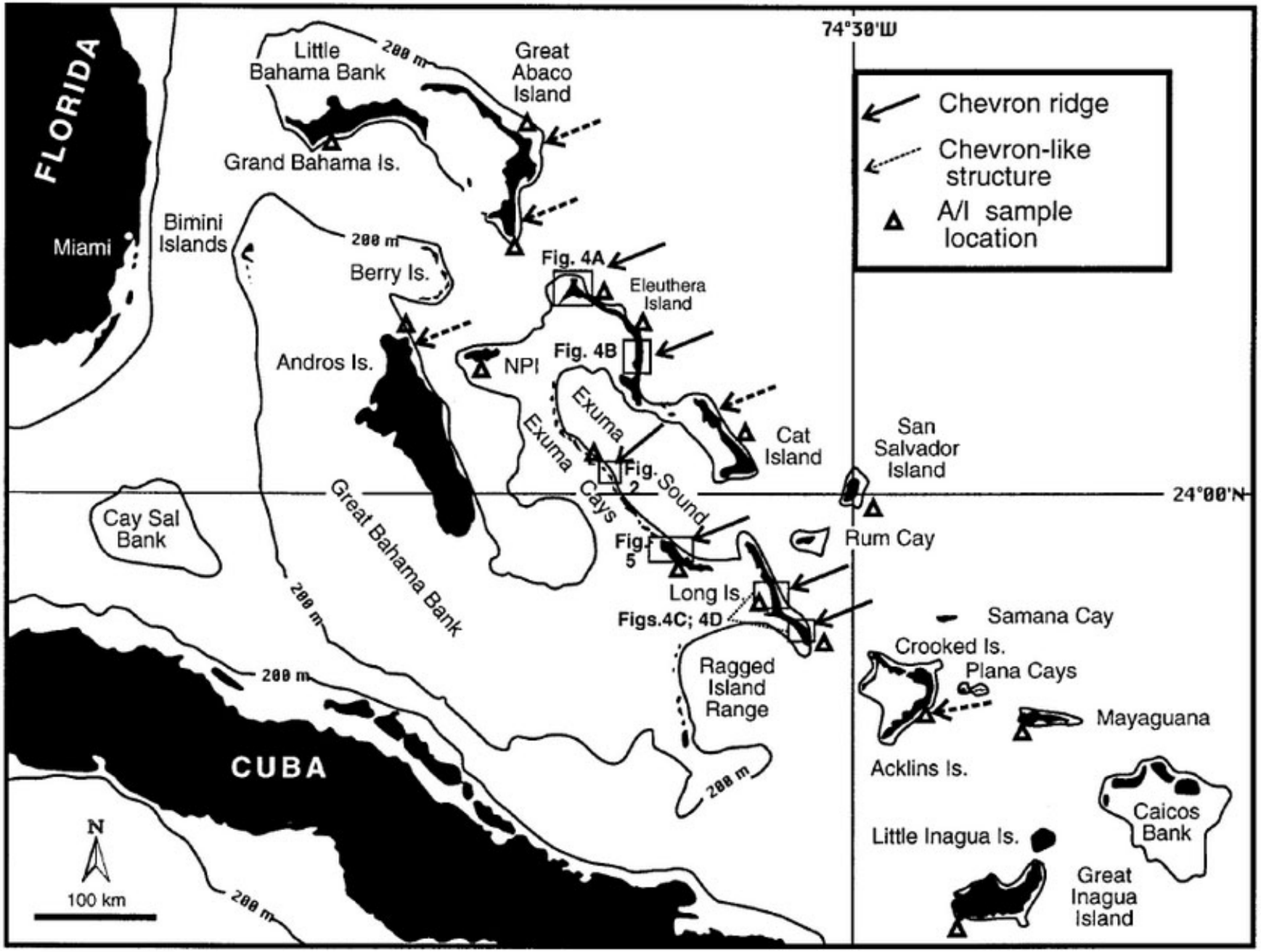


FIG. 3. Map showing location and approximate orientation (arrows) of chevron landforms and amino acid samples (Table 2).

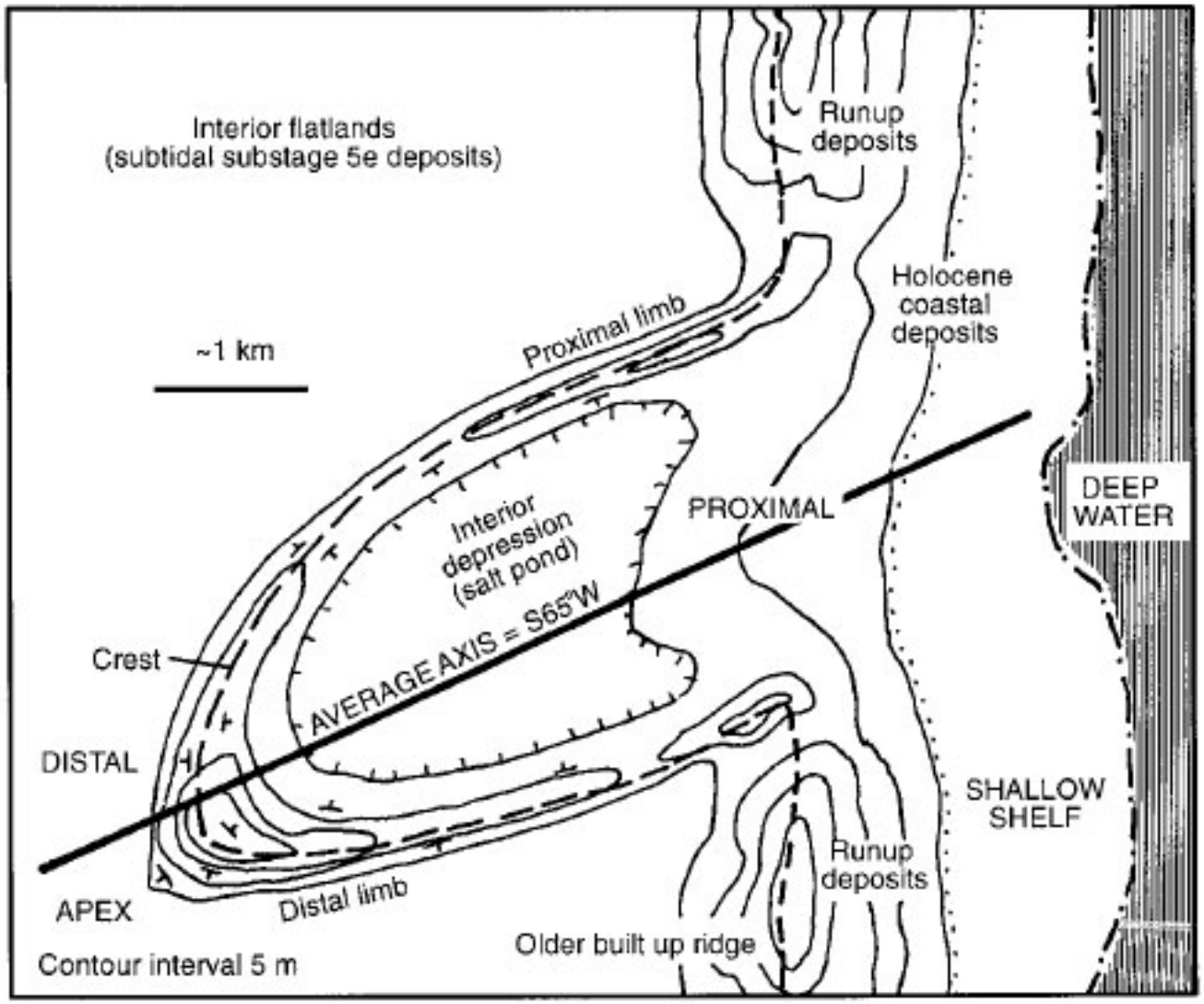


FIG. 1. Schematic map of chevron beach ridge.

Giant Waves created Chevron deposits 50 ft high and miles long, when washing back to sea

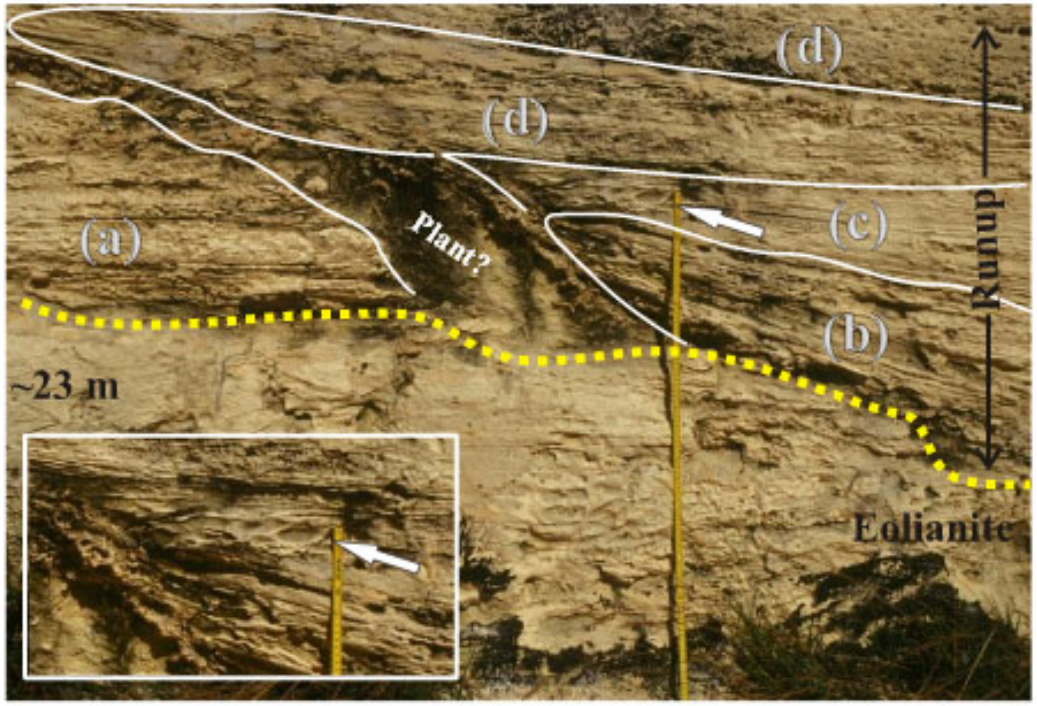


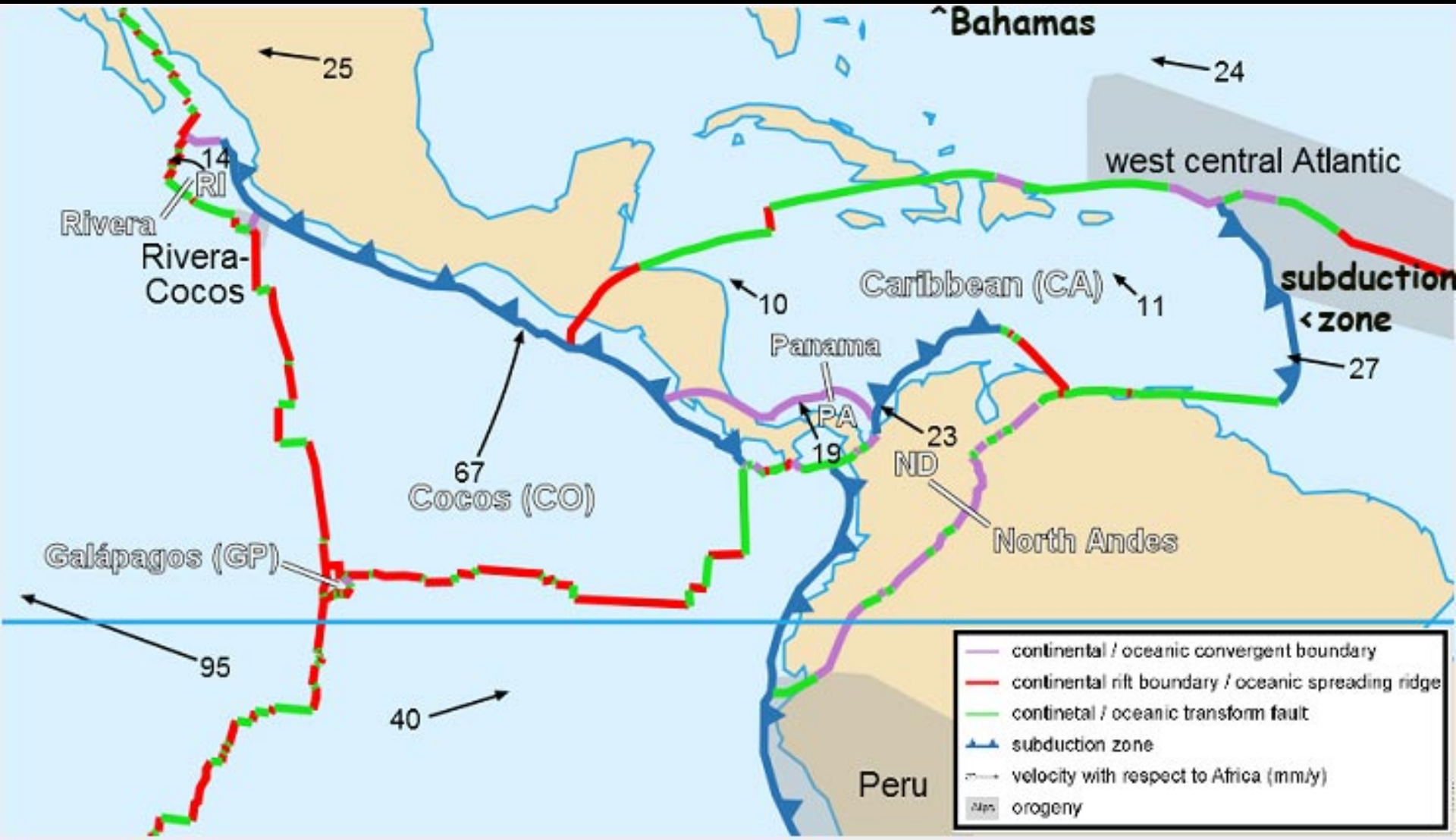
Figure 23. Photograph of runup deposits in a road cutting above +23 m (1 m scale in photo) on Old Land Road, Great Exuma Island, situated deep in Exuma Sound ~ 200 km south of North Eleuthera. The older built-up eolianite forms the lower half of the image; the upper half has multiple "packages" of planar, fenestrae-filled beach sets. The upper progression of sedimentary packages (labeled **a**–**e**) clearly shows an onlapping, rising sequence of beds, indicating increasing wave energy and degree of runup. Further, the individual laminae of scour structures (arrows and inset image) display the same onlapping, upward-climbing succession. It would be impossible to achieve such bedding if rain-saturated sediments were sloughing downhill on low-angle slopes under the influence of gravity, especially near the crest of a ridge.

Run-up stratigraphy shows later run-ups at higher energy, upward climbing succession – highly improbable by sediment sloughing downhill

<u>Thousand ton boulders tossed onto beaches, 50 ft high sand chevrons miles long…</u> Some find the strength of the storms which could do this hard to believe, and wonder if maybe tsunami's brought them up

- The massive, parallel chevrons throughout the islands argue against a slope-failure tsunami originating in the Bahamas, which would instead show a radiating or converging pattern.
- And earthquake-sourced tsunamis are associated with long, significant **subduction zones**
- **Is there a suitable subduction zone?**

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



Could a Landslide-Caused Mega-Tsunami Create the Bahamas Chevrons

- If the source was far from the Bahamas, then at least it would be consistent with the uniform 65 degrees SW orientation of the chevrons, but then it would have to be a huge volume of earth falling into the ocean all at once.
- A search showed no known mega-tsunami during the Eemian period
- Some fear that a large part of the volcanic La Palma volcano in the Canary Islands could slough into the ocean all at once, which would generate a wave sufficient to explain these features. An early paper claimed this, and was good fodder for a **scary, but not credible, episode of "Nova"**
- A good series of later papers and evidence from La Palma's past events itself, make a strong case that these sloughs have happened in only small pieces which only collectively add up to the larger volumes. But you only generate a tsunami capable of ~100 ft+ waves in the Caribbean and America if you have a single **large** event all at once, and **The evidence is the opposite (Hunt *et al.* 2013).** No such single large episode is in the geologic La Palma Island record.
- **Mega-Tsunamis in history**, and the American Geophysical Union scientists' rebuttal to the La Palma Island mega-tsunami scare is **here. No evidence of a La Palma megatsunami in the Eemian.**

Sea Level Rise

- *"Two conclusions are especially germane.*
- *First, subsurface ocean warming is an effective mechanism for destabilizing ice shelves and thus the ice sheets buttressed by the ice shelves.*
- *Second, large rapid sea level rise can occur as a result of melting ice shelves." – Hansen et al. p. 31*

There is a tight correlation in paleo data, showing CO2 is the driver of Earth Climate, Ice Sheets, and Sea Level

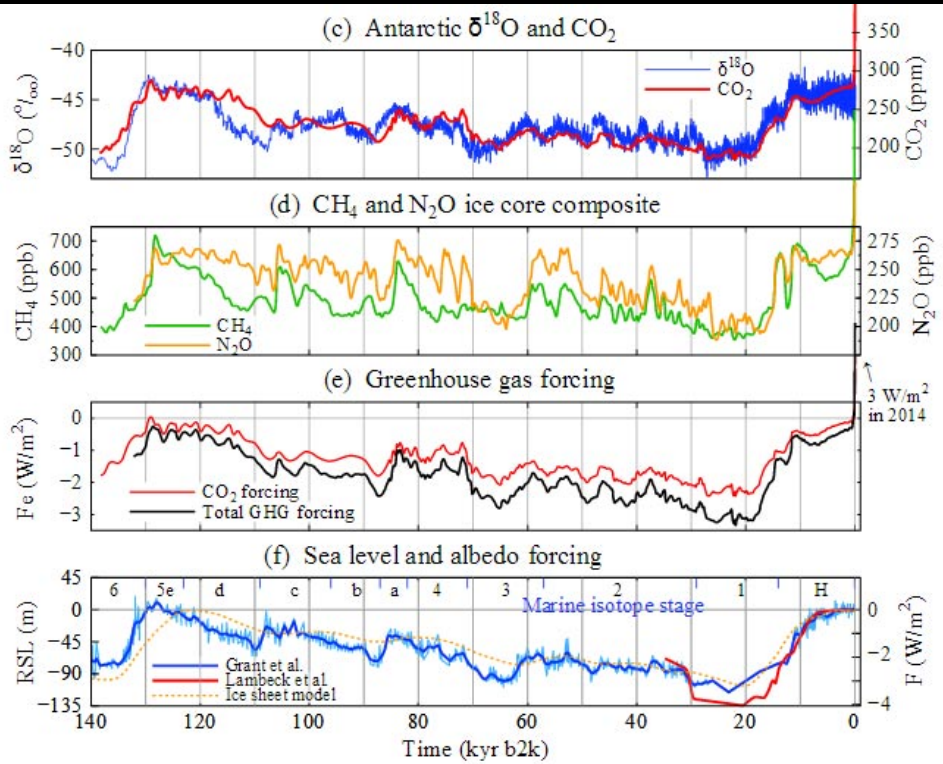


Figure 27. (a) Late spring insolation anomalies relative to the mean for the past million years. **(b)** $\delta^{18}O_{ice}$ of composite Greenland ice cores (Rasmussen et al., 2014) with Heinrich events of Guillevic et al. (2014). **(c, d)** $\delta^{18}O_{ice}$ of EDML Antarctic ice core (Ruth et al., 2007), multi-ice-core CO_2, CH_4, and N_2O based on a spline fit with a 1000-year cut-off (Schilt et al., 2010); scales are such that CO_2 and $\delta^{18}O$ means coincide and standard deviations have the same magnitude. **(e)** GHG forcings from equations in Table 1 of Hansen et al. (2000), but with the CO_2, CH_4, and N_2O forcings multiplied by factors 1.024, 1.60, and 1.074, respectively, to account for each forcing's "efficacy" (Hansen et al., 2005a), with CH_4 including a factor of 1.4 to account for indirect effect on ozone and stratospheric water vapor. **(f)** Sea level data from Grant et al. (2012) and Lambeck et al. (2014) and ice sheet model results from de Boer et al. (2010). Marine isotope stage boundaries from Lisiecki and Raymo (2005). Panels **(b–e)** are on AICC2012 timescale (Bazin et al., 2013).

Observed Sea Level During the Industrial Age, Rising at Accelerating Rate

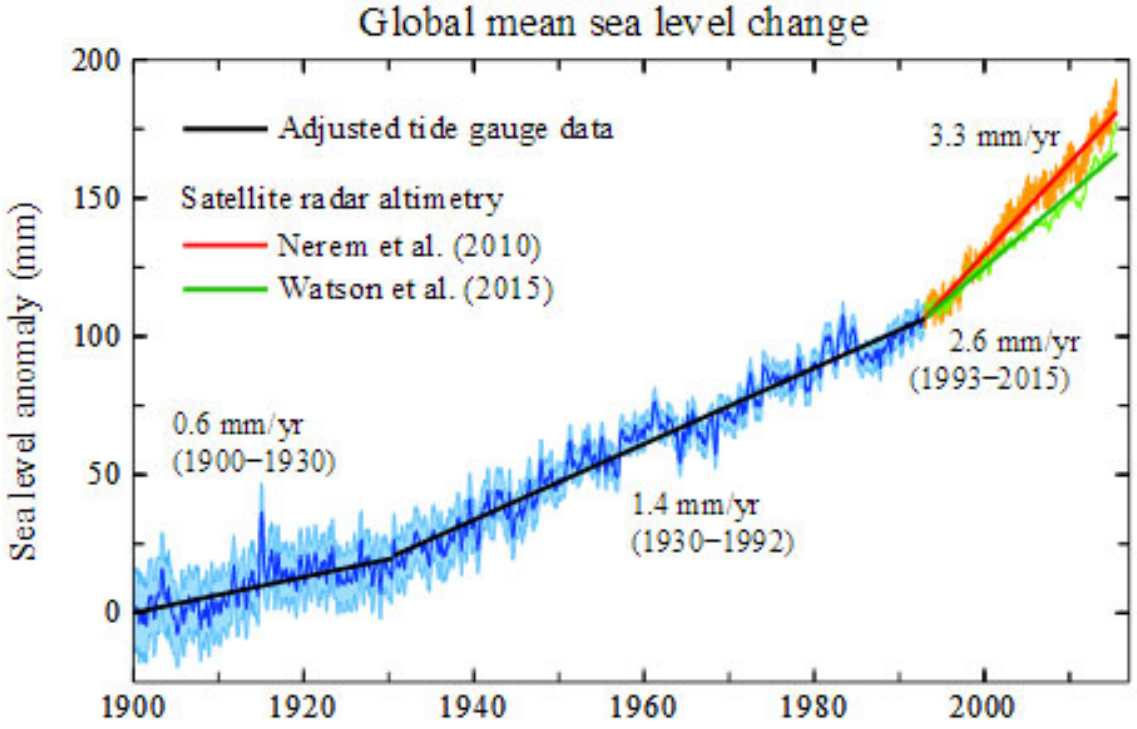


Figure 29. Estimated sea level change (mm) since 1900. Data through 1992 are the tide-gauge record of Church and White (2011) with the change rate multiplied by 0.78, so as to yield a mean 1901–1990 change rate of 1.2 mm year^{-1} (Hay et al., 2015). The two estimates for the satellite era (1993–2015) are from Nerem et al. (2010, updated at http://sealevel.colorado.edu) and Watson et al. (2015).

Accelerating Losses of Ice. Greenland loss rate doubling time ~13 years, and about ~8 years for Antarctica, from GRACE and Mass Balance methods. Still poorly constrainted by brief data

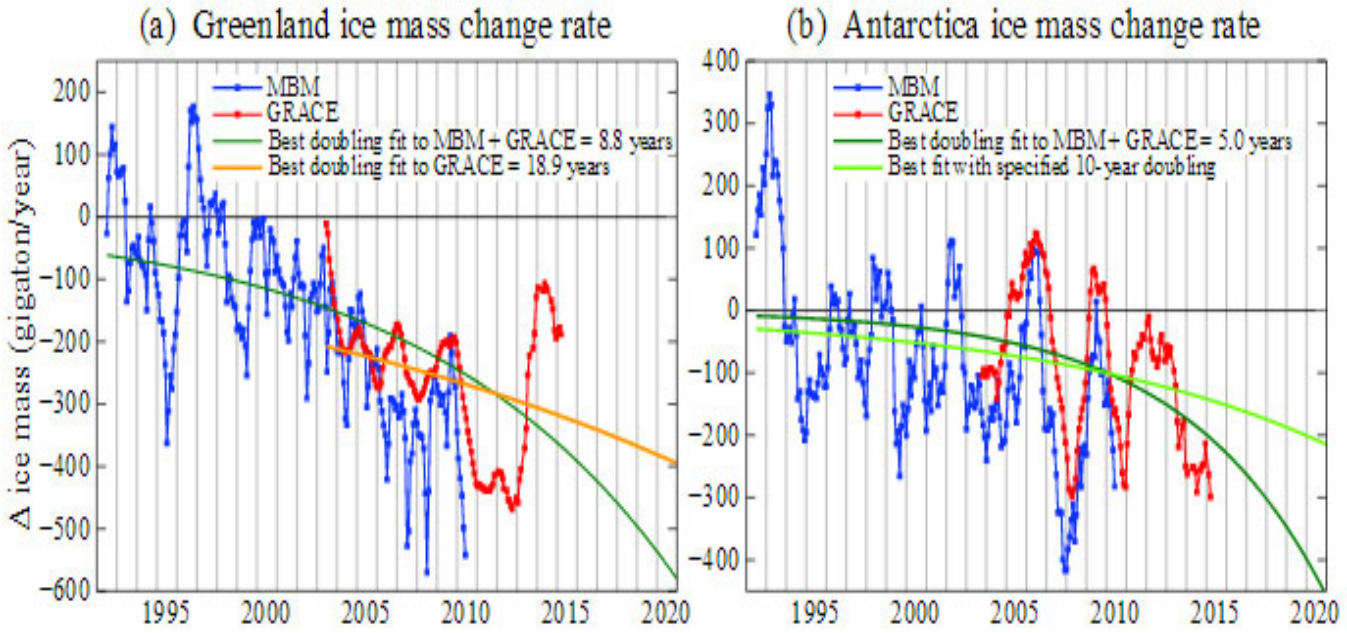
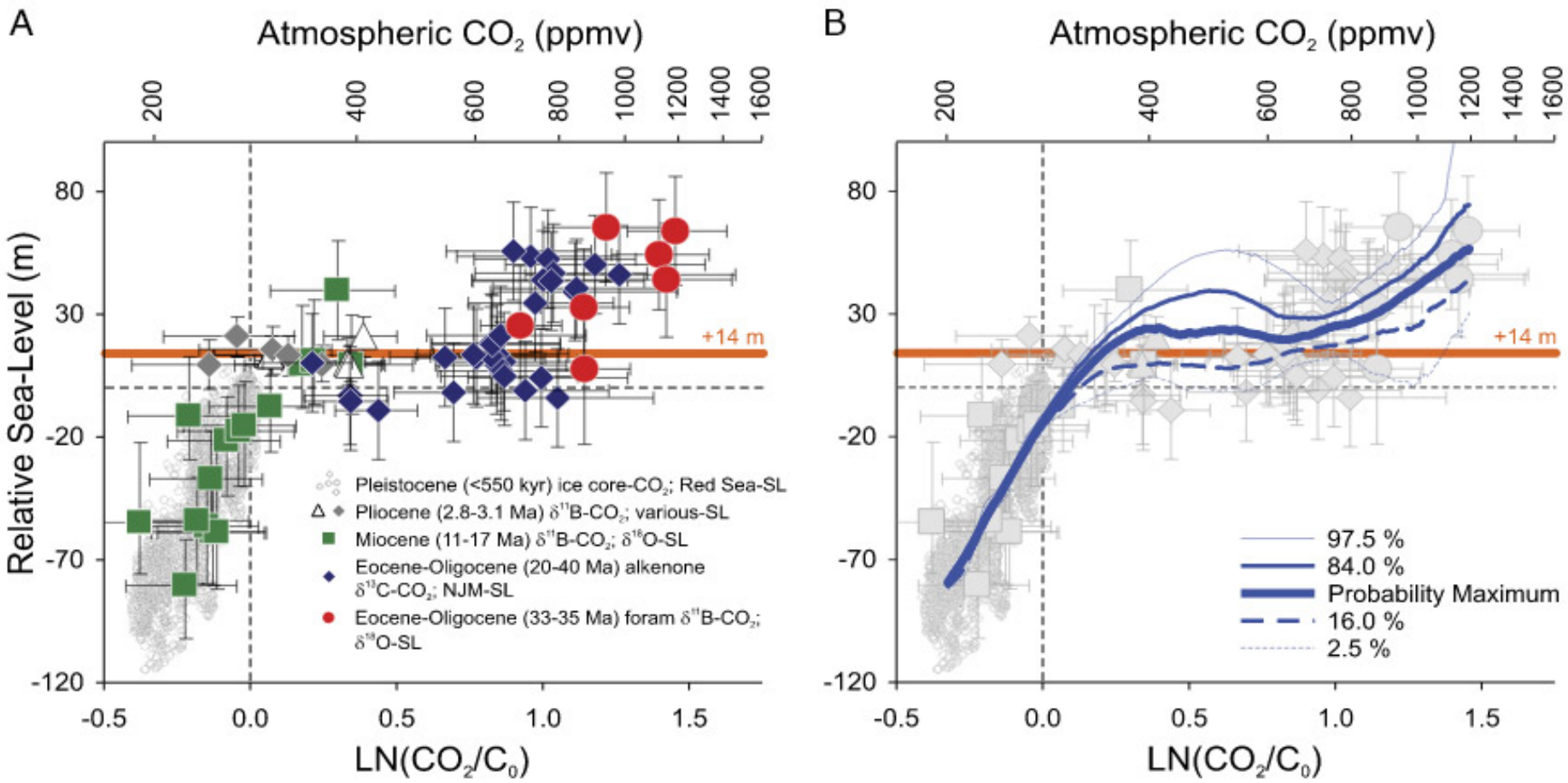


Figure 30. Greenland and Antarctic ice mass change. GRACE data are extension of Velicogna et al. (2014) gravity data. MBM (mass budget method) data are from Rignot et al. (2011). Red curves are gravity data for Greenland and Antarctica only; small Arctic ice caps and ice shelf melt add to freshwater input.

Studies using many locations around the world, show sea level rise will be far worse than early IPCC Estimates, which did not include ice sheet dynamics or other amplifiers

- **Raymo *et al.* 2012 studied just one location, the Bahamas, to show 20-40 ft sea level rise levels at today's temperatures in the past interglacial.**
- A year later, **Foster and Rohling (2013)** published a work consolidating evidence from the past ~40 million years at many locations to determine sea level rise at thermal equilibrium (when climate has finally stabilized at a given new CO2 level) for various CO2 levels
- ***They find that at CO2 of 400 ppm (8ppm lower than today's level), sea level will rise at least 9m and most likely ~24m above present levels***, due to complete melting of Greenland, and the West Antarctic Ice Sheet (WAIS), and part of the remainder of Antarctica as well. **24m = 80 feet.**
- **80 feet of sea level rise, will** submerge the Earth's greatest cities, and millions of square miles of continental area, including the prime farmland in delta regions worldwide (and California). **Geology.com** shows how such rising sea levels flood key areas, including Santa Cruz County.
- Delaware was the first state to join the United States, and it will be the first to disappear underwater (bits of Florida will still remain when Delaware finally is gone). **First in / First out. FIFO.** Cruelly ironic.

Foster & Rohling 2013 - Paleo climate shows that 400 ppm CO2 leads to final sea level rise of ~24m (80 ft) above today's, and conclude "Our results imply that to avoid significantly elevated sea level in the long term, atmospheric CO_2 should be reduced to levels similar to those of preindustrial times." (That's 280 ppm, vs. today's 408 ppm). 350.org's goal of 350ppm is NOT ENOUGH, scientists now say we need to return to ~280ppm

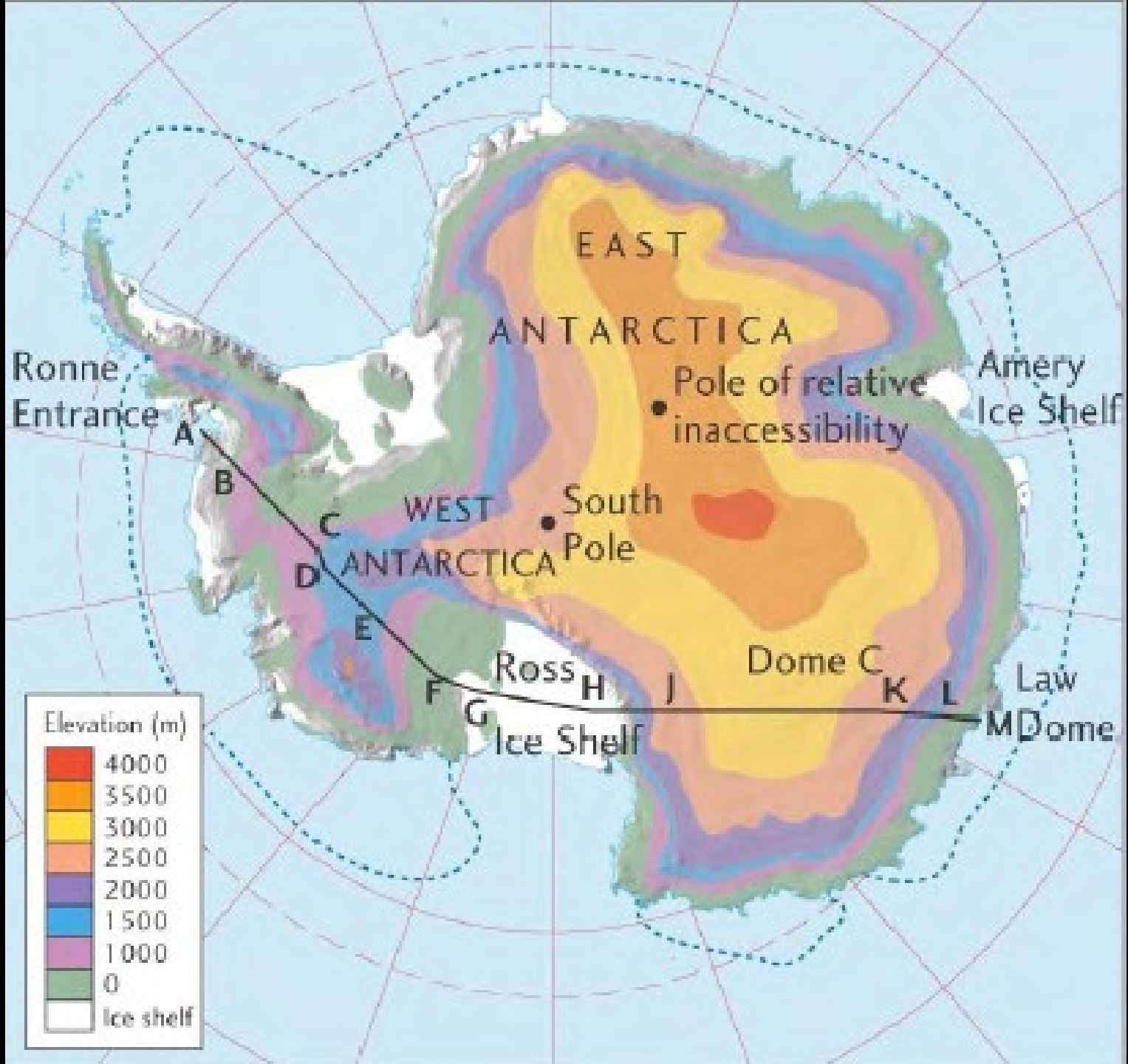


Evidence The Southern Meridional Overturning Circulation (SMOC) is Now Also Weakening

- The thermohaline circulation is global, and so it's perhaps not surprising that the Southern hemisphere circulation is also affected.
- **The Weddell Sea portion of the SMOC has weakened by ~17% from 1984 to 2008 (Huhn *et al.* 2008)**
- This is likely due to the melting of Antarctic ice, adding fresh cap of cold water onto nearby sea, (and thin ice sheet as well), forcing warmer waters deeper where they cannot radiate energy, instead melting the underside of local ice shelves
- **And in 2014, we discovered….**

Collapse of the West Antarctic Ice Sheet (WAIS) Has Now Begun

- NY Times Article on new published research paper.
- Warmer waters underneath the ice shelves at the terminus of the largest West Antarctic glacier has eaten away at the bottom of the ice mass, disconnecting the grounding line and begun the collapse of the ice sheet. It is now described as "unstoppable".
- **Thomas Wagner, director of NASA's Polar Ice Sheets program: "There's nothing that can stop it now".**
- While most of the cause is the warmer waters surrounding Antarctica due to greenhouse warming, exacerbated by the cap of cold meltwater, it is also being exacerbated by geothermal heating. A tectonic spreading zone underlies parts of West Antarctica (but no evidence this geothermal heating has been anything but constant over recent geologic time – Schroeder *et al.* 2014)


EAST
ANTARCTICA
Ronne
Entrance
Pole of relative
inaccessibility
Amery
Ice Shelf
A
B
C
D
E
WEST
ANTARCTICA
South
Pole
F
G
Ross
Ice Shelf
H
J
Dome C
K
L
M
Law
Dome
Elevation (m)
4000
3500
3000
2500
2000
1500
1000
0
Ice shelf

The West Antarctic Ice Sheet (WAIS) sits in a shallow ocean basin

- The West Antarctic Ice Sheet is grounded in a shallow ocean basin, which it fills. If that ice melts enough to pull the bottom of the ice off the sea floor ridges, it is no longer anchored, can no longer resist being pushed by the attached landed glacial ice sheets experiencing gravity, and they accelerate and slide into the warmer ocean.
- This is now the process we see happening with these new papers just published (**Rignot *et al.* 2014**)
- This process was **predicted back in 1978 by glaciologist John Mercer**
- From this alone, global sea level rise will almost certainly go up more than 10 feet going forward, the timing depends on our actions. **And more in the Northern Hemisphere, due to gravity effects.**

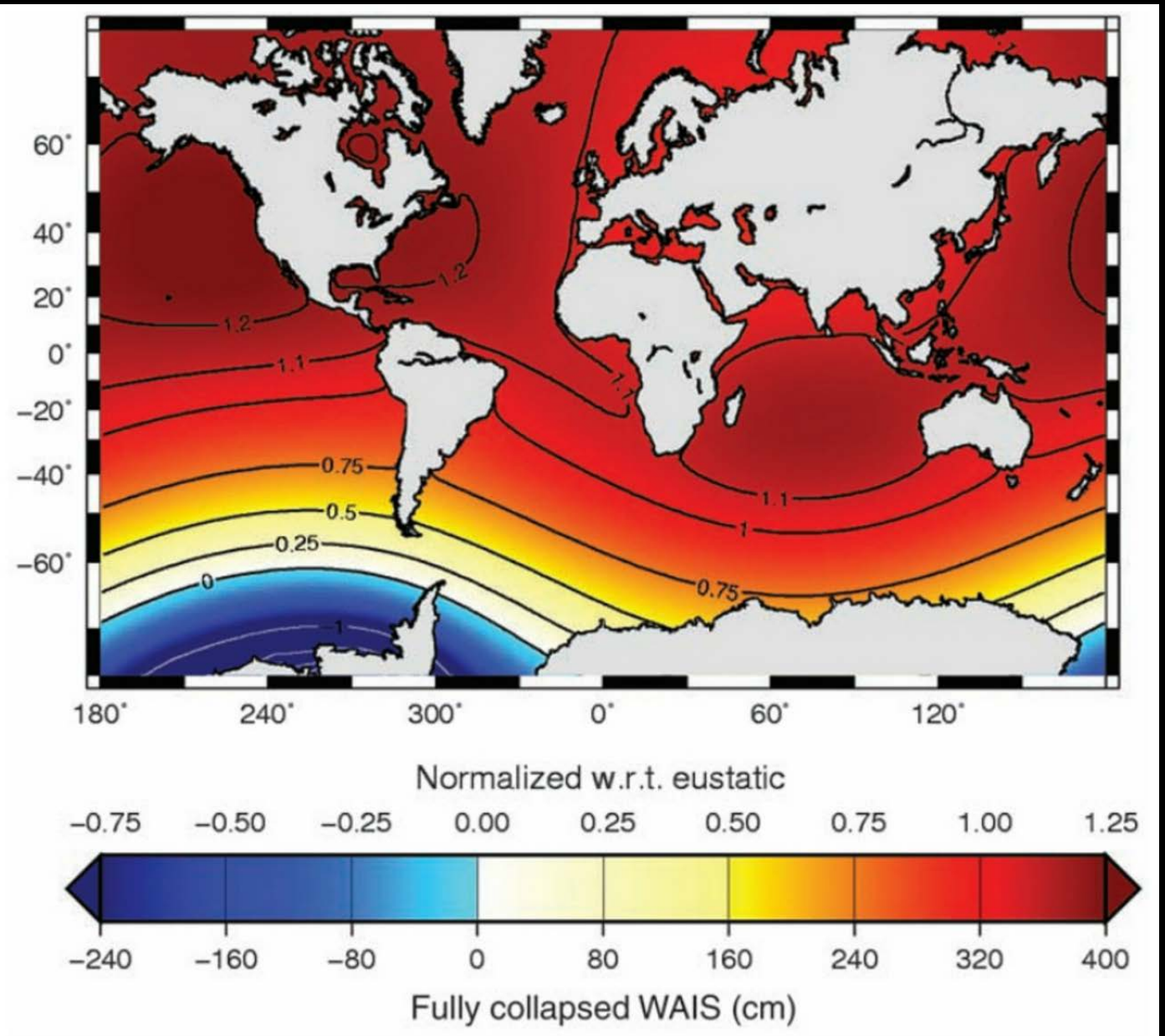
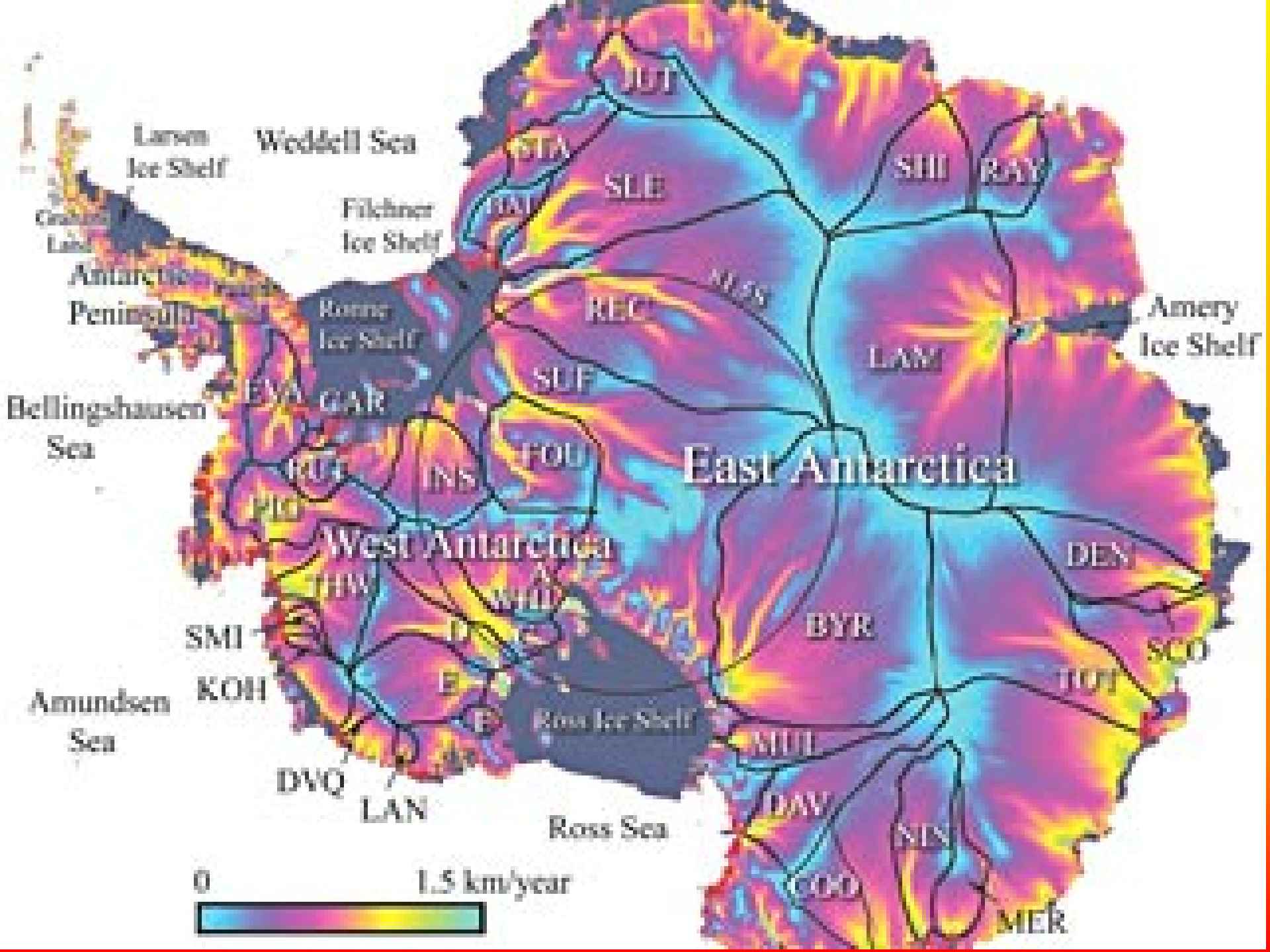


Fig. 3. Regional SLR after instantaneous removal of ice from the ROI, including the effects of self-gravitation, elastic rebound of the lithosphere, and Earth rotation perturbations but excluding the effects of ocean circulation (*29*) and other sources of ocean mass. w.r.t., with respect to.

The gravitational attraction of the oceans towards Antarctic Ice will lessen as it melts, preferentially raising sea levels in the NORTHERN hemisphere. <u>Worst is North America</u>


Larsen
Ice Shelf
Weddell Sea
Filchner
Ice Shelf
Antarctic
Peninsula
Ronne
Ice Shelf
Bellingshausen
Sea
Amery
Ice Shelf
East Antarctica
West Antarctica
Ross Ice Shelf
Amundsen
Sea
Ross Sea
0
1.5 km/year
JOI
SLE
SHI
RAY
REC
LAM
SUF
GAR
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BYR
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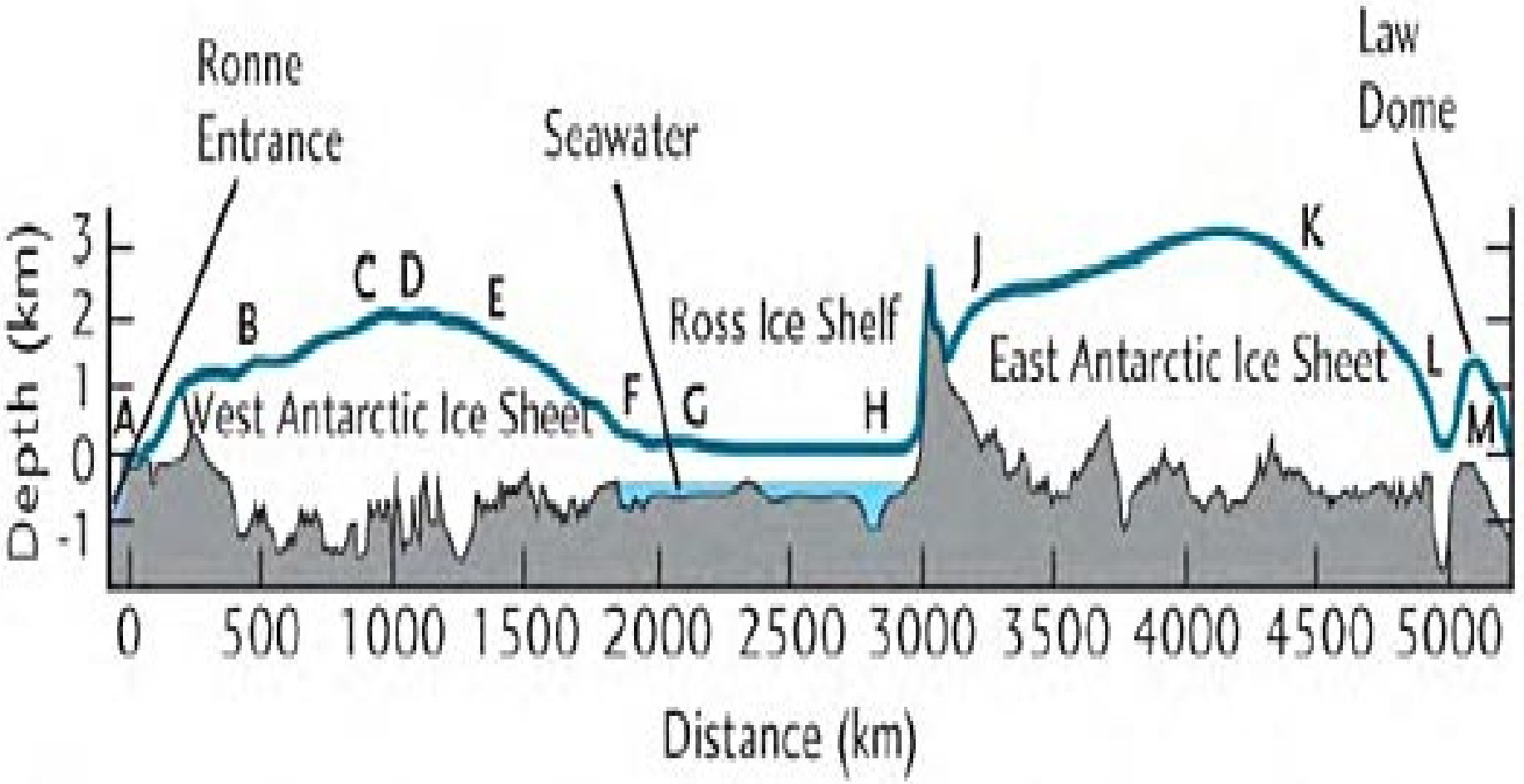
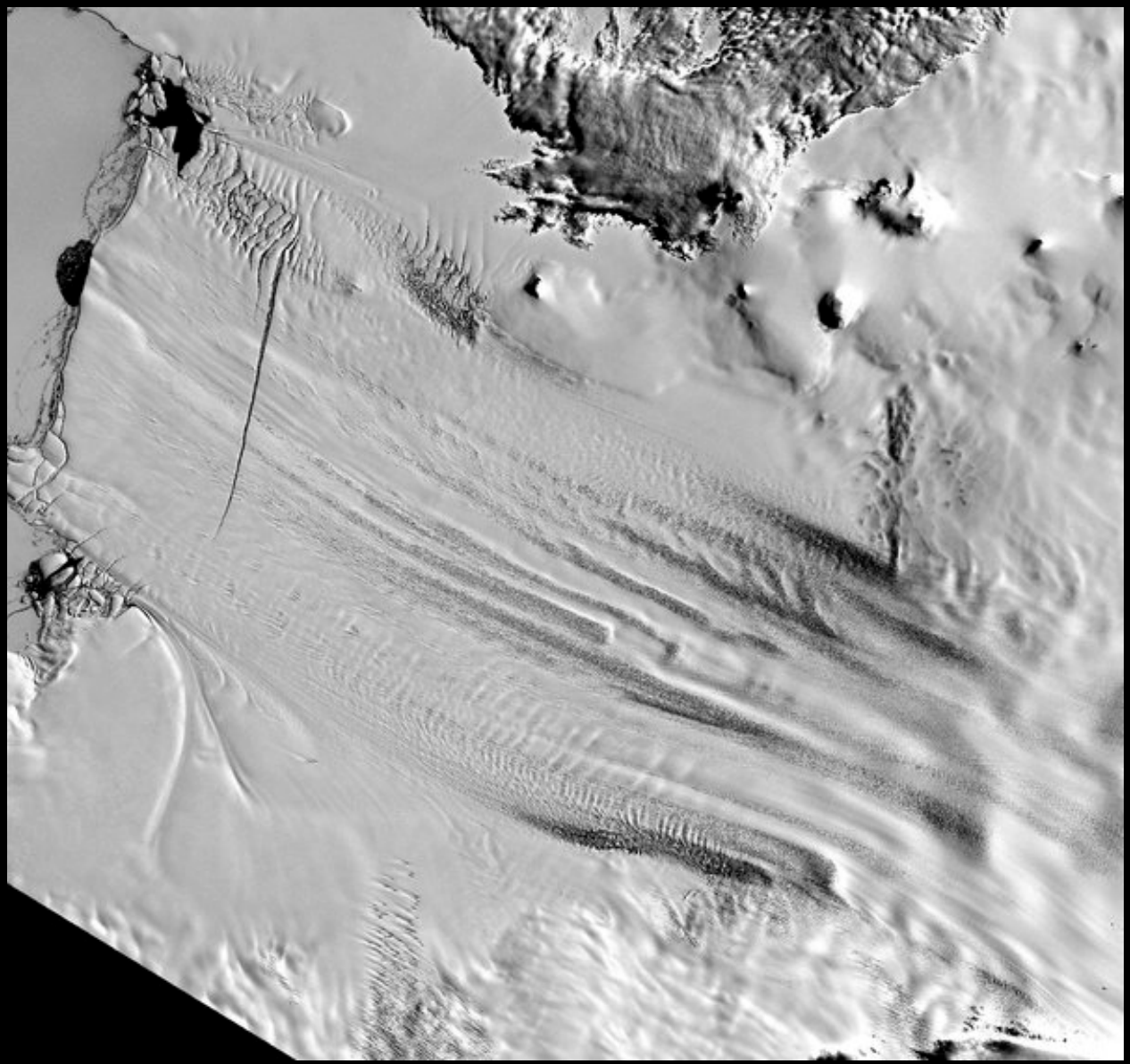
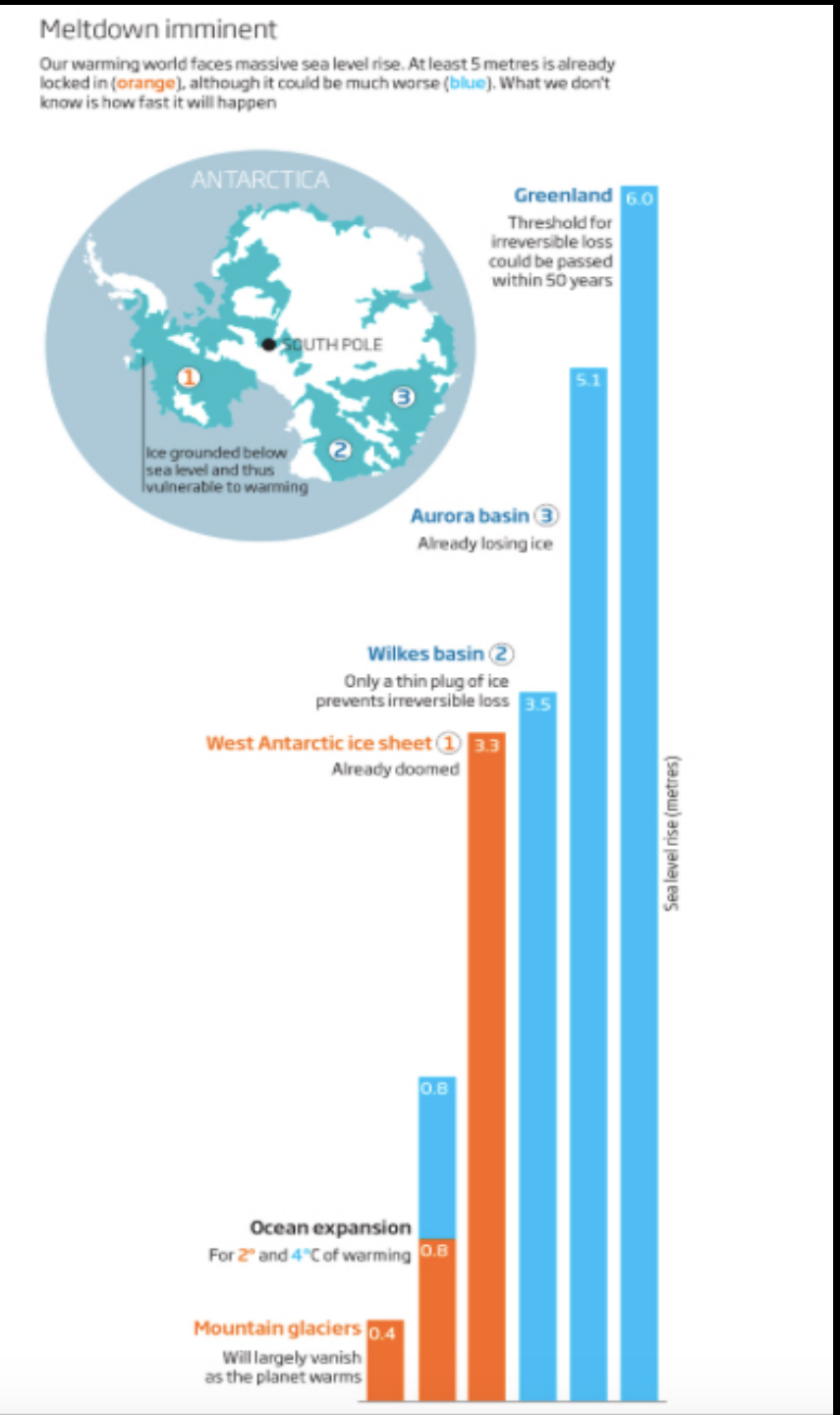
Antarctic ice sheets elevation profile: Note WAIS sits on a shallow ocean basin, grounded until now by the ridge line under the Ross Ice Shelf



Satellite photo: Breakup of the West Antarctic Ice Sheet Has Begun (May ‘14). Thwaites Glacier Terminus Here





Bars show how many meters of global sea level rise from most vulnerable sources. Ice sources in orange are already doomed

The Anthropocene and Hyper-Anthropocene

- Hansen argues, with Ruddiman (2003), that humans began affecting climate as soon as population began forest cutting and rice growing in significance, even thousands of years ago. If so, the Anthropocene likely began several thousand years ago, not just a century ago.
- Unlike Ruddiman, Hansen argues that the very weak effect of additional human carbon (~10ppm CO2) was sufficient to prevent cooling climate due to Milankovitch forcing because that forcing was very weak and the southern insolation trend was already positive and growing.
- Basically, he is arguing that climate is much more sensitive to CO2 than earlier had been assumed, but modelling proof of this is beyond current computer abilities, he says
- Now, we have entered the "Hyper-Anthropocene", with massive forcing from CO2 emissions by 1900. He points out…
- **Hansen *et al.* (2016)'s conclusions are fundamentally more dire than those of the IPCC AR5**

"Our analysis paints a very different picture than IPCC (2013) for continuation of this Hyper-Anthropocene phase, if GHG emissions continue to grow" – Hansen et al.

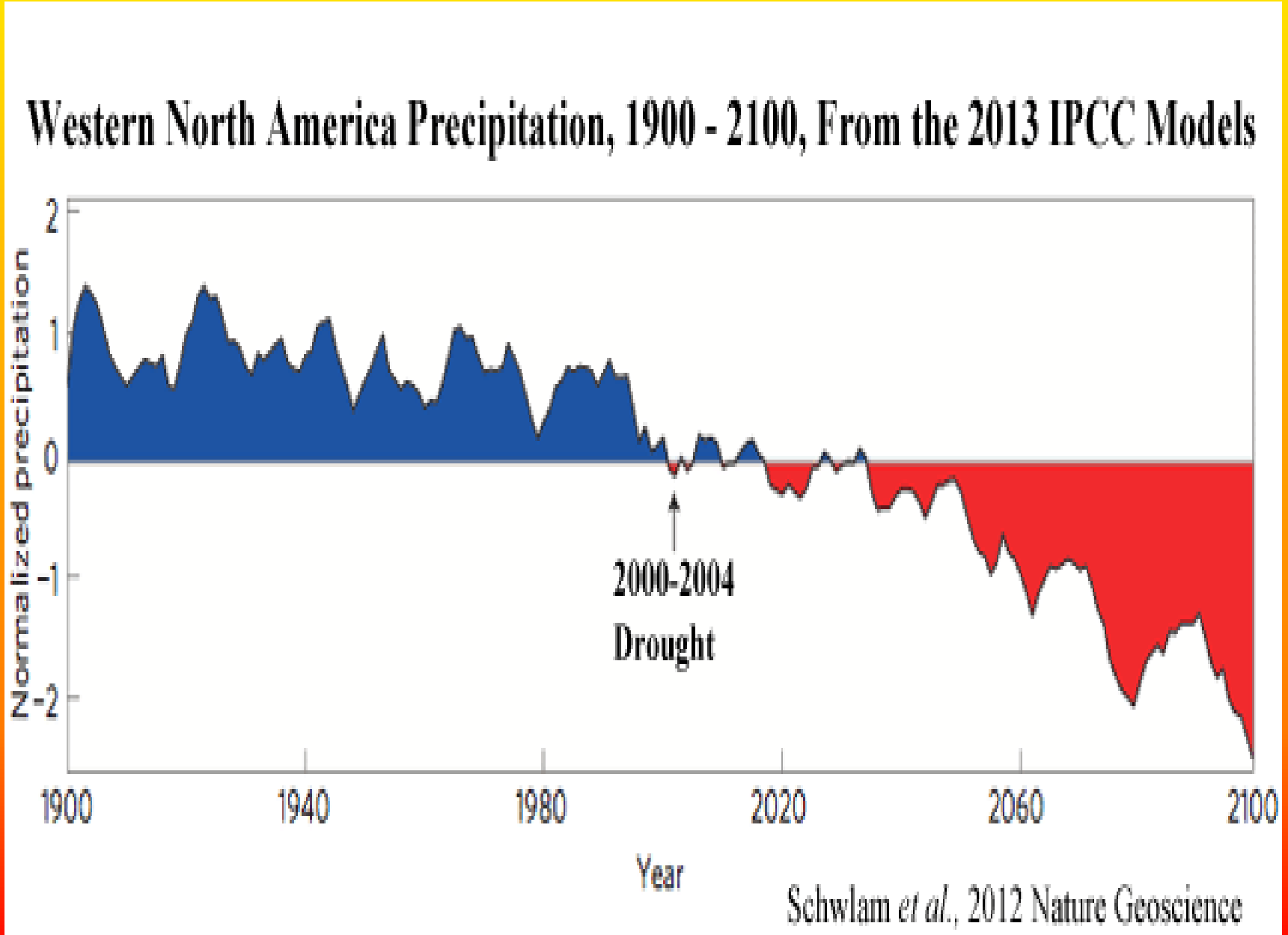
- 1. Unavoidable "multi-meter" sea level rise within 50-150 years
- 2. Full shutdown of the AMOC within a few **decades**
- 3. Super storms of such magnitude that *"all hell would break loose"* (yes, Hansen said exactly that. See his video summary linked on page 2)
- 4. Societal disruption and dire economic consequences
- 5. *"Conflicts arising from forced migrations and economic collapse might make the planet ungovernable, threatening the fabric of civilization."*

I Confess

- I can't do justice to this massive 52 page work in this brief talk. It is extremely well-referenced, articulate in its physical description of the logic and processes that argue for the conclusions
- And an hour or two is not enough, especially for a non-science audience.
- I'm very impressed with Hansen and his 18 co-authors' work. Knowing myself how much intensity it takes to organize thoughts and present the physical reasoning in a compelling and digestable way…. It's too rare.
- Of course it doesn't mean some inferences might not be wrong, because it's a complex undertaking and data is imperfect. But he's made strong cases for his conclusions.
- It argues for redoubled efforts on mapping the AMOC and SMOC, on atmospheric CO2 trends, and yet at a time when the Republican congress is seeking to cut climate science funding.

- Before confronting what we might do, here are the latest, and more local consequences for the coming century, from other research…

Even in IPCC Predictions – Western U.S. Droughts Are Just Getting Started. Schwlam *et al.* 2012.



These drought predictions may well be significantly too optimistic

- Climate change is predicted, and observed, to cause the northern tropical Hadley cell to expand north, bringing the desert belt with it.
- The problem is that observations are showing this migration is happening **3 times faster** than the simple IPCC models, which include no cloud feedbacks **(27:40 into this interview of cloud physicist Dr. Steven Sherwood, and Seidel *et al.* 2007**, quoting numerous studies)

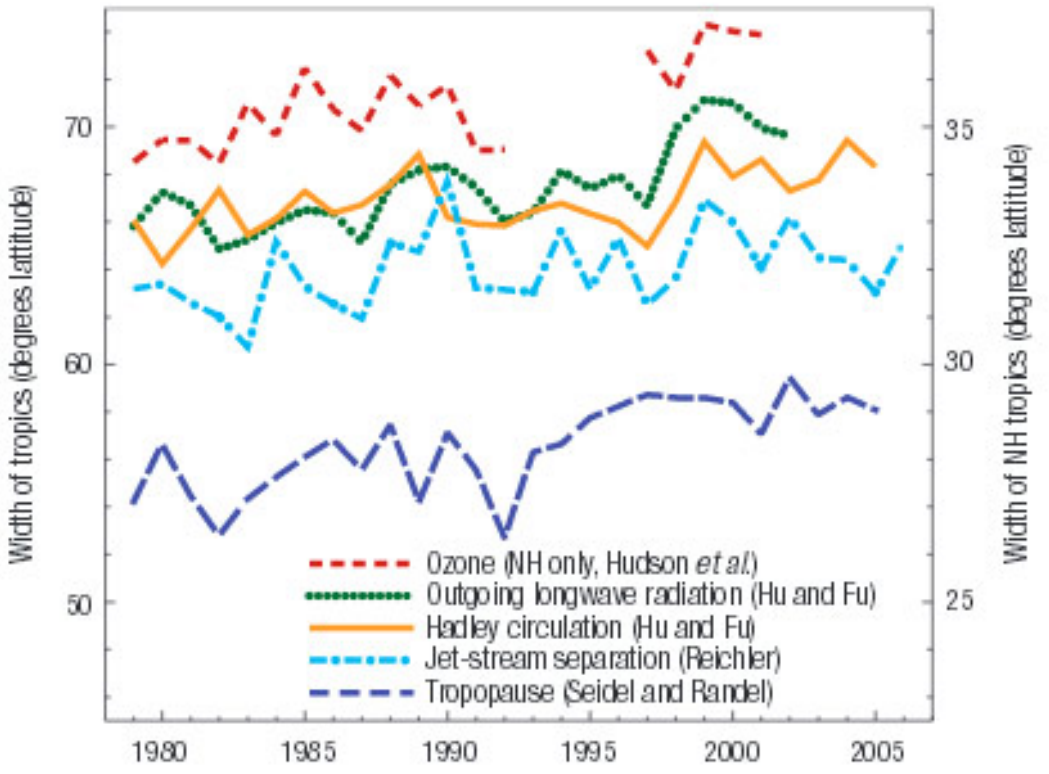


Figure 2 Changes in several estimates of the width of the tropical belt since 1979. These include: the width of the Hadley circulation, based on both outgoing longwave radiation and horizontal winds stream function[10]; the separation of the Northern and Southern Hemisphere subtropical jet-stream cores; 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.

Northward expansion of the Tropical Hadley cell boundary observed 1980 to 2005 (Seidel et al. 2007), is 3 times faster than climate models predicted

Redwoods define the beauty of Santa Cruz county. But **the current habitat for redwoods likely will no longer be able to support them before the end of the century** (19:39 into **this documentary**, w/ studies by county scientists). **The deserts of southern California are marching northward (Seidel 2007), already by ~140 miles from 1979 to 2007**

The 2015/2016 El Nino Might be a Sign

- Unlike past strong El Nino's (1997, 1982, 1955…), this one's rain was confined to the northern half of California, with Southern California getting hardly any.
- Even here in Santa Cruz, we only got 20th century "average" rainfall. Yet this was, by the temperature index, the strongest or second strongest El Nino on record.
- The jet stream boundary of the zonal flow was significantly farther north than in the past.
- What does that mean for non-El Nino years going forward?

Stanford's Prof. Ken Caldiera, Using Climate Modelling in a "Business as Usual" Scenario (in IPCC nomenclature; RCP 8.5)…

- …finds that by year 2100, the climate of the Santa Cruz/San Jose area will be that of dry, desert-like and chaparral-covered San Diego County, and Seattle's climate will warm and dry to become that of present day San Jose. (**Caldiera 2014 in Nature**)
- **This would spell the end of our redwood forests**

What Can We Do?

The Principle Physics Constraint

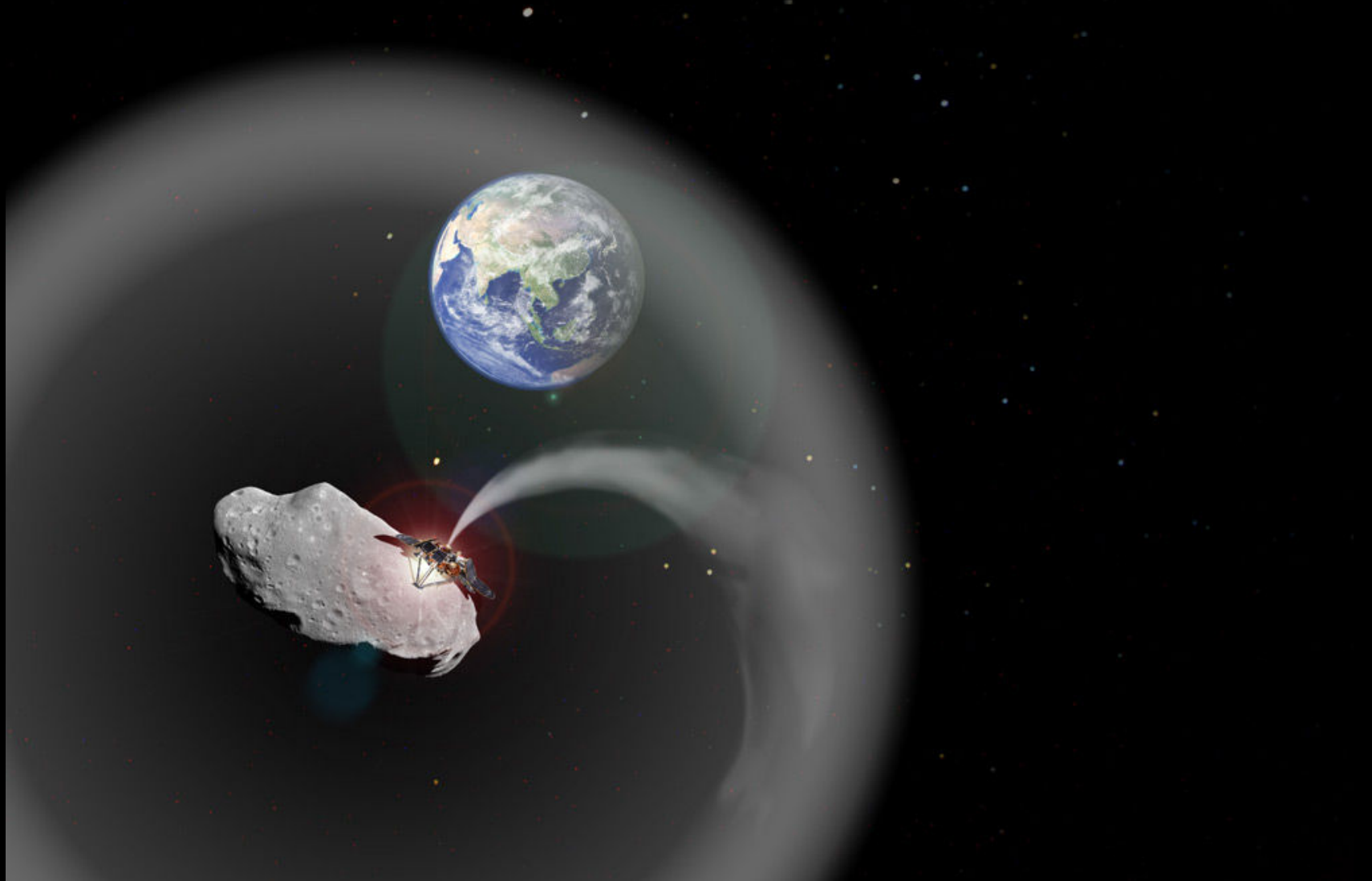
- Let's start with an obvious Truth: Earth has a heat imbalance problem. There are ONLY two solution catagories:
- **1.** You LOWER solar incoming energy from reaching the ground by reflecting it back to space before it arrives
- **2.** You RAISE the rate the Earth radiates its heat back to outer space.
- If it doesn't fit into these catagories, it's not really a long term solution

In the First Category

- The "Sun Shade" Strategies…

- Launch billions of controllable small "butterflys" to the L1 Lagrangian point (grav stability between Earth and Sun) to partially block sunlight (Angel, 2007)
- (but technology doesn't exist to make and get them there. Nor to control them.)

Or Maneuver an Asteroid to L1 and Sputter Dust off of it, to block sunlight



The L1 Lagrangian Point is an Unstable Equilibrium Point for Gravity

- It's a "hill" in the equipotential gravity surface, such that things there will tend to slide off; either falling into the sun, or falling into the Earth. This will happen unless you maintain active continual positioning.
- What if control failure happens?
- A big asteroid, falling off the L1 "hill" and accelerating towards Earth? - in the immortal words of Indiana Jones (before the A-bomb in the *Crystal Skull* movie) *"that can't be good"*

Injecting Reflective Aerosols into the Stratosphere?

- This would mimic the effect of large volcanic eruptions in their climate effect, and so we are confident they would indeed cool the planet

Injecting Reflective Aerosols into the Stratosphere

- This would mimic the effect of large volcanic eruptions in their climate effect, and so we are confident they would indeed cool the planet
- The “aerosol direct effect”, reflective sulfate aerosols injected into the lower stratosphere reflecting incoming sunlight, where they would remain for perhaps many months to a year or so because they’d be above the ability of rain clouds to pull them down and rain them out. Gravity, however, would still eventually pull them down.

But, More Climate-warming High Clouds?

- The “aerosol indirect effect” (seeding clouds) would hopefully not apply. In fact, if the aerosols actually caused an excess formation of cirrus clouds at this altitude, this would WARM the Earth, not cool it.
- This altitude has fewer nucleation opportunities than does the lower troposphere. That would appear to change with this strategy.
- However, ice nucleation is less sensitive to CCN’s and the guess is that this will not be a serious problem
- From 20th century volcanic events, it does appear the net of all effects is cooling Earth’s surface

Other Issues with Aerosol Injection

- Sulfate aerosols would come down out of the stratosphere on a ~2 years time scale at most. So need constant injection, however, the costs look quite cheap compared to other ideas
- Atmospheric sulfates make sulfuric acid. Continuous acid rain on our surface water. I've got no figures yet on how significant this would be, so it might be small.
- These aerosols would also accelerate loss of stratospheric ozone, especially with the added stratospheric water vapor. It would affect not only the poles, but all over the globe. But quite possibly minor, judging from volcanic experience.

More Issues

- Sulfate aerosols partially block Earth's outgoing radiative cooling, but their high reflectivity for incoming sunlight more than make up for this
- Astronomers would not be happy (but, they're not a significant voting block, so who cares?)
- **The moral hazard….**
- **– We use aerosol injection as an excuse to foot-drag on real and long term solutions. ALL sun shade strategies at best only cool the planet, by themselves, they do nothing to help the problem of CO2-induced ocean acidification if we continue to burn carbon.**

- However, **Kwiatkowski *et al.* 2015** find that comparing higher CO2 emissions but paired with sulfate aerosol shading, does lower sea surface temperatures and therefore helps with coral bleaching, vs. no aerosol shading and lower CO2 emissions. (but, it hurts aragonite calcification of the corals, so maybe the algae would be happier, but would they still have a coral host to be symbiotic with??)
- **As a desperation measure to halt temperature rise and therefore ice loss and sea level rise, they should continue to be investigated.**
- **But ONLY if we have the commitment to continue aerosol injection until atmospheric CO2 levels are somehow brought way down…**

“Business as Usual” Climate Models without, and with sulfate aerosol injection for 50 years. At end, aerosols rain out, and high CO2 forcing from now too-cool Earth causes very rapid catch-up warming (Robock 2014). SRM, once started, MUST be continued until atmospheric CO2 levels are artificially brought back down to levels in equilibrium with SRM-induced temperatures.

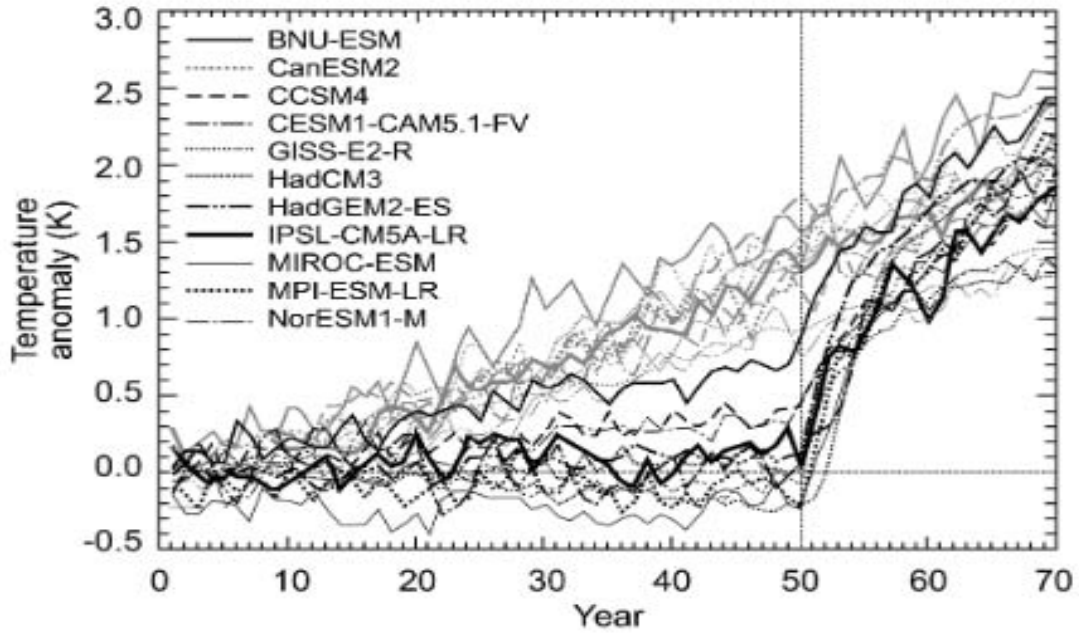


Figure 3 Evolution of annual mean anomaly of global mean near-surface air temperature (K) in the G2 simulations (black lines) with respect to the long-term mean from each model's control simulation. Time series from corresponding 1% CO_2 $year^{-1}$ increase simulations are also shown (gray lines). The termination of geoengineering in the G2 simulations is indicated by the dashed vertical line.
(Figure 1 from ref. 24; see this reference for climate model abbreviations and details).

From an MIT Tech Review Article by Rotman 2013

- *(Harvard's James) Anderson says that adding sulfates to the stratosphere worries him "tremendously" because of the potential impact on ozone. He points to a study his group published last year in Science showing that increasingly intense summer storms over the United States—triggered by climate warming—are injecting more water vapor into the stratosphere. That, he says, could speed the ozone-destroying reactions: "If nature is adding increased water vapor to the stratosphere and we're adding sulfates, it is a very lethal cocktail for ozone loss."*

Table 2 Benefits and risks of stratospheric geoengineering. The effects that are observed after volcanic eruptions are indicated by an asterisk (*).[56] (Updated from ref. 57).

Benefits	*Risks*
1. Reduce surface air temperatures*, which could reduce or reverse negative impacts of global warming, including floods, droughts, stronger storms, sea ice melting*, land-based ice sheet melting, and sea level rise*	1. Drought in Africa and Asia*
2. Increase plant productivity*	2. Perturb ecology with more diffuse radiation*
3. Increase terrestrial CO_2 sink*	3. Ozone depletion, with more UV at surface*
4. Beautiful red and yellow sunsets*	4. Whiter skies*
5. Unexpected benefits	5. Less solar energy generation*
	6. Degrade passive solar heating
	7. Environmental impact of implementation
	8. Rapid warming if stopped*
	9. Cannot stop effects quickly
	10. Human error
	11. Unexpected consequences
	12. Commercial control
	13. Military use of technology
	14. Conflicts with current treaties
	15. Whose hand on the thermostat?
	16. Degrade terrestrial optical astronomy*
	17. Affect stargazing*
	18. Affect satellite remote sensing*
	19. Societal disruption, conflict between countries
	20. Effects on airplanes flying in stratosphere*
	21. Effects on electrical properties of atmosphere
	22. More sunburn (from diffuse radiation)
	23. Continued ocean acidification
	24. Impacts on tropospheric chemistry
	25. Moral hazard – the prospect of it working would reduce drive for mitigation
	26. Moral authority – do we have the right to do this?

Difficult, thorny risk/benefit tally for stratospheric sulfate injection idea Robock (2014)

With all the Worry, though…

- It is the cheapest climate-significant action we could take.
- For about $1 billion/year we could inject ~1/4 million tons of sulfates into the stratosphere, far less than major volcanic explosions have done this past century, and yet enough to measurably cool global climate
- The effects on ozone, more cirrus clouds, changing rainfall patterns, and the rest, are not well known, but perhaps small scale experiments could bring enough confidence to the outcome to make it seriously on the table?
- Do I think we'll become desperate enough to try it? Yes. I do believe that day will come. In fact, now as of late 2016, many climate scientsts contend it's already here. We'd better study it and thoroughly understand what it will do, NOW.

Serious Political Problems with GeoEngineering Such as Stratospheric Aerosols

- Any GeoEngineering could be used as a weapon to *e.g.* increase/decrease rain for one country at the expense of neighbors or political enemies.
- Russia has no evident interest in halting climate change; they benefit from thawing of the Arctic permafrost and easier access to massive underground natural gas reserves there, and in the off-shore Arctic oil reserves. Any unilateral attempt by the US and/or Europe to begin massive stratospheric aerosol injection to re-freeze the Arctic may well be regarded as an act of War.

Enhance carbon capture by ocean phytoplankton by enhanced upwelling through pumps/pipes

- Looked at by Lovelock and Rapley (2007) and discussed here
- And also in this promotional video by Atmocean Inc. here
- Early evaluation: Too slow to matter (see next page), and quite possibly very dangerous to ocean ecosystems, about which we have only sketchy knowledge
- Deep ocean pipes (OTEC) have been around in a small way for almost a century, generating power using the thermal difference between deep and surface waters. As a climate strategy, they have been looked at by a number of research groups…

Pump Cold Ocean to the Surface! Is this our "Revolutionary" Solution to Global Warming? Our Pot of Gold at the End of the Rainbow search for GW Solutions?

Note How Elephants Deal with Heat…

…by sending warm blood to those big heat exchangers – ears!

Surface heat is able to radiate away easily. CORE heat is buried and unable to leave. Keep this in mind in what follows…

Capping the surface of the ocean with cold water will indeed cool climate – initially.

- But you are TRAPPING the Earth's heat (sounds a bit like GHG's, no?) under that cap.
- Recall another basic fact, that it is the thermal inertia of the oceans (~700x that of the atmosphere) which prevents temperatures from dropping even if we halt all GHG emissions. The ocean is the Elephant, and the surface and atmosphere are the Ears.
- Clearly - we need to **HELP** the oceans cool, not **make it harder**

So It should not be surprising that the long term effects of OTEC are very negative.

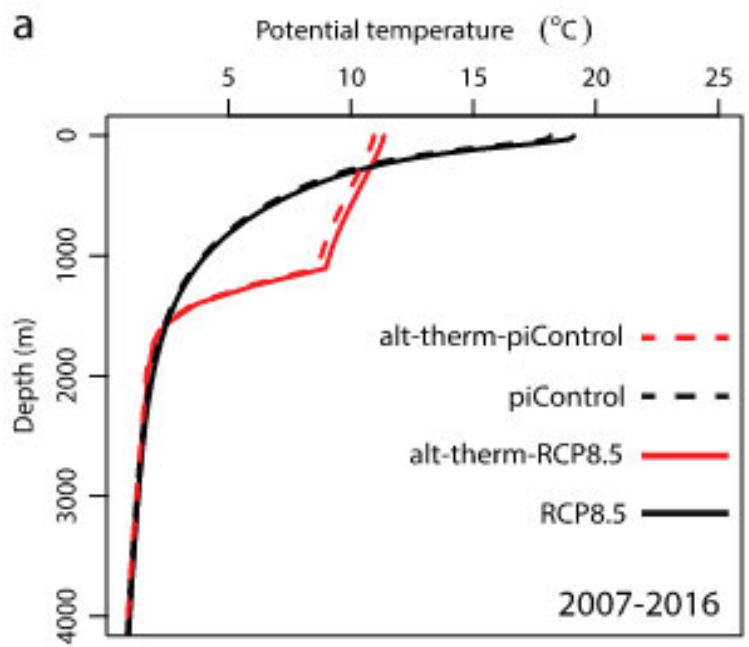
- **Kwiatkowski, Ricke and Caldiera 2015 in Envir. Res. Lett. (hereafter KRC15) studied the effects on climate of blanketing the oceans with OTEC pipes** (summaries are **here** and **here**)

KRC15's Methods:

- A high resolution fully-coupled climate model integrating ocean, land, air, cryosphere (land and sea ice), with cloud cover and bio/geo chemistry, and time-stepped 1200 years after thermocline altered as it would be by widespread use of OTEC pipes to 1 km depth, and left on throughout.
- Their standard case ran OTEC pipes at sufficient strength to reduce ocean surface temperatures by 7C. They also ran smaller vertical mixing strengths of 10% and 1% of standard. The 10% run reduced ocean surface temperatures by 3C which is closest to what was initially proposed by Alan Miller and his "Cool-it Earth" initiative for climate cooling.
- Each case assumed "business as usual" IPCC RCP8.5 human carbon emissions continuing (solid curves) and also a control case in which "pre-industrial" atmospheric CO2 was left alone (dotted curves in graphs that follow)

- KRC15 note that any real implementation of OTEC pipes would be on a smaller scale than they studied, **but the pattern and physics would be in the same direction as they find, and justified by their 10% and 1% cases which are all qualitatively the same in trends.**
- **Note they did not "disrupt" the thermocline. The initial conditions still have a thermocline, reduced in slope by the widespread OTEC pipes; More accurately, they "Altered" the thermocline, in KRC15's notation**

KRC15 Standard case: The initial effect is to cool the surface, as warm surface water is displaced deeper by upwelling pipes (left). But ~50 years later (right), the re-emerging buried heat raises the temperature of the entire 1km depth of the pipes, raising sea surface temperatures even higher than if OTEC pipes were never installed. True with continuing human CO2 emissions (solid), or without (dotted)



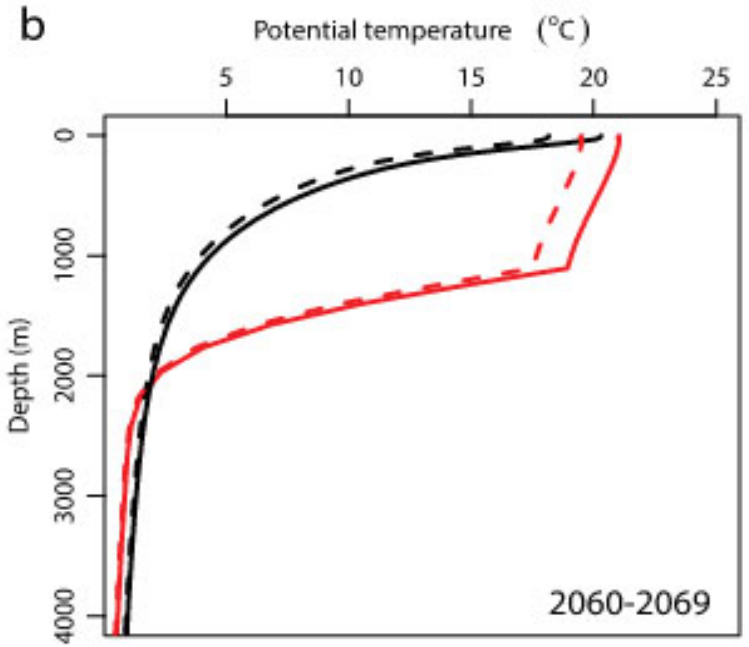


Figure 1. Thermocline impact. Mean (a) 2007–2016 and (b) 2060–2069 global potential temperature across the upper 4000 m of the water column.

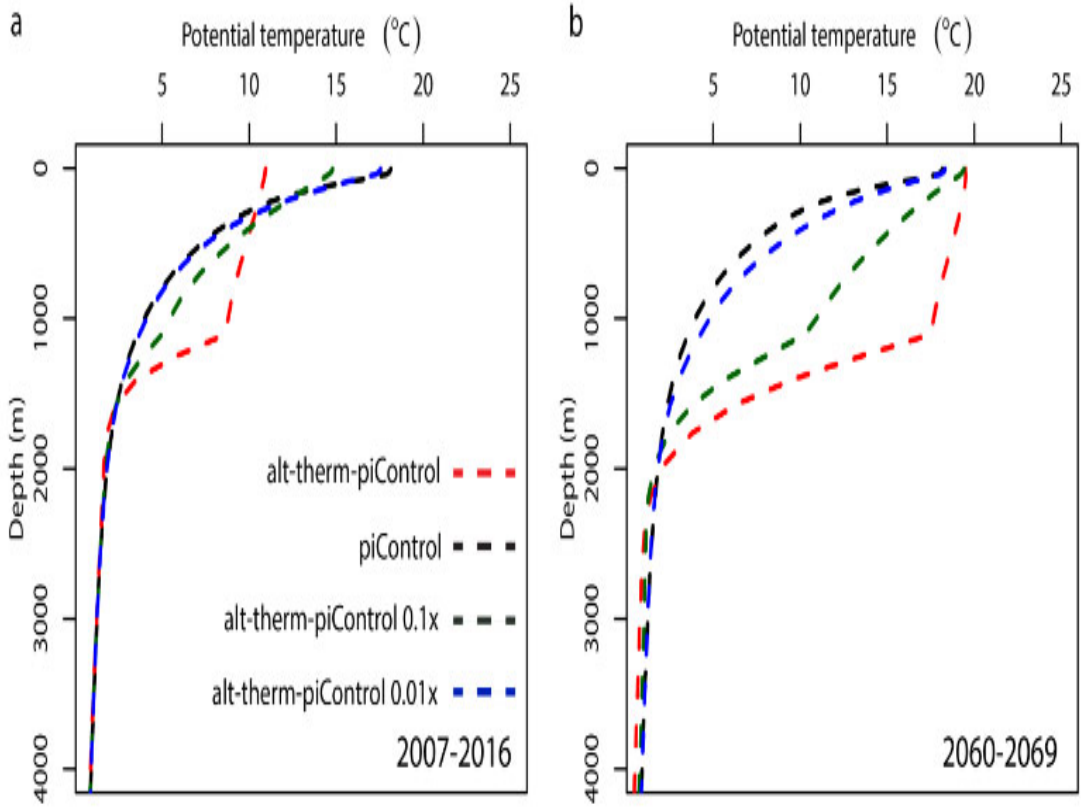


Figure S18. Thermocline sensitivity analysis. Mean a, 2007-2016 and b, 2060-2069 global potential temperature across the upper 4000m of the water column. The *piControl* simulation is shown in black and the standard thermocline disruption simulation in red. Enhanced vertical mixing simulations of 10% ($6cm^2s^{-1}$) and 1% ($0.6cm^2s^{-1}$) of the *alt-therm-piControl* simulation are shown in green and blue respectively.

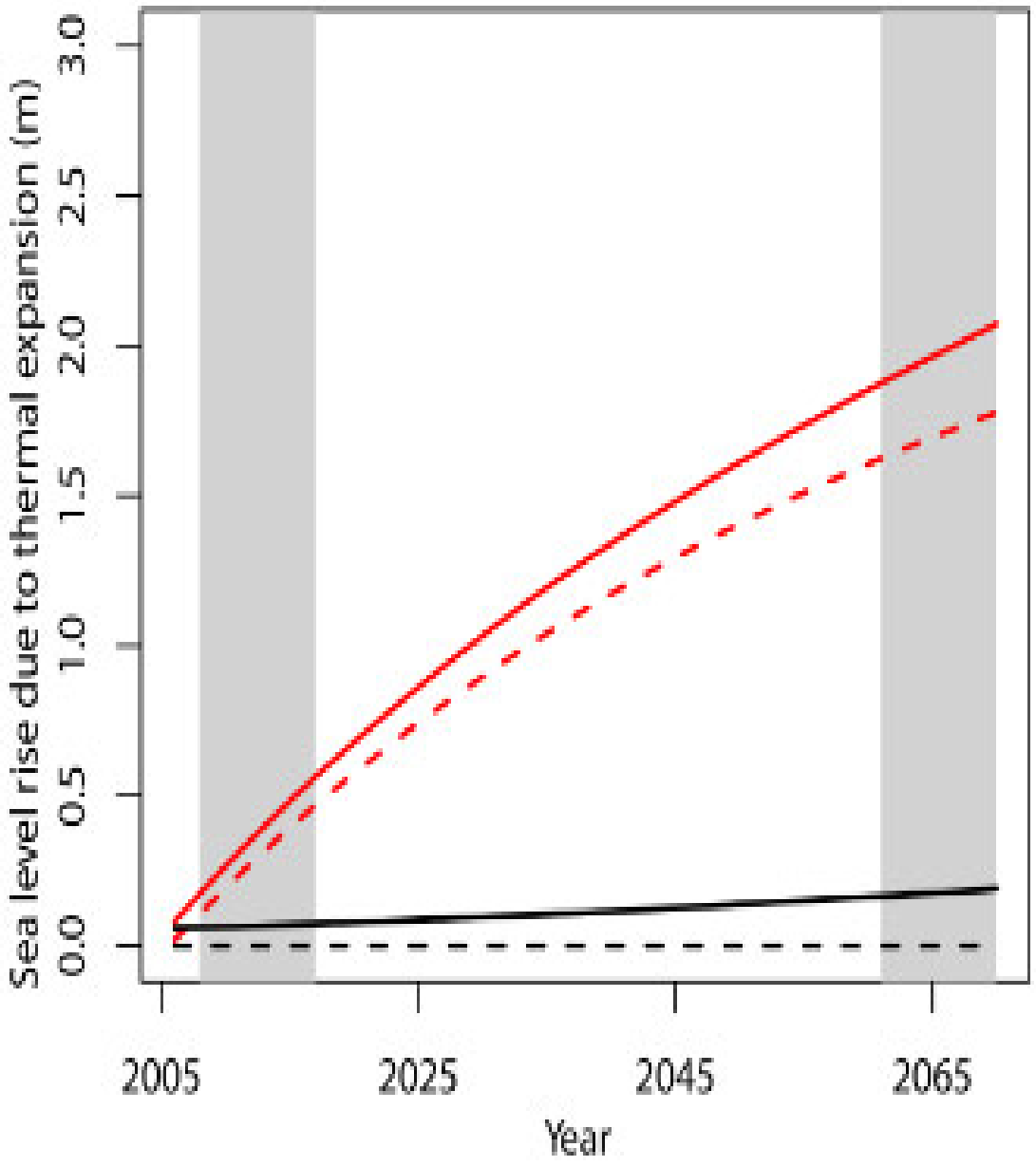
This is true even in the much milder 10% (green) and 1% (blue) cases. All runs, 100%, 10% and 1% include thermal mixing, show rising ocean temperatures right to the surface, as time goes on.

And again, All curves on this page have NO HUMAN CO2 Emissions

More bad effects: Reduced low clouds…

- The cooling ocean leads to a stronger differential between warm land and cooler ocean, causing increased rising convection over land together with now descending drier air over the oceans.
- This reduces surface convection and marine cloud cover, so incoming sunlight sees dark absorptive ocean instead of reflective cloud tops
- This raises Earth's absorption of solar heat, worsening our problems.

- And additional crippling effects…



KRC15 Standard case:

The trapped heat causes thermal expansion in the deeper ocean waters, raising sea levels. Solid red curve: RCP8.5 human emissions continue. Dashed red curve: CO2 at "pre-industrial" and no emissions. They're very close – ergo, sea level rise is almost all due to OTEC's trapping existing heat, very little due to heating from continuing human CO2 emissions

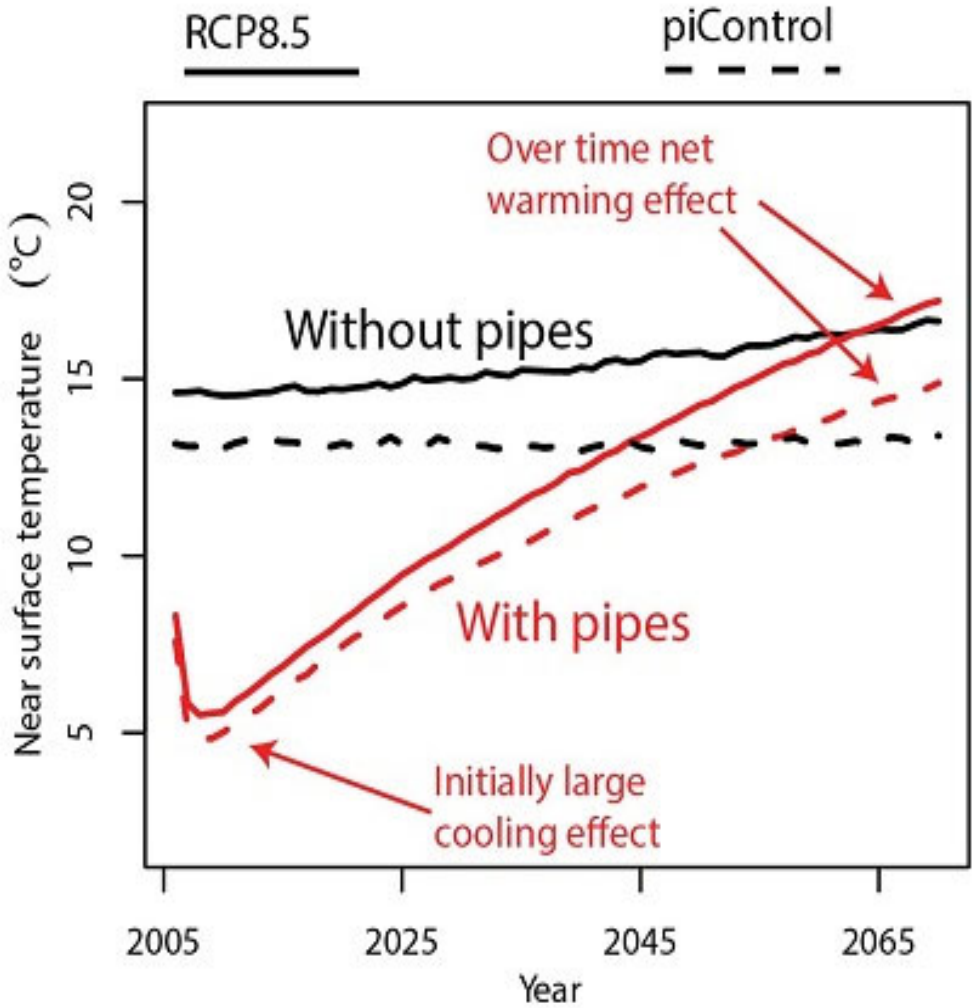
Worse: For the majority of the Ocean - The more OTEC is deployed, the more atmospheric CO2 is Boosted

- Pumping deep cold water to the surface also brings with it the dissolved CO2 within that water.
- As that water continues to warm near the sunlit surface, it can hold less CO2 and so will de-gas that CO2 back into the atmosphere
- The oceans now become a CO2 source, rather than the sink that it is now.

Ancient CO2 re-animated?

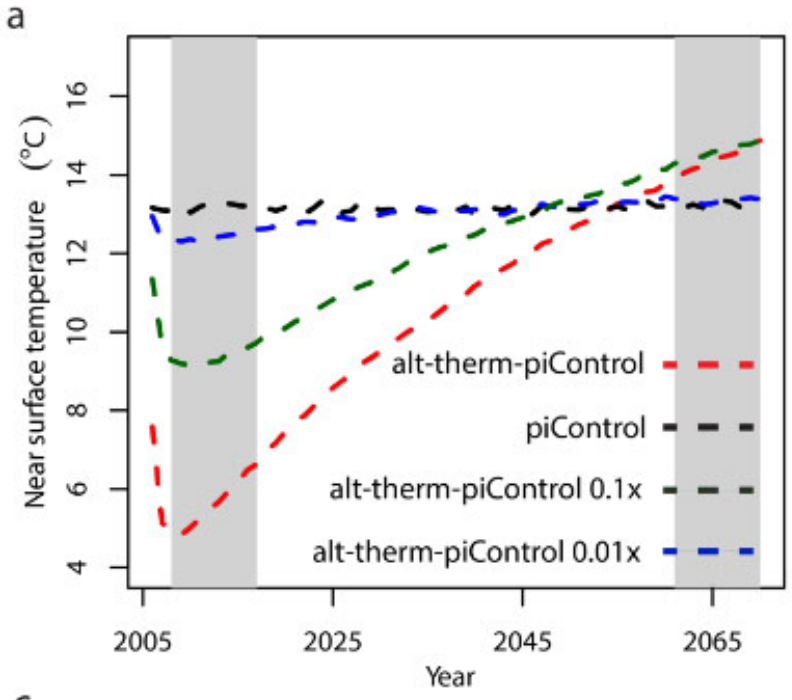
- This de-gased CO2 is from the deep ocean; it's CO2 that had long ago been sequestered, not the recent CO2 of what had been the undisturbed surface layers, so we may be taking CO2 that had not been an immediate danger of outgasing, and driving it up into the atmosphere. We'd be net adding CO2 to the atmosphere. However, there is some take-up of CO2 by land soils (Oschlies *et al*. 2010) from reduced respiration, until global temperatures go back up.
- These temperature changes would also significantly affect the phytoplankton ecology currently existing in these warmer mid-ocean surface waters in poorly known ways, as the ecological web is large and complex and with only bits and pieces so far studied. Initial claims mid-ocean upwelling via pipes would capture CO2 via photosynthesis and then sequester it when it drops, are guesses. Would it merely get re-circulated? Pipe currents very different than coastal upwelling.
- ~1/2 of Earth's oxygen is generated by ocean phytoplankton.

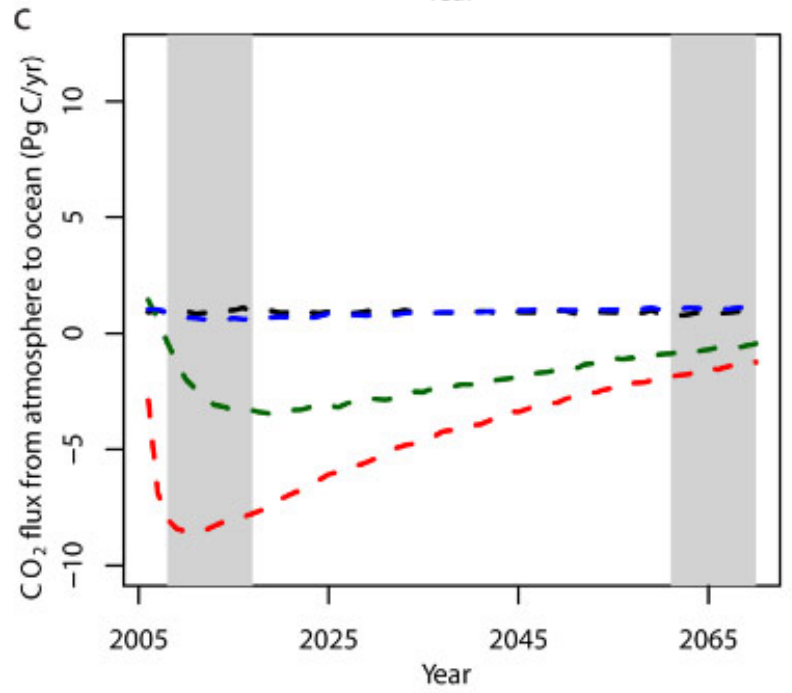
KRC15 Standard Case; Re-emerging buried heat added from below to current arriving insolation heat from above leads to global surface temperatures HIGHER than if OTEC was never installed. Note in particular that most of the temperature rise is NOT due to continuing RCP8.5 emissions (solid) but rises even with NO human CO2 emissions (dotted). This is the artificially buried heat arriving back to the surface.



Caption: This figure shows the change in near surface temperatures over time with ocean pipes and without pipes. It is provided courtesy of Lester Kwiatkowski, Ken Caldeira, and Katharine Ricke.

(Top image credit: NOAA Climate Program Office, NABOS 2006 Expedition. Photographer: Mike Dunn, NC State Museum of Natural Sciences.)





Top: Even the much milder KRC15 10% and 1% cases, with no human CO2 emissions, show OTEC pipes' buried heat re-emerges (with a vengeance for 10% case) by mid-century, rising past the "no OTEC" temperatures.

Bottom: Indeed, except for the 1% case (blue), deep ocean CO2 outgases back into the atmosphere when OTEC pipes are turned on.

Piping cold water from beneath the thermocline to the surface on a climate-significant scale, looks to be a calamity for climate, and for our future

- Yet Alan Miller, retired engineer from Lockheed-Martin, with a patent on this pipe, is seeking venture capital to advance this as a climate solution

The Claims…

- As of 2016, the promo says half the world's power needs would be solved, by using OTEC power generation to make huge amounts of ammonia on **~70,000 floating factories hooked to OTEC pipes**, to be visited by tankers to carry the ammonia to land where it could be burned as fuel to power the world.

Ammonia as our new Energy Source

- The combustion of ammonia to nitrogen and water is exothermic:
- $4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O\ (g)$ ($\Delta H^\circ_r = -1267.20$ kJ/mol) The standard enthalpy change of combustion, ΔH°_c, expressed per mole of ammonia and with condensation of the water formed, is −382.81 kJ/mol. Dinitrogen is the thermodynamic product of combustion: all nitrogen oxides are unstable with respect to N_2 and O_2, which is the principle behind the catalytic converter. Nitrogen oxides can be formed as kinetic products in the presence of appropriate catalysts, a reaction of great industrial importance in the production of nitric acid:
- $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$, which in the presence of oxygen, such as would happen in air, leads to NO_2 by the reaction
- $2\ NO + O_2 \rightarrow 2\ NO_2$ (a powerful greenhouse gas)
- ***Also, the combustion of ammonia in air is very difficult in the absence of a catalyst (such as expensive platinum gauze or warm chromium(III) oxide),*** because the temperature of the flame is usually lower than the ignition temperature of the ammonia–air mixture. The flammable range of ammonia in air is 16–25%.[22]

- So this would not appear to be an energetically favorable fuel, although the greenhouse power of the products would be less than carbon-based fuels
- Miller highly optimistically assumes that the cost curve for the pipes follows the same as did solar PV panels. But tiny PV chips were vastly more favorable for dramatic technological advance and cost cuts.
- These 10 meter diameter OTEC pipes are lower-tech and more of the cost is in materials and structure, not technology).
- He estimates they'd cost $1.2B apiece
- That's $84 trillion for 70,000, which works out to $12,000 for every man, woman, and child on Earth(!)

- **Consider the dangers of these floating factories…**

His numbers: 70,000 free-floating ammonia factories on the far open ocean, beyond the continental shelf so they have access to 1 km deep cold water. In an era of Super Storms (Hansen *et al.* 2016) – is this a good idea?

Oschlies *et al.* 2010 Also Studied Artificial Upwelling's Effect on Climate

- They use a very different climate model and assumptions.
- They employ pipes only where the ocean vertical profile suggests surface CO2 would not increase when OTEC is turned on. However, where these rare places are, are very different depending on data and/or model choice (see their Figure 1)
- *Their UVic climate model included no cloud modelling, and so the strong negative effects of a cooling ocean on low clouds found by the Stanford team are missing here. Yet, the decrease in marine clouds was a major contributor to the rising temperatures in the KRC15 models, and if this is missing in the Oschlies studies, would call their climate implication results into serious question.*
- ***Bottom line: Basing your claim of safety to climate by using climate models which include NO ATMOSPHERIC COUPLING …is not safe!***

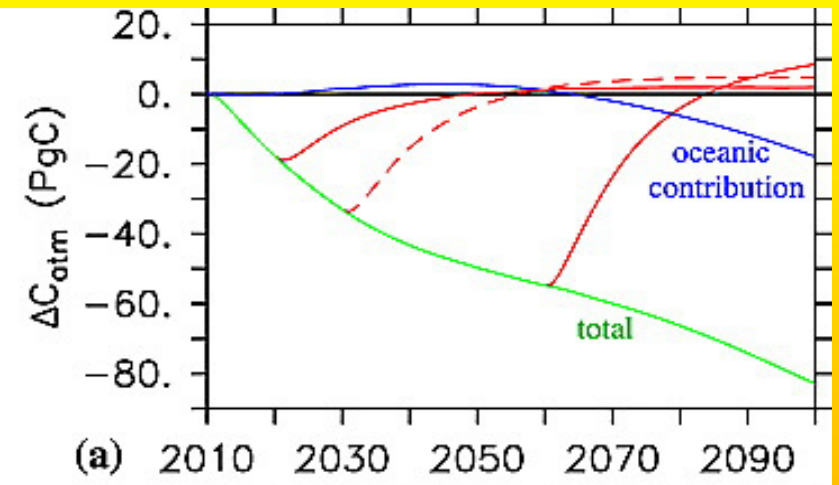
Even Very Limited OTEC Deployment Still Ultimately Causes Rising Ocean and Air Temps

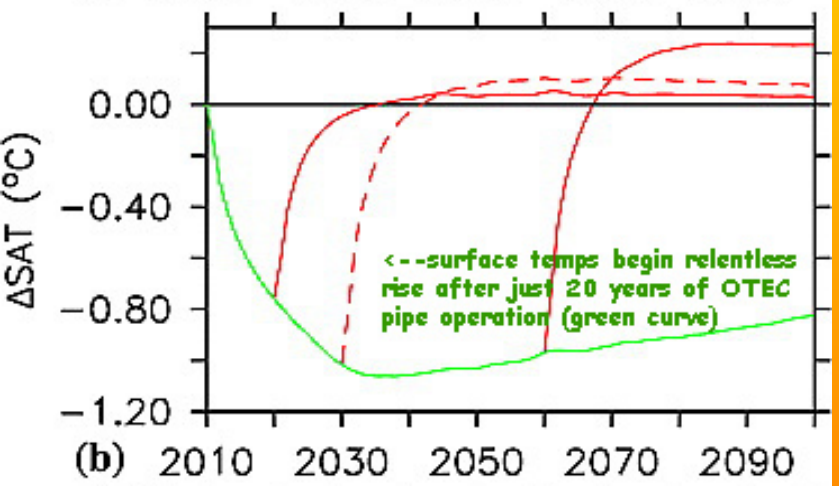
- Even the much smaller and more optimized OTEC deployment studied by (Oschlies *et al.* 2010) found that when the pipes are shut off, Earth warms to HIGHER than it would have been if no pipes had ever been deployed.
- The glib rebuttal from Miller was – *"why ever turn them off"?* At a promotional talk in Santa Cruz
- There could be many reasons, like unforseen tragedy to eco-systems, weather patterns, failure of the ammonia economy to take hold globally, or better, cheaper, less dangerous technology arriving.

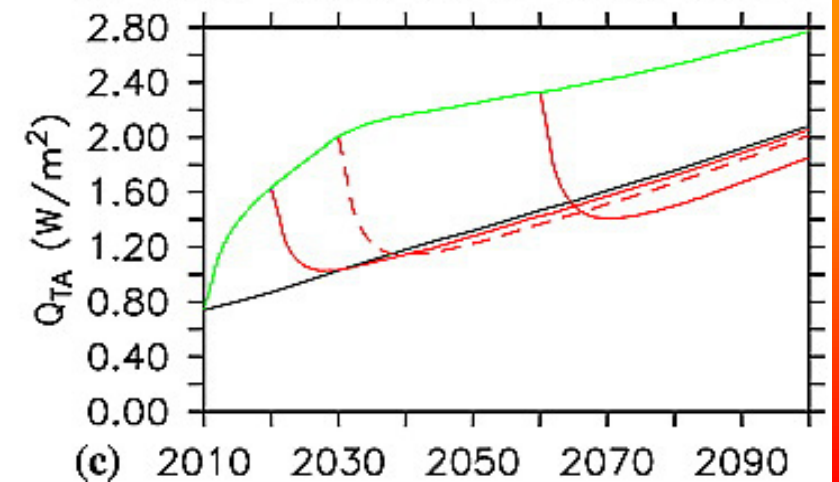
Worse – even if the pipes are NEVER shut off…

- …the surface ocean begins consistent warming only ~20 years after deployment (next slide).
- Miller responded (private comm.) that this was because human CO2 emissions continue (in the Oschlies et al. 2010 study). No doubt this is part of the reason, but note that even in the 1% case in the KRC15 studies, when there is NO human CO2 emissions, and when there is NO ocean-vented CO2 release (in fact, oceans continue to absorb atmospheric CO2, as shown), **still** surface temperatures rise after a brief initial drop. **The real reason – buried heat causing worsened radiative imbalance:** Again note in the KRC15 studies that human CO2 emissions do not dominate the rising OTEC temperatures, as we highlighted
- Oschlies *et al.* did not run a control case with no human CO2 emissions, which would have made the cause of their own rising temperatures clearer.

From Oschlies *et al.* 2010







(a) Simulated sequestration of atmospheric CO_2 relative to the standard run without pipes. (b) Simulated surface air temperature difference of ocean pipe simulation relative to the standard run without pipes. (c) Simulated radiation balance at the top of the atmosphere. Green lines refer to the standard pipe experiment with pipes deployed wherever a reduction in surface pCO_2 can be expected, and with a maximum vertical pipe extension of 1000 m. Red lines show results from simulations with artificial upwelling stopped after 10, 20, and 50 years, respectively. The blue line in Figure 2a denotes carbon sequestration due to oceanic uptake, the black line in Figure 2b refers to the control experiment without pipes. All simulations assume A2 emissions continue. No control case of no-emissions was run.

(b) (RN: NOTE THAT GLOBAL TEMPERATURES (MIDDLE GRAPH IN GREEN CURVE) REVERSE AND BEGIN RISING AFTER ONLY 20 YEARS, AS TRAPPED HEAT BEGINS TO RE-EMERGE , AND THE LONGER THE PIPES ARE ON, THE GREATER THE OVERSHOOT IN EVENTUAL TEMPERATURES. THE TREND AND ENERGY CONSERVATION SAYS THAT EVEN WITH NO PIPE SHUTOFF, TEMPERATURES WILL EVENTUALLY GO HIGHER THAN IF NO PIPES HAD EVER HAPPENED, JUST AS KRC15 FOUND. Some of this is due to human emissions, but according to KRC15, most is trapped heat)

OTEC pipes continually displace warm surface water from where it can RADIATE to space, down to depths, where it CANNOT

- Thermodynamics says that heat WILL build up, and the longer you engage these pipes, the bigger the thermal disaster when that trapped heat comes back to the surface, whether or not the pipes are ultimately shut off.
- This is just not arguable; it's the "loan shark" (buried heat) coming for his payment, which balloons "past due" with each passing year

A Key Question which Remains Unanswered by the Promoter of this idea

- Why seek venture capital money to launch such an ambitious expensive venture when the science is so clearly negative or at the very least, highly controversial? Venture capital expects a return on investment, *i.e.* expects the wisdom of deployment is already settled in the affirmative.
- Why not instead seek grant money for further research to clarify the effects? Was any application made for NSF money for such studies and rejected?
- Or alternatively, why not instead form a non-profit so that donations can help fund ongoing research?

- Another questionable claim: The OTEC-induced cooling planet would increase polar ice and set off an albedo feedback that would continue to keep the Earth cool.
- But these claims were not backed up with any references, and in fact, the KRC15 studies show otherwise. They find that the initial rise in sea ice caused by the lowered surface temperature in the early years of OTEC deployment, steadily decline as the surface ocean then reverses and warms while buried heat re-emerges (next slide)

KRC15: Even for the strongest OTEC cooling case (100% of standard case, no human CO2 emissions), the initial jump in sea ice (red dotted at left) begins decaying back down, and is even lower than initial by year 2070. **Worse: Sea level rise is severe** as the heat now prevented from radiating away causes additional thermal expansion of the oceans, over 1.5 meters by 2065 (right)

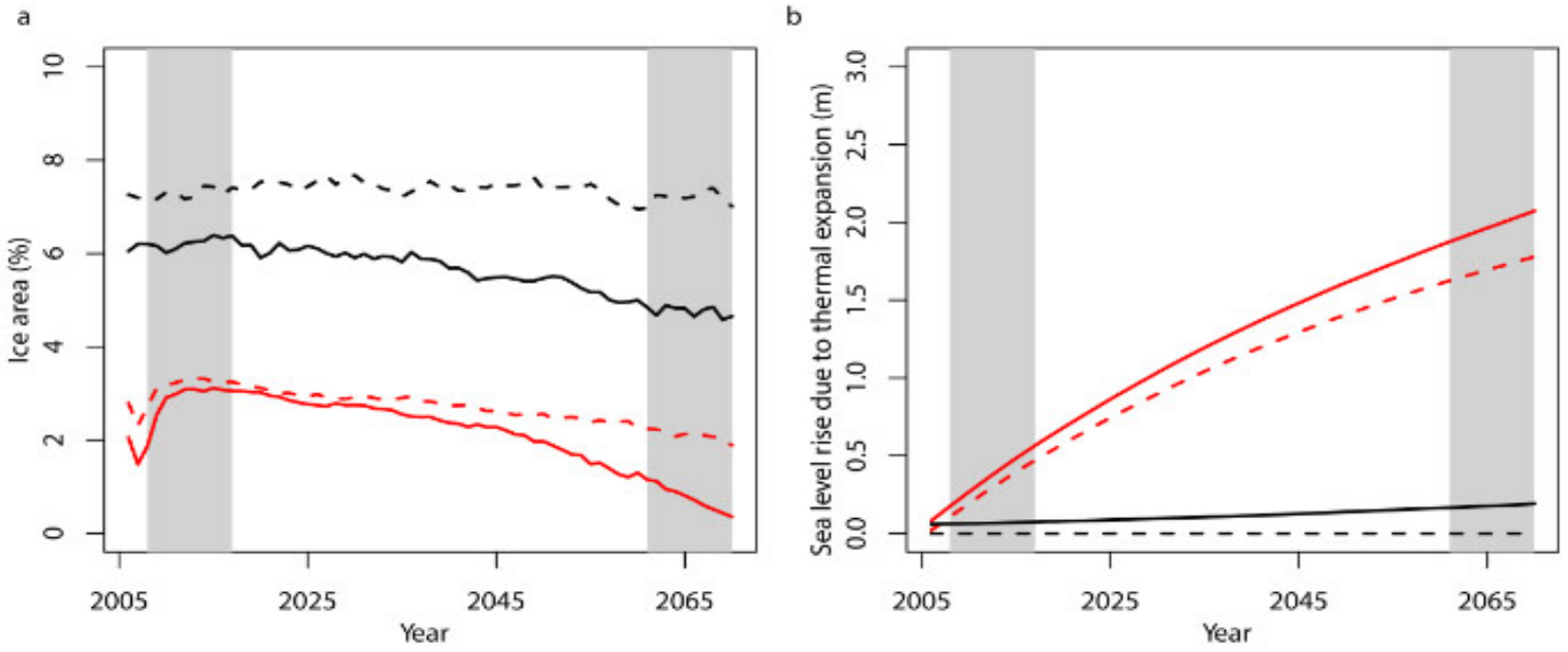


Figure S3. Mean global sea ice area (%) (a), and sea level rise (m) due to thermal expansion (b), for RCP8.5 (bold lines) and pre-industrial control (dashed lines) scenarios. *RCP8.5* and *piControl* simulations are shown in black and thermocline disruption simulations in red. Sea level rise due to thermal expansion is calculated based on (Kuhlbrodt and Gregory, 2012).

- ***"I cannot envisage any scenario in which a large scale global implementation of ocean pipes would be advisable," lead author Kwiatkowski said. "In fact, our study shows it could exacerbate long-term warming and is therefore highly inadvisable at global scales."***
- (Kwiatkowski video summary)

Why oh Why?

- All it took was a 5 second google query to come up with these peer-reviewed published study by highly regarded and legitimately brilliant Stanford climate scientist (and specialist in evaluating GeoEngineering) Prof. Ken Caldeira and fellow researchers. And severe reservations from other published research as well, as we saw.
- …and just a few minutes to read the Abstract; alone sufficient to indicate that climate-significant deployment of OTEC pipes was quite dangerous to Earth.
- Why couldn't the local self-described "brilliant scientific mind" who grandstanded in order to stubbornly promote this as "revolutionary" even after a first communication from me suggesting otherwise, and who sent this out to 61 climate-involved activists … **why couldn't he have done this simple bit of due diligence *first?***
- Then to have this OTEC idea hype'd as if he's an expert judge of its merits, despite zero examination. Is this person not concerned for the financial welfare of those pitched for "venture capital" who perhaps have bought into his relentless self-promotion as a "NASA Scientist" (which he is not) and are on the email distribution for this promotional?
- **I should not have to be the one to call out this kind of irresponsible behavior; apologies for having to do so at this local public talk on Hansen's work and implications. But this must stop.**

Radiative Forcings of GeoEngineering Strategies (Lenton & Vaughn 2009)

Table 2. Estimated radiative forcing potential of carbon cycle geoengineering options. Effects are calculated relative to a strong mitigation scenario in which a total of 1000 PgC are emitted and atmospheric CO_2 (and corresponding radiative forcing) reaches 450 ppm (2.58 $W m^{-2}$) in 2050, stabilises at 500 ppm (3.14 $W m^{-2}$) in 2100 and then declines to 363 ppm (1.43 $W m^{-2}$) on a millennial timescale.

Geoengineering Option	2050		2100		3000		
	ΔCO_2 (ppm)	RF ($W m^{-2}$)	ΔCO_2 (ppm)	RF ($W m^{-2}$)	ΣC_{seq} (PgC)	ΔCO_2 (ppm)	RF_{final} ($W m^{-2}$)
Enhance land carbon sink							
Afforestation	−41	−0.49	−34	−0.37	183	−16	−0.27
Bio-char production	−10	−0.12	−37	−0.40	399	−34	−0.52
Air capture and storage	−58	−0.74	−186	−2.5	>1000	>|−85|	>|−1.43|
Enhance ocean carbon sink							
Phosphorus addition	−5.9	−0.070	−12	−0.13	574	−52	−0.83
Nitrogen fertilisation	−4.5	−0.054	−9.3	−0.10	299	−25	−0.38
Iron fertilisation	−9.0	−0.11	−19	−0.20	227	−19	−0.29
Enhance upwelling	−0.1	−0.0017	−0.3	−0.0032	16*	−1.9	−0.028
Enhance downwelling	−0.08	−0.00095	−0.18	−0.0019	9*	−1.1	−0.016
Carbonate addition	−0.4	−0.0048	−2.3	−0.025	251*	−30	−0.46

* Activities assumed to continue to year 3000 hence larger airborne fraction than for other ocean options.

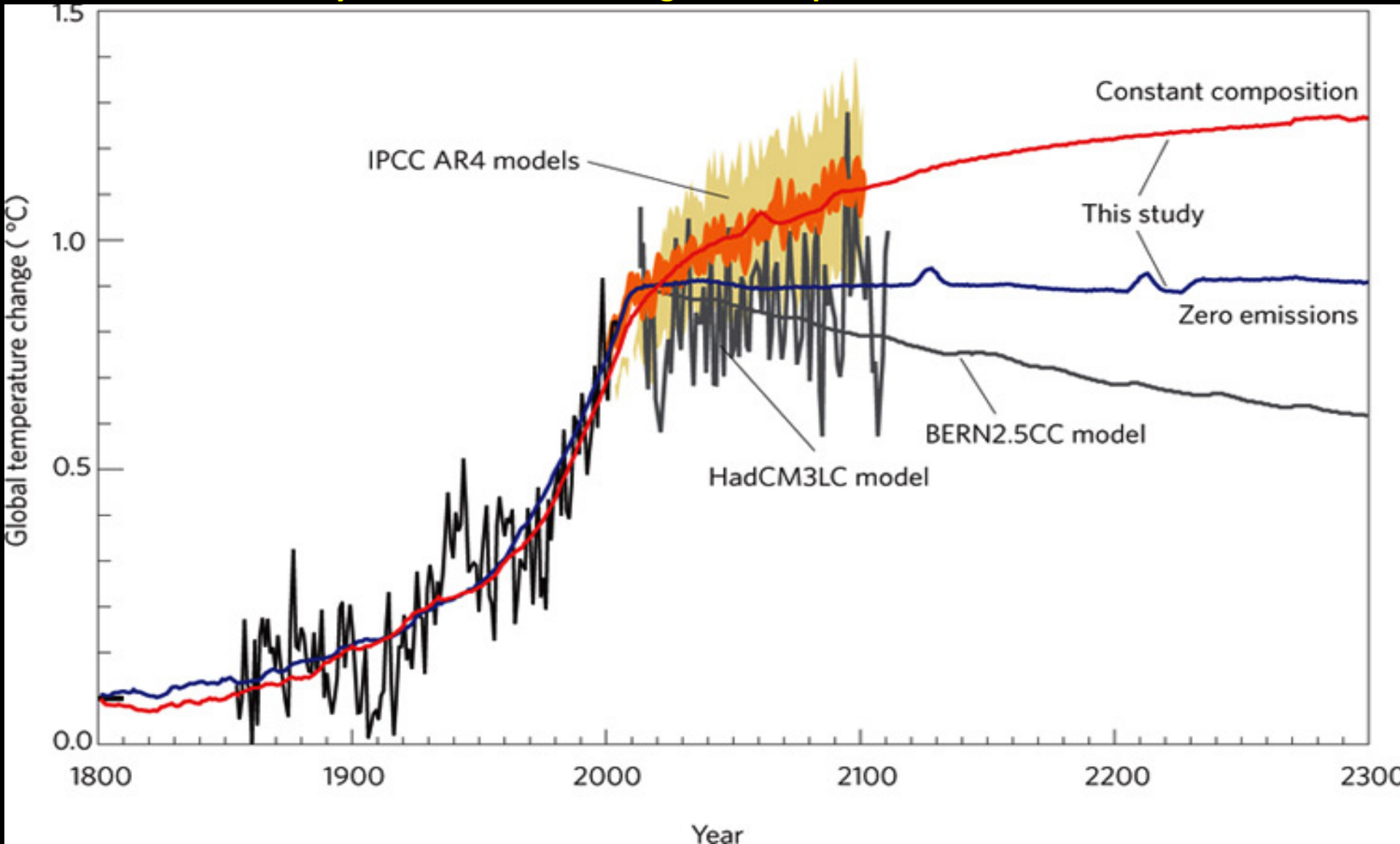
Keller *et al.* 2014 studied a wide range of Geo-Engineering strategies and find…

- *"…that even when applied continuously and at scales as large as currently deemed possible, all methods are, individually, either relatively ineffective with limited (<8%) warming reductions, or they have potentially severe side effects and cannot be stopped without causing rapid climate change. Our simulations suggest that the potential for these types of climate engineering to make up for failed mitigation may be very limited."*

Category 2: Help the Earth Radiate its Excess Heat Back to Space

- This means reducing greenhouse gases (and also NOT burying ocean heat under pumped up cold water, nor freshwater thin ice)
- It means more than just lowering our emissions rate – it means getting emissions to ZERO just for starters,
- Then sucking the CO2 out of the atmosphere that we put INTO it in the first place, and sequestering it permanently. It was our party - we must clean up our mess – that's increasingly what the climate physics is telling us.
- That sounds extremely hard - why can't we just reduce emissions significantly and still have our lifestyles and growth?
- The ocean has absorbed 93% of our greenhouse heating, and we are still out of radiative balance by +0.6 watts/m^2
- **Therefore, Earth temperatures will NOT go back down even if we end ALL GHG emissions. Pause and let that fact sink in. Then consider the evidence…**

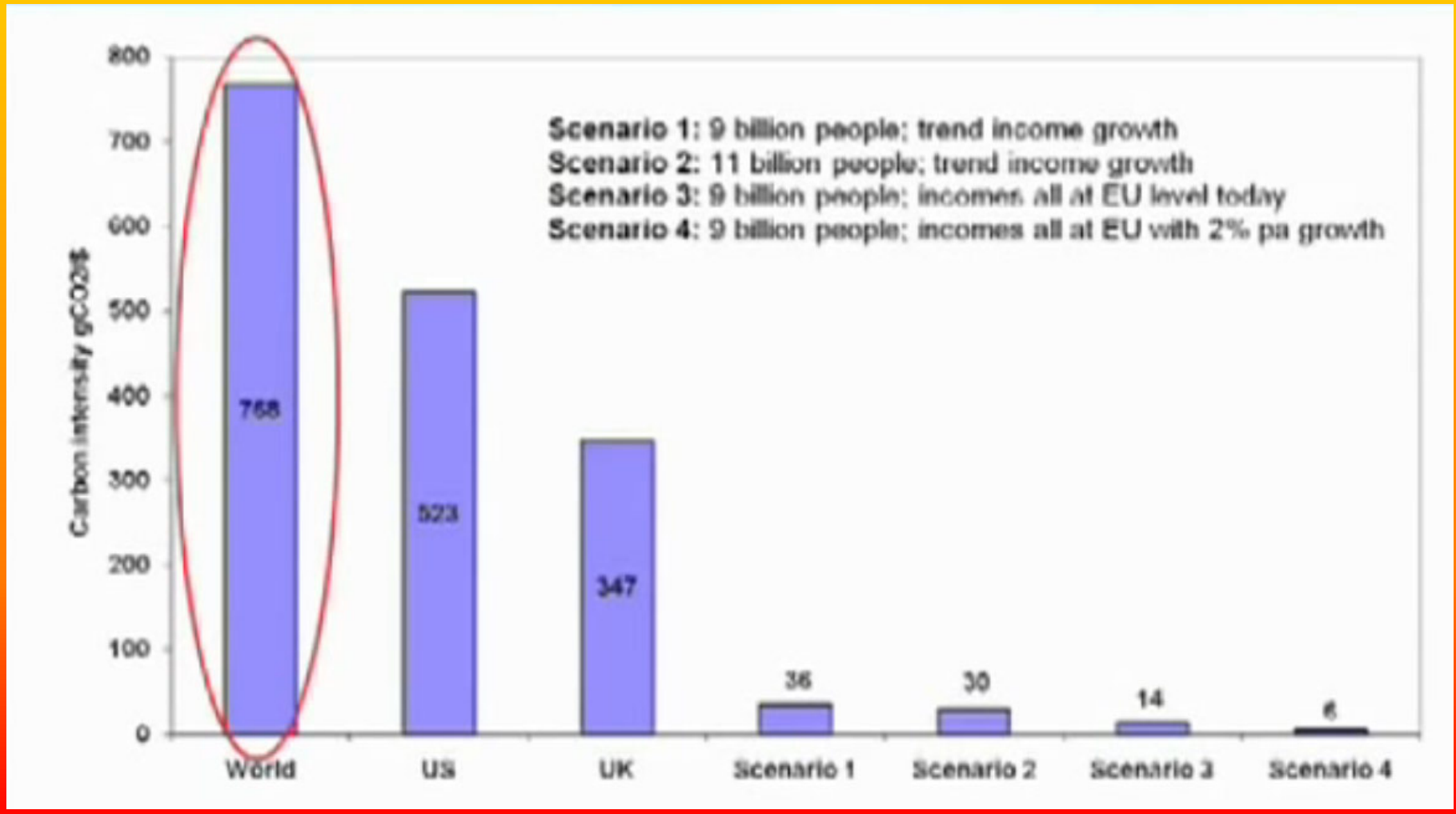
From Matthews & Weaver (2010) with explanation here. Confirms earlier work, that even with ZERO GHG Emissions (middle curve), Temperatures at best remain constant (The BERN2.5CC Model includes active and substantial atmospheric CO2 removal… [how, remains to be figured out]). This is w/o considering melting permafrost and assuming conservative equilibrium climate sensitivity of ~3.0C to a doubling of atmospheric CO2. New research is worse

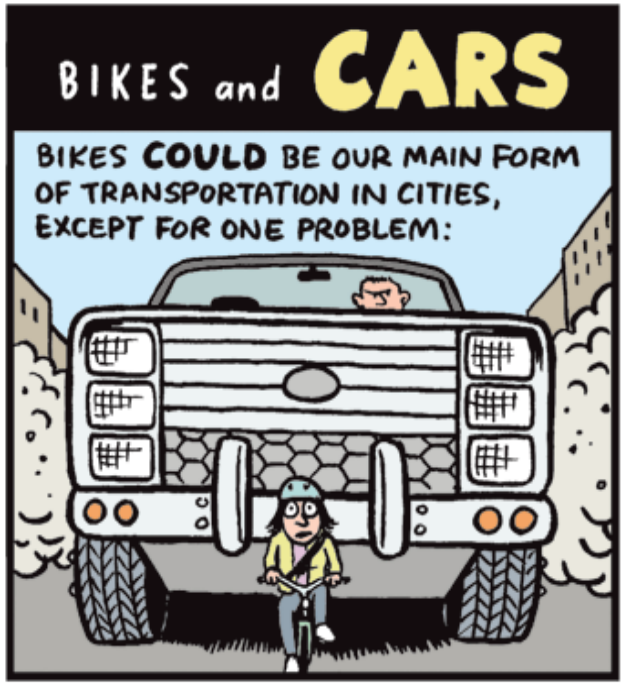


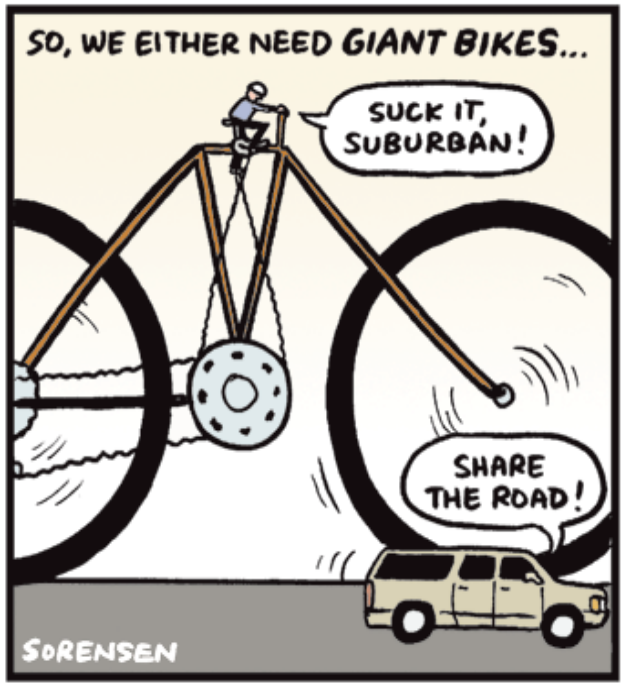
What Kind of Targets Are Relevant?

- We need ~**70% reduction** in CO2 emissions just to keep atmospheric CO2 levels constant (top orange curve is resulting rising temperature, due to existing radiative imbalance.
- But even that is too rosy. It fails to consider the **PCF (Permafrost Carbon Feedback)** from melting permafrost, and also the higher ECS of +4.9 C per CO2 doubling, as the latest research is indicating).
- In 2012, we'd have said we need **100% reduction** in greenhouse gas emissions to keep temperatures flat where they are, at +1.25C above 1880-1910 conventional pre-industrial, (as of late 2016).
- But that is now obsolete too. The permafrost is melting and will continue to melt, and when temperatures held at or above +1.5C we're committed to all of it melting, releasing carbon and methane (**Vaks *et al.* 2013**, **Lawrence *et al.* 2008**). Temperatures appear doomed to rise even if ALL human GHG emissions end

Even using the unrealistically conservative IPCC carbon budget to achieve +2C, as Economist Tim Jackson does here, requires Carbon Intensity per $ of GDP to drop to 1/130th of today's, by 2050, for a world at a European Union Standard of Living. That's *"10 times further and faster than any transformation in Industrial history"* (Tim Jackson)





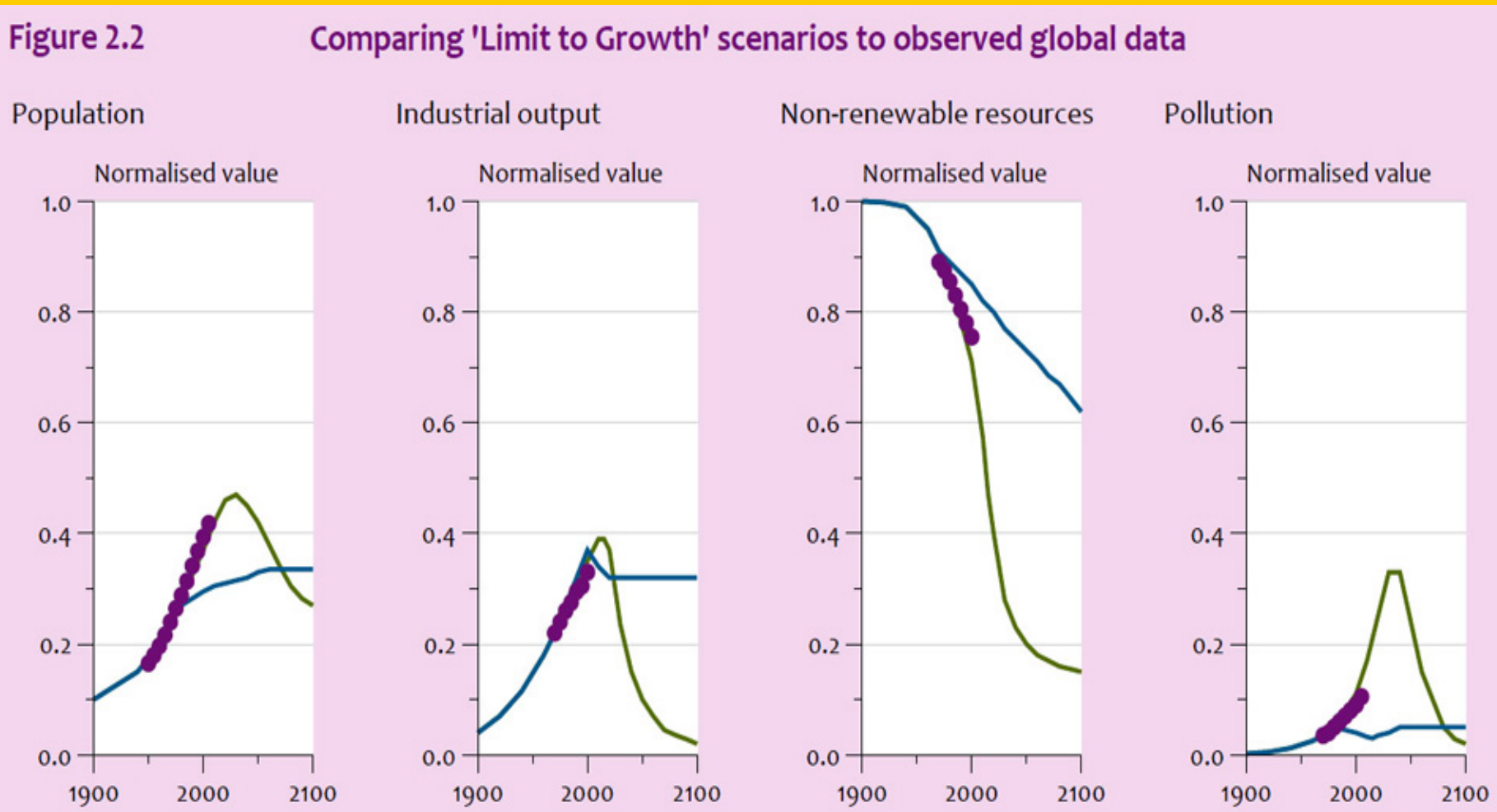


So while "Let's all ride bikes to solve global warming" sounds wonderful, it's nowhere near the level of wrenching change necessary

Our goal is actually much harder than even the previous discussion suggests

- Techno-solutions are not nearly enough, and so I will focus for this talk now on less obvious truths…
- **We have failed to include human laws along with our physics laws.**
- We hear so much about the great value of achieving energy efficiency
- But with unrestrained human nature as it is, this only accelerates our energy use and hence CO2 emissions
- What I've come to call **"Generalized Jevon's Paradox"** is the problem. We'll come back to this…
- But next, population and resource use…

Our population, industrial output, non-renewable resources, and pollution are all on overshoot-and-crash trajectories (see next slide, from van Vuuren *et al.* 2009). Why?



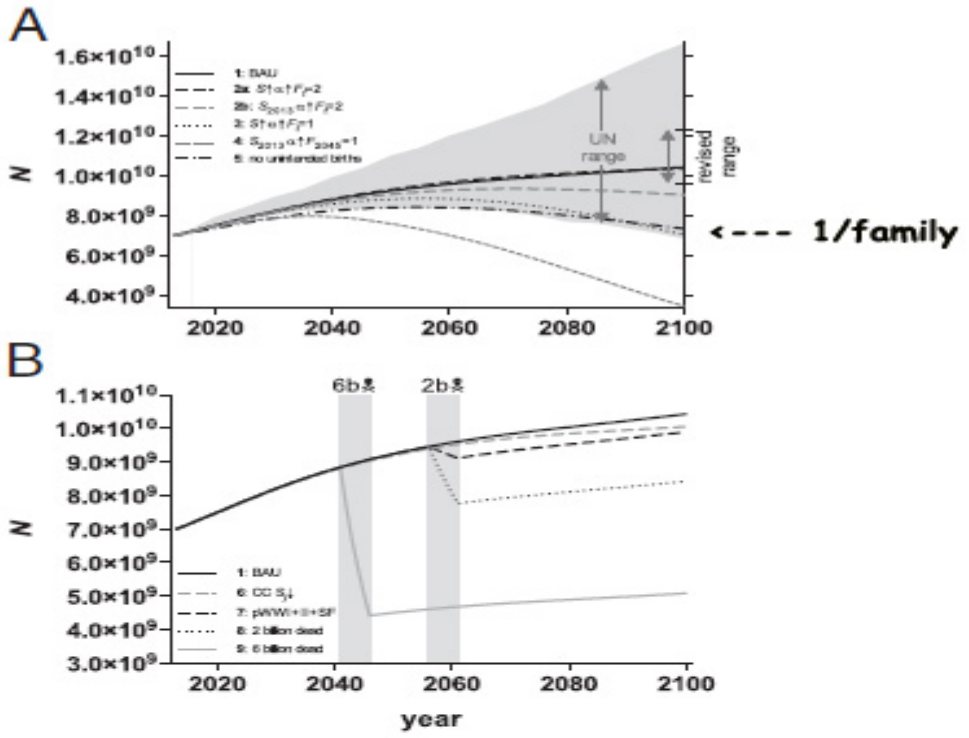


Fig. 1. Scenario-based projections of world population from 2013 to 2100. (*A*) Scenario 1: BAU population growth (constant 2013 age-specific vital rates); Scenario 2a: reducing mortality (M), increasing age at primiparity (α), declining fertility to two children per female ($F_t = 2$) by 2100; Scenario 2b: same as Scenario 2a, but without reduced mortality; Scenario 3: same as Scenario 2a, but $F_t = 1$; Scenario 4: same as Scenario 3, but without reduced mortality and $F_t = 1$ by 2045 and thereafter constant to 2100; Scenario 5: avoiding all unintended pregnancies resulting in annual births. High and low projections by the United Nations (12) are shown as a grayed area, and the revised range for 2100 (13) is also indicated. (*B*) Scenario 6: elevated childhood mortality (M_j) from climate change (CC); Scenario 7: mass mortality event over a 5-y period starting 2056, equal to the proportion of combined number of deaths from World War I, World War II, and Spanish flu scaled to the mid-21st century population; Scenario 8: 2 billion people killed because of a global pandemic or war spread over 5 y, starting midway (i.e., 2056) through the projection interval; Scenario 9: 6 billion people killed because of a global pandemic or war spread over 5 y and initiated one-third of the way through the projection interval (i.e., 2041). The mass mortality windows are indicated as gray bars.

Bradshaw and Brook (2014) population studies. Even transitioning by 2100 to 1-child per female worldwide doesn't begin to dent world population till late in the century. 1 (surviving to adult) child per family is **labelled "1/family".** Lowest curve is 1 child per female beginning in 2045 and includes unchanging infant mortality

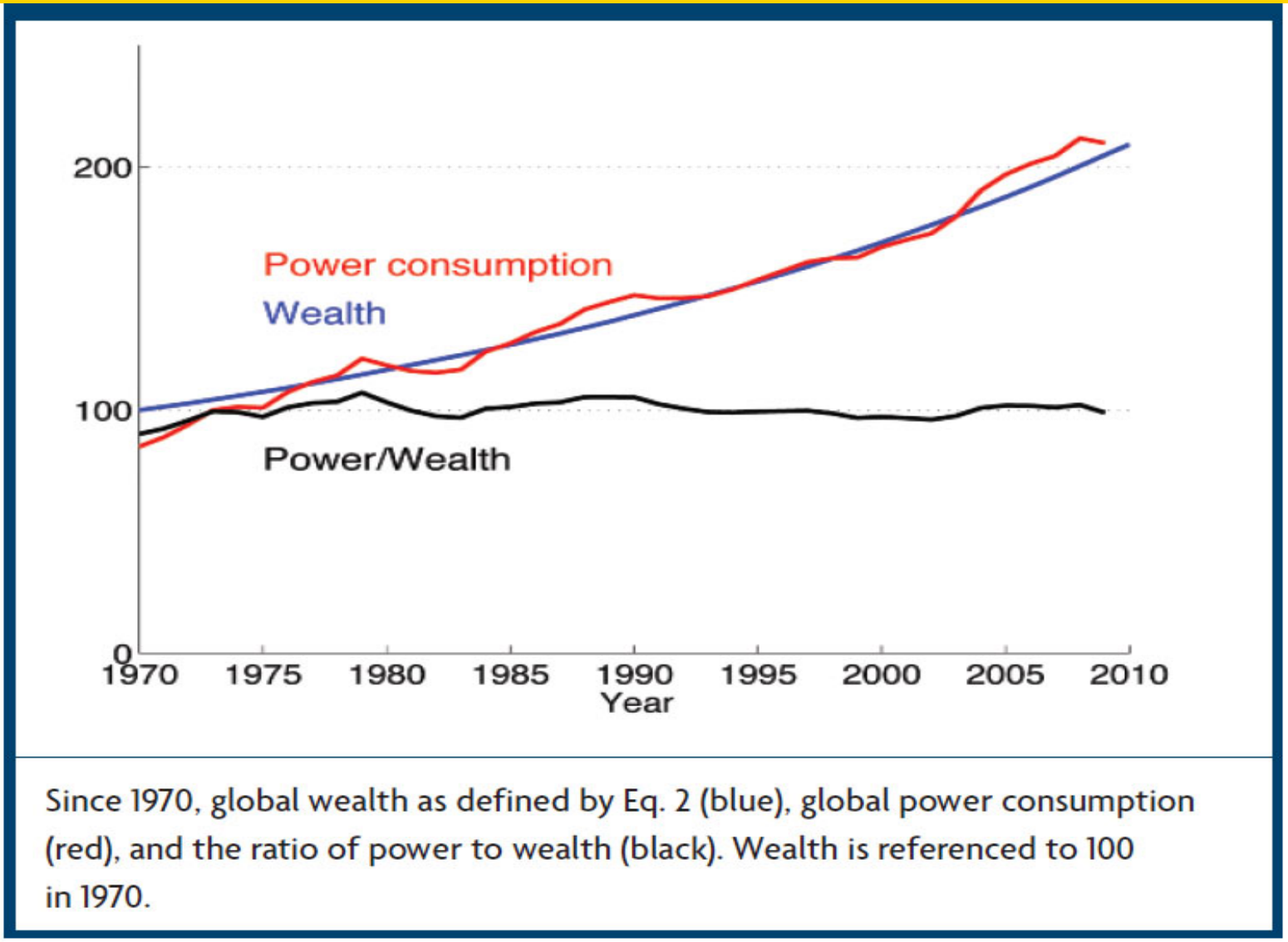
Even catastrophic multi-billion person die-offs (lower graph) due to climate chaos etc., bring us to sustainable levels **only if most people on Earth die.**

These are **NOT** encouraging projections.

Tim Garrett's Work: The Rate of Consumption of Energy is Proportional to the Accumulated Wealth of Civilization

- Tim Garrett (Garrett 2012 and references therein) has developed a thermodynamic model of the relation between the global economy, energy use, and carbon emissions. The underlying thermodynamic approach has proven to have wide application across dynamical systems .
- His discovery of a simple global relation between energy use and the accumulated Gross World Product (GDP summed over all countries, summed over all time) and its theoretical link to Civilization as a thermodynamic system, is a unique and insightful new synthesis and has sobering implications.

Energy consumption rate (power) and total accumulated wealth, plotted on top of each other for clarity. Result? They're directly proportional, *i.e.* the ratio (black) is flat. Recent new data extends this through 2014. Henceforth call this The Garrett Relation



Since 1970, global wealth as defined by Eq. 2 (blue), global power consumption (red), and the ratio of power to wealth (black). Wealth is referenced to 100 in 1970.

Now why is it true? First, the larger an economy, the more energy required merely to maintain its current state against the natural forces of decay (inflation, poor investment, etc)

- But even distant past spending's physical goods which are now long gone still enhanced our ability back then to grow into what we are today. Properly appreciated, the relevant "Wealth" is not merely present existing goods – it is **total** accumulated wealth over all time.
- Thus, the discovery that the global rate of energy consumption is in fact proportional not to GWP (GWP = **G**ross **W**orld **P**roduct), but to the total ACCUMULATED GWP of the world over all time, should not be that surprising.
- Global wealth is not merely physical stock like buildings, it's also intellectual and cultural achievements. These too require energy for production and enable further growth of civilization at a higher future rate. The real wealth is in the active networking we create, and that requires continuous energy to power it.

Thermodynamic laws are only simple in a CLOSED system. It turns out Energy and Economic Growth are Elegantly Simple as well, but only seen in a GLOBAL (hence "closed") System

- Many of the great advances in physics have come from the discovery and appreciation of elegant symmetries obeyed in Nature.
- Should we be surprised that one product of Nature – humans and human enterprise – might also obey elegant simplicities when the artificial isolations employed by most economists are removed?

Climate is global - recall that the diffusion time for CO2 is only a few weeks.

- The atmosphere's greenhouse gases are "well mixed". This is fundamentally important. All countries' CO2 becomes all other countries' CO2 very quickly.
- **Likewise, economies, too, are "well mixed" in the modern world** – the flow of wealth between countries is rapid compared to the evolution time scale of the global economic system as a whole.

Therefore, studying one country in isolation, and ignoring the material, energy, and money flows across its borders can lead to dramatically wrong conclusions.

- In the same way, The **2nd Law of Thermodynamics** will **appear** violated if one only looks at an increasingly (ordered) complex growing system and ignores the even larger amount of disorder imposed on the rest of the surrounding environment.
- Not only does this approach greatly simplify studying the relation of economics to energy and climate, but in fact…We NEED to consider things globally in order to avoid making fundamental errors due to false (or especially) missing feedbacks between the hundreds of parts of traditional complex economic models
- **But there's a deeper truth here…**

Jevons' Paradox

- Most eco-friendly advocates assume that if we just increase energy efficiency, we'll make big strides in cutting CO2 emissions
- **But this implicitly assumes that the dollars saved in efficiency are never spent**. It assumes, essentially, that they are **destroyed.**
- **This assumption is violated by history. Instead, those savings are going to be used to GROW Civilization, including its ability to access new energy sources.** And since there is 7.1 milliwatts of new power needed to maintain every (2005 inflation-adjusted) dollar of goods and services ever produced, net CO2 savings do not happen, but in fact (absent near complete decarbonization) get worse.
- **This is "Jevons' Paradox"**, first discussed by William Stanley Jevon in 1865, who observed that increasing the efficiency of steam engines' burning of coal made for a significant INCREASE, not decrease, in coal consumption.
- This phenomenon is also commonly called **"Rebound"**

Those Who Dispute Jevons' Paradox Look Closer…

- Narrowly interpreted (coal steam engine to coal steam engine, say), yes, it does not always apply, and indeed the **link here** includes links to advocates who believe that "green taxes", for example, do not display Jevon's Paradox, **but here, they fail to realize that ANY economic activity requires energy. THAT is key to understanding how CO2 emissions relate to economic growth**
- **In other words, even if the savings of coal in coal-fired steam engines did not stimulate making more steam engines burning more coal, the money saved would have gone SOMEWHERE, and that SOMEWHERE would have needed coal (then) as energy to fuel it.**
- **To distinguish this globally understood form from Jevon's early formulation, and the "straw man" it has become for some policy people, I will call this…**
- **Generalized Jevons' Paradox**

Generalized Jevons' Paradox

- Increasing energy efficiency (*i.e*. the ability of a given quantity of energy to produce more economic wealth) will lead not to a lessening of energy consumption, but rather to an increase in energy consumption, as the savings from the increased efficiency can now be spent in ANY area of life, and theory and historical evidence both show that any spending will require the continuous consumption of energy to enable it and maintain it into the future.

But Wait, You Say…

- Money saved through efficiency might be spent in less energy-intensive ways - Maybe I'll take the money saved and buy more vacation days, and on my vacation days I could go hiking or just reading.
- But to the extent that you don't spend those savings dollars, they are not getting reflected in GWP (and integrated GWP means energy, as data show). And if they are spent (even to buy a bike or running shoes), then the 7.1mW of power per 2005 dollar of accumulated global wealth does apply. Either way, the consideration above is already reflected in the historical data verifying the relation.

Efficiency Gains lead to MORE Energy Expenditure, not LESS

- This key fact (**Garrett 2012**) is simply missed, ignored, or distorted into a "straw man" by many policy "white papers", position statements, and promotional publications and speeches.
- They ignore what humans actually DO with efficiency gains in energy production – they do not destroy that new wealth, they do not get happy with a static lifestyle that costs less. Instead, they strive to grow further, and that means more power consumption.
- This is the key difference between reality-based analyses like Garrett's, and extrapolations focusing only on assumed declining carbonization, with no thought to what energy is required to be newly generated to accomplish that decarbonization, or how improved efficiencies will affect actual human economic activity.
- For more detailed study of Garrett's work, see key papers linked near the top of this page of mine.

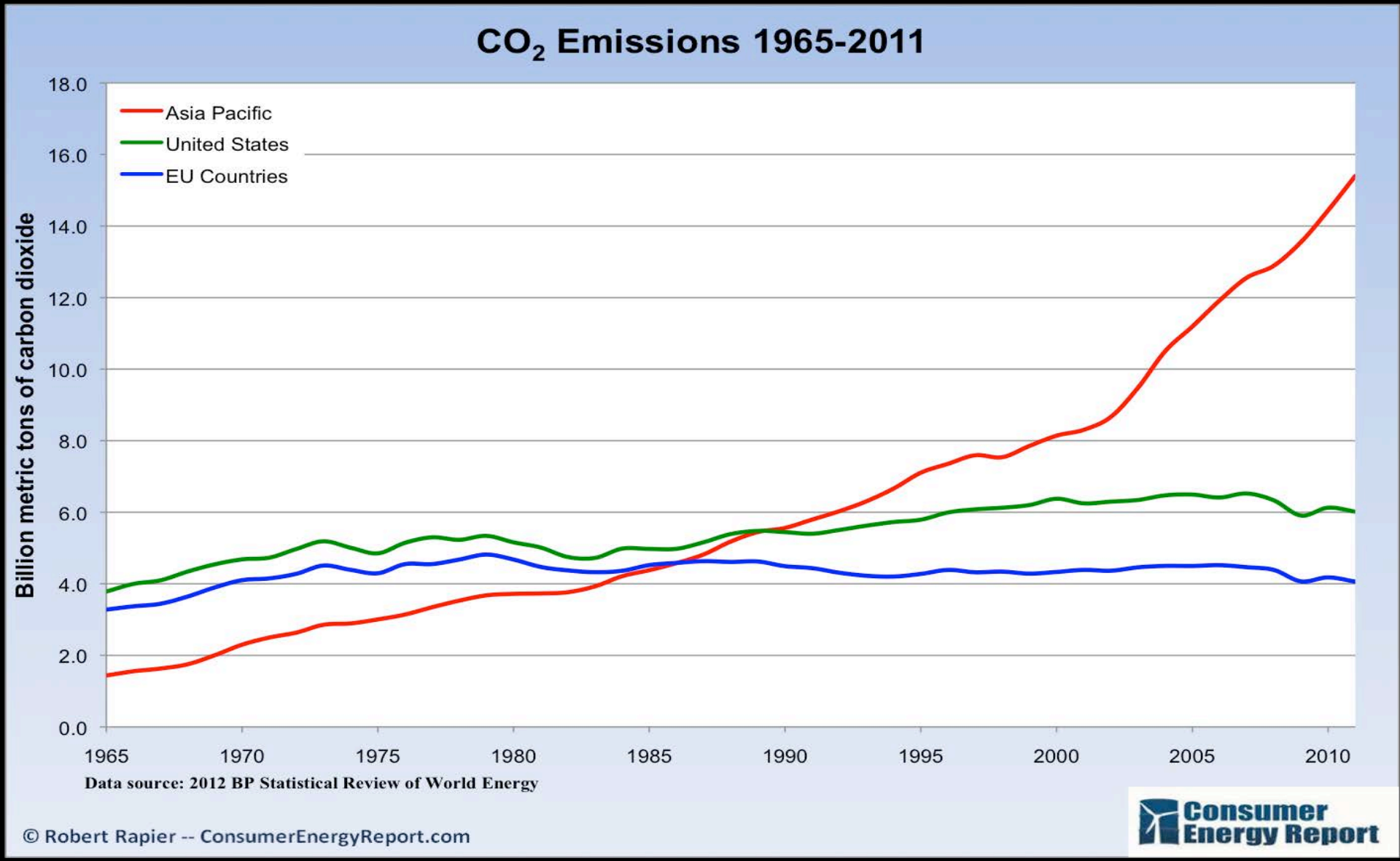
But Wait, Isn't there a Point Where Even Energy Gluttons are Satiated?

- I could believe that the tendency to consume more energy for oneself might not rise as fast as one's wealth, beyond a certain high level of personal wealth.
- But the "larger" your life, the larger your energy needs
- And, post-diction experiments run by Garrett (2015) show no evidence of this, even at the wealthy end.
- And likely the most relevant: most of the world is anything BUT "satiated". They are adamantly determined to spend whatever energy (carbon or not) they can lay hands on to increase their wealth to AT LEAST the level of those ostentatious Americans. Half the world lives on $2.50/day or less.
- So if there is such a point, it's not relevant for today's emergency. Data in the more distant future may tell.

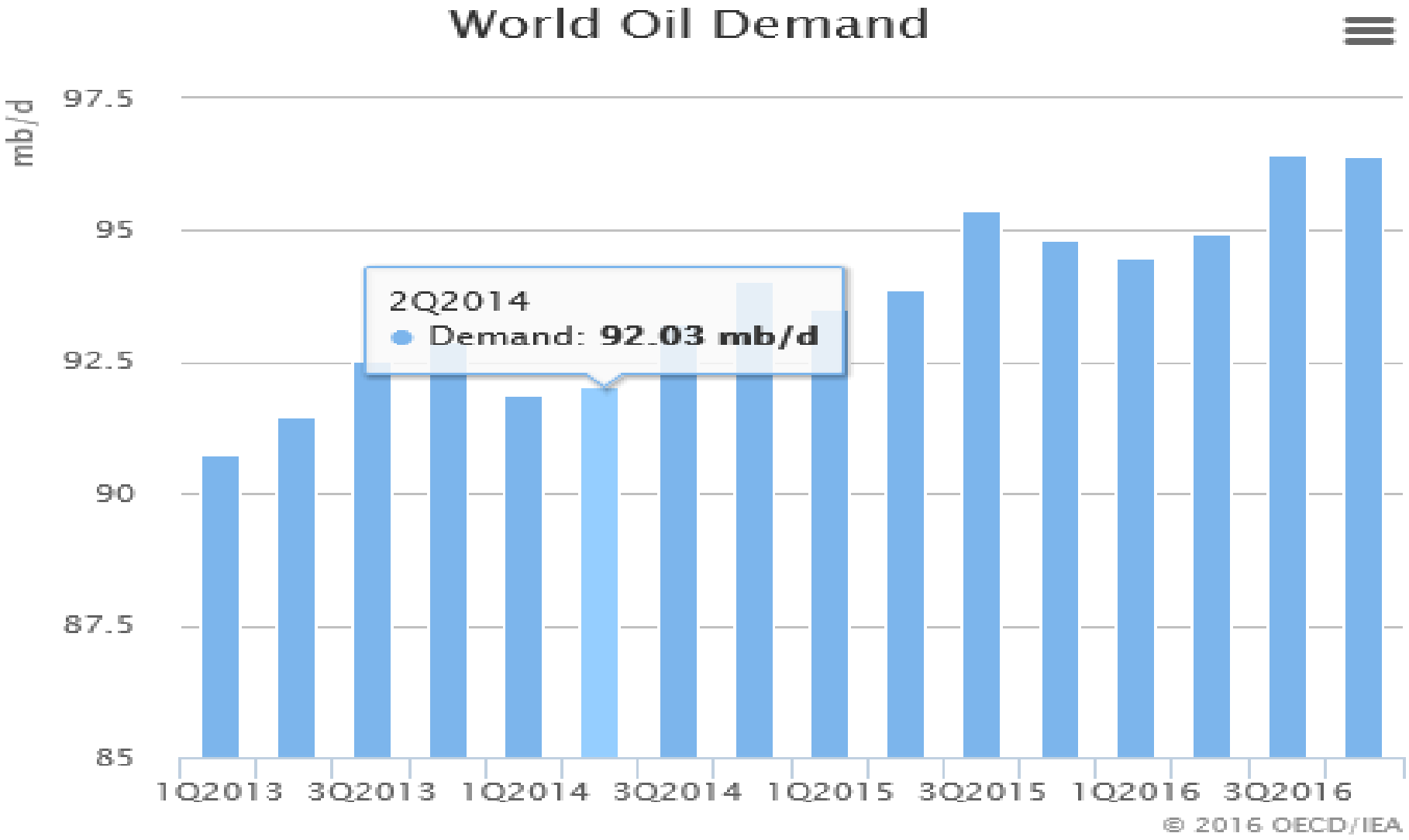
Then we Need to Decarbonize that Energy, Right?

- Yes! But observe how hard that will be – for every 2005 inflation adjusted dollar spent, 7.1 mW of power will forever have to be plugged in, and for a long time, most must be carbon energy. It's over 80% of primary energy today.
- As long as there exist cheap old gasoline engines and fossil fuels, they'll be used by those that can't afford to buy new renewables-powered equipment. This will be even more true as economic inequality continues to worsen. When you're poor, why replace what ain't broke yet?
- Even to decarbonize, requires a vast effort to transform the grid, replace every diesel, gasoline, oil-fired engine. Factories have to do that, powered by… carbon in large part. As energy analyst Vaclav Smil observes *" To replace the largest infrastructure system the world has ever known – our energy infrastructure - is the work of generations of engineers."* (That might be a bit overstated, I hope)

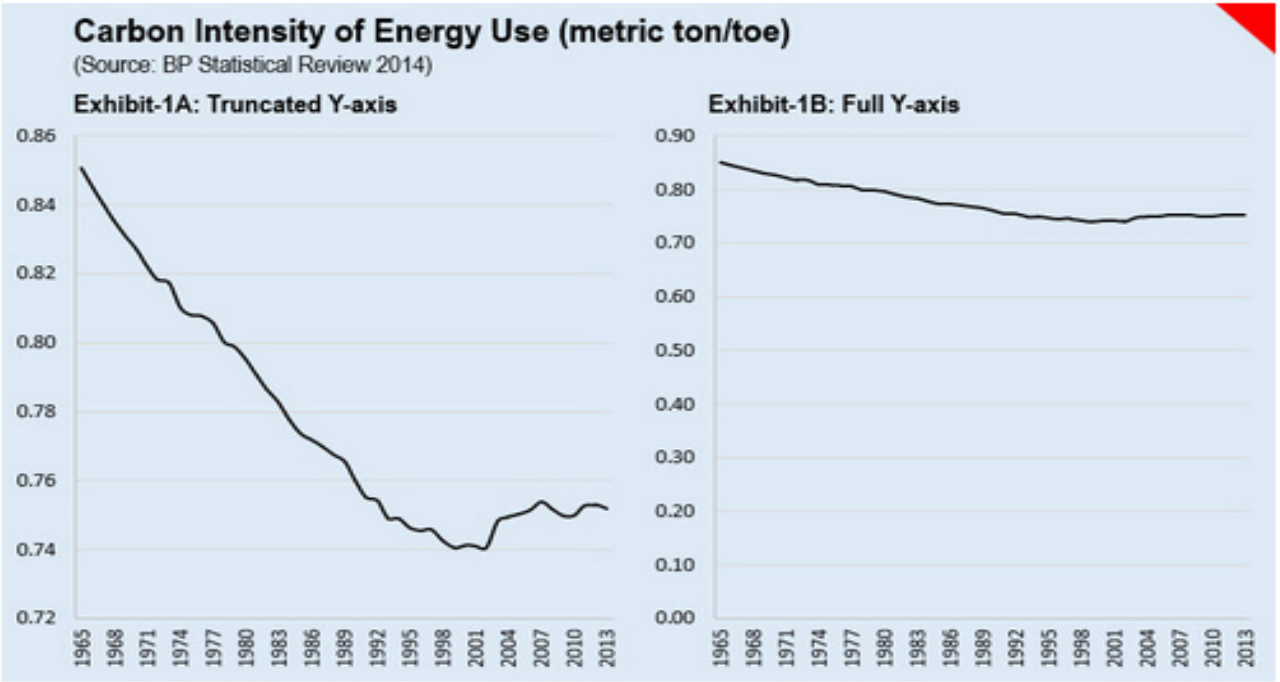
U.S., Europe have Exported Manufacturing (hence CO2 emissions) to Asian Manufacturers. So; we can look noble, and they look like the bad guys. This graph ends in 2012. Surely less grim since then, right?...



No. Here's the last 3 years: Continuing net rise quarter by quarter even during the global economic slowdown of the past 1.5 years

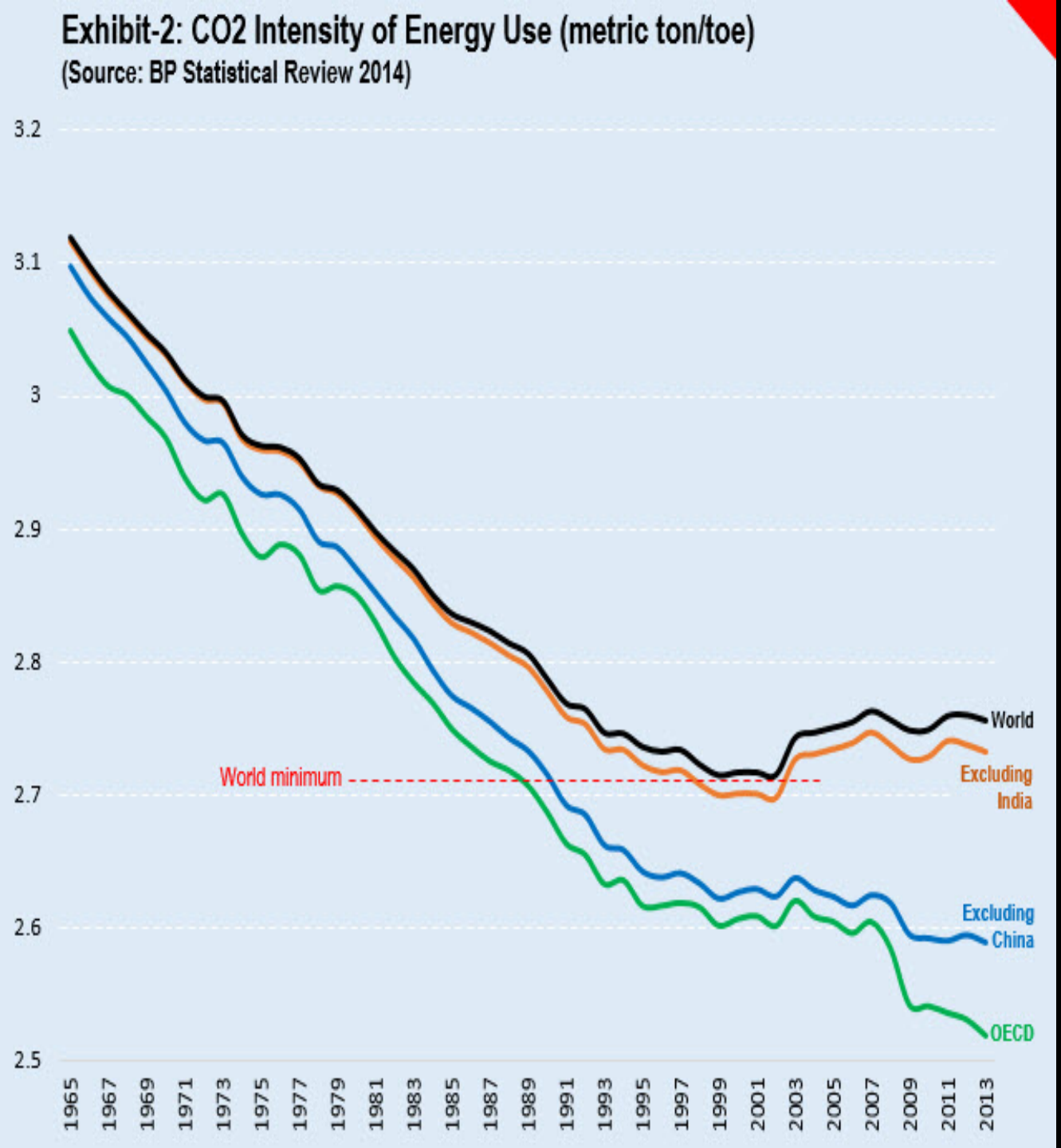


Global carbonization of energy dropped in the 20th century, but in the 21st it halted and reversed, despite the rise of solar and wind power. Economic growth has been faster than the strides made in renewables. Decarbonizing has at least contributed to the unfortunate reversal of decarbonization trends, because of the energy required to build renewable energy sources, but also the rise of Asia's fossil fuel powered economies.



A Closer Look

From here on, the numbers will show CO2 intensity instead of carbon intensity, because the original data from BP and the EIA report CO2 emissions. To convert CO2 to units of carbon (C), simply divide by 3.667. Carbon intensity and CO2 intensity are used interchangeably in the text – both are ratios that depict emissions generated versus energy produced. In the relevant literature, CO2 intensity is also reported as a ratio of CO2 emissions to GDP--which includes the effects of prices. In this note however, CO2 intensity is measured in physical units--metric tons of CO2 per tonne of oil equivalent (toe). Also, 1965 is the first year for the data published by BP.

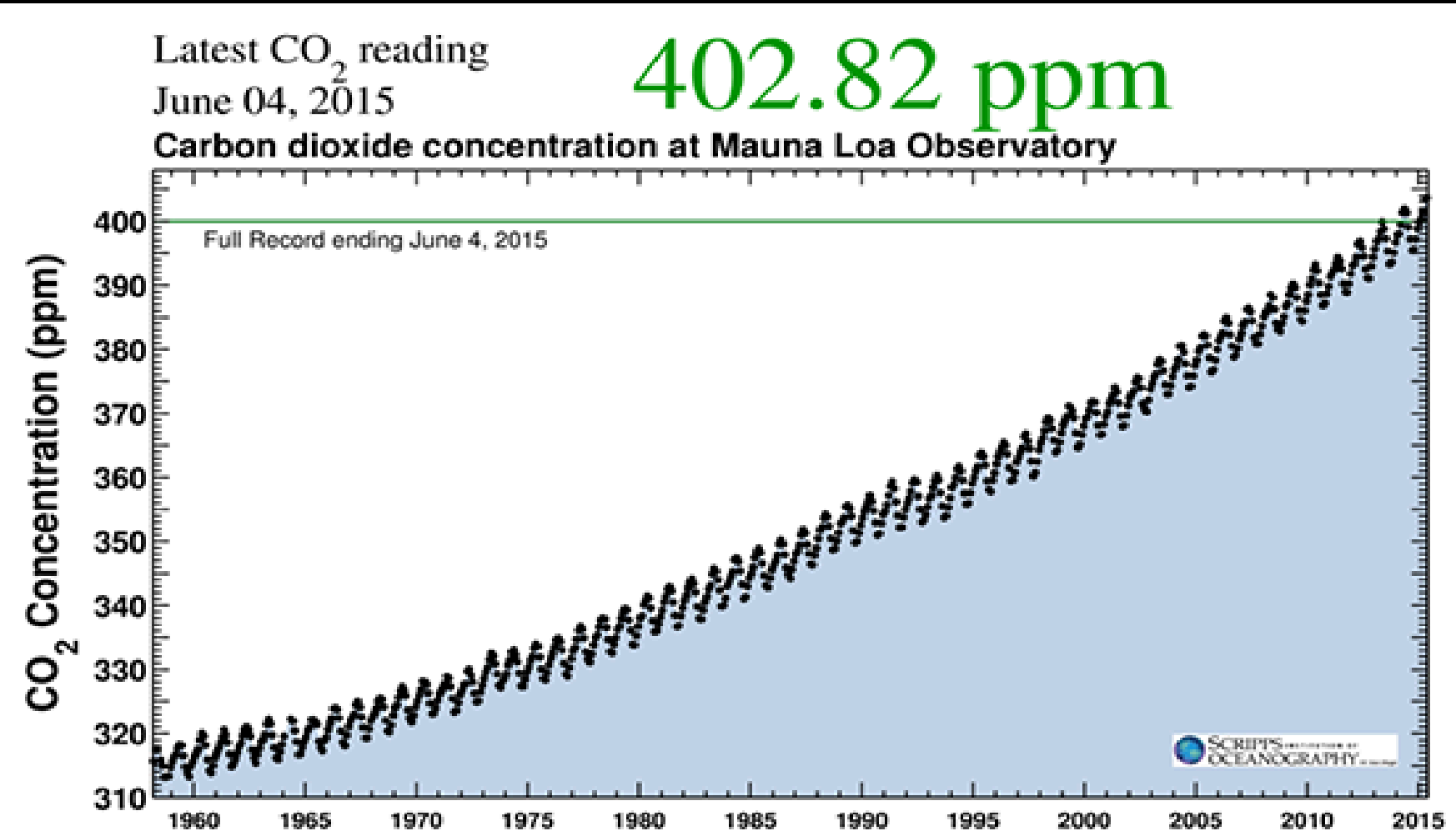


CO2 intensity per ton of oil equivalent.

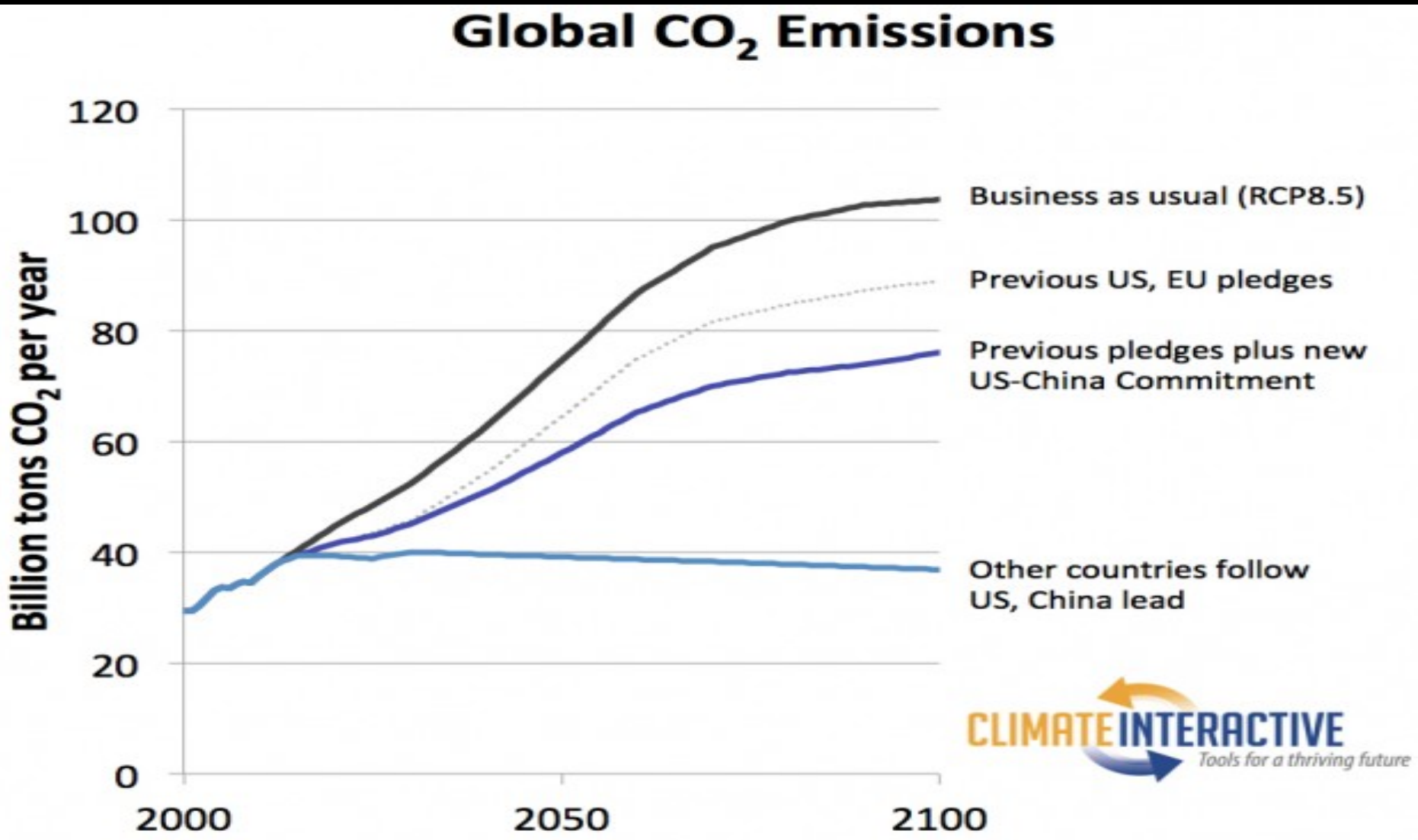
Strong fossil-fueled growth from China halted decarbonization this century. The non-China world (blue) has slowed although it's still decarbonizing. Developed world (OECD green) is doing better. The current (2016) global economic slow-down may see these curves resuming downward, is my guess.

But *Climate cares ONLY about the "world" curve – the worst of them*

So, renewable energy has come a long way during these many years. How are we doing on reducing CO2 emissions? **Answer:** Atmospheric CO2 is not going down, not staying level, not merely increasing linearly… rather, **it continues to accelerate upward as of 2016**. **<u>When all is said, this is the ONLY curve that matters</u>**



The Wildly Hype'd US/China Emissions Pledges… do very little. Even if the entire world follows our lead, CO2 emissions per year at best stay constant so that atmospheric CO2 continues to climb



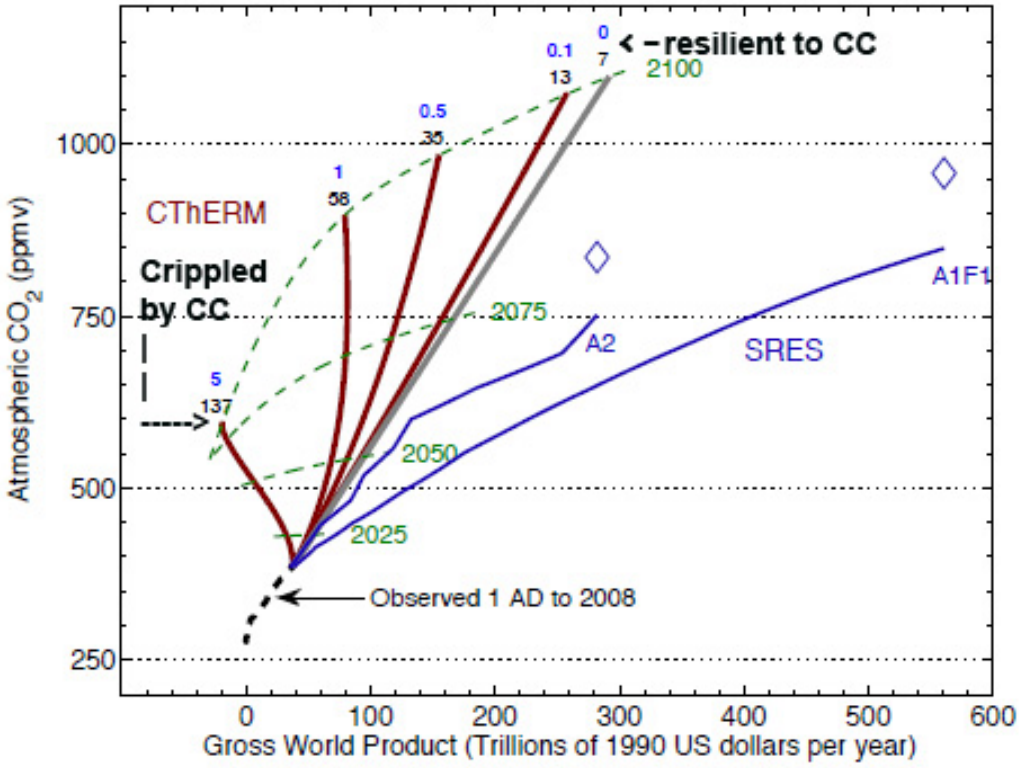


Fig. 6. As for Fig. 5, except for CThERM trajectories calculated out to 2100, with the model initialized with conditions in 2008 and assuming that $d\beta/dt = 0$ and $dc/dt = 0$ for a range of values of inverse resilience $1/\rho$ (blue numbers expressed in % yr^{-1} change in the decay coefficient γ per CO_2 doubling). Small numbers in black correspond to the calculated inflationary pressure $i = \gamma/\beta$ (Eq. 25) in year 2100. Green dashed lines represent the modeled year. Shown for comparison are the IPCC SRES A1F1 and A2 scenarios based on the CThERM linear sink model for CO_2. CO_2 concentrations for these scenarios using the Bern carbon cycle model are shown by blue diamonds. Historical data from 1 AD to 2008 is added for reference (see Appendix C).

Incorporate the Garrett Relation, assume no further increase in the rate of return on accumulated Wealth (i.e. keep at 2.2%). Garrett's CThERM model runs *vs*. range of assumed resilience of civilization to Climate Change: Here, de-carbonization follows its historical (very slow) trend. Note that even when civilization is assumed most crippled by climate change (CC), with GWP cut to below zero growth, still atmospheric CO2 rises 50% above current levels by 2100.

Suppose we massively reduce the carbonization of energy?

- The graph on the next page assumes we replace carbon energy with non-carbon energy at a rate such that the CO2 emission rate per unit of power drops exponentially with a halving time of $t_{1/2}$=50 years
- With that assumption, let's follow the trajectory of CO2 in our atmosphere *vs.* growth in total wealth in the next slide's graph.
- It might be a bit confusing to look at, because time is not one of the axes. Instead, time evolves generally upward along each of the curves, time ticks are the green dotted lines

Same resilience curves as earlier slide, but now including steep de-carbonization, with halving time $t_{1/2}$ = 50 years. They are all significantly worse than the unmodified IPCC eco-friendly scenarios (in blue). CO2 levels never drop for any CThERM scenario. Economic growth is far less, and CO2 far worse, than the simple IPCC scenarios which consider varying some relevant parameters but in artificial isolation from each other (see 2 slides later).

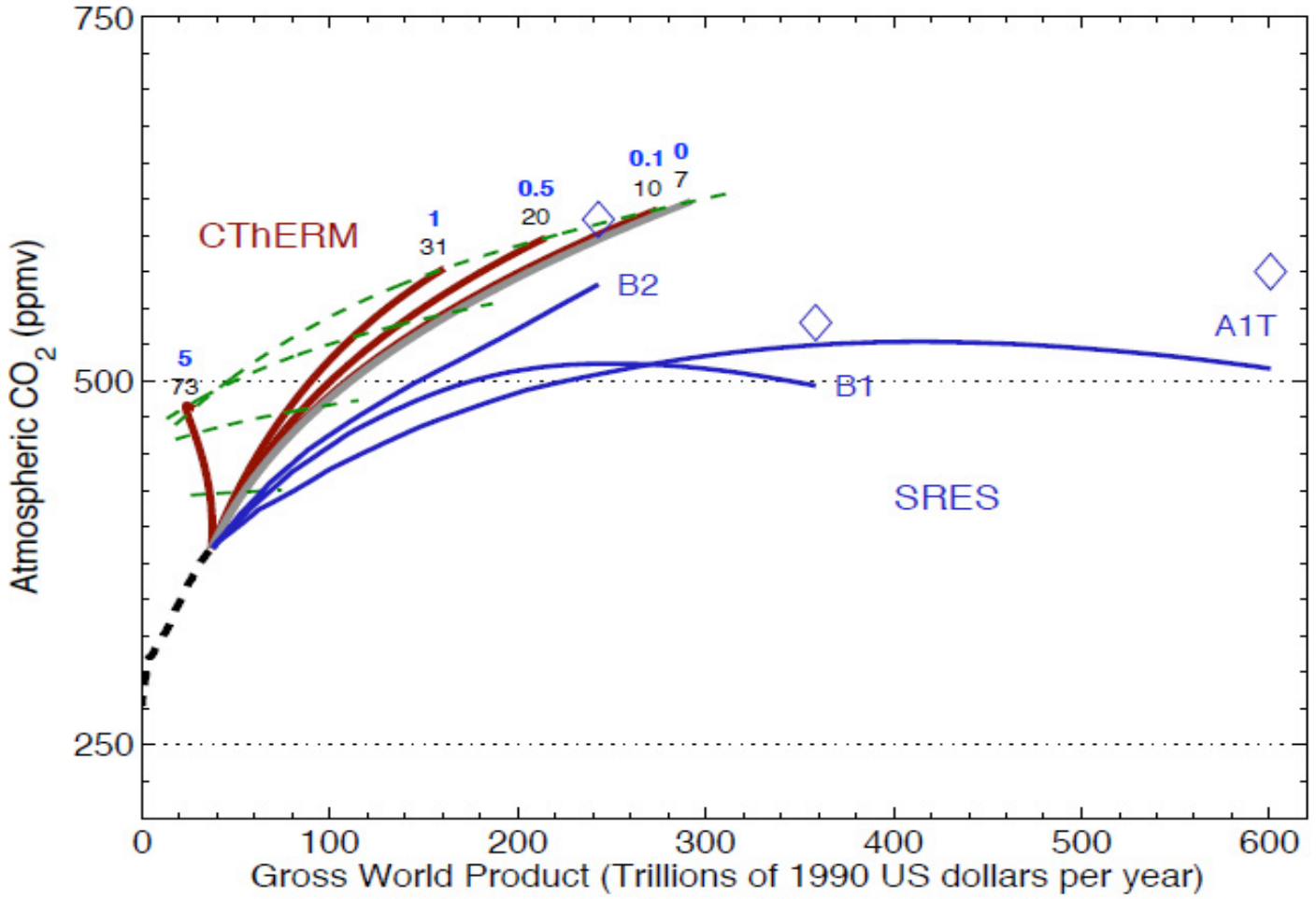


Fig. 7. As for Fig. 6 except that it is assumed that the value of carbonization c has an assumed halving time of 50 years. For comparison, the IPCC SRES trajectories that are considered are the A1T, B1 and B2 scenarios.

Let's Emphasize the Conclusion of that Last Slide…

- Even if we decarbonize at a much more rapid rate than we ever have, such that the carbon intensity of energy drops in half every 50 years, even if climate change cripples civilization such that we have a permanent Economic Depression with lower growth rate every year for the rest of the century, to the point that Global Wealth growth rate is cut in ~half by 2100…
- **STILL, atmospheric CO2 levels climb, and are as high as 485 ppm by year 2100.** 485ppm is high enough to trigger tipping points for permafrost complete thaw, and likely James Hansen et al. (2016)'s horrific scenarios
- **Garrett's discovery and incorporation of the constant ratio between inflation-adjusted time-integrated Global GDP and the rate of consumption of energy – The Garret Relation, is a very powerful game-changer in a very negative way.**
- Of course, if we have ENOUGH collapse and even faster decarbonization, then we can halt CO2 rise. But until I (or Tim) run those even more extreme models, I'm not sure where that is.

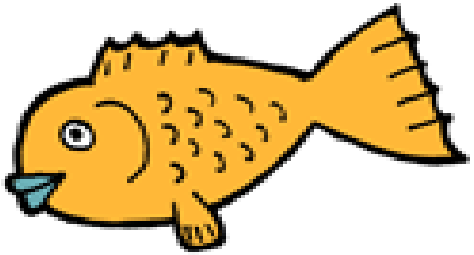
How do the IPCC, CThERM Models Differ?

- The IPCC's SRES models split off the evolution of **population**, global average **standard of living**, and **energy efficiency** (*i.e.* energy expenditure's useful return to civilization) as separate independent drivers, set independently of each other (see sec. 5 here).
- But the actual behavior of our past shows that population growth and standard of living growth rates are only constrained by our access to energy and changing energy efficiency, and are thus actually **dependent** variables, not independent variables.
- In other words, population evolution and standards of living growth **can both be predicted** knowing only the available energy and changing productive efficiency of that energy, given human nature…
- The **CThERM** model reproduces observed economic growth rates year by year, accurate to 0.1% in the mean, over the 1990-2014 period (*i.e.* where data is available). The SRES model only reproduces this with a particular "worst case" carbon scenario (Raupach *et al.* 2007)

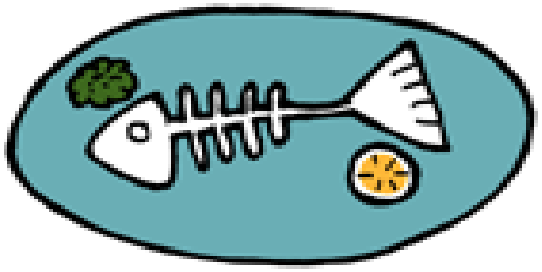
What is the Fundamental Driver?

- **My thoughts, and likely Garrett's as well…**
- For the vast majority of human genetic history, it was an advantage to evolve a biological drive to fight for our place in a vast wilderness of dangers and competitors for our desired resources – ***Grow. Or Die.***
- When we became more efficient, we became better at carving away that wilderness. This is reflected in the CThERM model, implicitly
- Now in the 21st Century, unconquered Nature is mostly gone, and we've taken essentially all arable land, stripped the oceans, commandeered over a 1/3 of the entire primary productivity of the planet to ourselves… and sanity requires that **growth must end.**
- **Alas… We still have the same genetic inheritance and urges – to grow, to conquer, to expand. Especially, as we saw in PowerPoint K40b (Psychopathologies of Climate Denial), those with least-developed forebrains (the Conservatives) most loudly voice this unquestioned mindset. Review K40b for the evidence of that.**

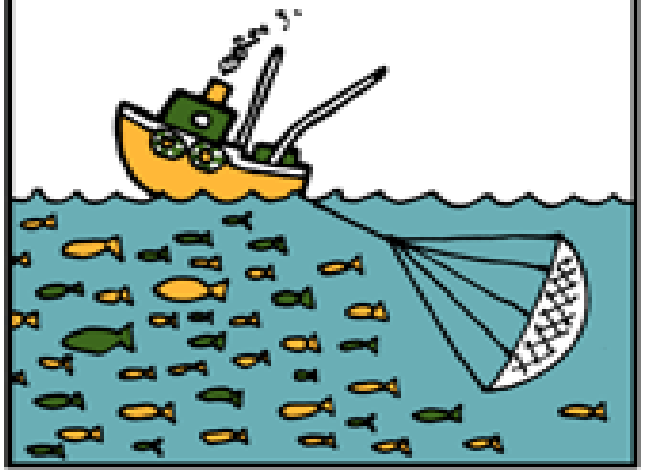
GIVE A MAN A FISH...



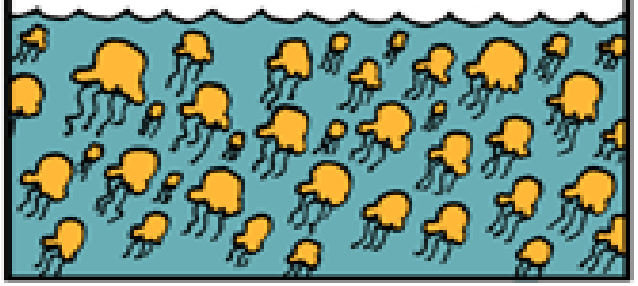
AND HE'LL FEED HIMSELF FOR A DAY.



TEACH A MAN TO FISH...



AND HE'LL SYSTEMATICALLY SCOUR THE OCEANS CLEAN OF ANYTHING EDIBLE.



Constant ‘mere’ 2% Growth, as Wall Street Complains about Every Day (Listen to CNBC) as Too Low, is Still Exponential Growth

- It leads to a doubling of the consumption rate of food and raw materials every 36 years, even if you pave the rest of the Earth with solar panels.
- **Growth WILL end! Earth IS finite. And the other planets are nasty places to try and live. Trust me on all 3 of these.**
- Our **ONLY** choice is this: Do we learn that lesson BEFORE we trash and doom the last square mile of unspoiled Earth, or AFTER?
- If AFTER, what end will **WE** meet?

Our Forebrain. Cause for Hope?

- The only bit of hope I see, is that as part of our evolutionary survival mechanisms, Nature also evolved in us a forebrain – capable of reason, of identifying principles, of applying them, and forecasting the future to enable planning.
- It's our forebrain *vs.* our "reptilian brain". For most of our history, they both mostly led to the same goal - domination. Now… they are in conflict, and our survival and well-being requires that we let our forebrain assume agency. Will we do so, in time? Can we, at all?
- Can such deep fundamental change in human behavior happen, such that it would break the fundamental essence of the CThERM model – the constancy of the ratio of integrated global wealth and required energy consumption – **the Garrett Relation**?

Genetic Inheritance is Destiny?

- Remember from Chapter 0 – our brain is only ~2% of our body mass, but uses 20% of our energy (which must come from food grown by our agricultural industry)
- If you've ever tried to over-rule your biological desires (going on a diet, say), you know how hard it is, it demands energy.
- Willpower will go only so far. It takes real biological ENERGY to fight against desires and exert **will power.** It's like holding up a barbell. No matter how strong you are, eventually that Olympic barbell is coming down. That path requires strongly enforced global government policy action, against human desires.

Small is Beautiful?

- If instead, we personally evolved to ENJOY a new “less is more”, “small is beautiful” way of being, perhaps this consideration would not as much hold sway
- But this classic E.F. Schumacher book was published in 1973 - 43 years ago - and clearly not embraced except by a tiny fraction of our population.
- So I fear that will take such intensive human psychological maturing on an individual and then massively global scale, and accomplished so impossibly quickly, that it would seem quite unlikely.
- Without that, I fear that the human evolutionary inheritance will, globally, lead us to our fate.

Nolthenius' First Law: "People Learn the Hard Way"

- I know from experience and that of others, that it usually takes long-standing pain to motivate a person to change. And then, it takes real work, real commitment, to overcome ingrained patterns of thought and achieve emotional maturity in order to really grow.
- How can we expect this of the entire global population?
- **A few do learn. We hear their voices from the science community, and some from the Green community, and elsewhere. But they are a tiny minority – the upper tail end of the bell curve. Despite what growth is doing to this planet, most of the Earth is peopled by those desperate for MORE, not LESS. And not a single leader will dare talk of limiting population, or limiting growth in wealth.**
- And worse, our global political/economic power systems are designed to reward short-term greed, not nurture long term planetary health.

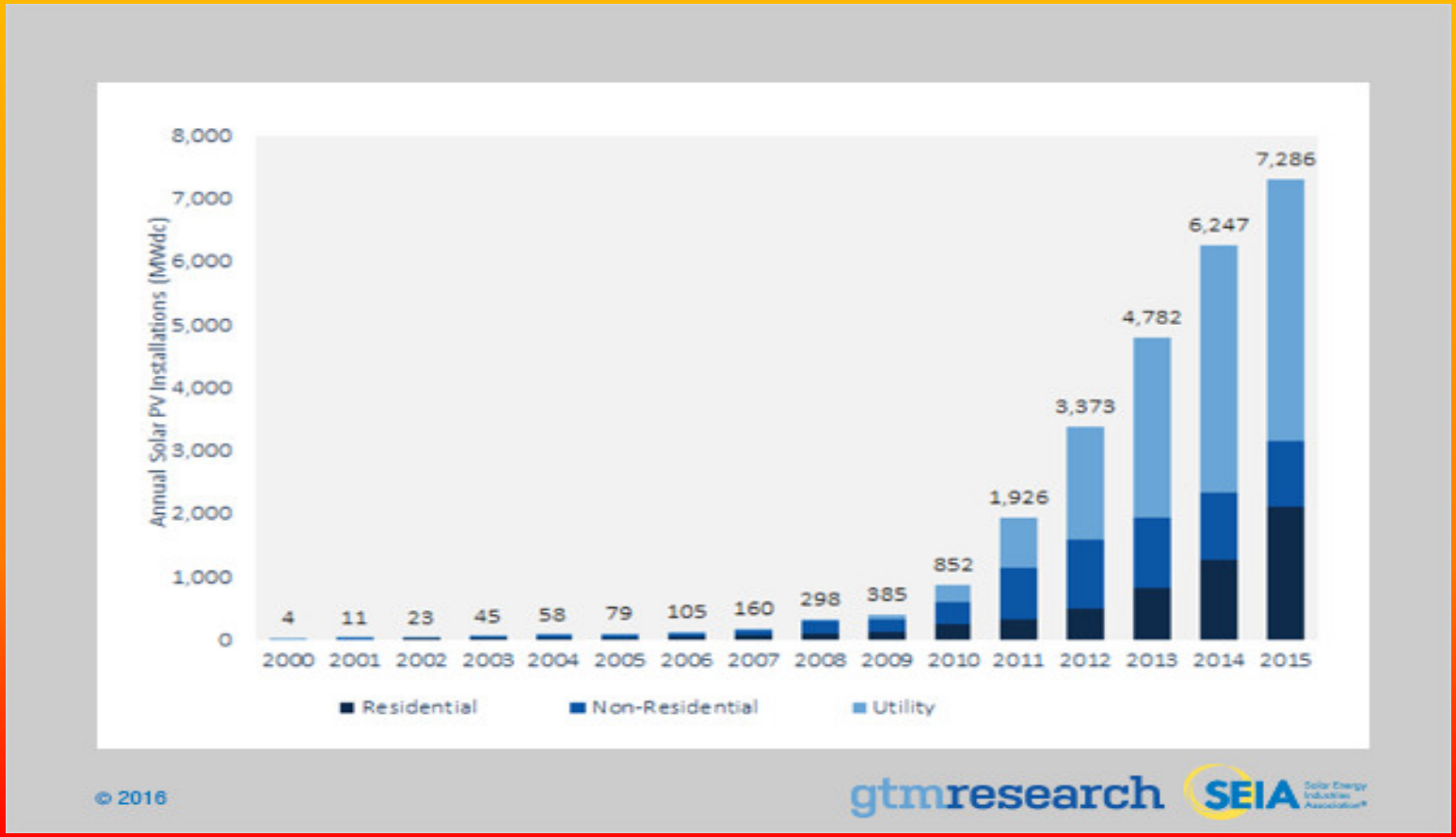
"It is difficult to get a man to understand something, when his salary depends upon his not understanding it."

—**Upton Sinclair**

Some Key Results of Garrett's Work

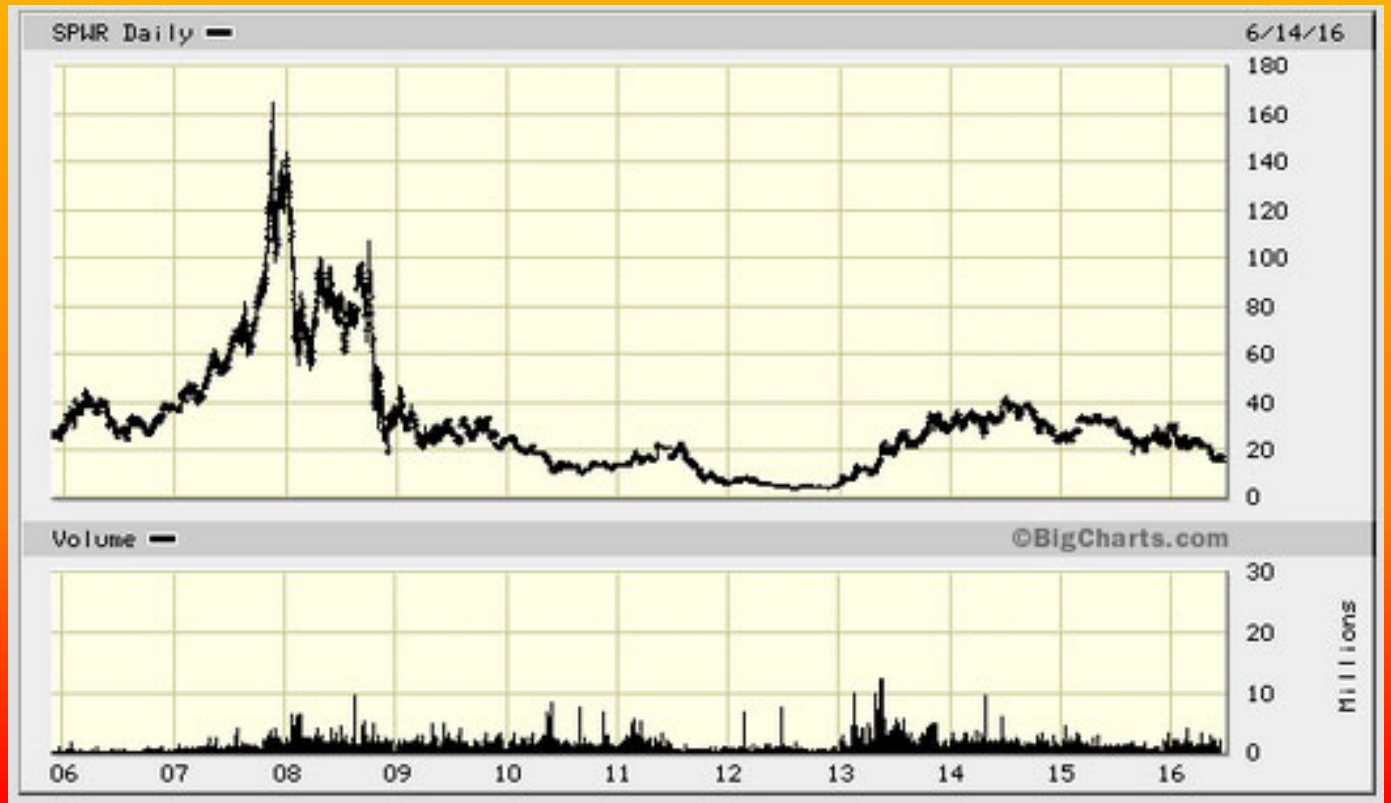
- Improving energy efficiency requires accelerating CO2 emission growth, in part because for now, doing ANYthing, including improving energy efficiency, requires carbon-generating energy to accomplish
- Energy consumption is determined by the size (in $) of Civilization, which is determined by all past growth and therefore cannot be changed, and hence has significant inertia. It cannot be stopped easily (absent collapsing the world economy and/or a rapid and large increase in death rates).
- **Merely halting the further rise of CO2 emission rates requires the equivalent of 1 new carbon-free massively large 1 Gigawatt power plant PER DAY (based on an economic growth rate of 2.1%/year as has applied for most of this century).**
- **A new carbon-free 1 Gigawatt power plant needs to be built every day just to continue emitting "only" 40 billion tons CO2 per year as we are currently, as Garrett shows. This is FAR beyond what we're actually doing.**

For comparison, the U.S. installed 7.3 GW of solar in all of 2015. And 59 GW globally. That rate is only 16% of what's needed globally to merely keep CO2 emission rates constant at 40 Gt CO2/year, based on average growth rates of the 21st century. (And for the past 5 years, that solar growth rate has risen only linearly, not exponentially, in the U.S. Most of the gain is in utility-scale projects)



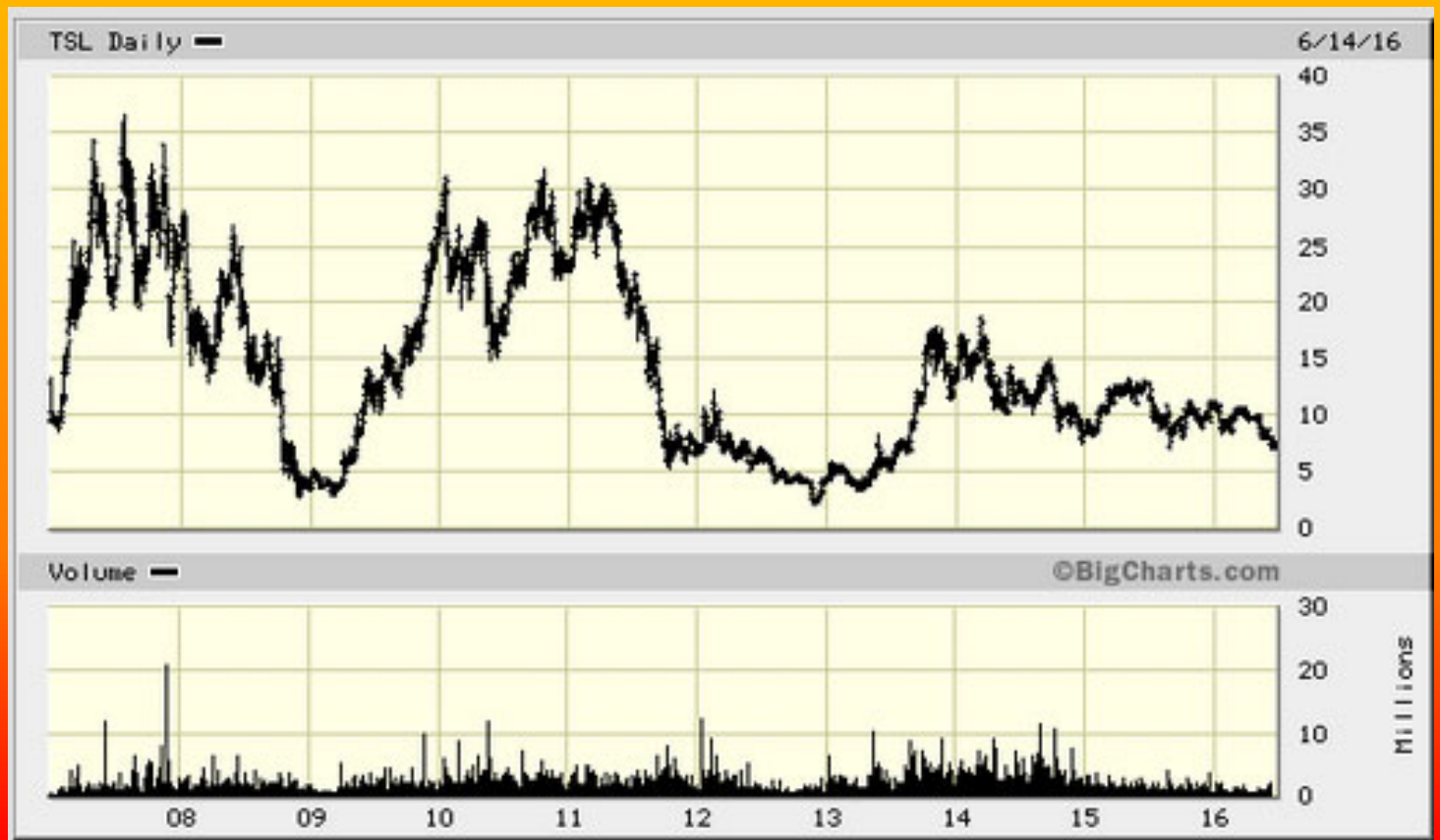
But surely the solar PV companies must be doing *GREAT!* Expanding, stock prices moving up. Right?

- Not really. Most of the efficiencies of production and technology have already happened. Profit margins are razor thin, or negative, even with subsidies. The largest – Sun Energy – went bankrupt this year.
- Here's the stock chart for the highest efficiency and ~largest solar panel maker in the U.S. – **Sunpower**. Investors net **LOST $ this decade**



I know what you're thinking: It's CHINA - they're making Huge strides! So how's their State-favored large manufacturer – Trina Solar, Inc. - doing?

- Not good. Nor are the other China majors; JA Solar, JK Solar, CSIQ…. All similar stock charts



Prof. Kevin Anderson Points Out

- Global energy consumption in 2015 was 105,000,000 Gigawatt-hrs
- Nuclear power provides 2.5% of that
- Merely to get nuclear to provide ¼ of our power means we need to build 4,000 new ~1 Gw power plants in the next 30 years. Instead, we have scheduled 70.
- His bottom line is, whether it's wind, solar, CCS, or whatever the new technology trumpeted **– "you cannot build them fast enough"** to prevent us from blowing through our carbon budget to hold temperature rise to ~+3C
- And this is without the additional constraint discovered by Garrett.

Why not count on inspiring selfless acts of social conscience towards a low carbon lifestyle?

- The numbers simply make this strategy futile (next slide).
- Climate is GLOBAL. CO2 is GLOBAL and recognizes no personal, political, or national boundaries.
- Most new carbon pollution is now from Asia, whose people desperately want “the good life” we have enjoyed in the West for generations, and are quite resistant to being told by the U.S. that the Earth can’t afford their energy-intensive desires. ***“Sorry – you missed the party”***, doesn’t sit well.

Let's Do the Math…

- Suppose we motivate, through whatever inspirational work, **100 million people to voluntarily cut their carbon footprint in half** (almost certainly impossibly optimistic today, considering Garrett's work)…
- In the US, the per capita **CO2 footprint** is 17 tons/year per person. Assume all 100 million inspired people are high-carbon Americans
- 2015 global CO2 emissions were 40 billion tons/year
- Therefore: 17 x ½ x 100 million people = 850 million tons of CO2/year savings = only **2.1% of the world emission rate.... Negligibly small**
- OK - Raise it to **1 BILLION** people voluntarily cutting their carbon footprint by ½ and use a correspondingly more realistic 10 tons CO2 per year per person (they can't all be Americans) and you still only cut global CO2 emissions by 15%. That's ALMOST no difference to our future
- **Repeat for emphasis: Convincing 1 billion people in the high-carbon-footprint industrial world to voluntarily cut their carbon footprint IN HALF by drastic cuts in lifestyle and conservation, only cuts global CO2 emissions by a paltry 15%, when we need to cut it to ZERO, RAPIDLY, just for starters.**

So I am not one to Guilt-Trip anyone for not individually, voluntarily lowering their personal carbon footprint

- We may be shy to admit it out loud, but **we all know** – one (or even one billion) person's noble sacrifice will do nothing for solving the ACTUAL PROBLEM, and yet may entail a significant loss to a person and their family.
- Such sacrifice needs to be WORTH it!
- But if we **ALL** make severe sacrifices, such that we actually **do** save a livable future – that's an entirely different proposal!
- **Therefore, what is required is government policy, universally enforced. Voluntary local/individual conservation, realistically looked at, isn't near enough. It may feel good, so do it, but don't let magical thinking get in the way of realism – it won't solve climate.**

But Look at Inspiring Figures in History who Changed the World – Do you forget, Rick?

- When the time was right and the population at large was willing to sacrifice, a single figure CAN be the trigger, the tipping point, to change the paradigm, I agree!
- This is why I teach, to help get people to the point of education where they are motivated when the trigger happens.
- But the solutions themselves HAVE to be UNIVERSALLY enforced, against people's natural tendencies. Globally we're clearly NOT willing to sacrifice (we're willing to have the bad guys in this drama sacrifice, which isn't the same!) It's particular to the nature of the atmosphere and ocean. Local activism won't help local climate. Only global activism can help local (or global) climate

It's been argued to me; "what about Gandhi", inspiring a nation to throw off British Imperialism?

- ….and likewise, small local actions may inspire more local actions, until our leaders listen (**really?)**
- **My response:** Gandhi wasn't facing climate change. With tipping points being crossed while we complacently believe we have time to wait for little shoots of green to grow into a changed world (will the green shoots even grow, after the "low hanging fruit" of eco-friendlies have already been educated?). **Gandhi could be patient. We can't.**
- A better analogy is this – what would Gandhi do if he were in the back seat with Thelma and Louise, 300 ft from the cliff edge, speeding at 100mph? A gentle hunger strike? Or jump into the front seat and slam the brakes, crank the wheel into a fish-tail spin? Which is an **actual** solution? Which are **you** choosing?

So What do we Do?

- Yes, we need to decarbonize, and solar and wind energy at this point are the fastest way, and ready to deploy… given political will
- We also need a **Global Economic Depression of fearsome proportions** to dramatically reduce carbon energy use as well, and even then, societal upheaval looks very likely as the **Permafrost Carbon Feedback** takes over and CO2 levels continue to rise (MacDougall et al. 2012, Friedrich et al. 2016) .
- But people will not elect for Global Depression voluntarily

So we need gut-wrenching global policy action

- …to FORCE people into Spartan lifestyles and put all available effort into decarbonizing the energy we can't do without, and digging deep to develop atmospheric CO2 removal technology
- **We need Tax-and-Dividend to motivate away from carbon energy**
- **We need stiff trade sanctions against countries not instituting their own tax-and-dividend**
- **Strong population control, an engineered global Depression of long duration…**
- **See my "K44 – Policy" for a longer Presentation**

A New Amendment to the Constitution

- I propose a 28th Amendment to the Constitution…

- ***"Congress shall permit no law denying the rights of present and future citizens to safe commons, including air, ground water, river water, and natural forest. Congress shall permit no laws which interfere with the existence of a natural environment in harmony with the right to life and the pursuit of happiness by future as well as present citizens."***

How to Bring About These Policies?

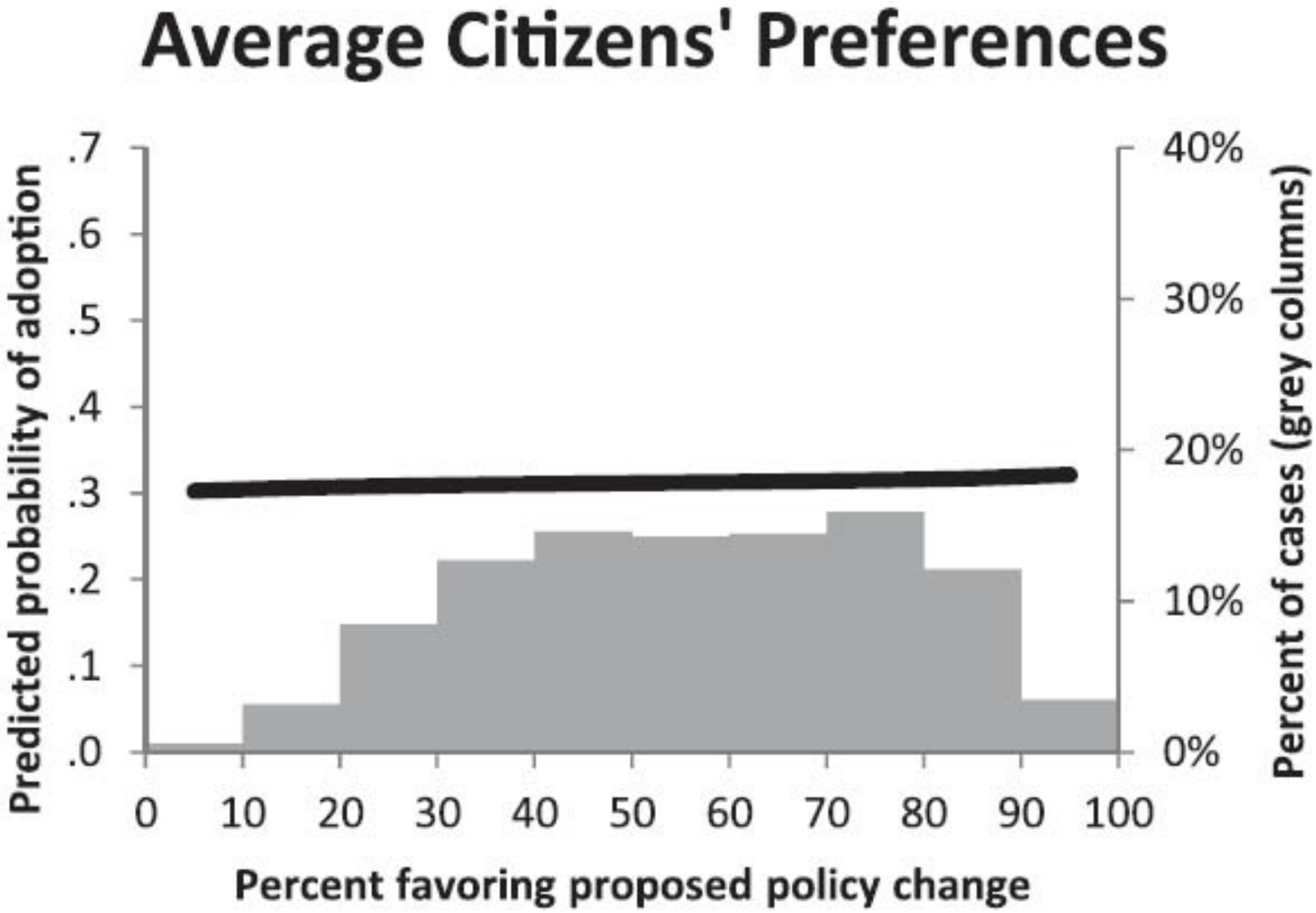
- The hard evidence says politely asking “please”, hat-in-hand, of our law-makers will continue to go nowhere…

- Princeton University research (**Gilens and Page 2014**) studied the key variables of 1,779 policy issues contained in congressional legislation bills proposed and passed over a 20 year period
- This period included the Clinton, Bush, and Obama years, and both Democratic and Republican dominated Senate and House periods.

What Did They Find?

- They found that **the influence of the desires of the average citizen had a "miniscule, statistically insignificant" (i.e. *zero*) correlation with what legislation was actually enacted**
- **ZERO CORRELATION.**
- Instead, enacted legislation had very **high** correlation with what was desired by the economic elites and their lobbies.
- You might want to take some blood pressure meds before following along…

Whether average citizens hated or loved a policy proposal had zero correlation (flat line) with whether the policy was enacted (Gilens and Page 2014)



But the legislative preferences of Economic Elites correlated ~perfectly (correlation coeff =0.78) with what was enacted. (Perfect=1.00)

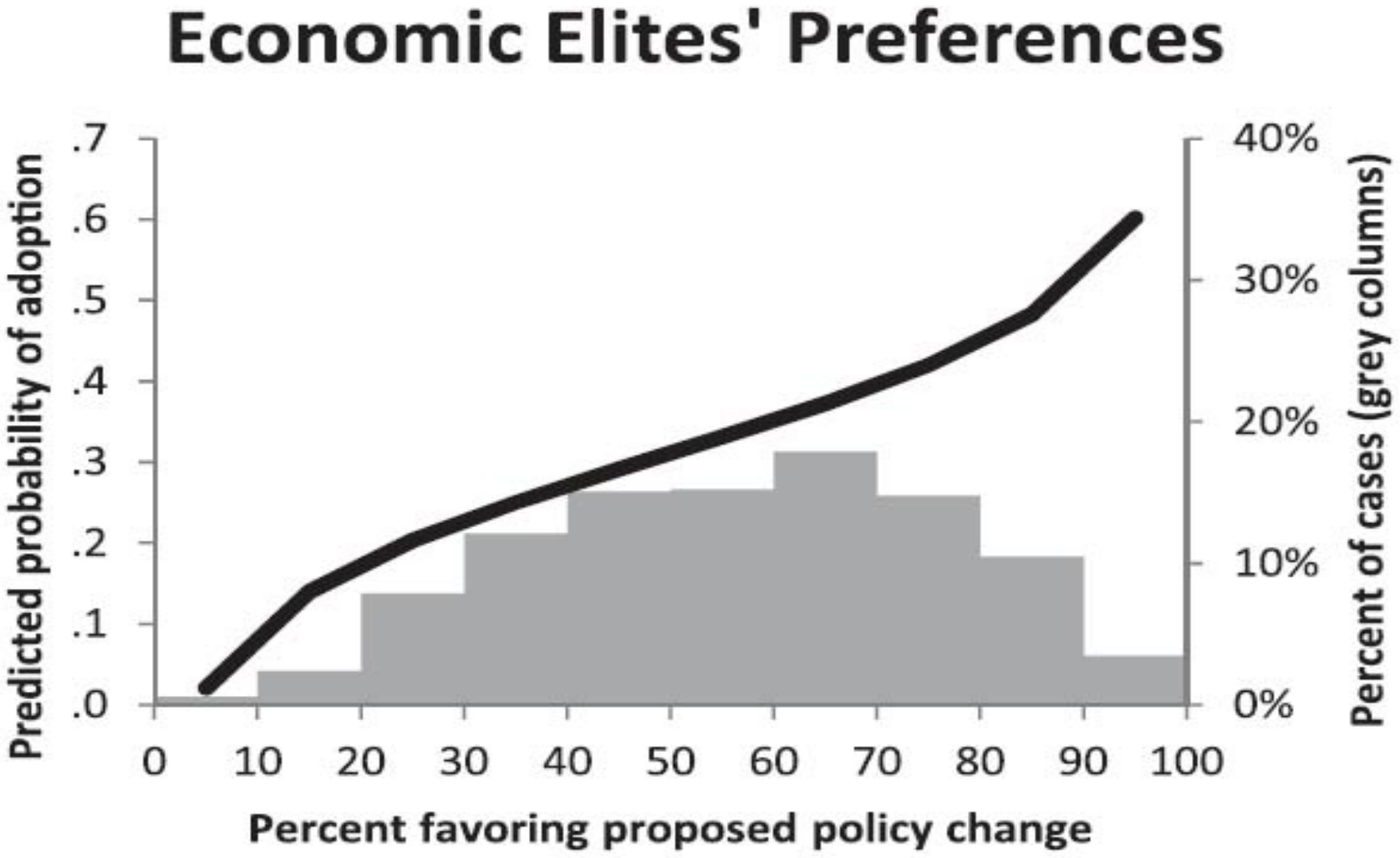


Table 4
The separate policy impact of business-oriented and mass-based interest groups

Average citizens' preferences	.05
	(.08)
Economic elites' preferences	.78
	(.08)***
Mass-based interest groups	.24
	(.07)***
Business interest groups	.43
	(.08)***
R-sq	.07

***p<.001

Note: All predictors are scaled to range from 0 to 1. The dependent variable is the policy outcome, coded 1 if the proposed policy change took place within four years of the survey date and 0 if it did not. Predictors are the logits of the imputed percent of respondents at the fiftieth ("average citizens") or ninetieth ("economic elites") income percentile that favor the proposed policy change, and the Net Interest-Group Alignment Indices described in the text. Standard errors are asymptotically distribution-free, and all analyses reflect estimated measurement error in the predictors, as described in Appendix 2. N=1,779.

***Average Citizens:** ~0 correlation.

***Mass-based lobbies**, like CCL, 350.org: not much better; 0.24 correlation.

***Business interest groups**, significant (0.43) correlation.

***Economic elites**: very strong (0.78) correlation

Most Important for Climate…

- ***Notice the left end of the previous graph; that **when economic elites and their lobbies strongly opposed legislation, it had a 0% chance of being enacted.**
- **They were 100% efficient in stopping legislation which they strongly opposed.**
- Today, the economic elites include the right-wing ideologues who strongly oppose climate science, climate scientists, and government interference in fossil fuel business (except for huge government oil and coal subsidies – they're OK with that part)
- So what chance does "write/talk to your congressman" actually have in getting enacted the policy ideas we've discussed?
- What has "write/talk to your congressman" accomplished so far? Have we gotten action, or just stall tactics, empty promises, handshakes, and the rest of the artful dodging obvious for decades? I leave that as an exercise for the student. OK, exercise over – here's the answer:
- **The evidence is overwhelming …**

Your Influence on Policy Enacted: *ZERO!*

- **I will not be convinced people actually have as their actual primary goal the halting of climate change until they face this brute fact and stop the insanity of doing the same thing over and over and getting the same zero result, as our planet tips over the edge.**
  - ***"We Are What We Repeatedly Do" – Aristotle***
  - **What does that say about your Congressperson's Integrity?**


I don't mind
you being rich.
I mind you
BUYING
MY
Government!
Gracy Knauss

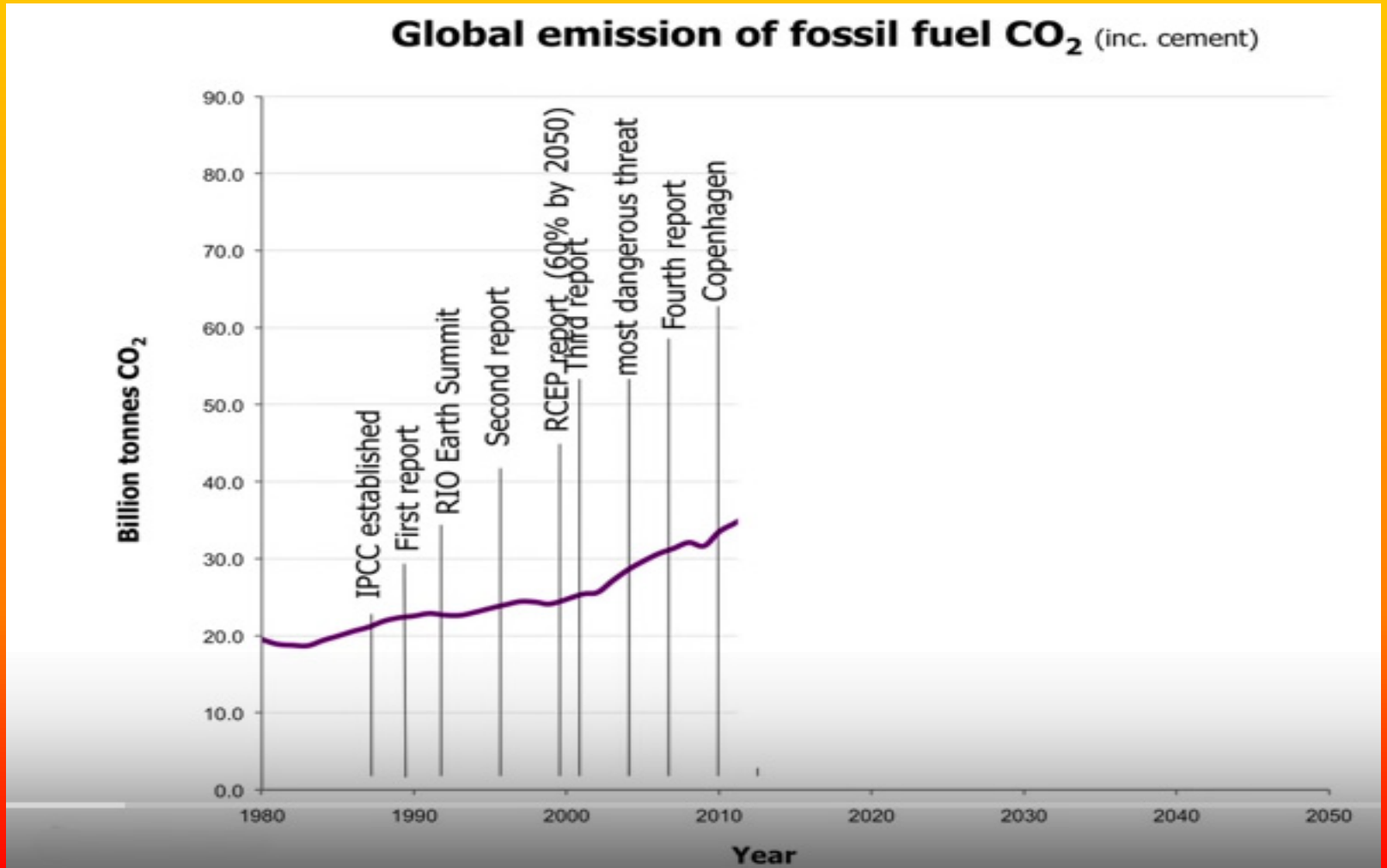
I've Heard the Response: But I LIKE My Congressman…!

- "…It's all those OTHER congressmen who are the problem!"
- Perhaps you too have heard this, or said this.
- Yet the favorability rating of Congress hit 11% last Fall, and I've even heard a 7% reading.
- In can't help but interpret this stubborn refusal to confront Gilens and Page (2014) as evidence for **Stockholm Syndrome**
- **Stockholm Syndrome:** When a person feels helplessly ruled by others, there is a strong psychological bent towards adopting a delusional belief they are good, not evil, because the idea that one is helplessly at the mercy of evil brings up overwhelming fear.
- An alert and mature person should consider this, and make a conscious attempt to step back and look at the evidence, and confront the frightening prospect that you are ruled by people who do NOT have your best interests in mind

From a New Book by an Anonymous Democratic Congressman…

- "Most of my colleagues are dishonest career politicians who revel in the power and special-interest money that's lavished upon them."
- "My main job is to keep my job, to get reelected. It takes precedence over everything."
- "Voters are incredibly ignorant and know little about our form of government and how it works."
- "It's far easier than you think to manipulate a nation of naive, self-absorbed sheep who crave instant gratification."
- "Fundraising is so time consuming I seldom read any bills I vote on. Like many of my colleagues, I don't know how the legislation will be implemented, or what it'll cost."
- "We spend money we don't have and blithely mortgage the future with a wink and a nod. Screw the next generation. It's about getting credit now, lookin' good for the upcoming election."

We shouldn't be surprised to see the rate of CO2 emissions steeply rising despite the continued Climate Summits and IPCC Assessment Reports. Not just total CO2 emission, but emission rates below, have nearly DOUBLED since the formation of the IPCC.



Maybe We Need to Be A Little More Insistent, on Insuring a Future for Our Children

Honorable people ACT, and BEHAVE like leaders.

- Dishonorable people worry what their corporate sponsors will feel.
- Dishonorable people pretend to listen, but in fact do not.
- Dishonorable people work at perfecting the art of handshaking and smiling, and kissing babies, while having no backbone to act as if this is the emergency that it genuinely is.
- **Honorable politicians should be begging us, the common citizens, to shut down the government and thereby FORCE them to ACT. They are not. Instead they mumble excuses about their busy agenda**.
- We've known about the danger to life on Earth due to fossil fuel greenhouse effects for over 100 year now! We have waited past critical tipping points and our future is now fated with increasingly serious disasters for generations to come, because of the continued cowardice, greed and short-term selfishness of lawmakers and their corporate sponsors.
- They fail to act not because they do not understand. **We compound their utter disregard for the average citizen by naively believing that one more letter will illuminate them. It is also insulting – to us! And further emboldens them to do nothing.**

1 in a Million

- Realize that the lawmakers of the United States – the 435 members of Congress, the 7 Supreme Court Justices, and the President, add up to about 1 millionth of the U.S. population
- They are the **One in a Million** who ACTUALLY MAKE the laws the other 350 million of us have to obey
- That is an awesome responsibility. They have staffs, they have funding to accomplish their job… yet they do nothing. At best, making excuses or repeating campaign platitudes.
- This is the most urgent and massively consequential issue of this and all later generations. Scientists have been warning us for decades. So, don't tell me they're earnest and honorable and well-meaning, but just "too busy" and need more letters of gentle reminder.
- They could call news conferences and educate ALL about the truths I'm relaying here. Yet they do not
- **We are what you DO – and they clearly have no intention to make necessary policy – PLEASE! CONFRONT this CLEAR FACT before continuing!**

But maybe if we're patient, and we're not confrontational, and we're diplomatic with our congresspeople, then through patient spade-work we can compromise to find solutions – I've heard this style advocated. I Ask You to Consider the Consequences…

- Motesharrei *et al.* 2016 *"…all societal collapses over the past 5,000 years have involved both 'the stretching of resources due to the strain placed on the ecological carrying capacity' and 'the economic stratification of society into Elites [rich] and Masses (or 'Commoners') [poor].' This 'Elite' population restricts the flow of resources accessible to the 'masses', accumulating a surplus for themselves that is high enough to strain natural resources. Eventually this situation will inevitably result in the destruction of society."*
- *"Elite power, the report suggests, will buffer 'detrimental effects of the environmental collapse until much later than for the Commoners,' allowing the privileged to 'continue business as usual despite the impending catastrophe.'*
- *"'Science will surely save us', the nay-sayers may yell. But technology, argues Motesharrei, has only damned us further…"* (by way of Jevon's Paradox)

“Power yields nothing without demand”

- Fredrick Douglas

Then How?

- At one time, I considered an internet-organized effort to identify in each congressional district and state, new candidates who would make climate action their top priority
- Followed by a large effort to write-in those candidates, funded only through grass-roots efforts
- I no longer think this is the way
- It would take too many successful campaigns to win, and would require changing too many minds… It would require voting majorities over a majority of districts, and it would take too long, even if it eventually might succeed.
- **So…**

I Offer This Idea: Occupy Washington D.C.

- **The power of media attention, with images stirring public conscience, can be instantaneous**
- **We either deal with climate change, or little else really matters about the future – that's the first fact to appreciate**
- If climate activists, rather than celebrating inconsequential meetings with their congresspeople, instead canvassed the country to get just 1 to 2 million people who would commit to going to Washington D.C. for a different kind of demonstration…

Occupy DC's Goal Would be…

- To nonviolently, peacefully, but with determination, prevent "business as usual" from continuing…
- To march on the Capitol and White House and walk past those who would stand in their way.
- **It would be to OCCUPY the core government building areas of D.C. until congressional leadership publicly spoke to the assembled press with a commitment to pass a steep and progressively steeper Tax-and-Dividend law, and stiff trade sanctions against all other countries who don't do the same within 1 year.**
- **Not promises of "we'll work on it". Not this time. No…. A commitment with promise of their immediate resignation if they fail. Filmed, <u>FOR the RECORD</u>.**
- It would be to PREVENT any other legislative action until these promises were made, by a march so vast in number that normal business could not continue. The model would be Martin Luther King, and Nelson Mandela.
- Arrests may happen. Let them happen, peacefully and without resistance. Any violence would be a choice committed by the government, not the occupiers. Until every jail cell is filled and no more can be arrested.
- But it would take at least a million, better if it were 2 million**. That's less than ½ of 1% of America.** Sufficiently educated, it is conceivably do-able. A mass of humanity impossible to ignore, and that may inspire millions more by their sheer courage and audacity.

Occupy DC

- …would NOT be to try and negotiate in congressional offices. Remember: THEY work for US. I'm thinking of the classic line of George Clooney in the film "**Michael Clayton**" – ***"Do I LOOK like I'm NEGOTIATING!?"***
- It would not be for getting a warm buzz by communing with other placard-carriers
- It would not be about fellowship
- This would be different…
- **This would be Focused. It would be As Serious as the Consequences of Climate Change**
- …it would be to deliver an ultimatum on behalf of all future children and all Earth's species

There are those who feel drawn to Political Action

- **I am not one of them**. I love science, and teaching, and identifying the truth of things, and thinking what actions might make an actual difference in halting climate change, once I understand the issues fully.
- But to those who are drawn to political action, **I challenge them to take up this cause.**
- Tim Garrett's insights make even the most drastic policy actions perhaps only helping us towards a future of exponentially rising costs, instead of a future barely worth living in at all. But that's still worth doing.
- **"Disobedience"** – is a new film which has interesting suggestions to make.

I'll End with this Small Factoid on What Effort is Needed to Pull Atmospheric CO2 Back Down

- Atmospheric scrubbing technology is hard. ~Half of the cost is in the energy needed for removing CO2, since it is a tough and tightly bound molecule.
- The current cost estimates are several $hundred up to $1,000 per ton of CO2, which we talked about.
- $1000/ton means the cost is **$56,000 for every man, woman, and child on Earth, to get down to 280ppm pre-industrial CO2**, a climate-stable level.
- And so, what amount of carbonate rock (a stable sequestration product) are we talking about being necessary to make?...

A Mt Everest-sized Block of $CaCO_3$ to get back to Pre-Industrial Atmospheric CO_2 Levels

- This would require making 8×10^{17} cc's of limestone rock, or a cube 1 million centimeters on a side, which is a ***Limestone block higher than Mt. Everest (30,500 ft on a side) from sea level. Or a pyramid 43,000 ft high***
- That's also going to require a lot of calcium. Calcium is common, but mostly it is found as - calcium carbonate!
- Destroying $CaCO_3$ in order to make $CaCO_3$ is *questionable*. This is **not** the most promising strategy
- Greg Rau at UCSC has ideas on taking existing $CaCO_3$ and combining with CO_2 to produce Calcium bicarbonate, a safer idea, and dumping it in the ocean. See “K45 Strategies: Technology” for more

Start Smaller?

- To instead immediately drop current CO2 atmospheric levels from 400 ppm to 350 ppm would require a cube of calcium carbonate of ”only” 23,000 ft on a side; still higher than any mountain in the Western Hemisphere.
- At current production rates of ~40 billion tons of CO2 per year, it requires an additional cube-shaped mountain 8,000 ft on a side every year.
- Is it possible to build "scrubbers" for the atmosphere that could accomplish such a vast task? Where do we put it all - the ocean? We'd better make sure ocean acidification levels don't reach levels that begin to dissolve existing oceanic aragonite calcium carbonate (as they will this century, on our current trajectory). When that happens, the problems we have been presenting so far will pale by comparison.

Maybe instead of putting it in the ocean, we could take a cue from the ancient Egyptians… Visualize oil company executives conscripted to toil under the hothouse conditions on 21st Century Earth, building the Great Carbonate Pyramids, miles high, sufficient to clean up our atmosphere. At wages comparable to those of the poor souls who built the pyramids of Egypt. Likely we'd find people to donate the necessary land just for the satisfaction of watching them toil.

The last half of this talk has drawn heavily from slides from my more complete presentations from my Astro 7 Course

- Please visit the **Astro 7 PowerPoint List** to see the latest ideas on climate change strategies, the thermodynamic limitations on civilization's choices, policy options, and technological ideas.
- I wish I could say that we just have to, (like Watney in **"The Martian"**)*" …science the hell out of this":* Stabilize climate and not suffer any tough consequences; just let the smart techno guys figure out how to let us have what we have now, and stable climate too. But…
- Alas, there are no easy solutions. It is very late even for hard solutions. **Climate evolves slowly… but inevitably**