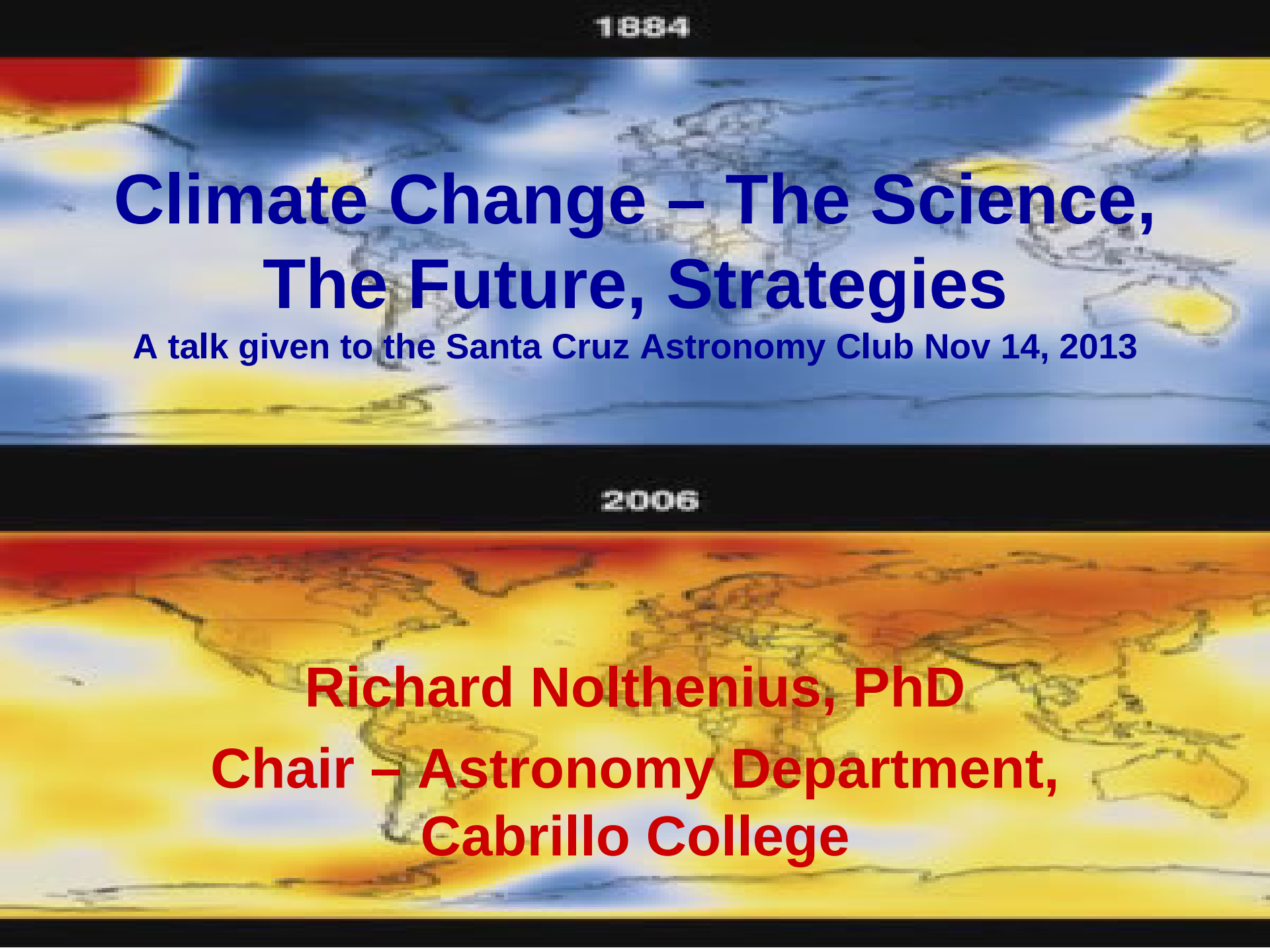


Climate Change – The Science, The Future, Strategies

A talk given to the Santa Cruz Astronomy Club Nov 14, 2013

Richard Nolthenius, PhD

Chair – Astronomy Department, Cabrillo College


EXTREME WEATHER
CLIMATE CHANGE IS A HOAX!
© 2012 PITTSBURGH POST-GAZETTE

Is there a Scientific Controversy about the Cause of Global Warming?

No

- Climate scientists themselves are (and have been, for over 20 years) convinced by the evidence: Global warming is human-caused, primarily by fossil fuel burning.
- AGW = Anthropogenic Global Warming, a useful abbreviation

The Politics of Climate

- Hundreds of Millions of dollars of oil money is financing a mis-information campaign to seed cynicism towards legitimate science in the American public and in politicians about the cause.
- The goal – to prevent any policy changes which threaten fossil fuel corporate profits
- **Prof. Robert Brulle at Drexel University estimates that (as of 2013), in the past decade over $500 million has been given to organizations who are dedicated to slandering the scientists and their science**
- **$500 Million will fund a LOT of *"Proof by Loud Assertion"!*** Much of it quite ugly…

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

—**Upton Sinclair**

Example: Part of The Heartland Institute's Billboard Campaign

- **"The most prominent advocates of global warming aren't scientists," Heartland's president, Joseph Bast, said in a news release. "They are Charles Manson, a mass murderer; Fidel Castro, a tyrant; and Ted Kaczynski, the Unabomber." He said other "global warming alarmists" include Osama bin Laden and James J. Lee, who took hostages inside the headquarters of the Discovery Channel in 2010.**

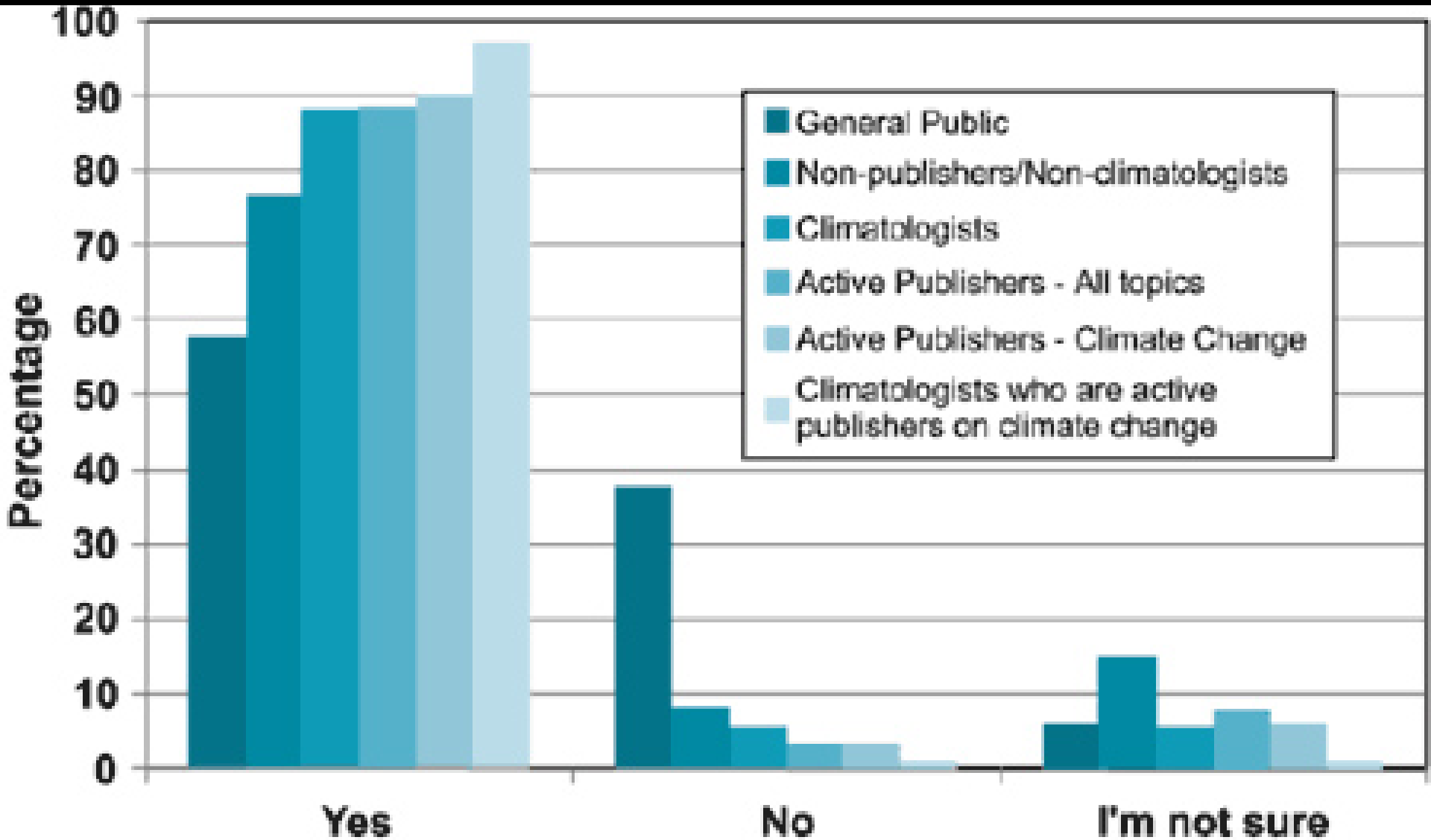
A Quote From Carl Sagan…

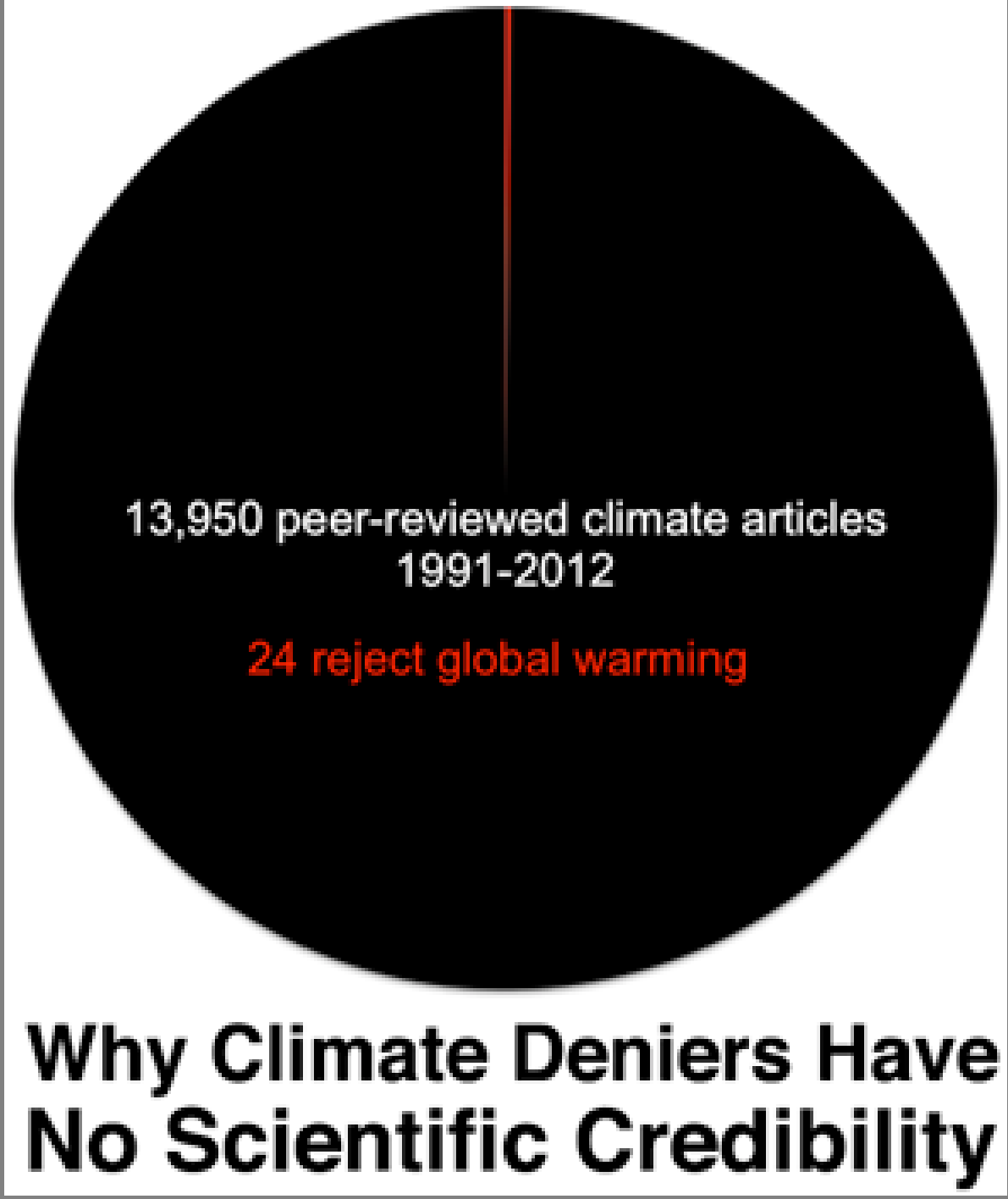
- *"In science it often happens that scientists say 'You know, that's a really good argument; my position is mistaken' and then they would actually change their minds and you never hear that old view from them again. They really do it… change is sometimes painful, but [in science] it happens every day. I cannot remember the last time that happened in politics or religion"*

  – Carl Sagan

- This is my experience as well

Note the Strong Correlation – Greater Competence in Climate Science goes with Greater Conviction it is Human-Caused (Anderegg *et al.* 2010)





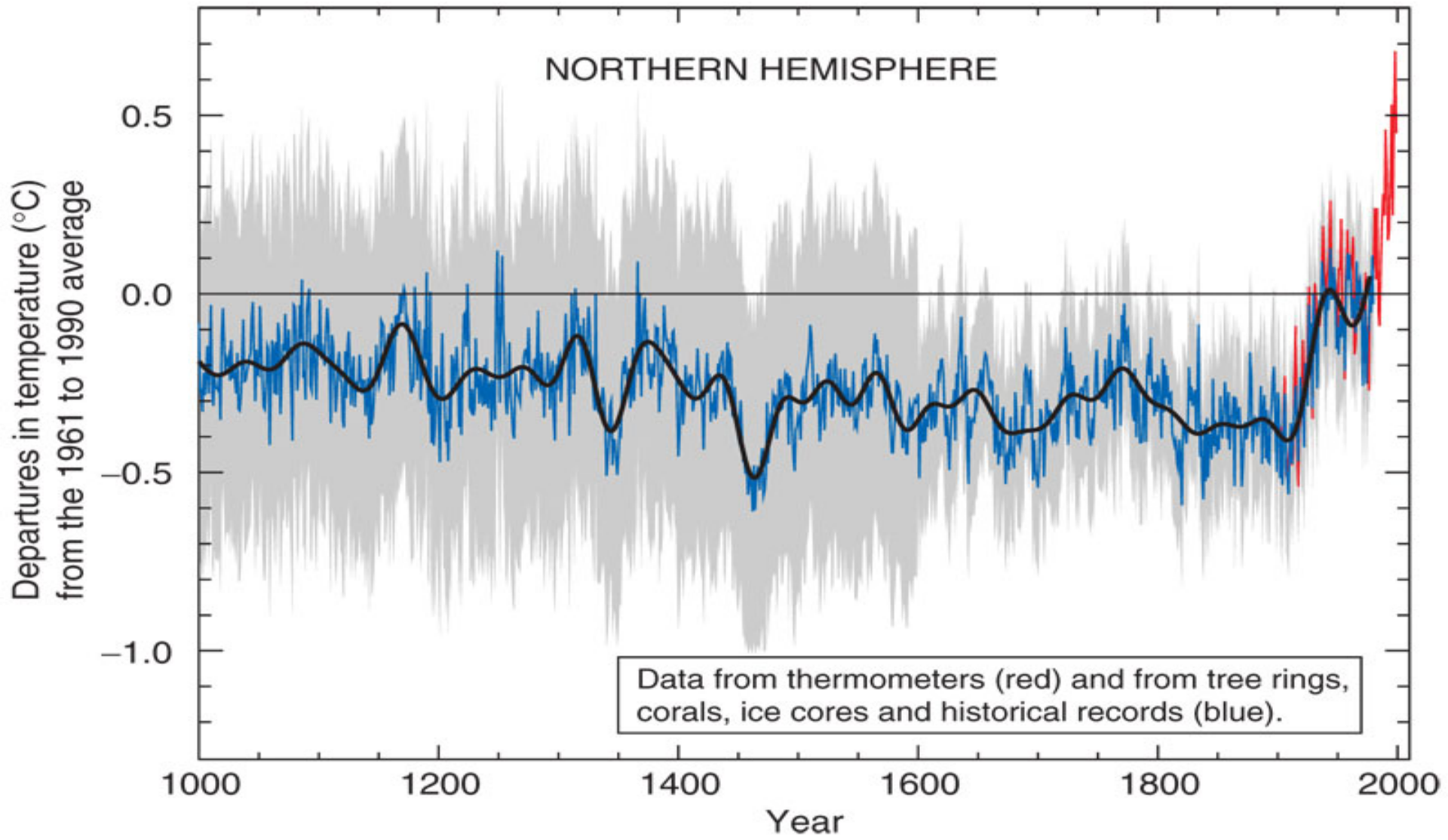
By 2012: Even more overwhelming – only 0.17% of Scientific Journal papers Reject AGW

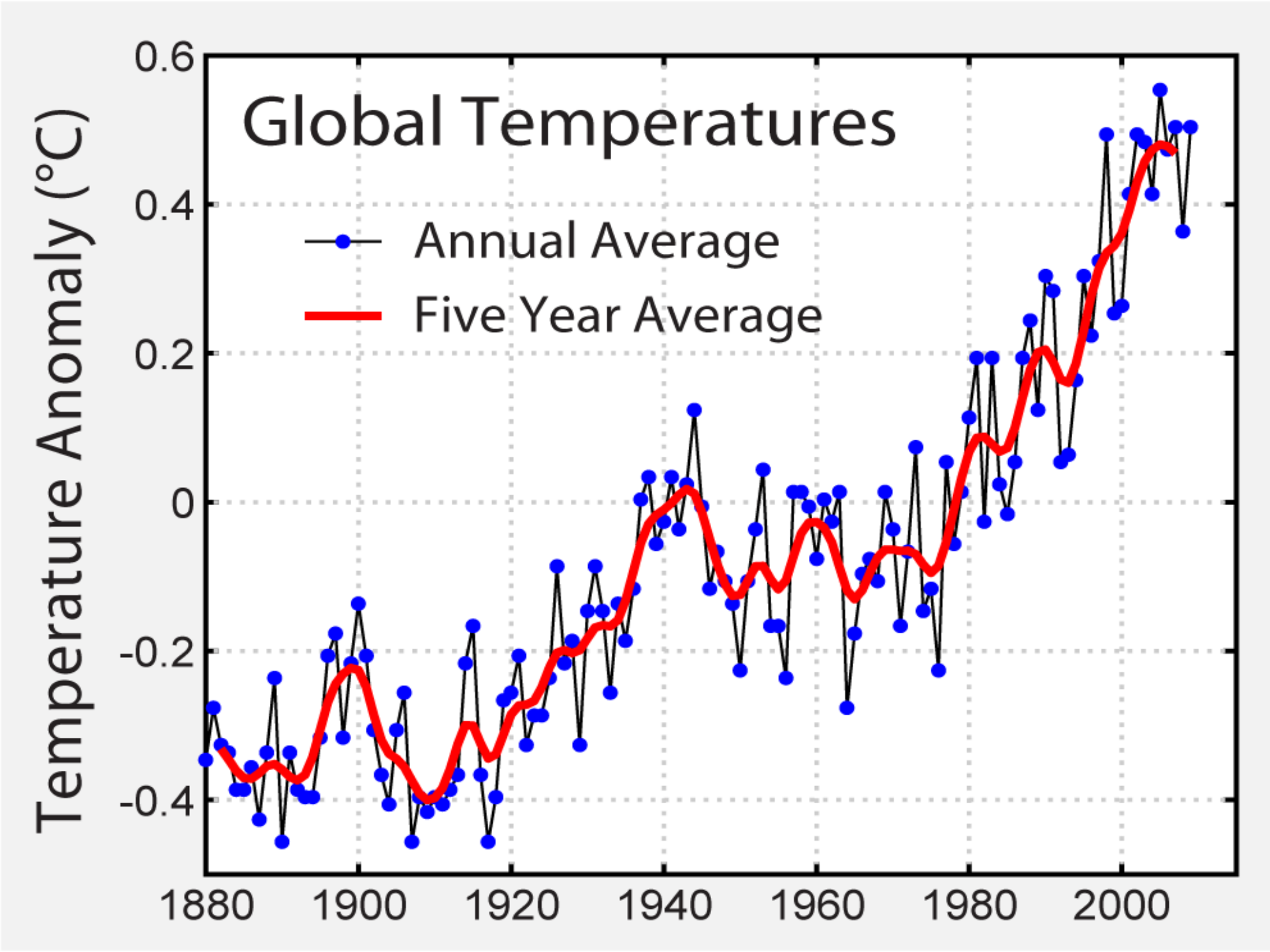
By 2013: Only 1 Author rejected AGW (in an obscure Russian Journal)

BETWEEN NOV '12 & DEC '13 ONLY ONE AUTHOR OF A PEER-REVIEWED ARTICLE REJECTED MAN-MADE GLOBAL WARMING.

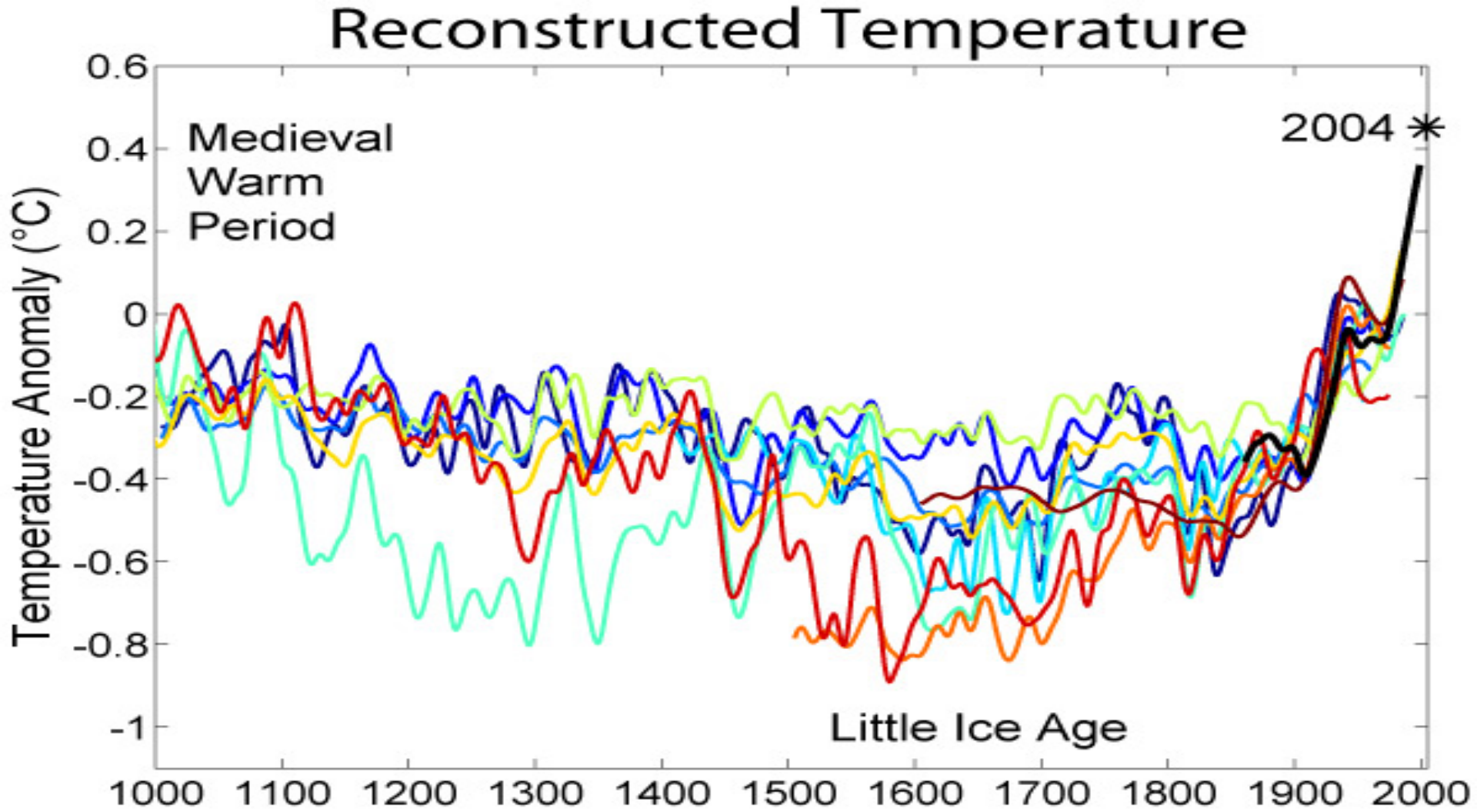
So, What Has Convinced Climate Scientists that Current Climate Change is Human-Caused?

First; Global Average Temperatures Rising Rapidly and Significantly compared to Recent Geologic History ("Hockey Stick" graph from Mann *et al.* 1999)




Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
1880
1900
1920
1940
1960
1980
2000

Given the importance, the work was re-done with a wider range of temperature proxy assumptions and additional care to avoid statistical over-fitting. Still a Hockey stick. Black=observed. Note **the Medieval Warm period is actually a Northern Hemisphere phenomenon, not global. Nearly all the temperature records in the earlier 1995 IPCC graph was from Europe, mainly England – NOT global.**



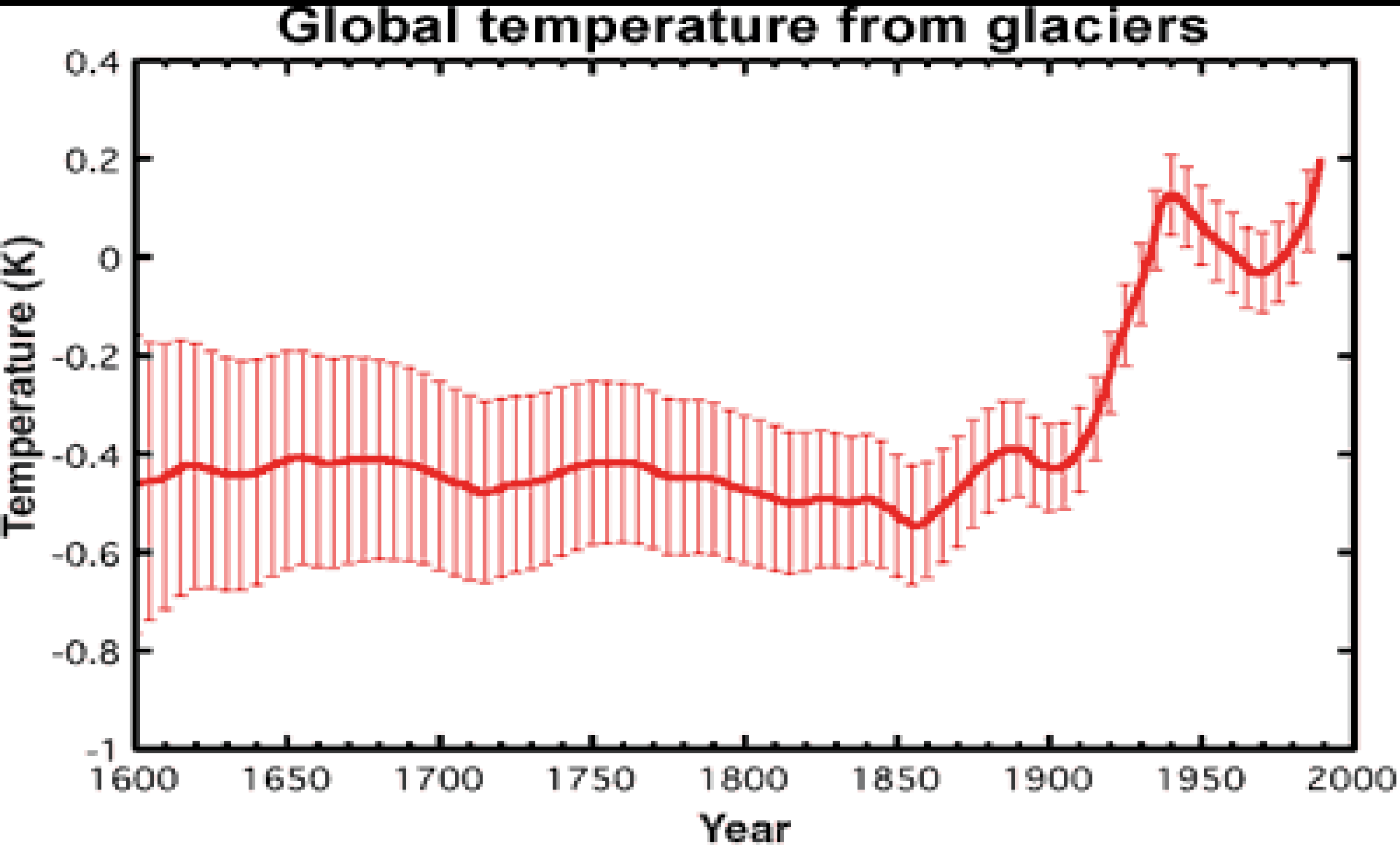
So, OK - Global Temperatures from Modern Records and Proxies for Ancient Data Are Rising in the 20th Century and Beyond, Far Faster than in the Past.

- Well, Is there independent confirmation of this unprecedented rate of temperature rise?

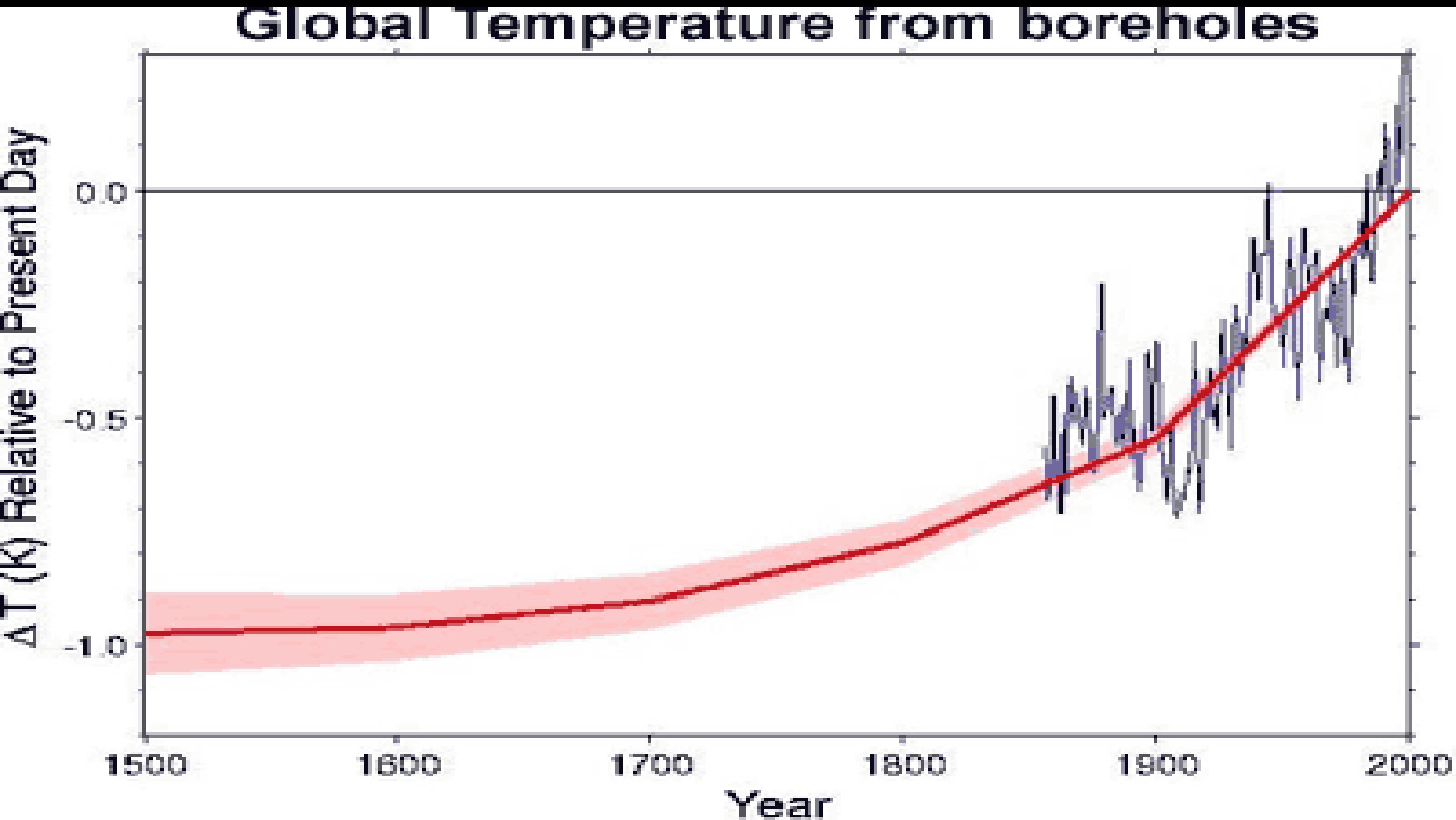
- **Yes**

400 Years of Glacier Length Data Calibrated then Converted to a Temperature Proxy (from old photos and written accounts).

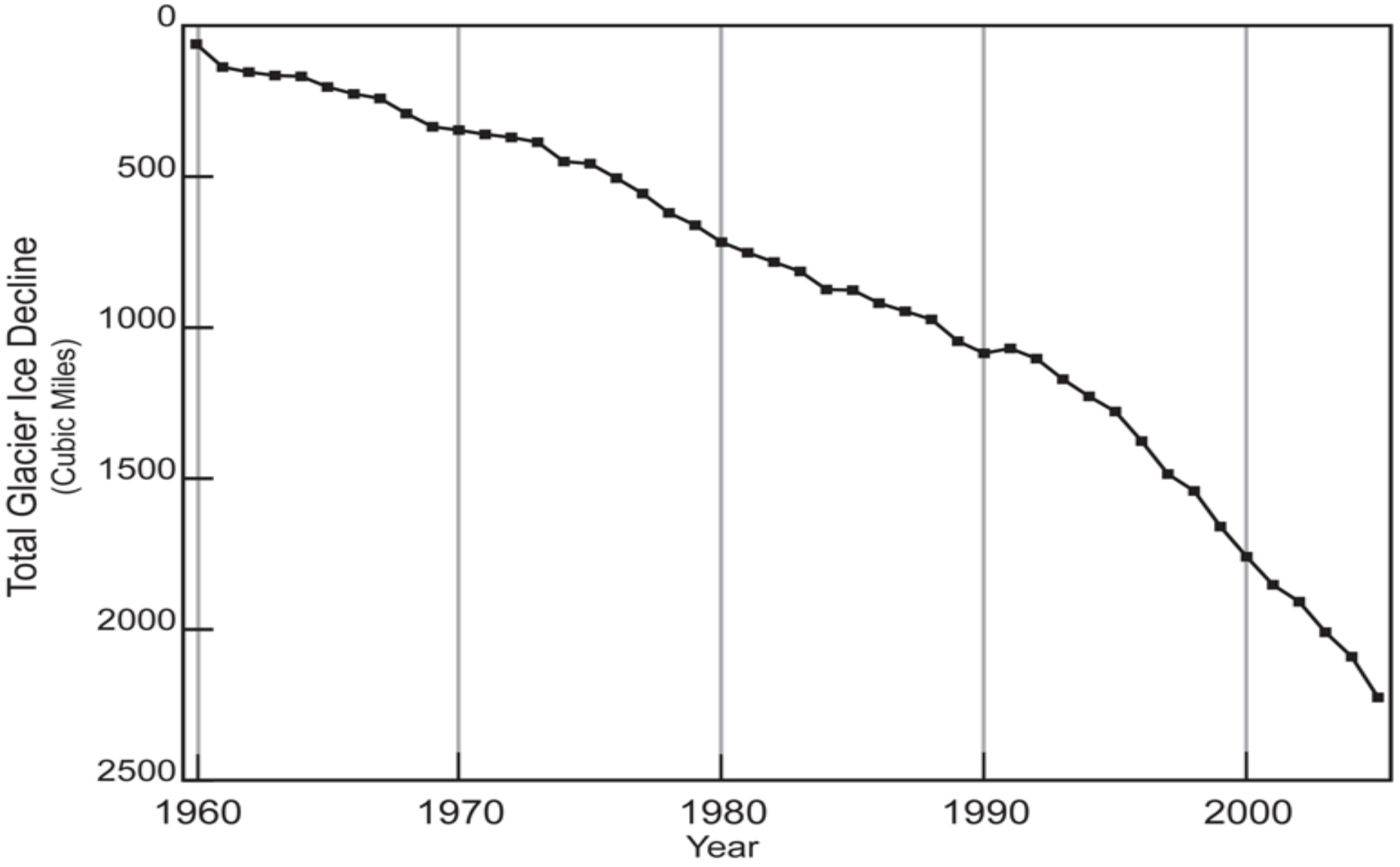
Still a hockey stick



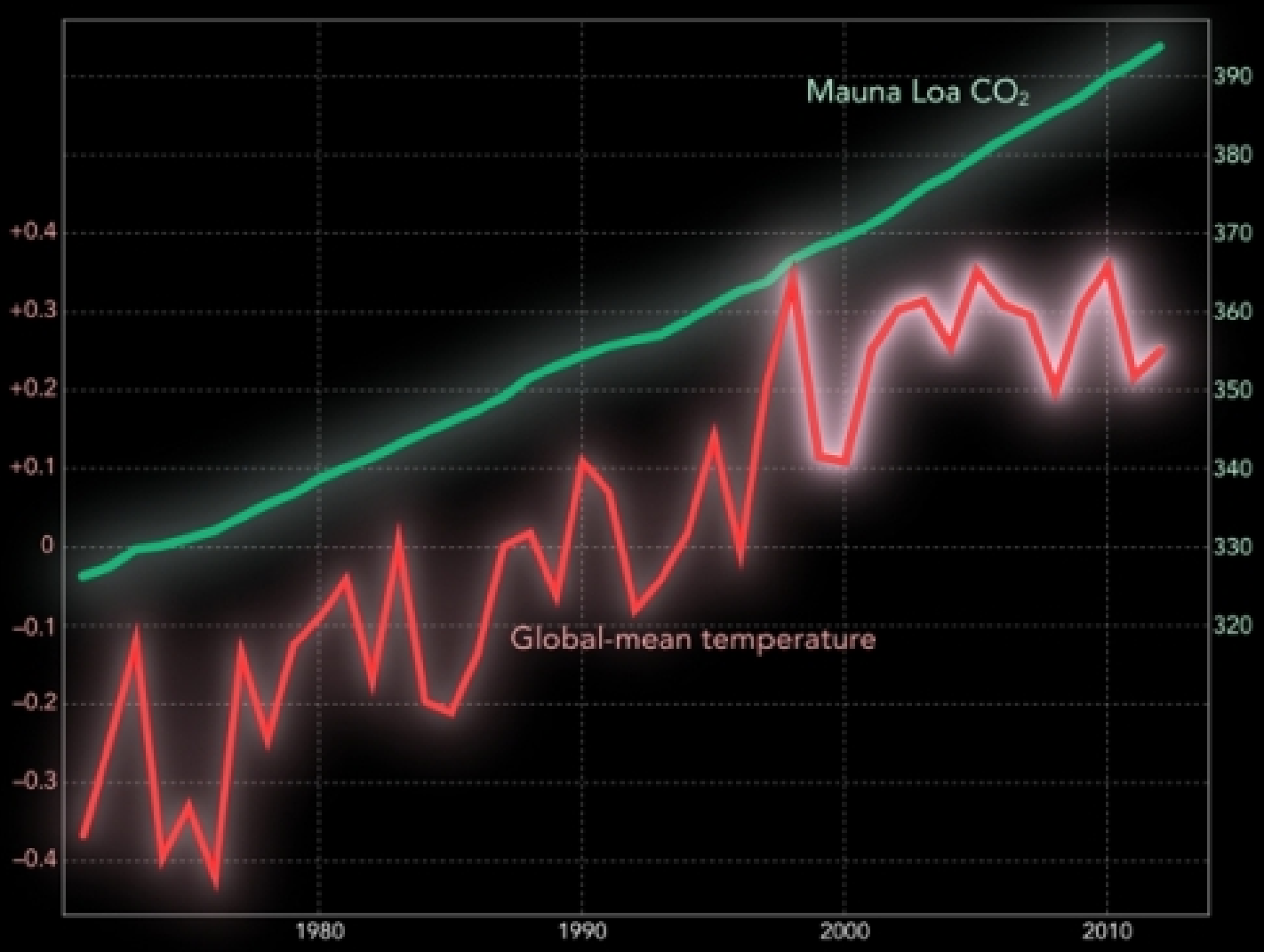
Global surface temperature change over the last five centuries from boreholes (thick red line). Shading represents uncertainty. Blue line is a five year running average of HadCRUT global surface air temperature (Huang 2000). Borehole data confirms the other temperature proxies. **Still a hockey stick**



Volume of World Glaciers: Dropping At Accelerating Rate

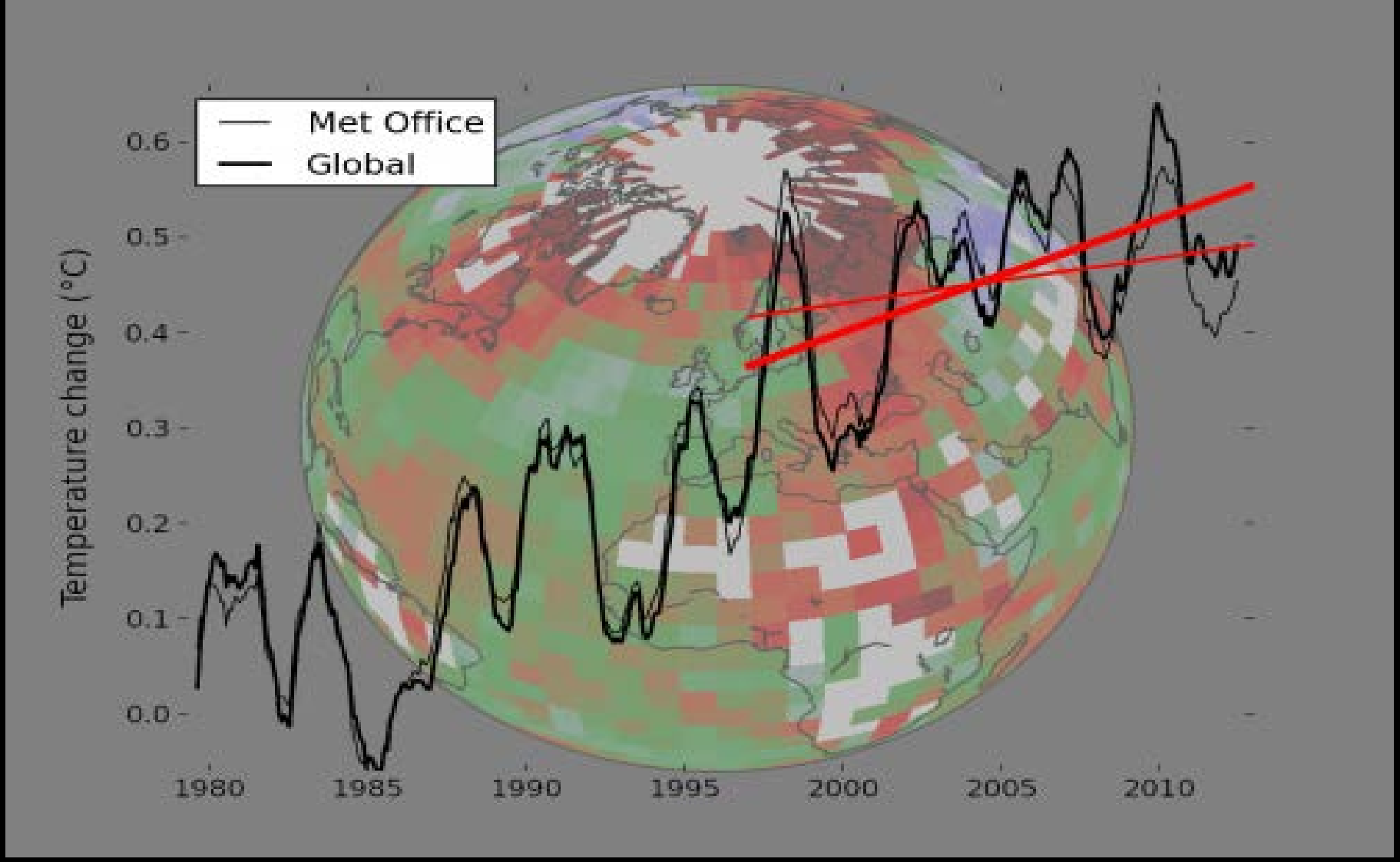


OK, This All Looks Bad, but Hasn't Global Warming Now Stopped, Over the Past ~15 years?



This is the Meme the Denialist Blogosphere has been Pumping the Hardest Lately.

- The answer – **No**, warming has NOT stopped. Three pieces of evidence, old and new…
- **#1.** We've seen over the past century that so called "Hiatus Decades" when surface warming was slower, corresponded to periods when the heat transport was more strongly going into the deeper ocean layers (Meehl *et al.* 2011 in *Nature*)– i.e. it's just a "turbulent heat flow" issue, not unexpected given that heat flow via ocean currents is indeed irregular. These are the "La Nina" periods of the Pacific Decadal Oscillation (more later)
- **#2** Denialists conveniently "cherry pick" their start date at 1997/98, when the strongest El Nino in modern records happened, with unusually warm Pacific Ocean and air global temperatures.
- **And #3 …**

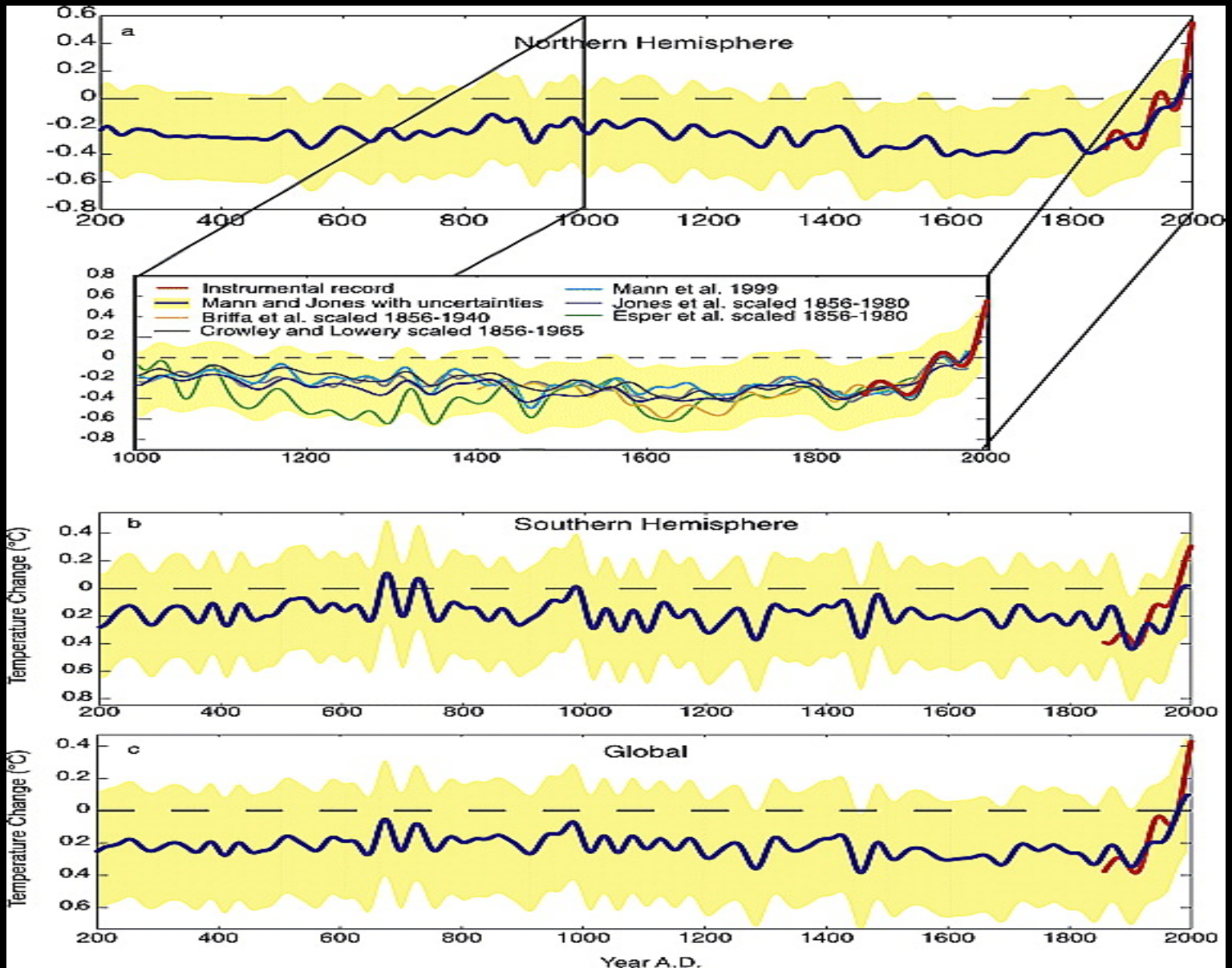


- The Arctic has had poorly sampled weather data, but new analysis and satellite data fills in those gaps (Cowtan *et al.* 2013 in *J. Roy. Met. Soc.)*
- Finds Arctic warming **8x faster than rest of Earth**. Black curve above is the new data, and older UK Met. Office HADCrut4 data in light gray.

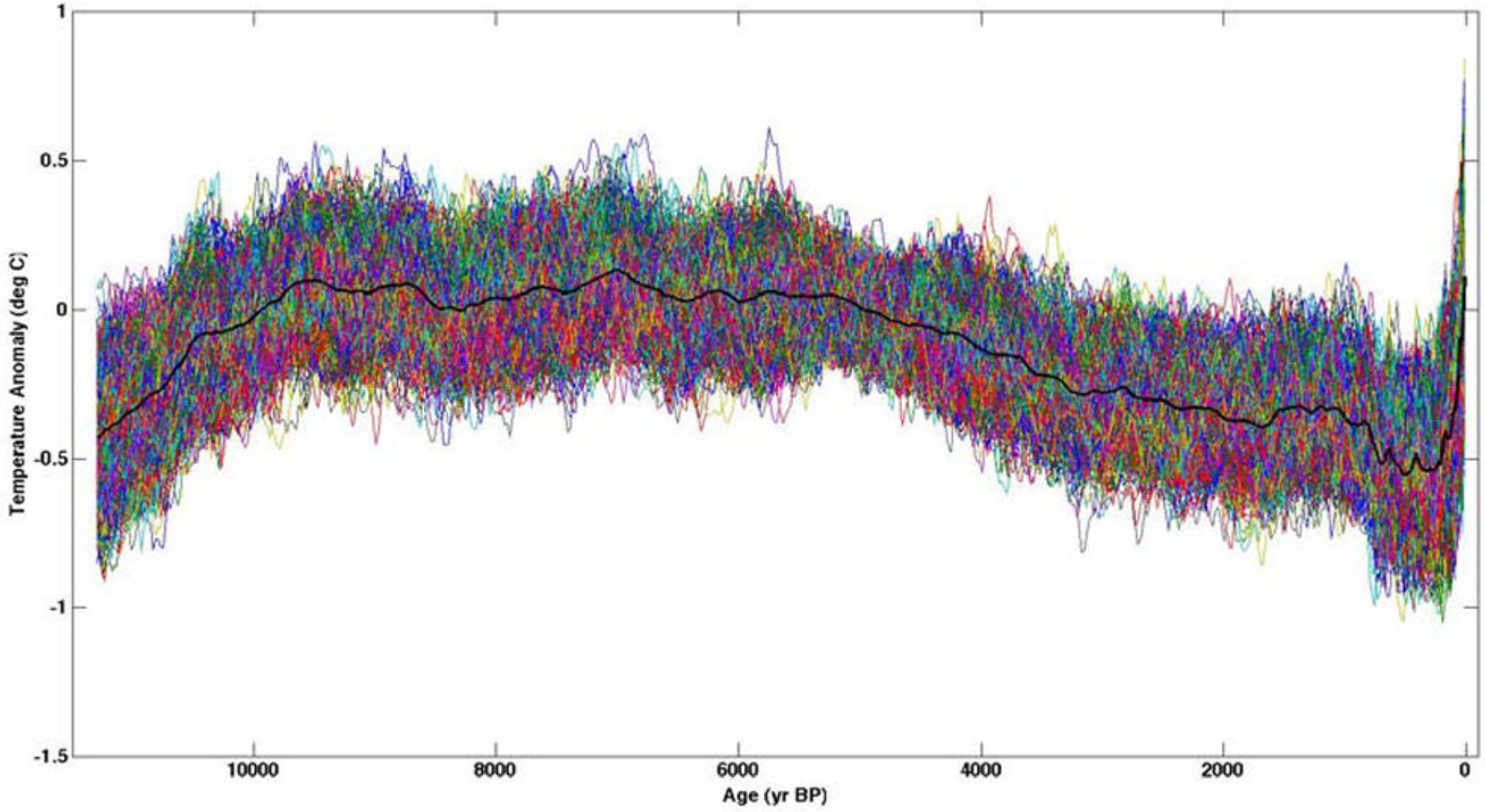
Well OK, But Maybe if We Could Go Back Farther, then Today's Temperature Rise Would Look Like Simply "Natural Variation"?

No.

Jones and Mann (2004) temperature reconstructions using proxies, now going back almost 2000 years, with global temperatures at the bottom pane. Actual instrumental temperatures shown in red. Proxies and instruments both show - Still a Hockey Stick



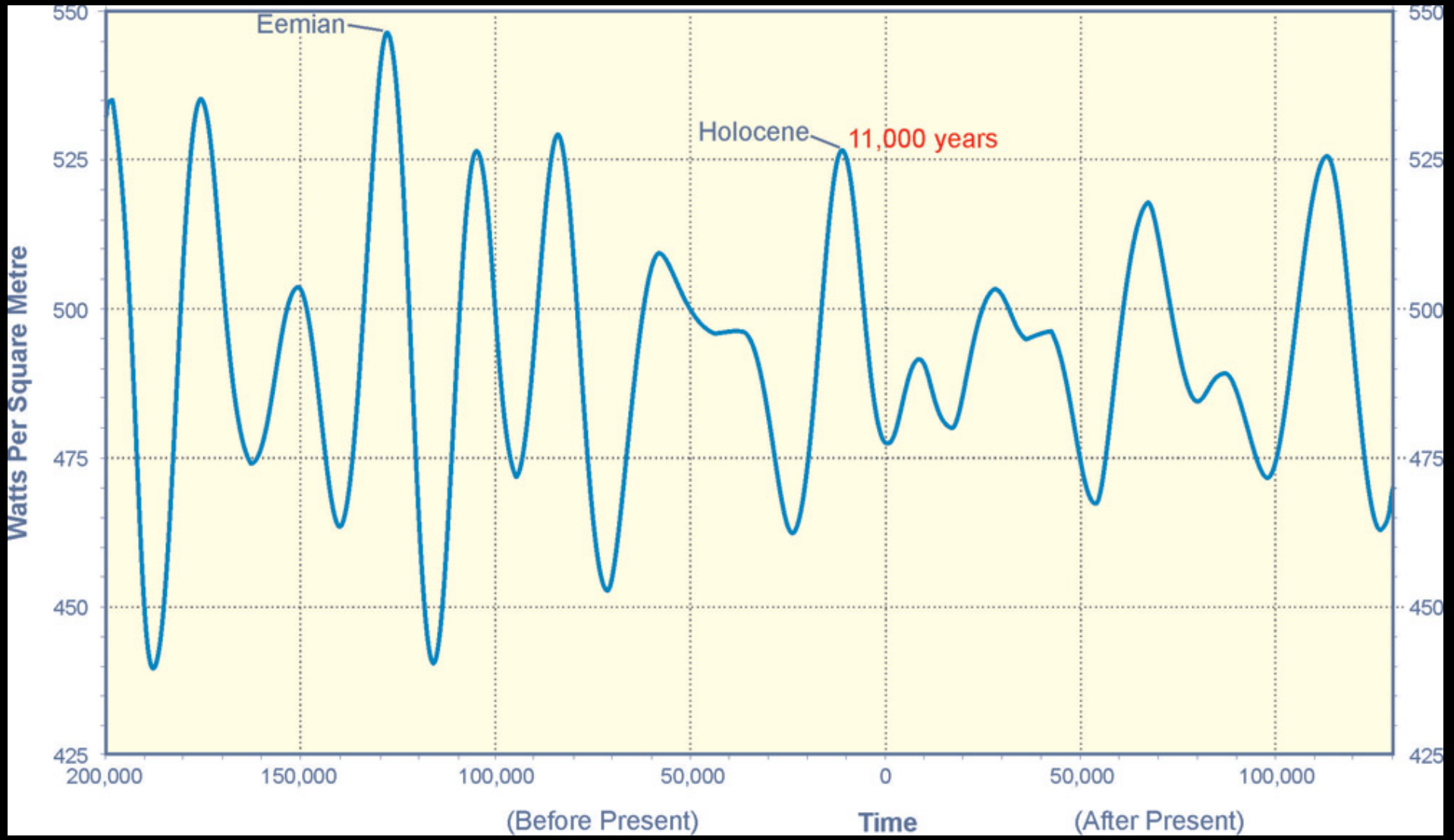
In Fact, Let's Go 10x Further; Back to Emergence from the Last Great Ice Age… And Include More Proxy Data, now Back 12,000 Years. Result: Still A Hockey Stick



You might be wondering about the slow decline of Pre-industrial Global Temperatures…

- Past ~3 million years has seen CO_2 levels low enough to support Ice Ages, caused by the Milankovitch cycles in the Earth's tilt, orbital eccentricity, and orbital orientation.
- Ice Ages happen if summer insolation (astronomically determined) is insufficient to melt all accumulated snow at the Arctic Circle. Albedo and CO_2 Feedbacks then amplify temperature oscillations
- For all of Homo Sapiens history, we have been in a period of slow decline in summer Arctic insolation, although not nearly enough to generate a true Ice Age

We've been in a Milankovitch Cooling Period for ~10,000 years, That will end ~200 Years in the Future



Fine, But How Do We Know it's Humans Who Are Causing Current Warming?

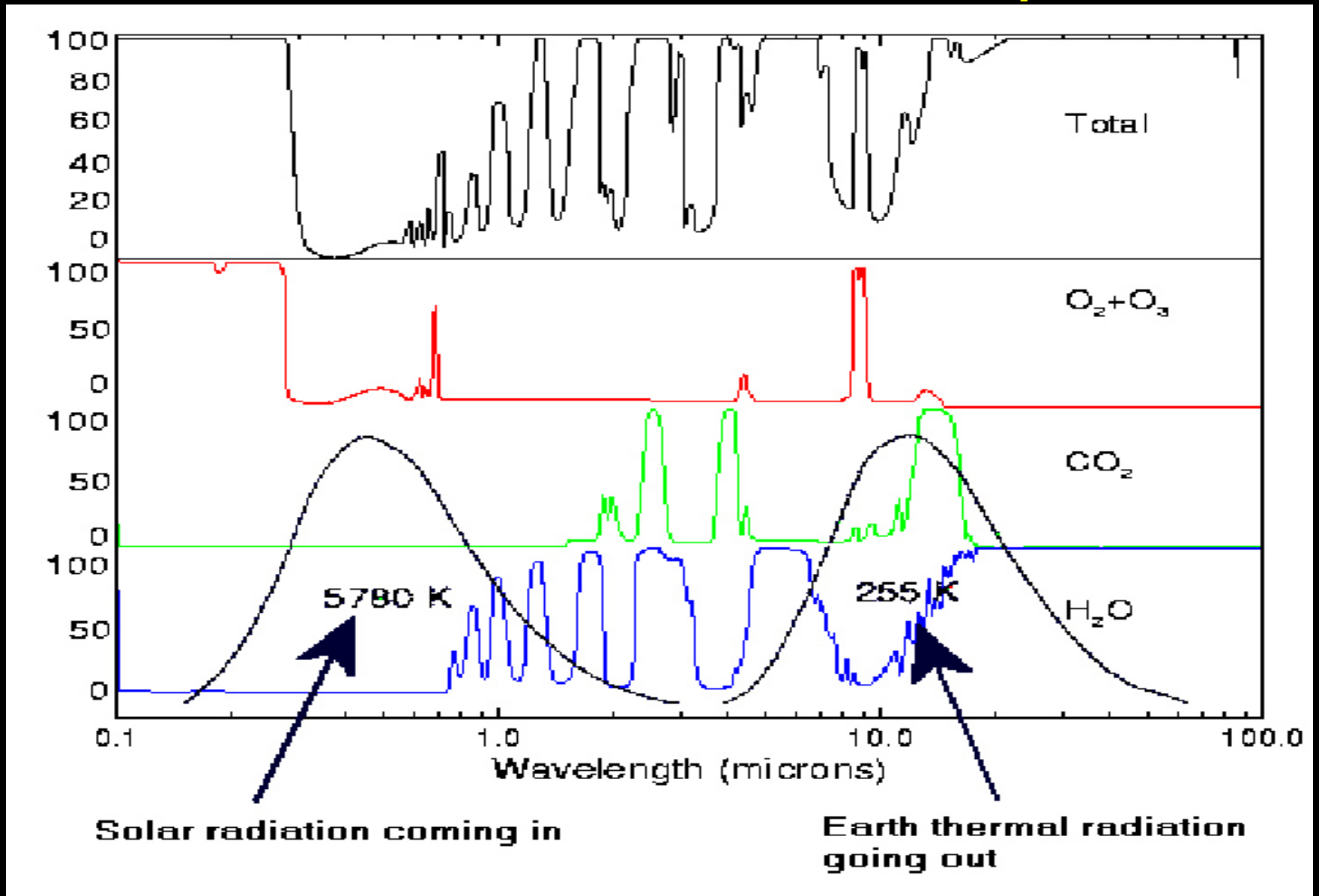
- The weight of evidence is overwhelming, and as close to proof as one could imagine…
- First, CO2 IS a powerful Greenhouse gas, and the O2, N2, and Ar which make up over 99% of the remainder, are NOT Greenhouse gases
- This knowledge dates back to the 1890's, and the precise spectral measurements to the 1950's.

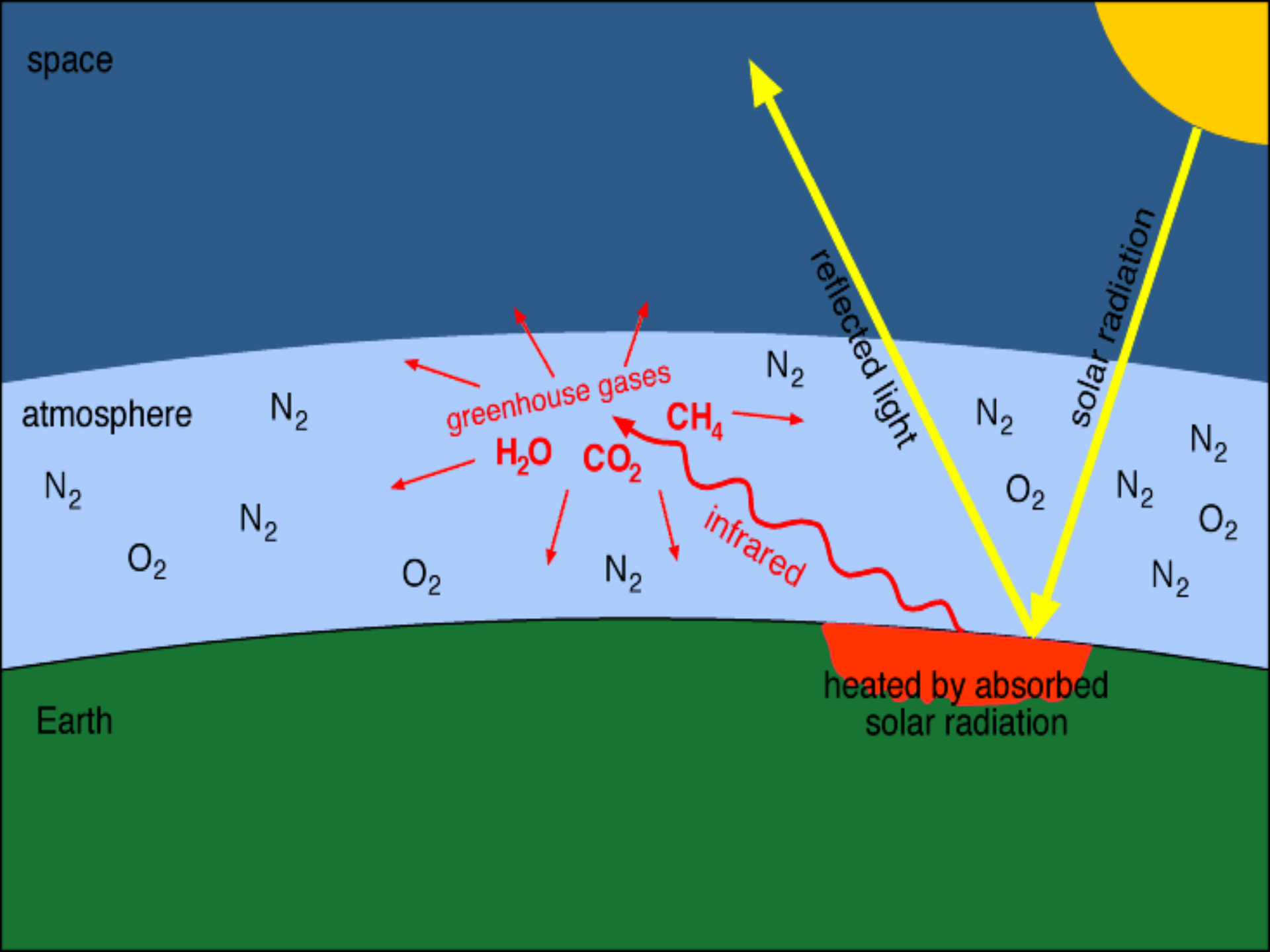
The Greenhouse Effect

- Light from the sun (T=~6000K) is at visible wavelengths and easily arrives at the ground, warming the Earth surface.
- The Earth's surface then radiates according to its temperature (~300K), which means – it radiates in the infrared.
- CO2, H2O, methane, and any molecular gas other than symmetric diatomic gases (e.g. O2, N2) have strong, wide absorption bands in the IR
- IR absorption is re-radiated again in the IR, so this IR is scattered essentially, by the atmosphere. ~half those scatterings go downward where they have another chance to be absorbed by the ground.
- Essentially, the thermal "R value" of the atmosphere is increased.
- The top of the atmosphere must radiate as much energy as we receive from the sun before equilibrium is restored. The higher "R value" requires a higher temperature gradient to force across that required energy to the top of the atmosphere… the surface MUST warm!

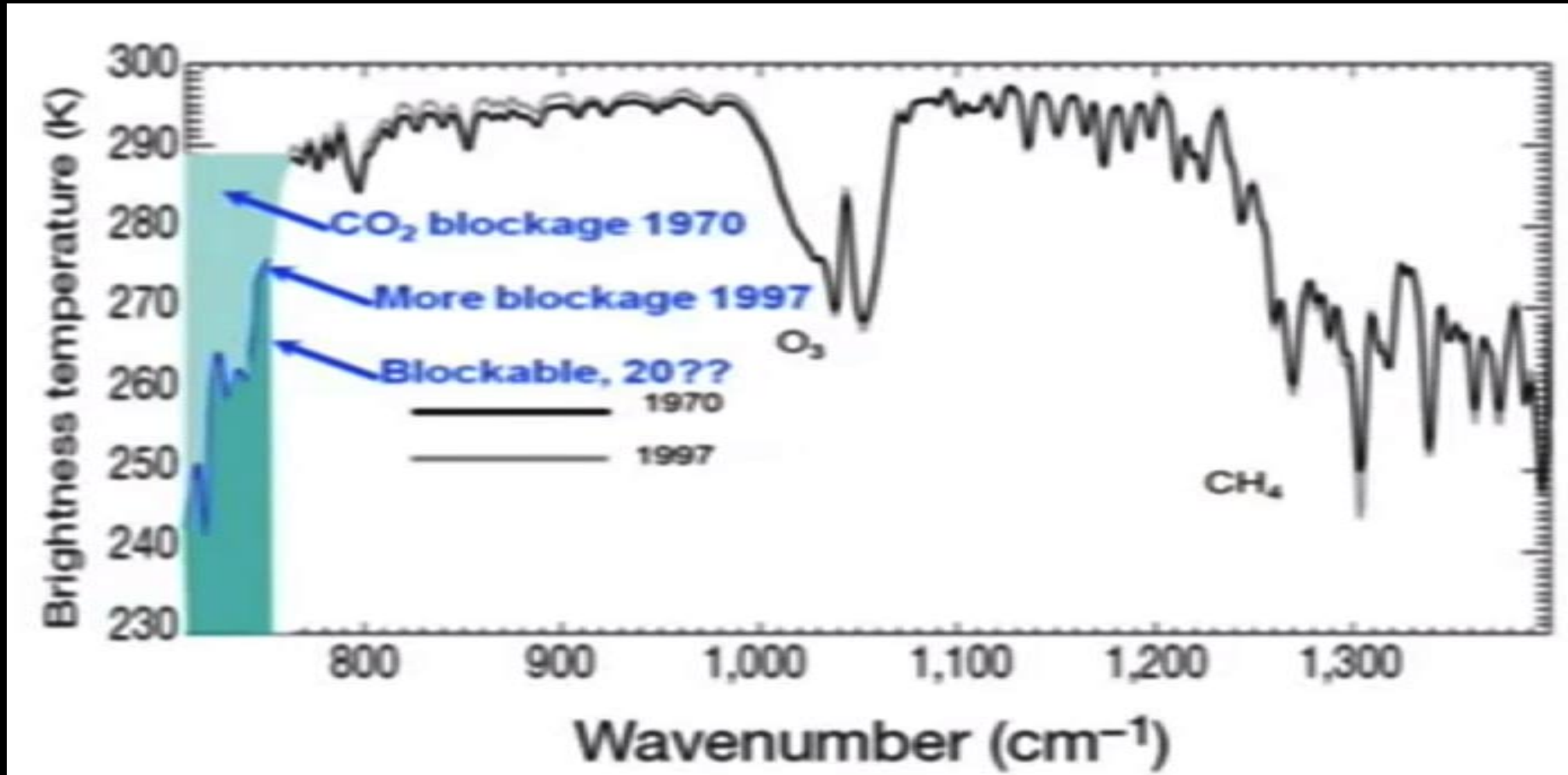
- Basic "CO2 greenhouse" physics understood by Arrhenius in 1890's. The Air Force precisely measured the IR bands of CO2 and water vapor in the 1950's as part of their research into heat-seeking missile technology

The Infrared Absorption Features for CO2 and Water Vapor

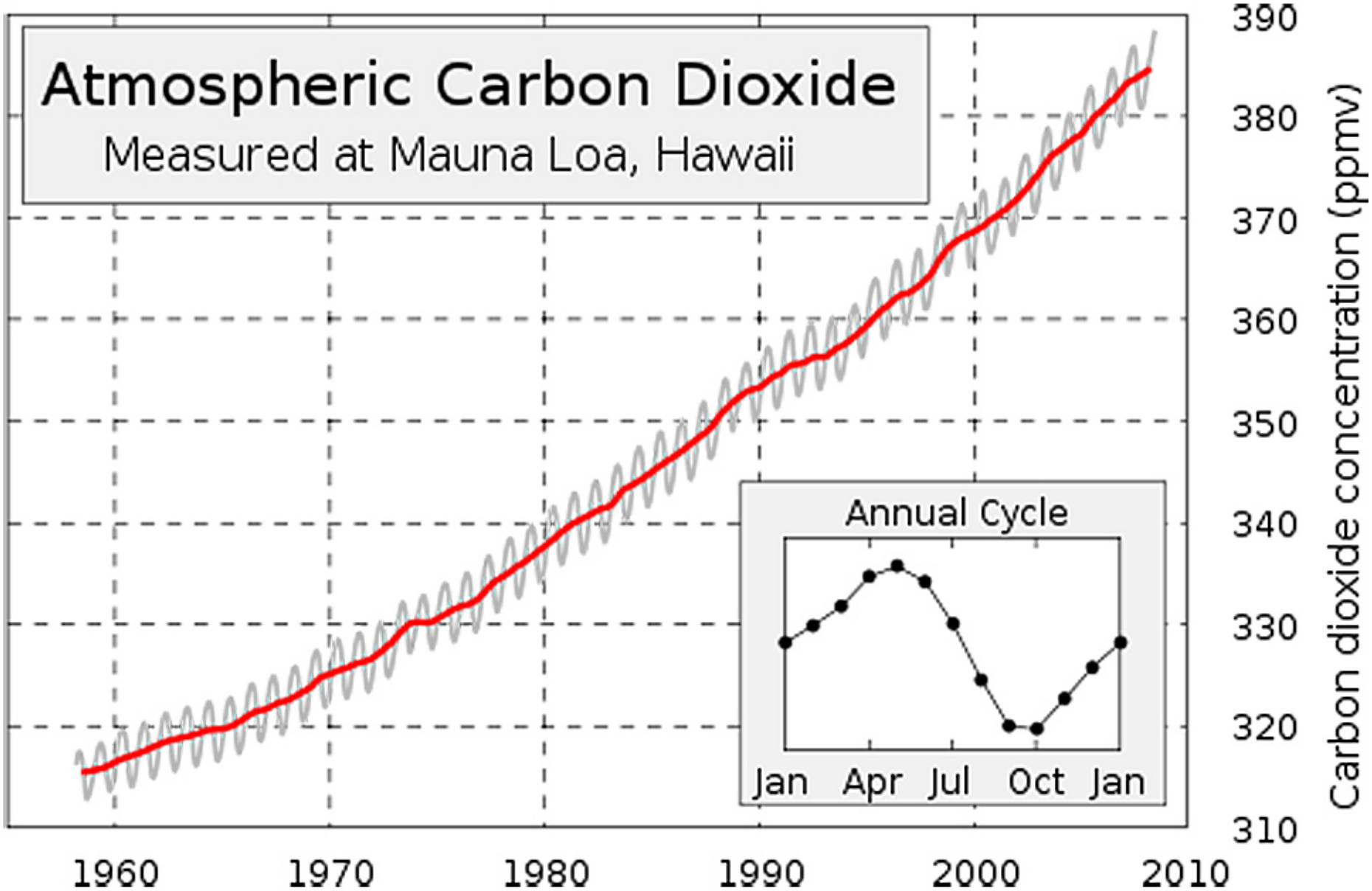



space
atmosphere
Earth
N_2
O_2
greenhouse gases
H_2O
CO_2
CH_4
infrared
reflected light
solar radiation
heated by absorbed
solar radiation

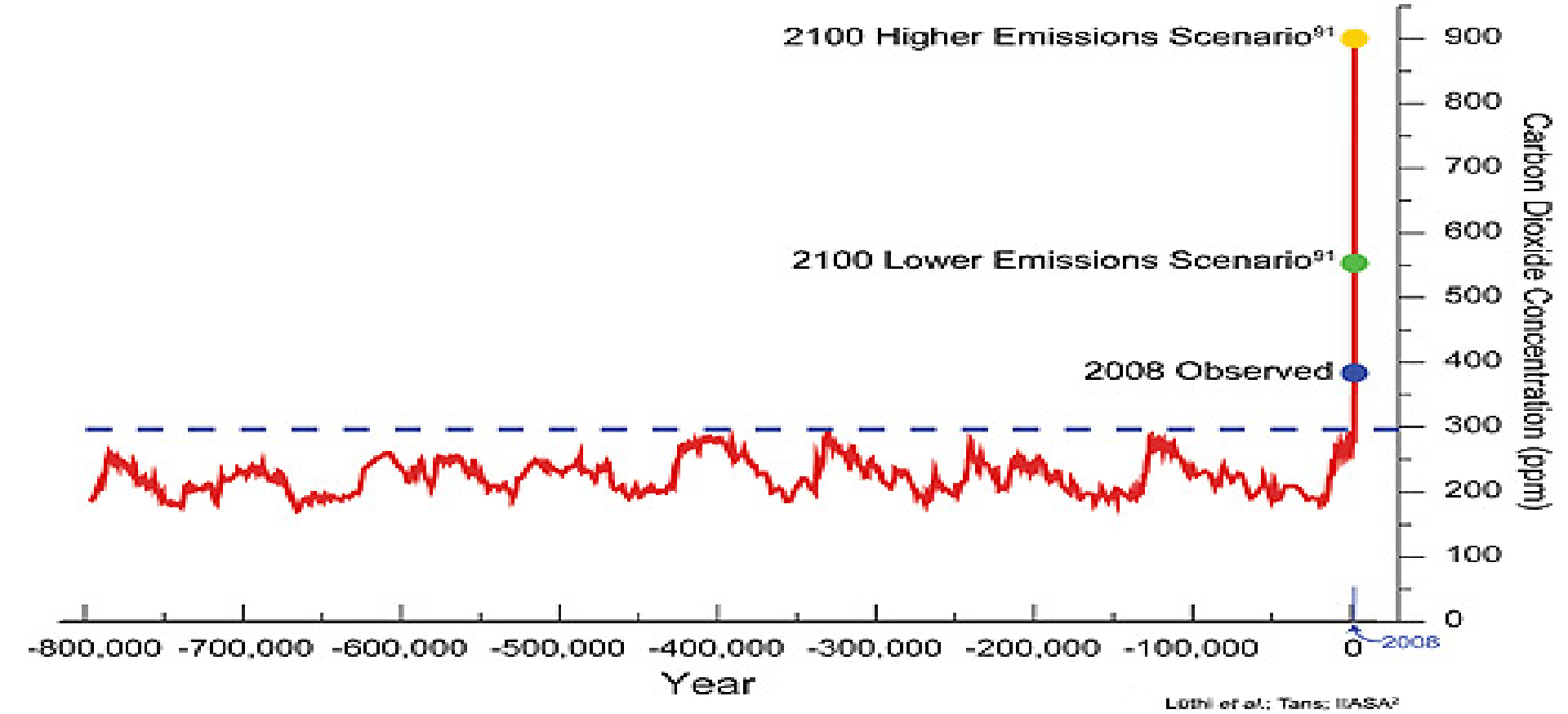
CO_2 Absorption Bands Observed to be Getting Stronger as CO_2 Levels Rise



CO2 levels 1958-2009 (400 ppm in 2013).
A 30% Rise in Just 50 Years. Is this Unusual?



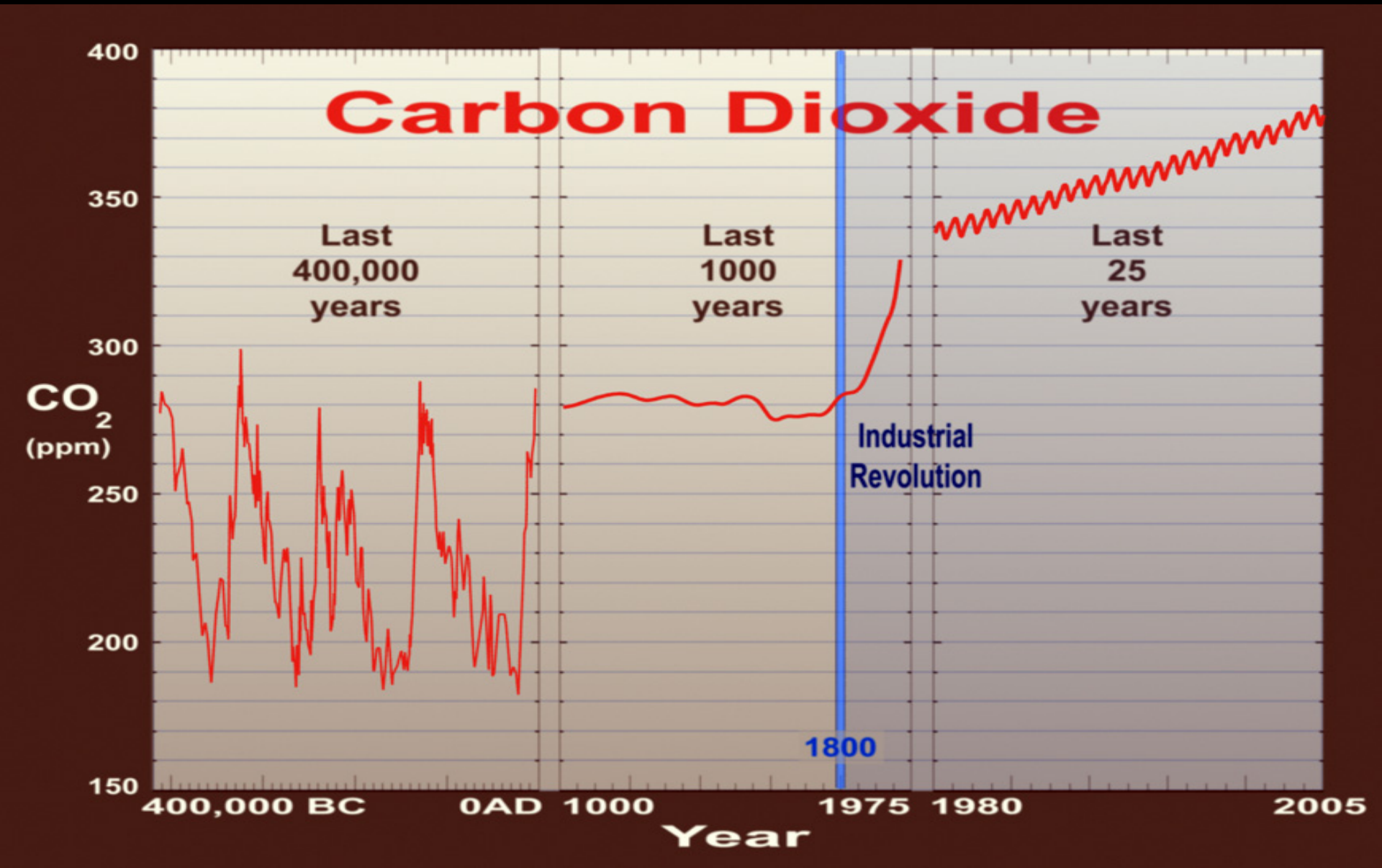
…Very! CO2 Levels Measured from Trapped Air Inside Ice Cores, Past 800,000 years



Lüthi *et al.*; Tans; IIASA[2]

Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. Over this long period, natural factors have caused the atmospheric carbon dioxide concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in the carbon dioxide concentration increasing to a level that is roughly 2 to 3 times the highest level occurring over the glacial-interglacial era that spans the last 800,000 or more years.

A Progressively Expanded Time Scale Needed to Show how Rapid is the CO2 Rise of Today vs. Geologic Past



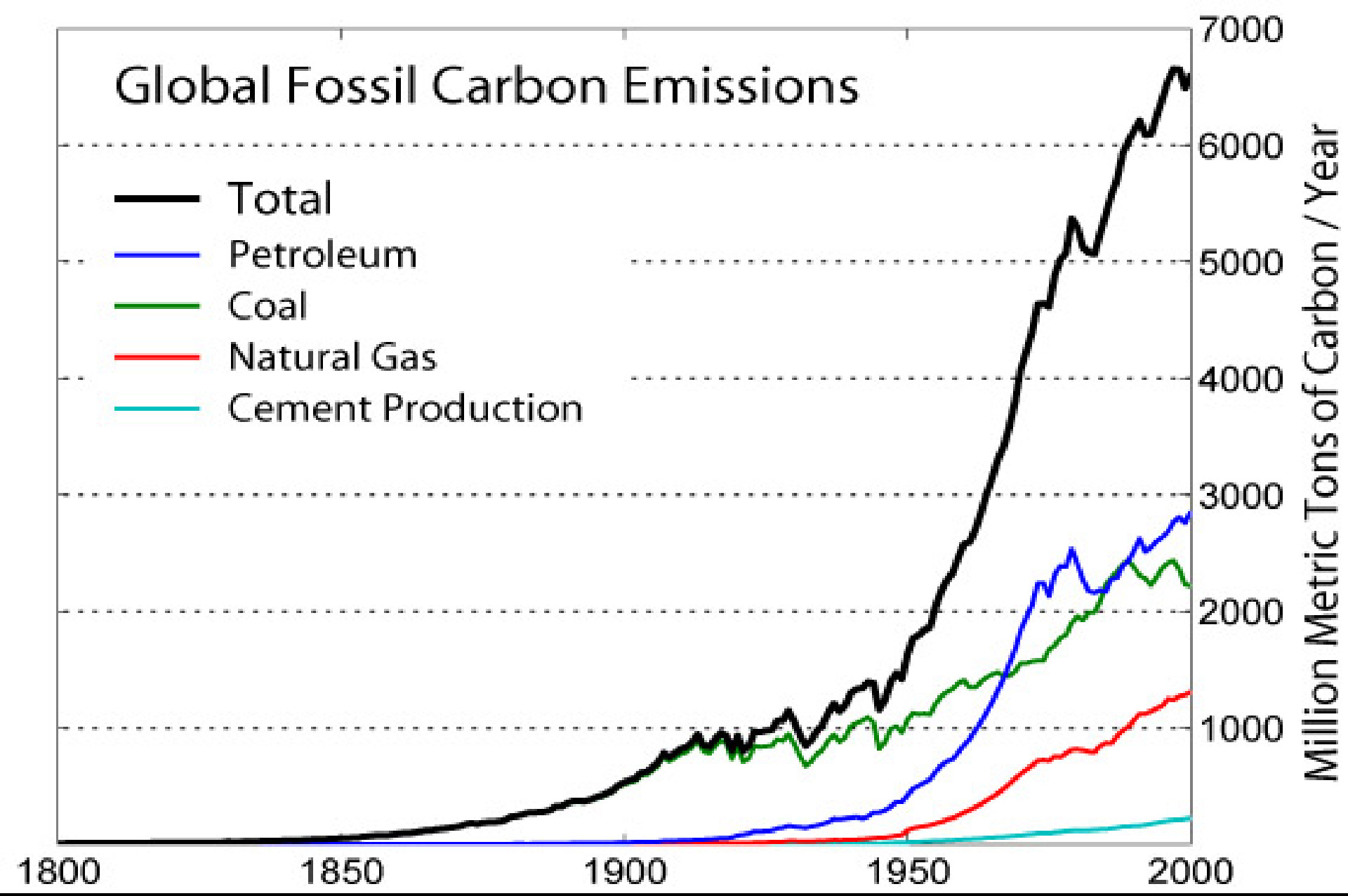
OK, CO2 is Rising Rapidly, and It is a Greenhouse Gas. But How Do We KNOW it's Our CO2??

- After all, Maybe it's really from volcanoes?
- This has been another "proof by loud assertion" from climate denialists

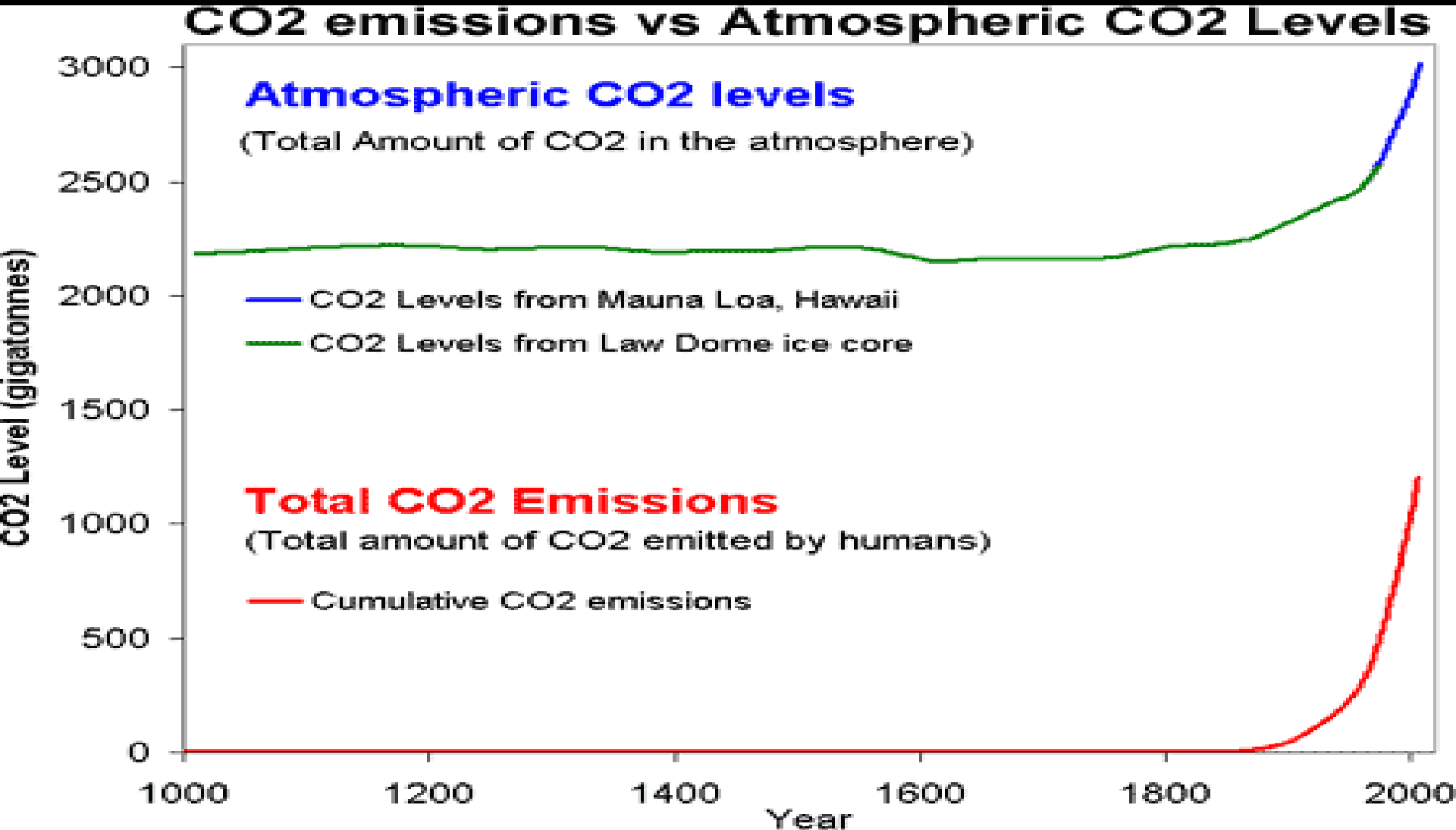
NO

- Volcanoes have emitted, averaged over the 20th century, at a rate only 1% the rate of human-generated CO2 (U.S. Geological Survey data), mostly at the beginning of the century.
- Note also that the 20th Century has not been unusual in its volcanic activity *vs.* prior centuries

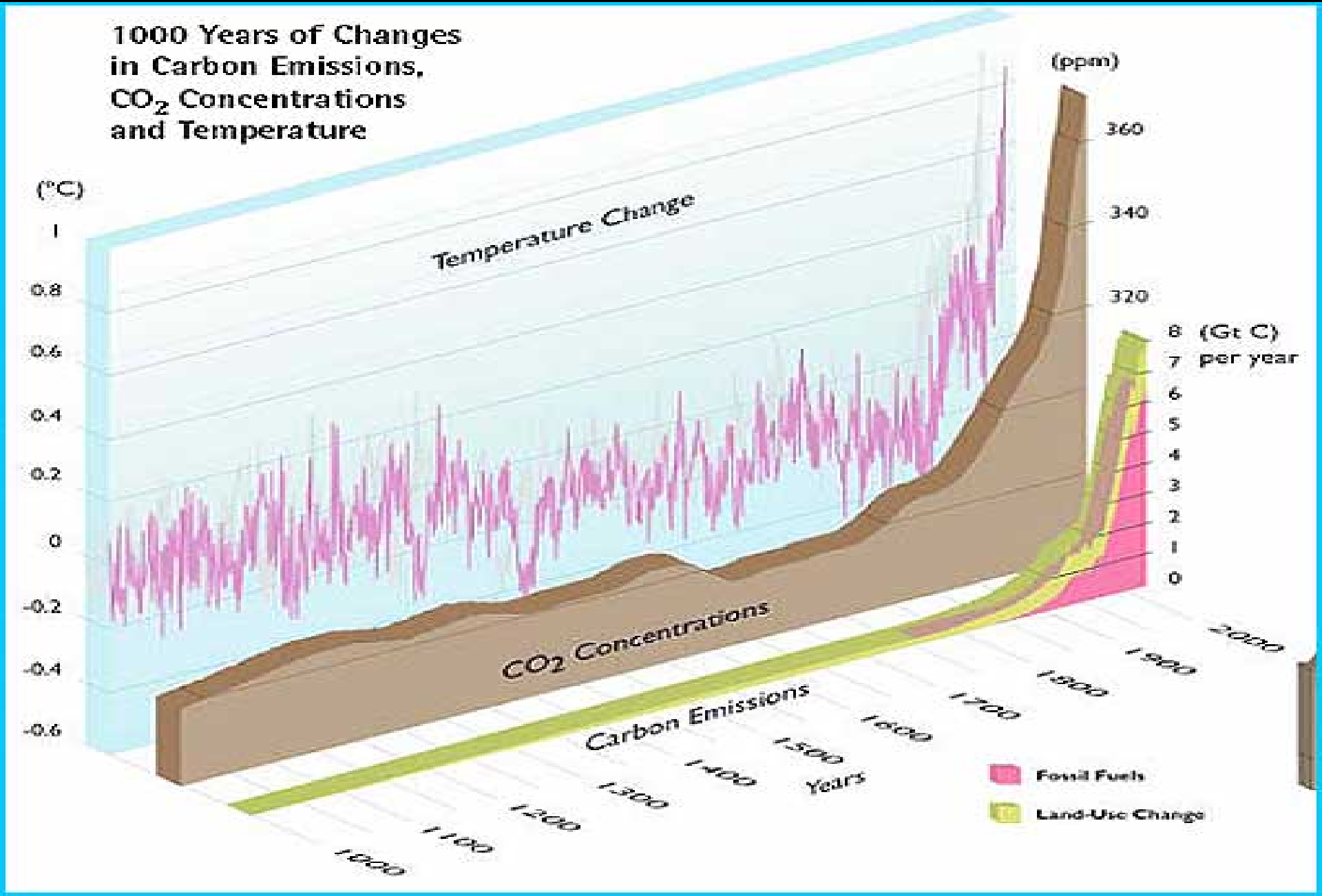
We KNOW Anthropogenic CO2 Emission rates!



They provide more than enough CO2 into the atmosphere to account for the observed atmospheric rise (~half our emissions go into the ocean, plants and soil)



Global Temperatures *vs* Atmospheric CO2 *vs* CO2 Emissions by Humans – Last 1000 Years. Coincidence? Of Course Not.



Also, The Dropping C^{13}/C^{12} Isotope Ratio Shows the CO2 Added to the Atmosphere is from Fossil Fuels

- Atmospheric carbon in pre-industrial times had a C^{13}/C^{12} ratio nearer to the cosmic ratio.
- C^{13} is a stable isotope of carbon, not radioactive like C^{14}
- But plants preferentially take up C^{12}, and oil, coal, natural gas are made from plants from the ~60 Million Year Long Carboniferous Era
- Thus, burning fossil fuels would be expected to raise C^{12} and hence lower the C^{13}/C^{12} ratio.
- It would also be expected to alter the oxygen balance, lowering atmospheric molecular oxygen as it combines to make CO2
- We see both, and in the amount expected

Plants (hence, fossil fuels) preferentially take up C^{12}. As fossil fuel generated carbon is pumped into the atmosphere, C^{13} thus is expected to make up a diminishing fraction of total carbon – exactly what we see here. From known emission levels, we can predict the ratios, and the observations shown here are just what models predict. Note rapid drop in C^{13} after 1950 with enhanced fossil fuel use in post-WWII rebuilding. (From Francey *et al.* 1999)

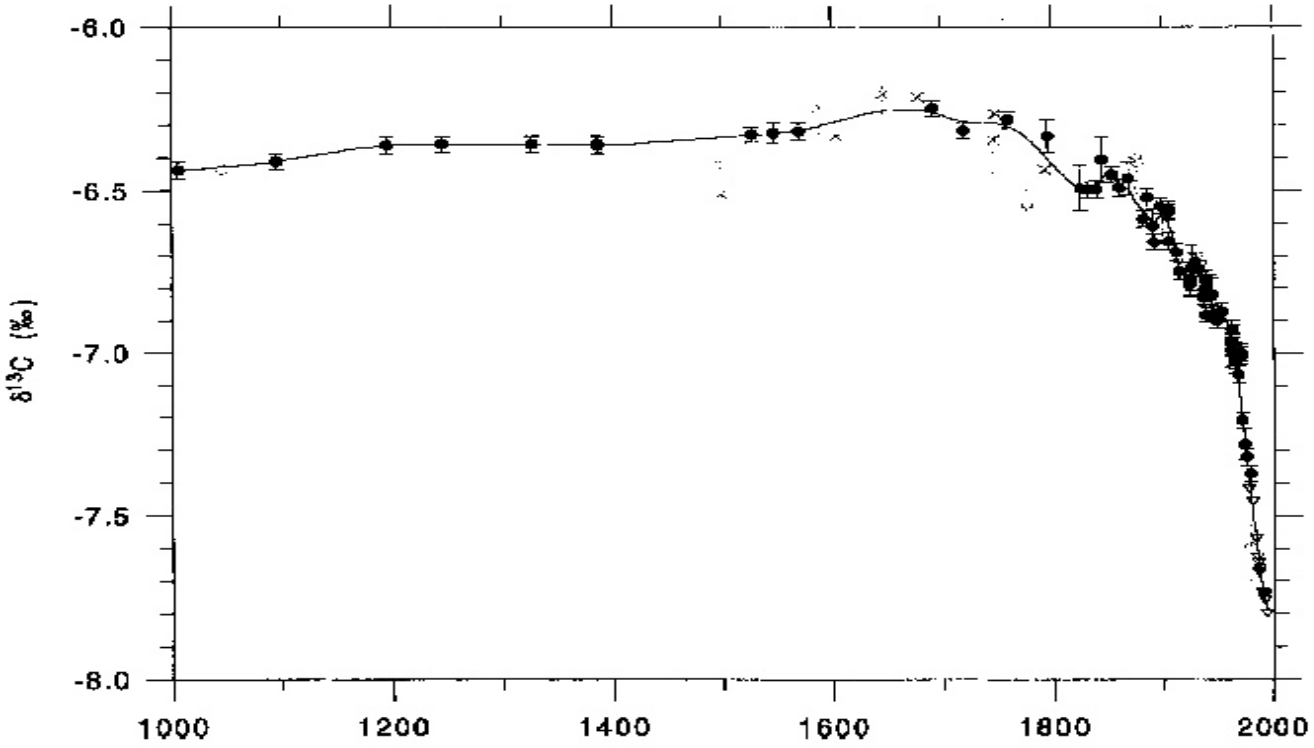


Fig. 9. The complete record of CO_2 and $\delta^{13}C$ from the Law Dome ice cores and firn. The smoothing spline is weighted by the statistical error in, and density of, data; effective smoothing is 25 years after 1800 AD and ~130 years before 1800 AD. (Light grey symbols are rejected points from the section "Summary of data selections and corrections" and are included here only to provide a perspective on the selection processes. Crosses indicate ethanol contaminated samples, open circles are other rejections).

Anthropogenic CO2 production and Dropping C^{13}/C^{12} Ratio Trend: Rising Atmospheric Carbon Levels are Indeed from Fossil Fuel Burning

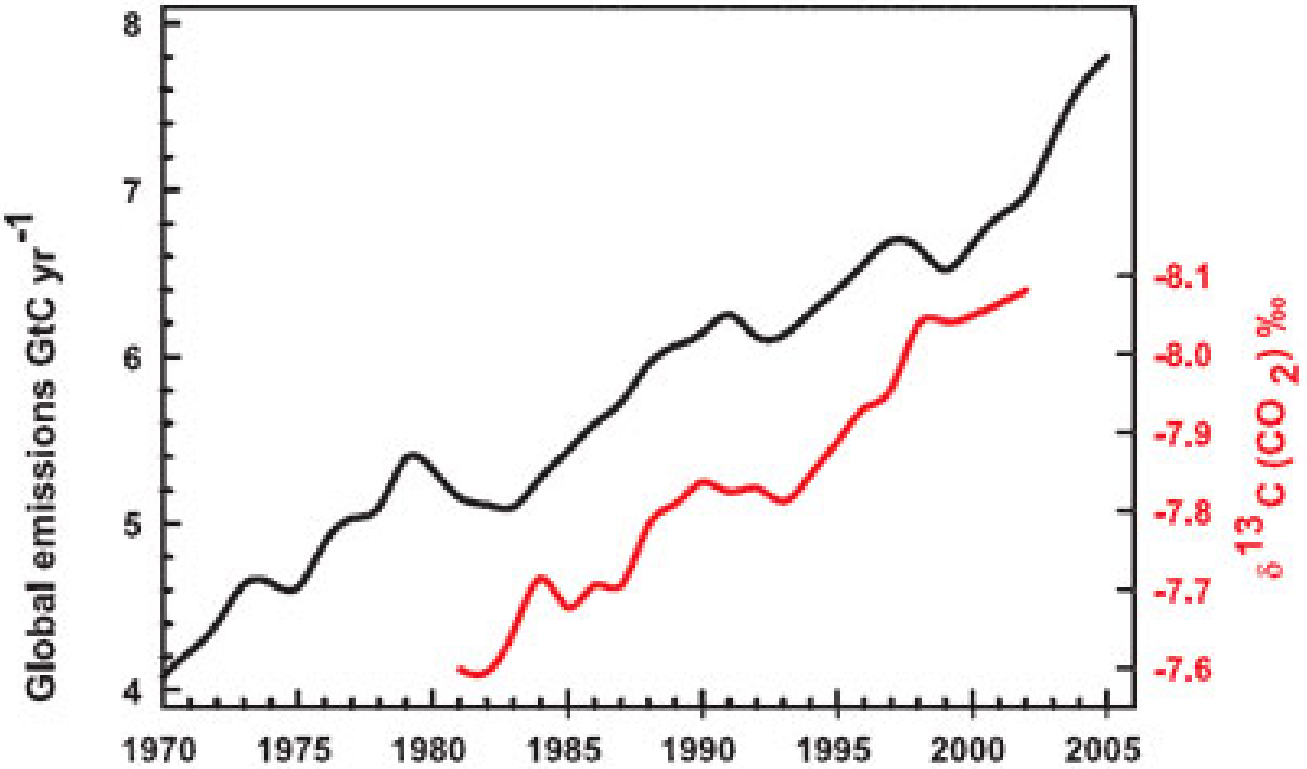
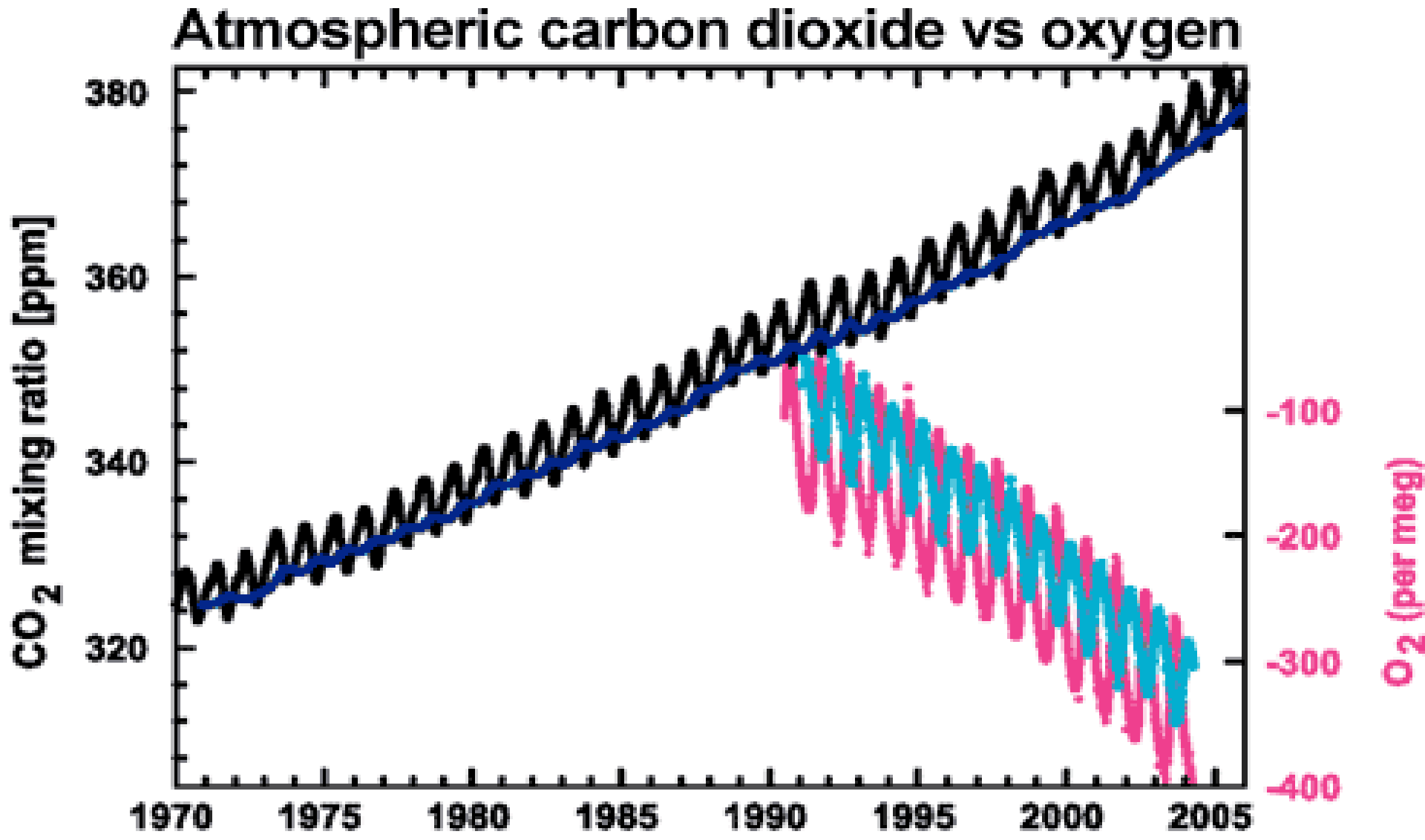
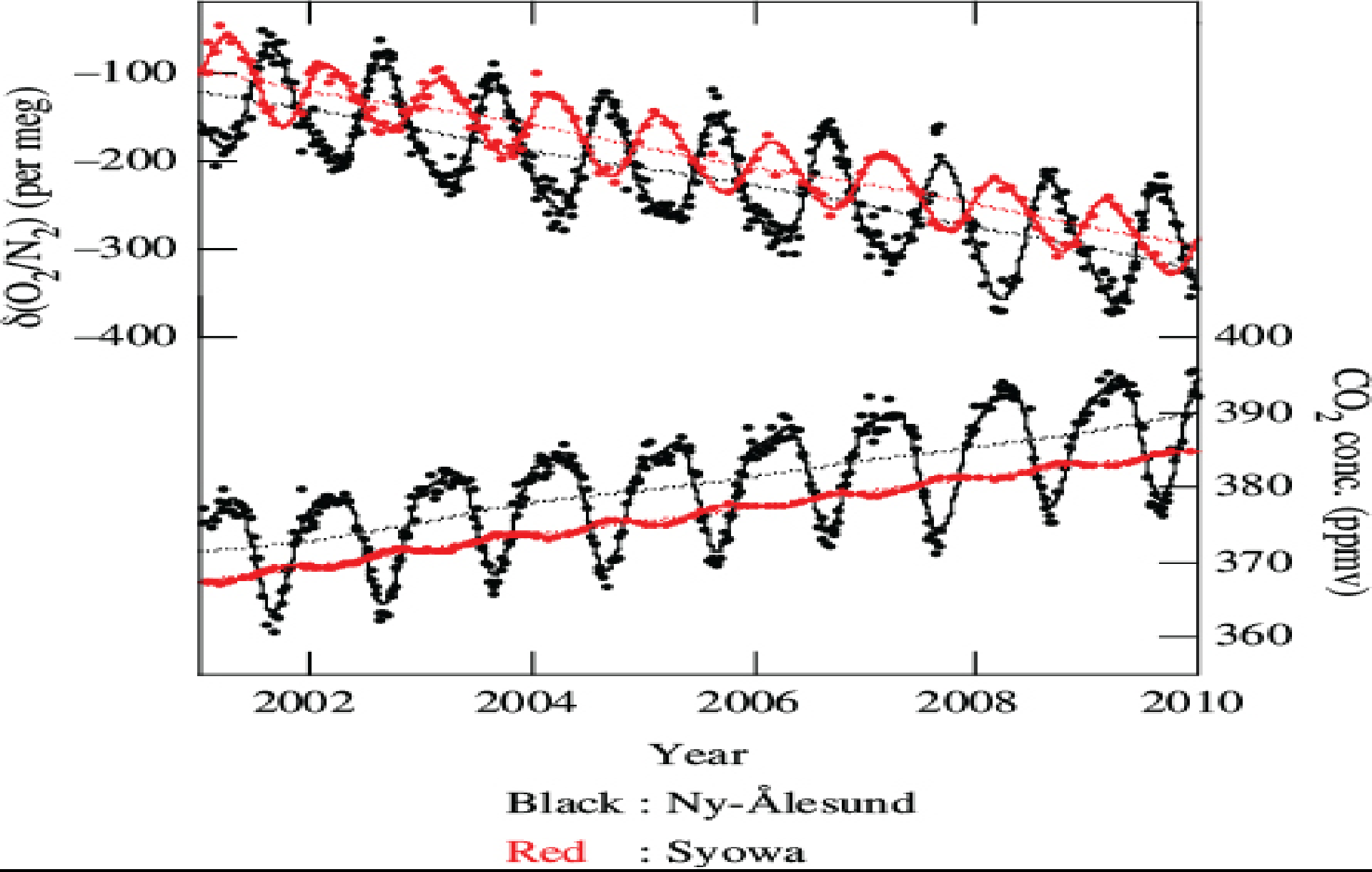


Figure 2: Annual global CO2 emissions from fossil fuel burning and cement manufacture in GtC yr?1 (black), annual averages of the 13C/12C ratio measured in atmospheric CO2 at Mauna Loa from 1981 to 2002 (red).). The isotope data are expressed as d13C(CO2) ‰ (per mil) deviation from a calibration standard. Note that this scale is inverted to improve clarity. (IPCC AR4).

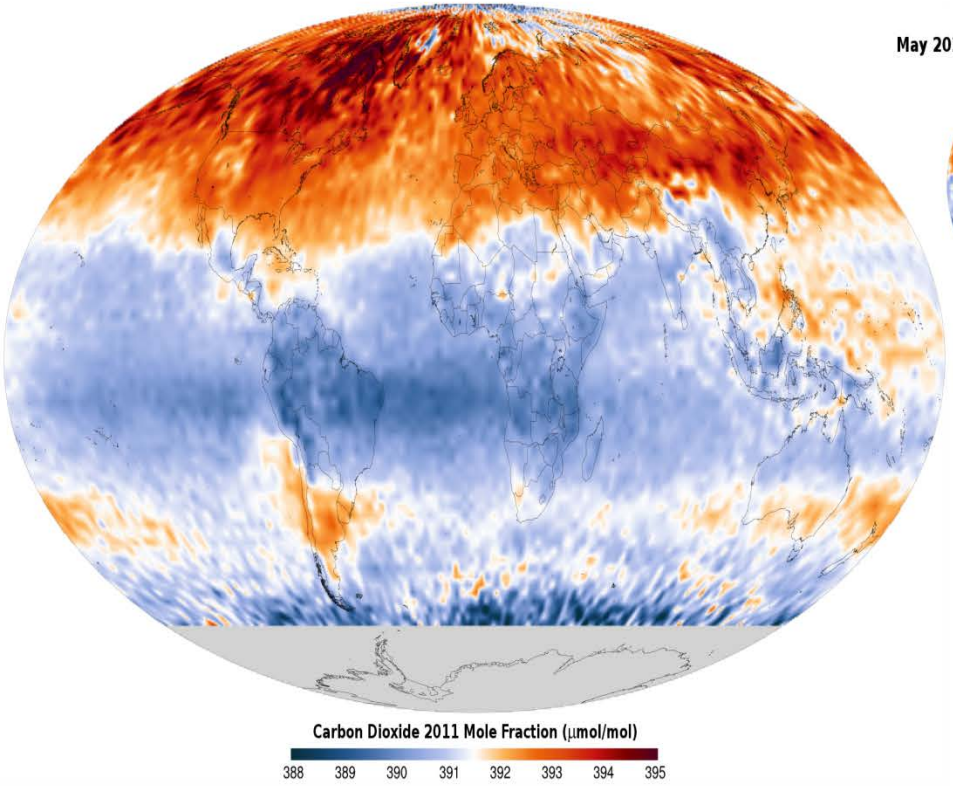
Rising CO2 Effects also Deplete Oxygen (pink, blue=N,S hemispheres) – Observed Rates are in Agreement with Theory (IPCC AR4, adapted from Manning 2006)

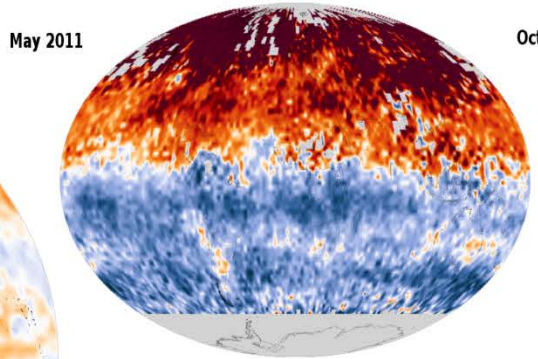


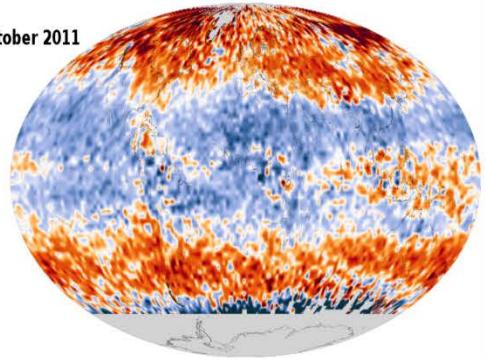


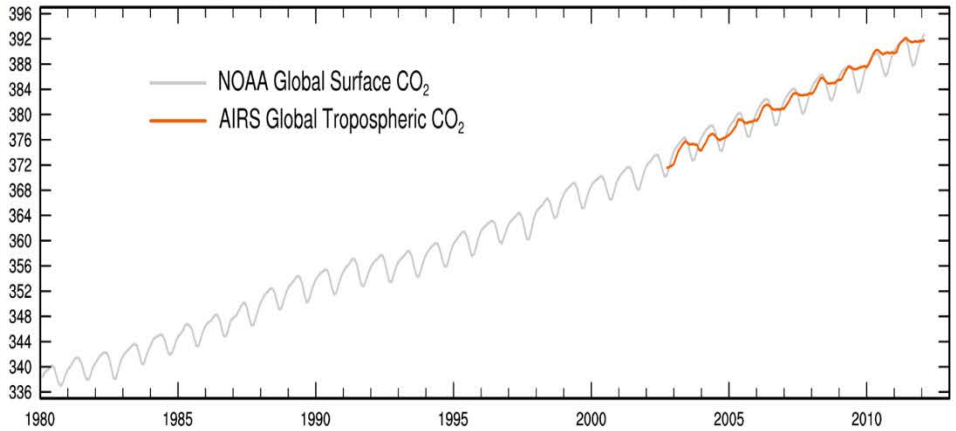
Oxygen levels dropping: O_2/N_2 ratio dropping as CO2 levels rise, in agreement with theory as fossil fuel carbon pulls O_2 from the atmosphere and is converted to CO2. Data from Norway (black) and Antarctica (red) (Ishidoya *et al.* 2012)

Also, Atmospheric CO2 Concentration Distribution – the Clear Source: Human Industrialized Population. Atmospheric gases are all well mixed (i.e. note how narrow is the scale), but there is still a concentration gradient which is focused across the densely populated mid-northern latitudes. Note the surface CO2 seasonal cycle more pronounced (due to plants) than tropospheric average. Ferrel Cell tropospheric "westerlies" blow fresh CO2 northward

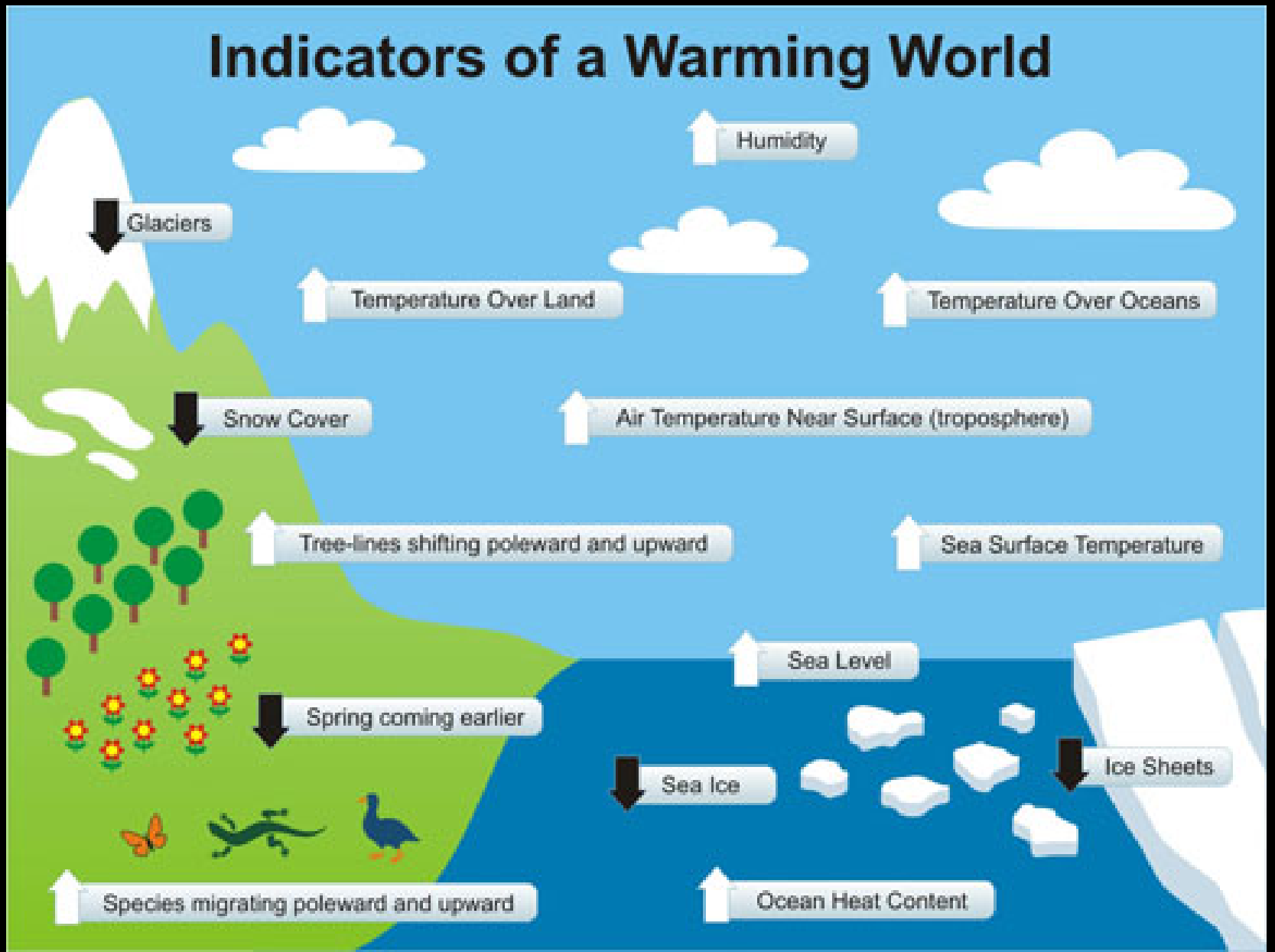








Multiple Observational Evidence for Rapid Climate Change, Not Just Thermometers



Climate Denialists will Have You Believe There's a Massive Global Scientific Conspiracy and Human-Caused Global Warming is a Hoax!

But If There's a Massive Global Conspiracy …

Then there's only one conclusion possible…

They're IN on it!

- The Massive Global Conspiracy to Hide Data, Defraud You and Me, and complete the **Communist One-World Hedgemony**!!
- **The Birds! The Bees! The Flowers! The Trees!!**
- **They're ALL…. IN….. !!**

CONSPIRACIES

If you knew what I knew, then I'd have to kill you.

A Scientific Conspiracy? Does that Pass the "Smell Test"?

- Imagine what that means: it means that each and every year, each and every one of the hundreds of young grad students and post-doctoral fellows beginning their research careers in climate science, are first taken aside into a smoky room and "inducted" into the conspiracy. These are young people inspired by science and who want to make a contribution.
- And – not a SINGLE defector?

What Are The Claimed Motivations?

- Grant money-grubbing? But one would think that grant money would be EASIER to get if they instead promoted “doubt” so that more money would lead us to know with more certainty, so that makes NO sense.
- But far more important, a scientist is rewarded with fame, glory, prizes, prestigious academic positions… when they are shown to be RIGHT, and especially if they are right and the consensus has been WRONG!

- So any and all “conspirators” would have FAR more motivation to instead blow the whistle and expose the Truth (if it were the Truth!).
- Can you imagine a young scientist who may not feel he’s brilliant and wonders if he can really compete, and then finds he’s presented with a huge opportunity for fortune and glory – by showing the “Hoax of Human-Caused Global Warming” – he’d jump on it in a New York Minute!

OK, a Hoax Makes No Sense, But Maybe Temperature is Also Rising for Other Reasons?

- Directly, by the sun perhaps?
- **No.** We have had satellites measuring the sun's luminosity since 1980, fully 3 solar cycles. The sun's luminosity has not increased, in fact it has decreased slightly over the past 60 years.
- Note you DO see Earth surface temperature following the solar cycle… the reason is simple,
- … a 0.1% solar luminosity variation with the sunspot cycle – higher solar activity and sunspots go with higher solar luminosity (magnetic field energy reaching the surface, thermalizing, radiating away), but effect is tiny… (see graph next slide)
- That's nowhere near enough to cause the temperature rises we're seeing.

The Sun's Luminosity Oscillates only 0.1%, with NO secular Increase

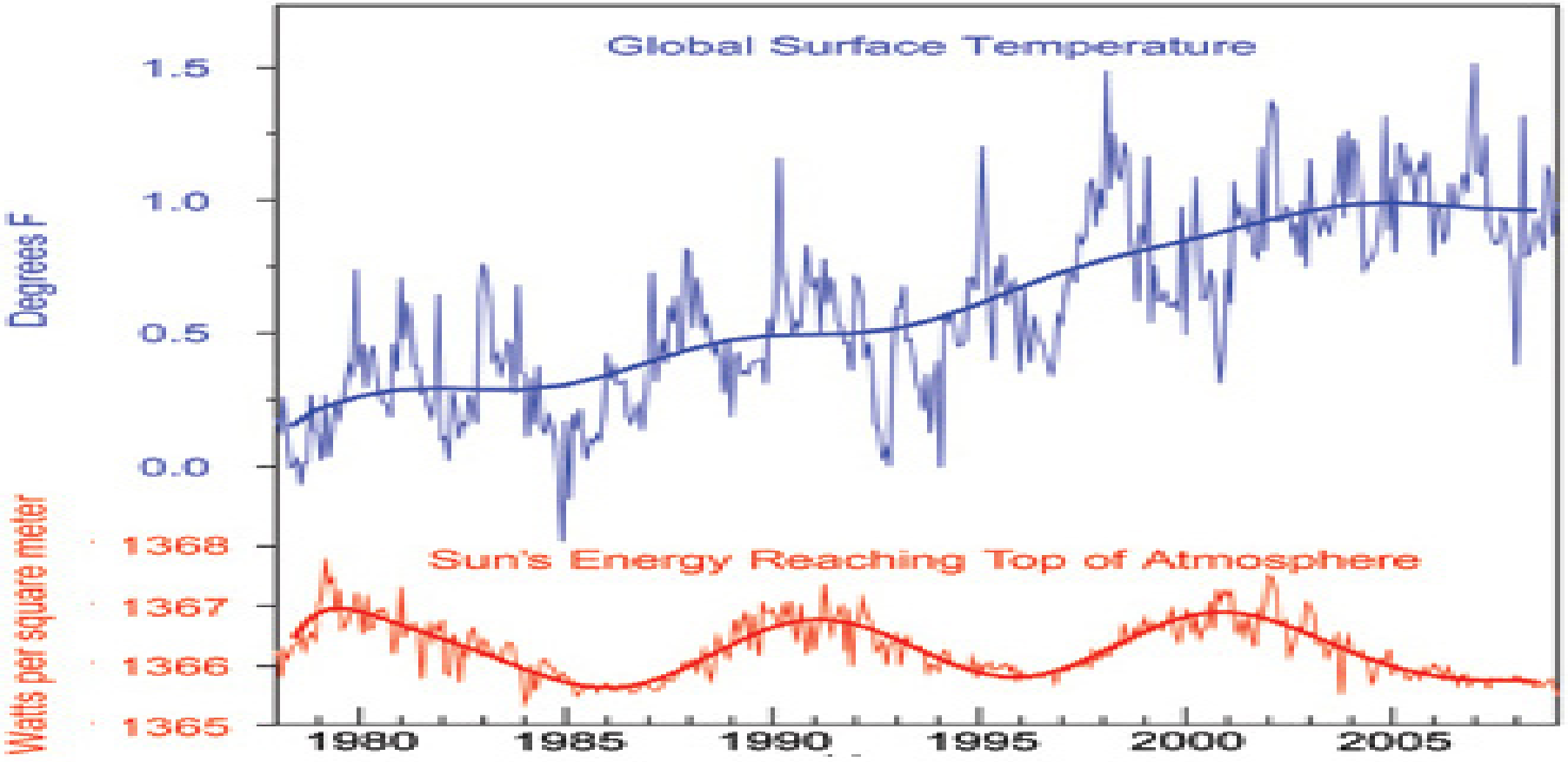
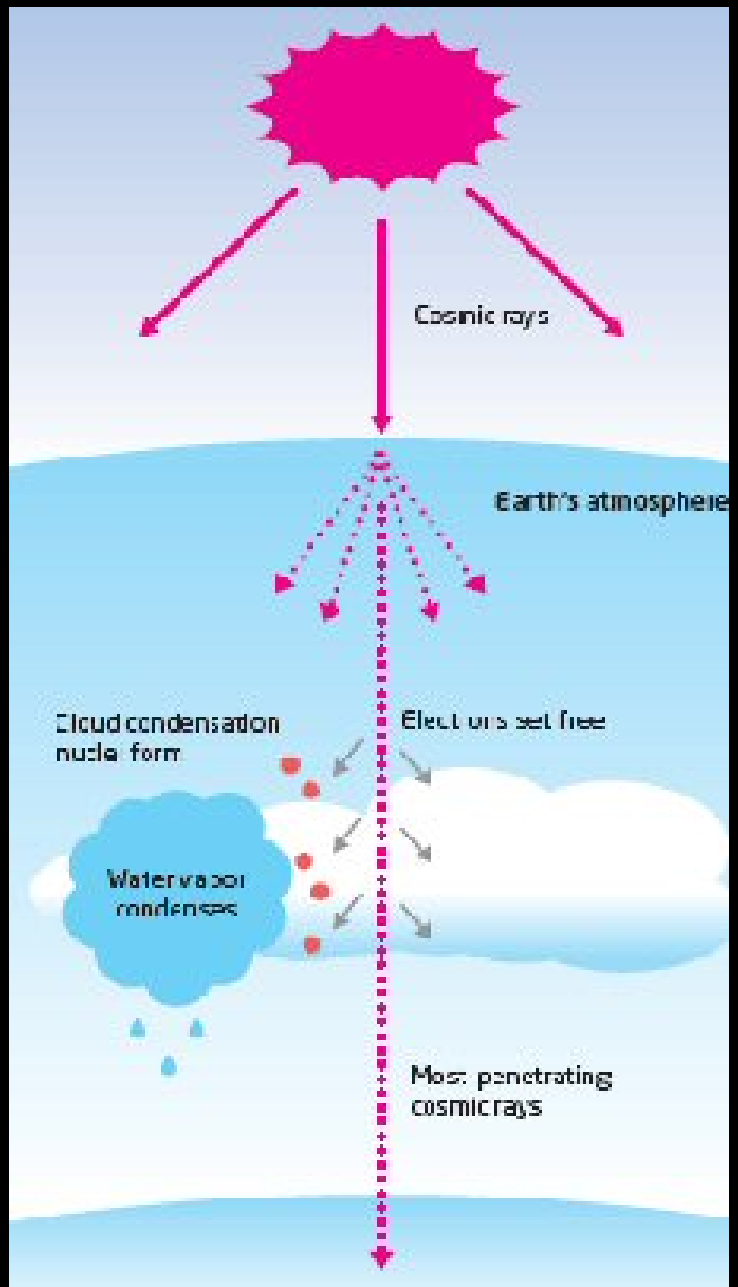


Figure 2. Satellite observations show no increasing trend in solar output. The 11-year solar cycle is evident, but this cannot be driving the overall increase in global average temperatures. (GCRP, 2009, p. 20)

Well, Maybe Indirectly It's Still the Sun…

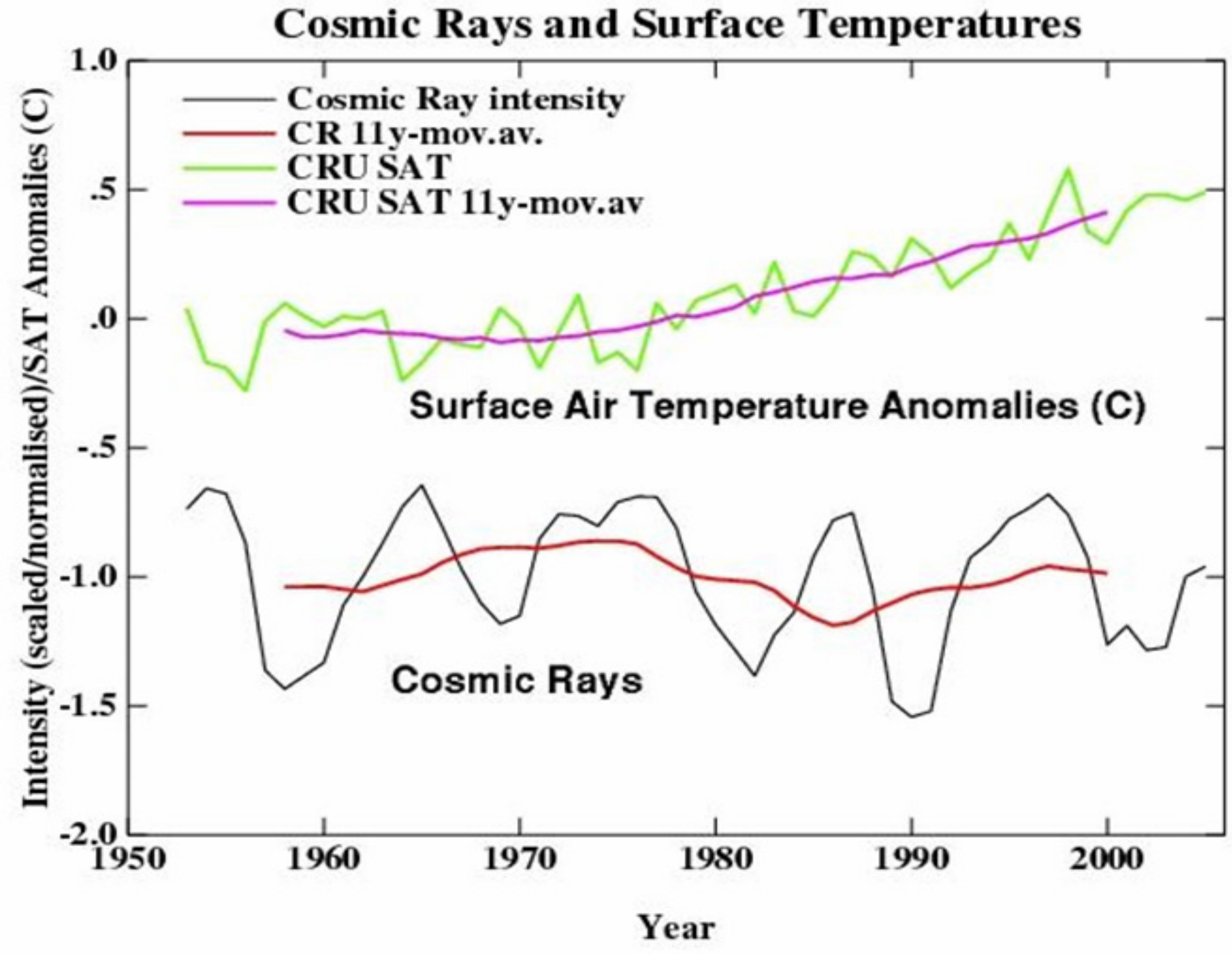
The Svensmark hypothesis.

- Solar activity could be moderating cosmic rays flux on the Earth, moderating cloud nucleation.
- After all, more low clouds would cause cooler temperatures, so if cosmic rays produce fewer cloud condensation nuclei and fewer low clouds, then you would expect rising surface temperatures



No. Wrong in Many Ways

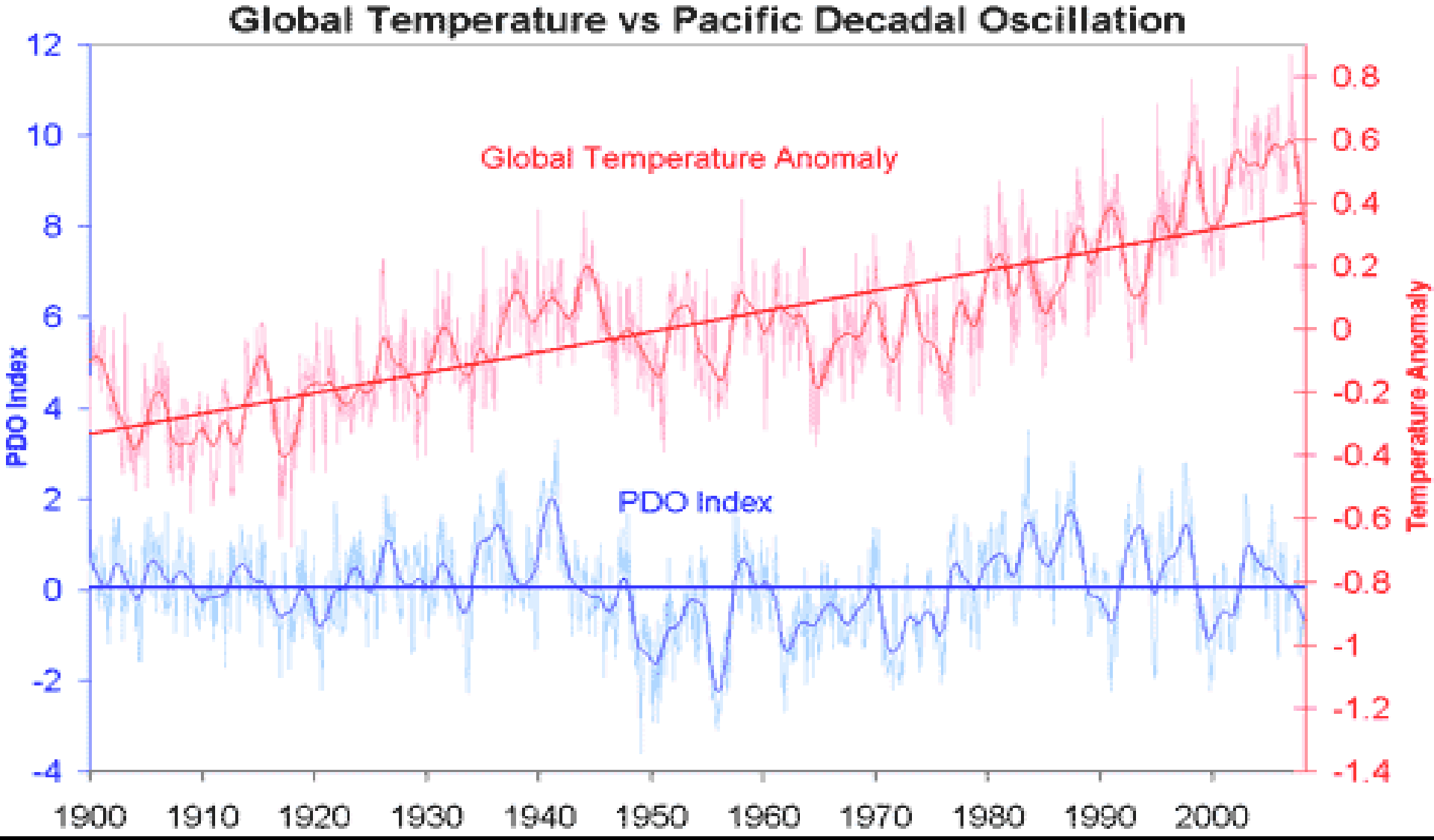
- There are already FAR more aerosols to act as cloud condensation nuclei in the troposphere than needed… by 999-to-1 according to cloud physicists
- What controls tropospheric clouds is temperature and humidity, not the availability of tropospheric cloud condensation nuclei – we have plenty in all sizes
- While solar activity/solar magnetic strength DOES moderate cosmic ray flux to Earth, there has been NO trend in solar activity in the past 60 years, except a slight decrease –
- and a decrease in solar magnetic strength would be expected to let in MORE cosmic rays, producing MORE low clouds, and COOLer temperatures, according to his hypothesis – the exact OPPOSITE to what we see


Cosmic Rays and Surface Temperatures
Cosmic Ray intensity
CR 11y-mov.av.
CRU SAT
CRU SAT 11y-mov.av
Surface Air Temperature Anomalies (C)
Cosmic Rays
Intensity (scaled/normalised)/SAT Anomalies (C)
Year
1.0
.5
.0
-.5
-1.0
-1.5
-2.0
1950
1960
1970
1980
1990
2000

Well… Maybe it's Long Term Ocean Surface Temperature Oscillations Somehow Causing Global Warming?

No

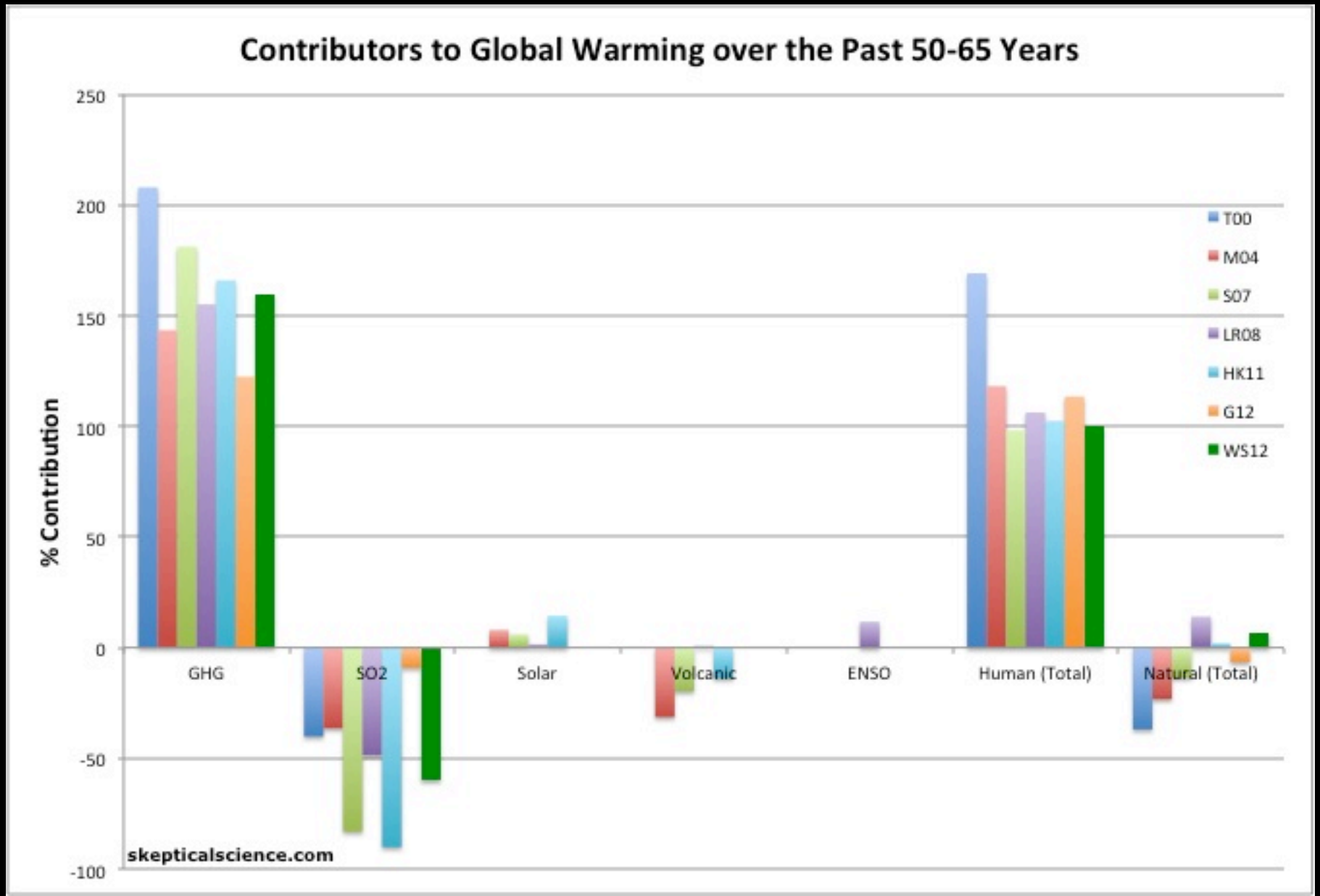
- First, it's the atmosphere and sun which heat the ocean. The ocean can't net heat the Earth atmosphere unless the atmosphere alREADY input that heat into the ocean to begin with.
- Also, the strongest ocean heat oscillation is the El Nino / Southern Oscillation (ENSO). It does clearly show in the temperature record, but it has only a ~5-8 year oscillation
- The IPCC studies show it has negligible contribution to net global warming over the 20th century (previous slide)
- The longer term Pacific Decadal Oscillation (PDO) is not correlated to secular global warming either…



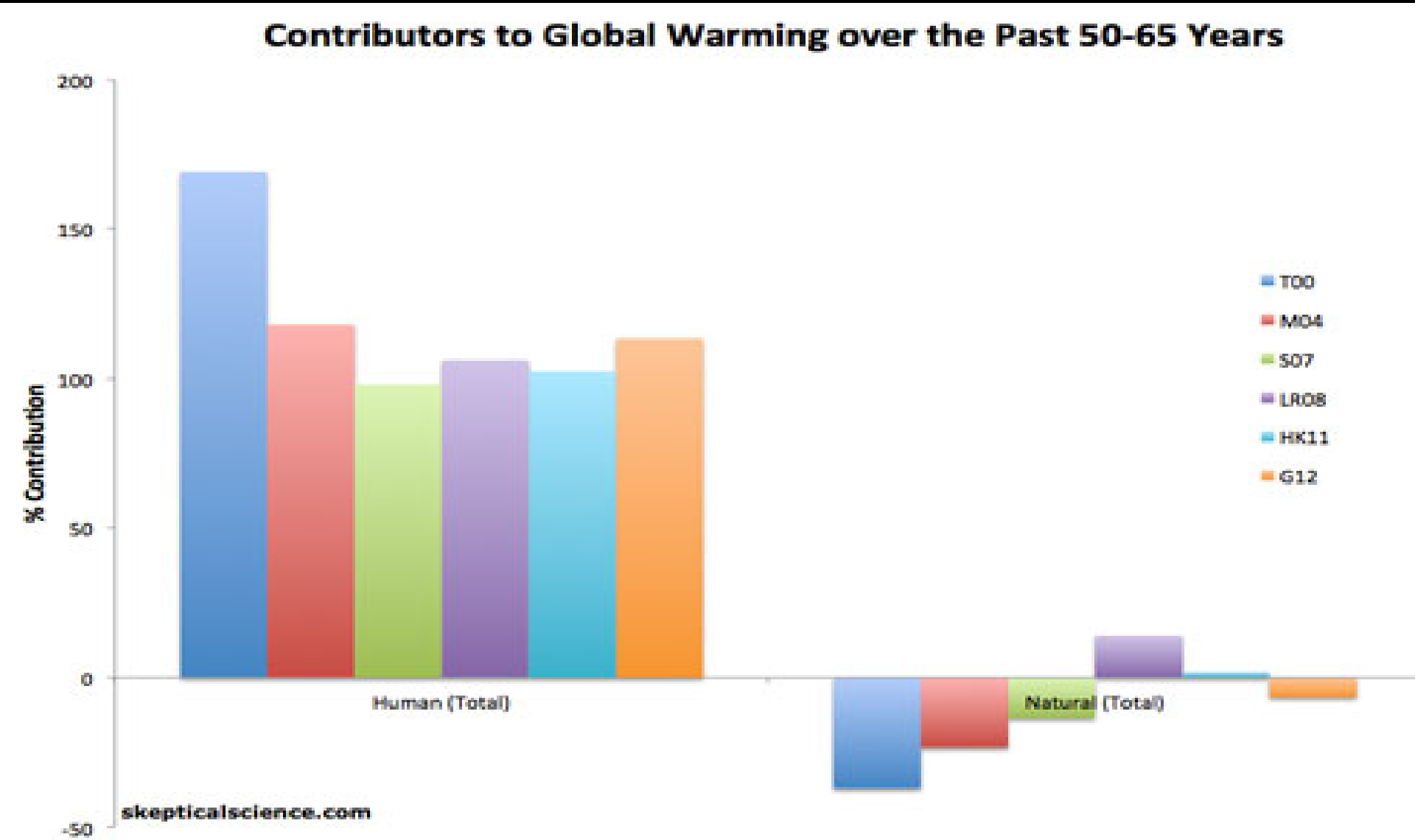
As CO2 levels rise and more completely dominate climate changes, the mild correlation between the PDO and global temperatures disappeared in mid 1980's. Since then, the PDO has trended down while temperatures more strongly trend upward…

The PDO does NOT explain Global Warming

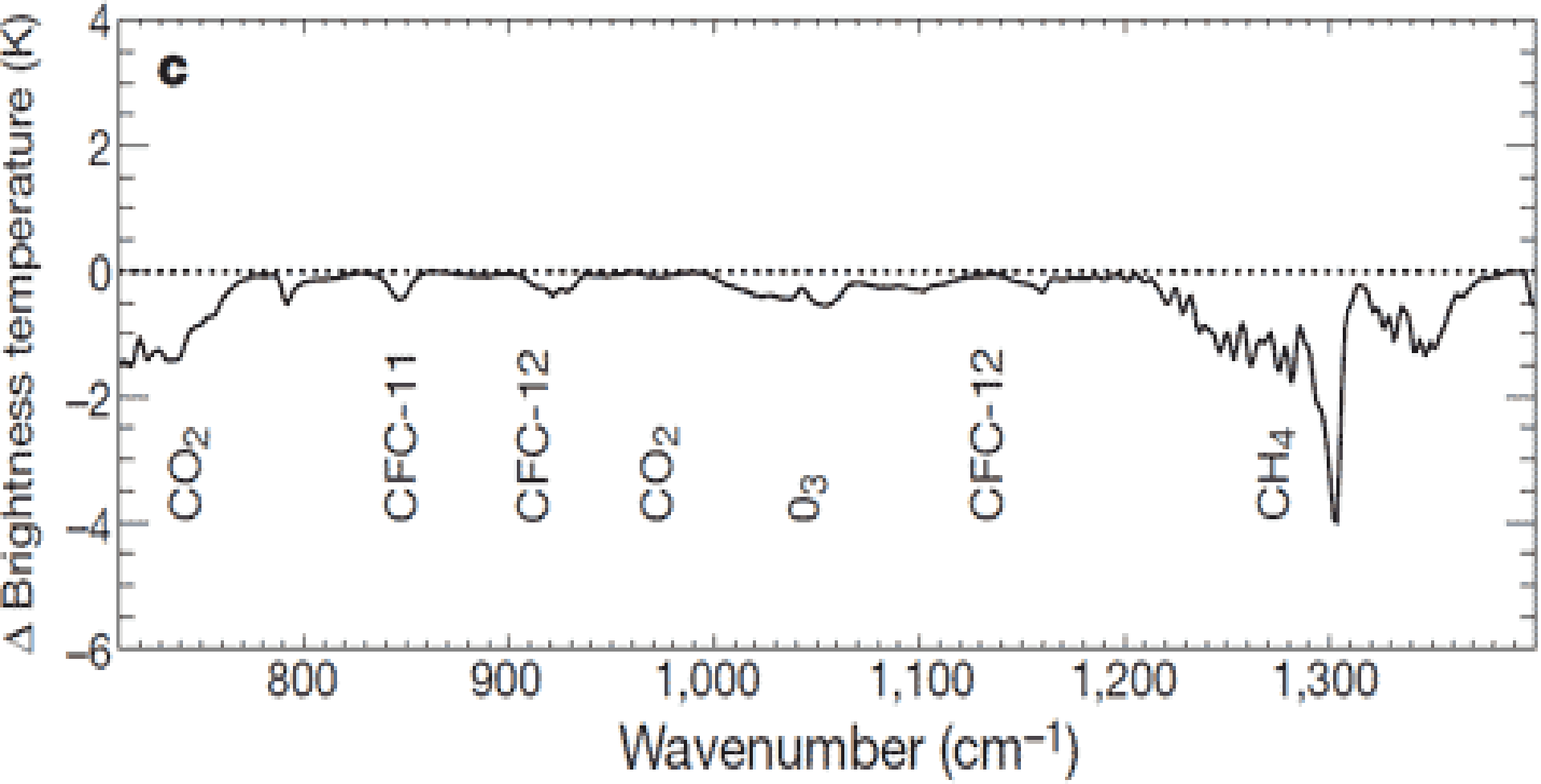
Human vs. Solar, Volcanic, Ocean Oscillation Forcings – It's 100% Human



It's ALL Us. "Natural Variation" Has Actually Provided A Slight Net Cooling (6 different studies)



Infrared outgoing radiation has been getting progressively trapped by primarily CO2 and CH4 (methane) in this IR spectral band. Graph plots the observed DIFFERENCE in outgoing radiation 1970 *vs.* 1997 (Harries 2001)



Other Strong Evidence The Warming is Greenhouse Warming

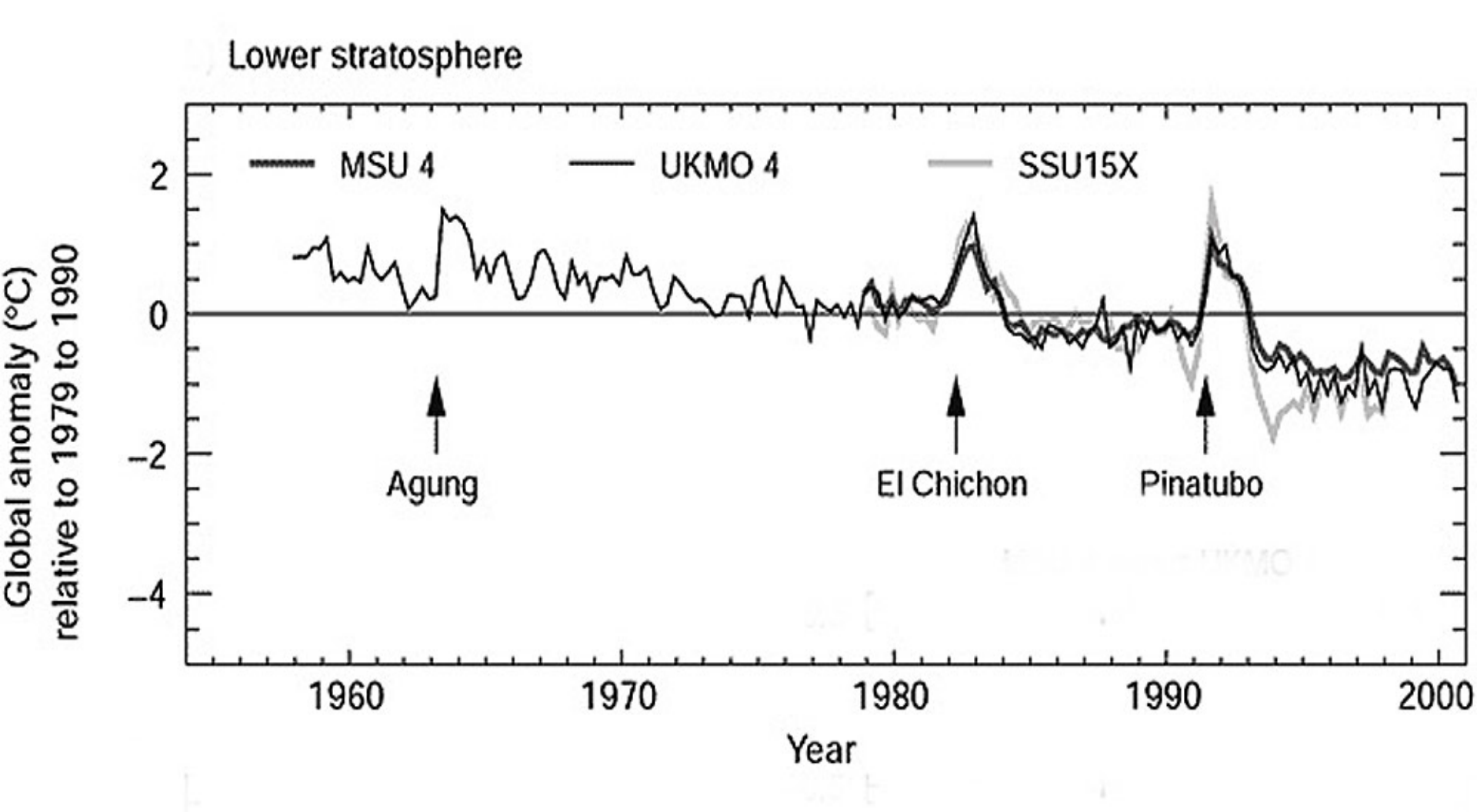
- Only Greenhouse warming produces both a warmer troposphere (standard Greenhouse Effect) and at the same time a COOLER lower stratosphere

- Note the stratosphere is heated from ABOVE – by ozone absorption of solar UV

Rising Stratospheric CO2 Acts as a Stratospheric Coolant

- Why? The stratosphere sees less upgoing IR radiation because it is trapped by the troposphere (*i.e.* global warming!), but more CO2 means more frequent CO2 collisions, causing molecular collisional excitation, which can de-excite by IR emission, much of which goes to space. This is thermal energy turned to radiative cooling
- Net effect = cooling of stratosphere
- Climate modelling must include both the ozone depletion, and GHG cooling effects together, at all levels of the stratosphere, of course.
- The effects of rising CO2 are dominant, and obvious even when anthropogenic CO2 was only a small fraction of today's values (Schwarzkopf and Ramaswamy 2008)

Cooling stratosphere: A unique signature of GHG's. Note data is affected by dropping ozone levels until 1989 when Montreal Accords banned CFC's. (Also note volcanic eruptions into the stratosphere briefly heat it)



OK, Climate Change is Caused, by Us, Mainly by Fossil Fuel Burning

- What are the knock-on effects?
- Positive Feedbacks make the warming significantly worse…
- Positive Feedback #1: Air will hold 7% more water vapor for each rise of 1 degree Celsius in temperature (!!). That's a lot! Water vapor is itself a powerful greenhouse gas.
- This feedback alone will approximately DOUBLE the heat forcing due to CO2 alone.
- Hotter and more humid world

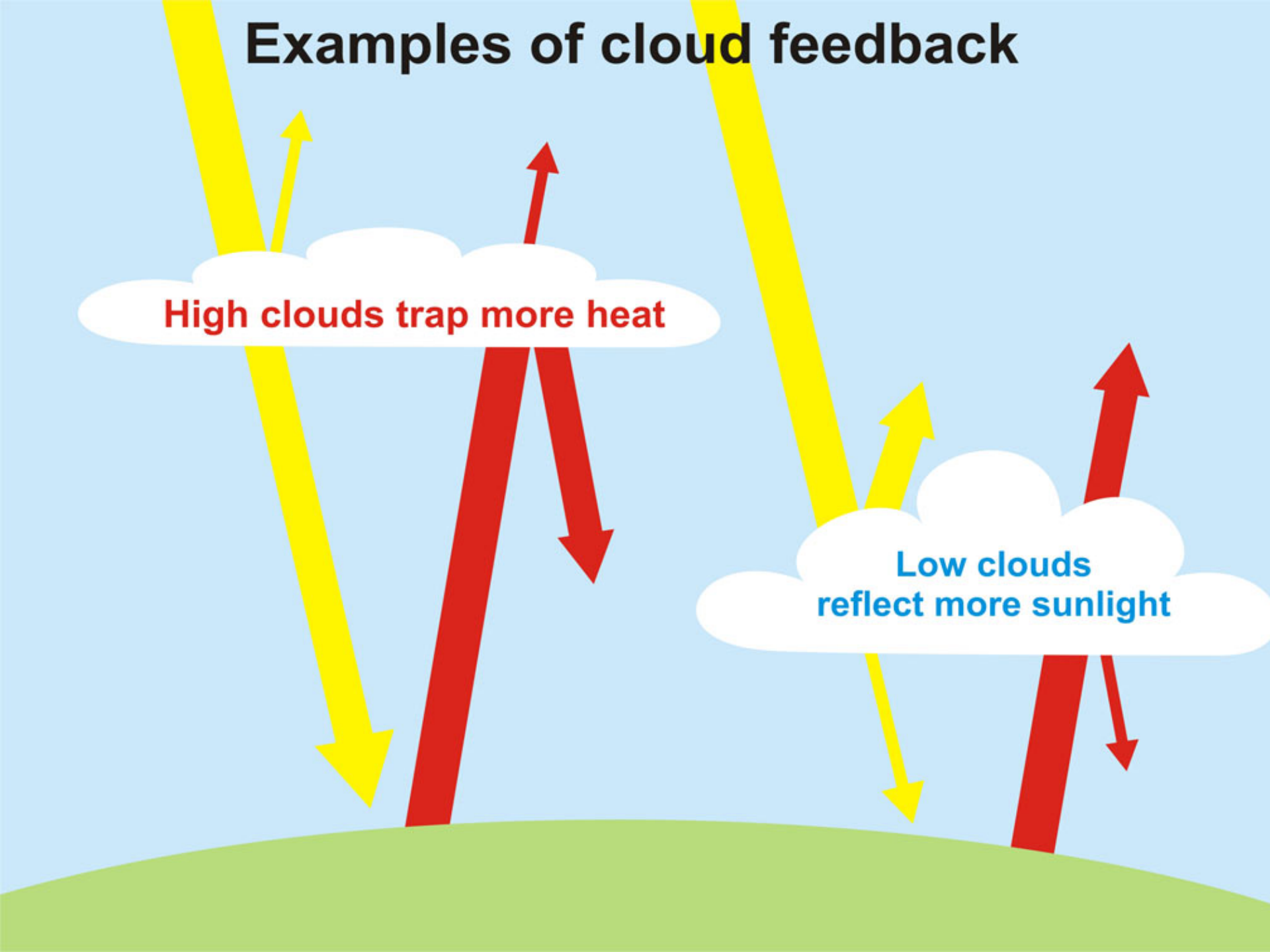
Positive Feedback #2: Clouds

- So far, temperature rise is only 0.9C, and observed cloud feedbacks have been relatively small, but they are positive feedbacks (Dessler 2010)
- Later this century, with stronger temperature rise, will the sign of the feedback change? Not known, but theory says rising convection due to hotter surface means taller convection clouds and more high clouds and stronger greenhouse effect – but other effects may alter this; much bigger computers needed.
- Radiation physics of clouds is well known, but what type of clouds will form and how they non-linearly interact with the landscape *etc.* requires far too much dynamic range to calculate in current climate simulations.

Cirrus Clouds are Poor Reflectors of Sunlight, better Reflectors of Upward IR, and are Cold, Inefficient Radiators to Outer Space, Thus Warming Climate

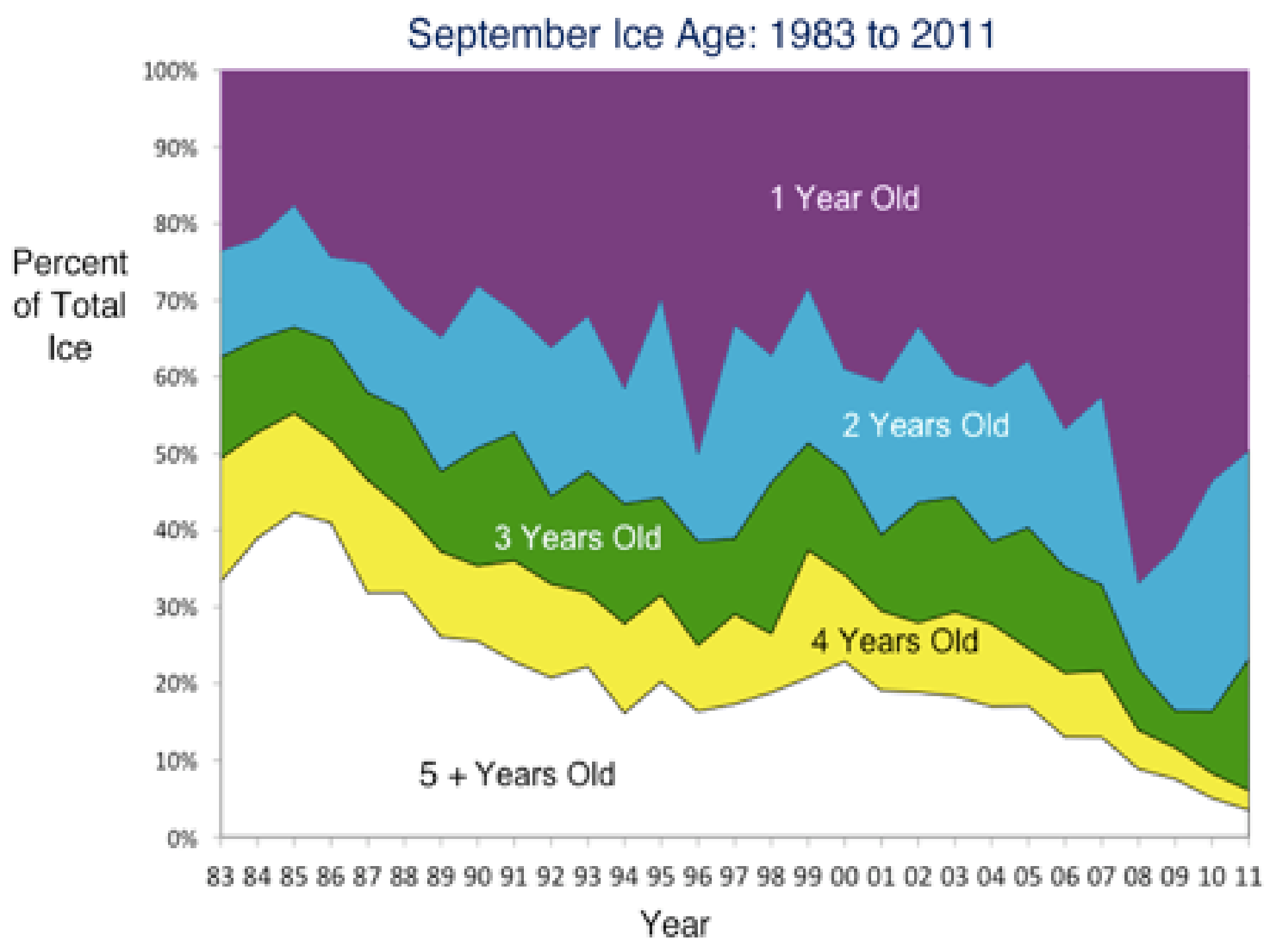
Thick clouds, especially low thick clouds, reflect sunlight. And low clouds have warm tops, So, are Good radiators to outer space –> cool climate

Examples of cloud feedback

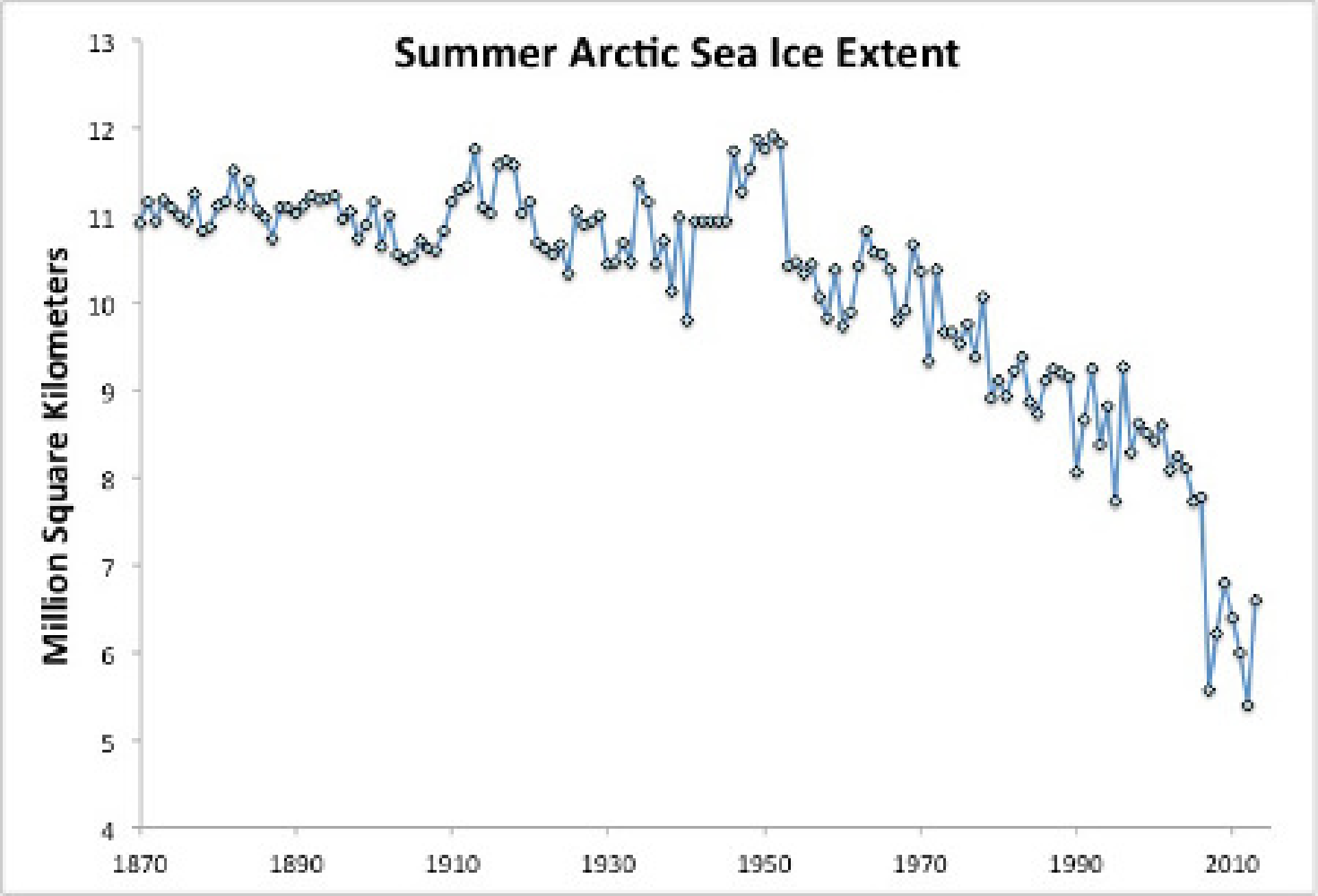


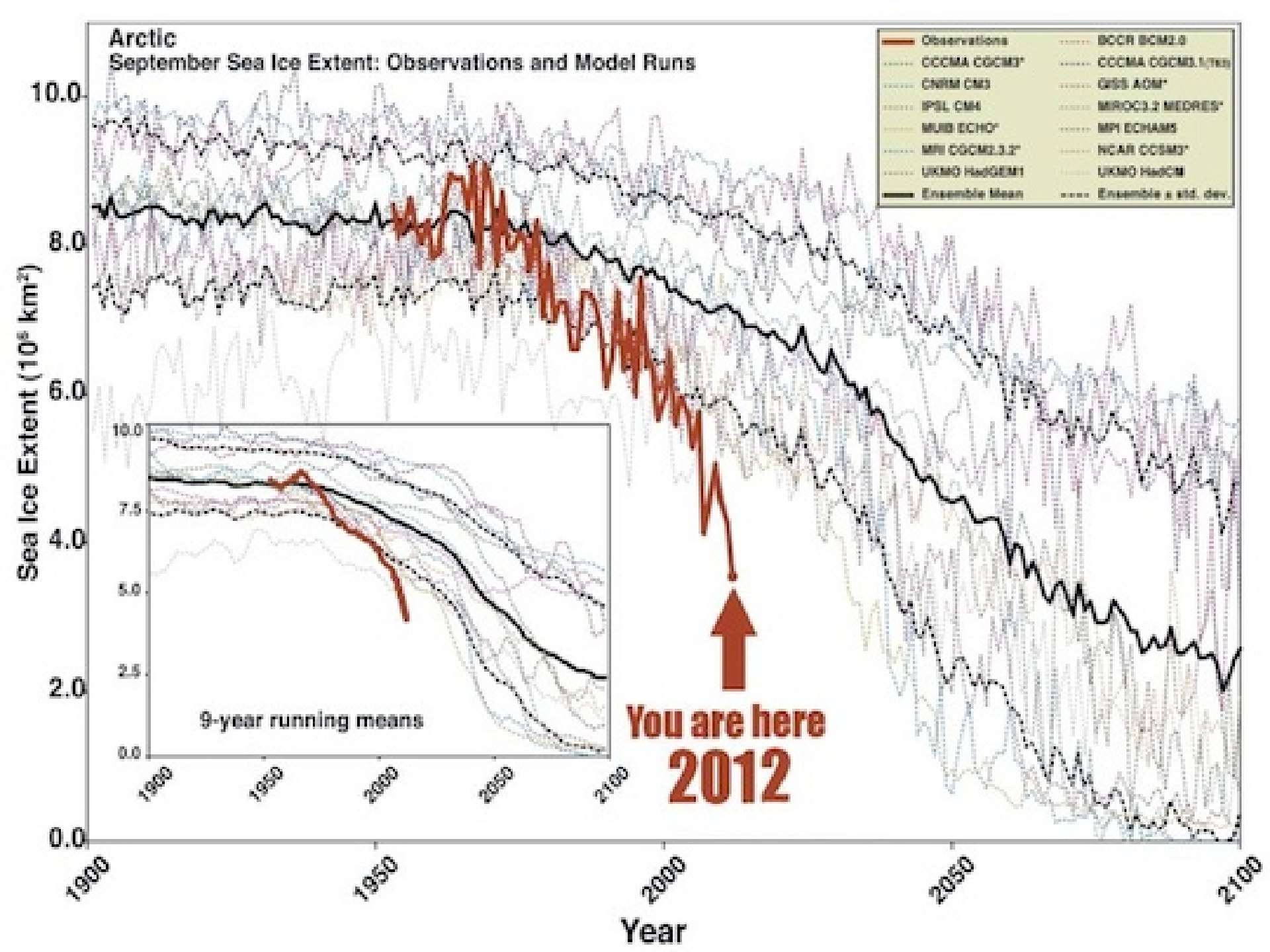
Positive Feedback #3: Loss of Polar Ice

- It has taken most of the 20th Century to melt through most of the long term permanent ice covering the Arctic Ocean. Only ~4% of 5yr+ old ice is left.
- The Arctic Ocean is now more than half ice-free in summer.
- Dark water absorbs sunlight rather than reflecting it, heating water, melting further ice from underneath it
- The more ice is melted, the lower the albedo of the Arctic and the more that sunlight will warm the Arctic further, amplifying the heating by removing yet more ice


September Ice Age: 1983 to 2011
Percent of Total Ice
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 Year Old
2 Years Old
3 Years Old
4 Years Old
5 + Years Old
83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11
Year

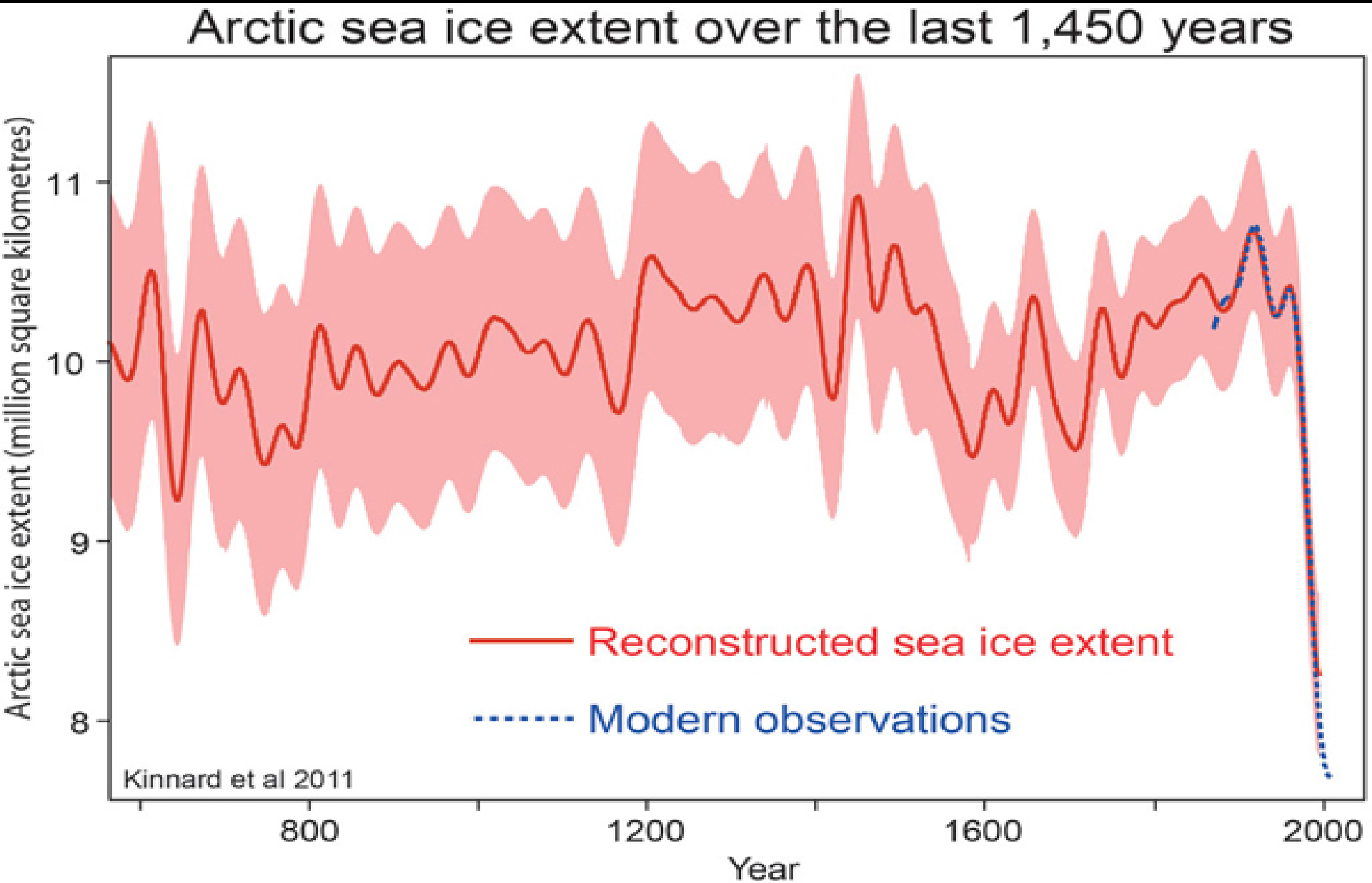
Loss of Arctic Sea Ice Area – Past 140 years



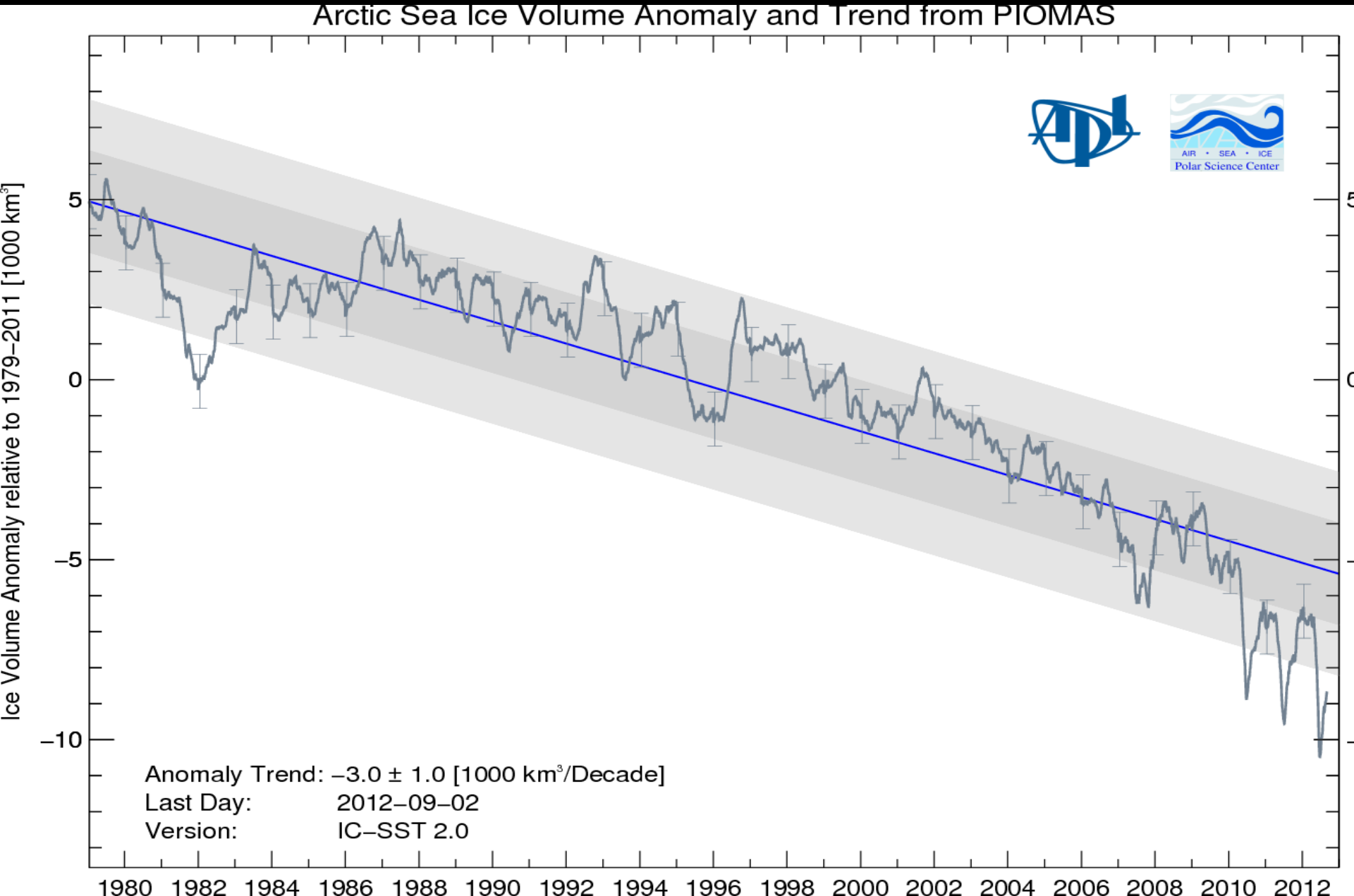

Arctic
September Sea Ice Extent: Observations and Model Runs
Observations
CCCMA CGCM3*
CNRM CM3
IPSL CM4
MUIB ECHO*
MRI CGCM2.3.2*
UKMO HadGEM1
Ensemble Mean
BCCR BCM2.0
CCCMA CGCM3.1(T63)
GISS AOM*
MIROC3.2 MEDRES*
MPI ECHAM5
NCAR CCSM3*
UKMO HadCM
Ensemble ± std. dev.
Sea Ice Extent (10^6 km^2)
Year
9-year running means
You are here
2012

2012 - A New Record Low Summer Ice Area

Past 1400 yrs… Does this collapse Look Like Just "Natural Variation"?

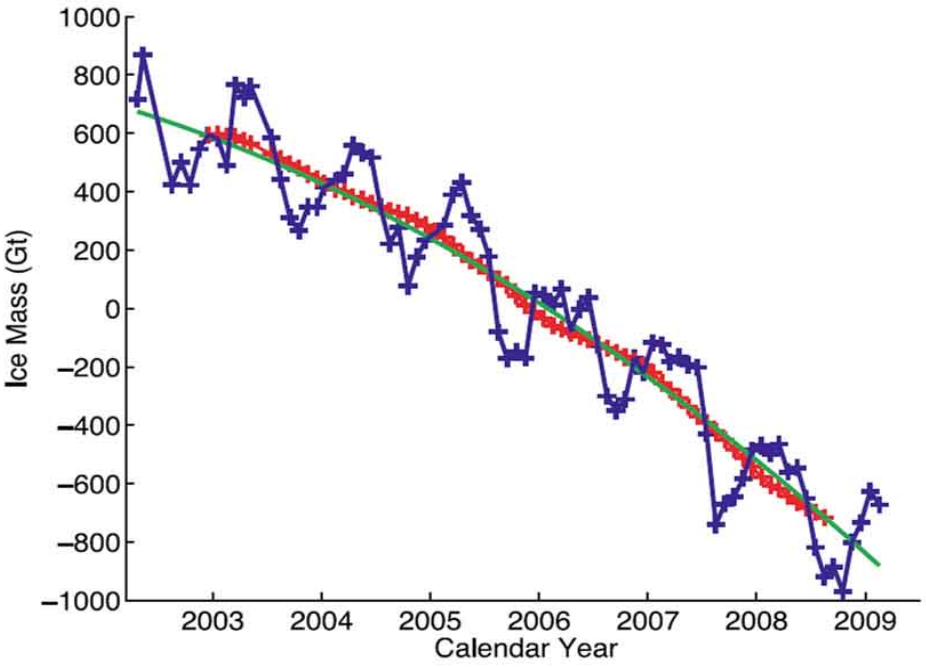


Arctic Ocean Ice Volume and Mass Dropping Too

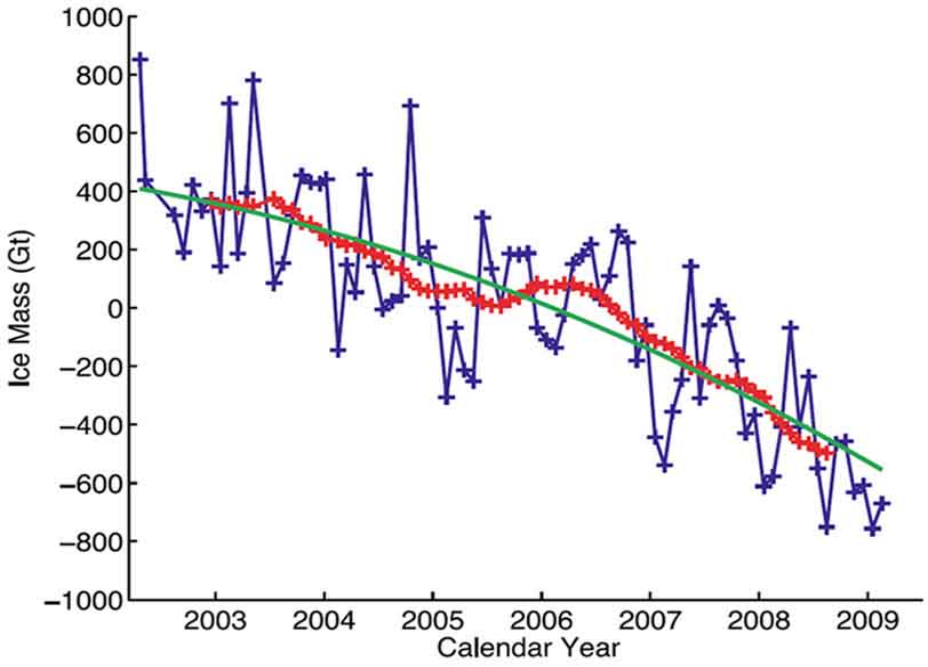


Not Just Ice Cover Area, but Ice Mass as Well

Rapidly Increasing Polar Ice Loss



Greenland



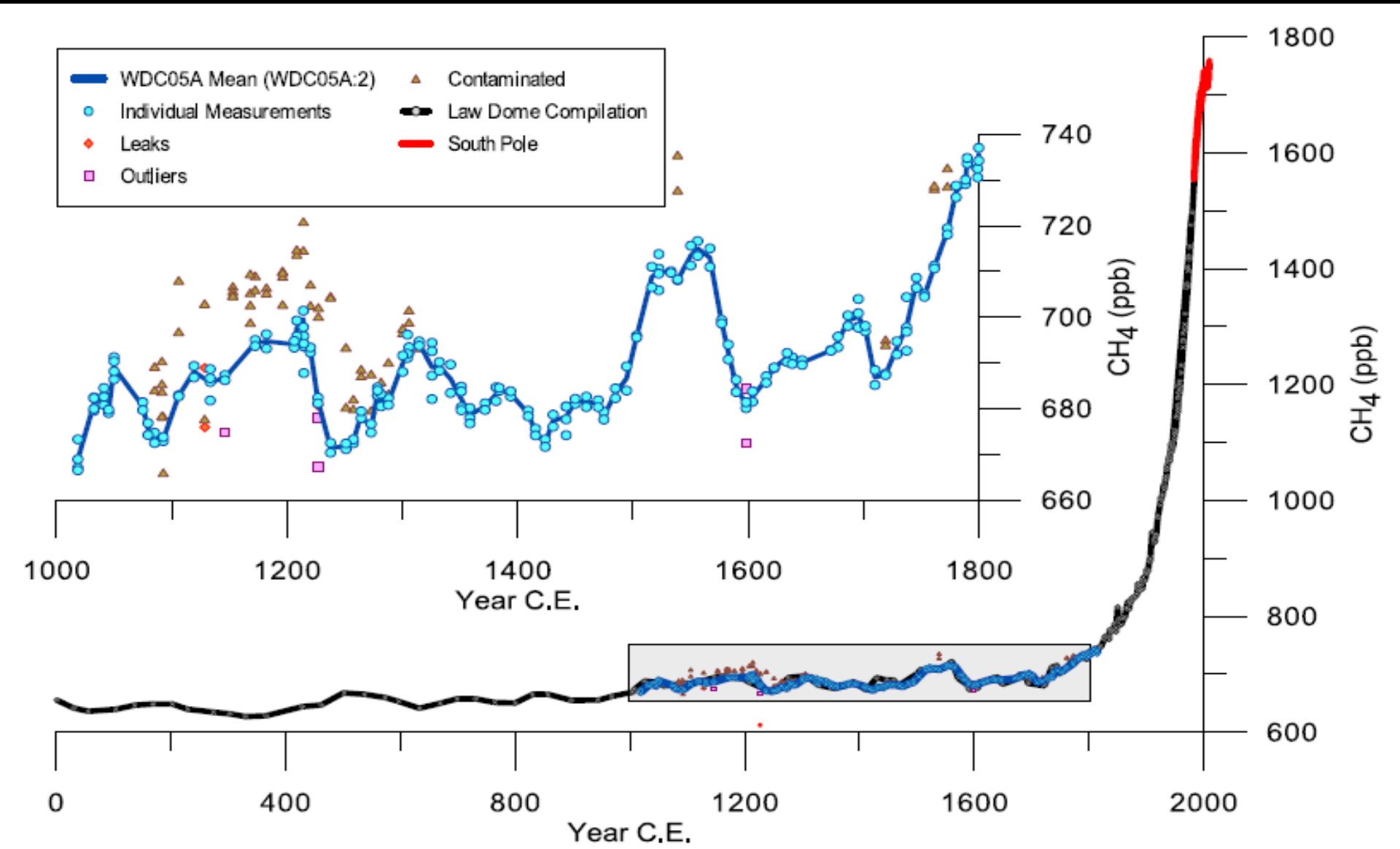
Antarctica

This data shows ice lost from Greenland and Antarctica. The information comes from the new GRACE satellites. These satellites are gravity measuring satellites that are 100 times more sensitive than the previous generation of gravity measuring satellites. What this data shows is a continuous loss of ice from both ice sheets, but more importantly, the loss rate is accelerating. Greenland lost 230 gigatons and Antarctica lost 140 gigatons in 2009. The acceleration in 2009 was 56 gigatons per year. A gigaton is one billion tons. The City of Los Angeles uses one gigaton of water per year. Combined, the ice loss raises sea level by 1.1 mm per year, every year, and this rate is increasing by 15% per year. This means that we will crass the barrier island stability threshold about 2012 or 2013. Reference: *Velicogna, Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE, Geophysical Research Letters, October 2009.*

Positive Feedback #4: Methane Release from Thawing Permafrost

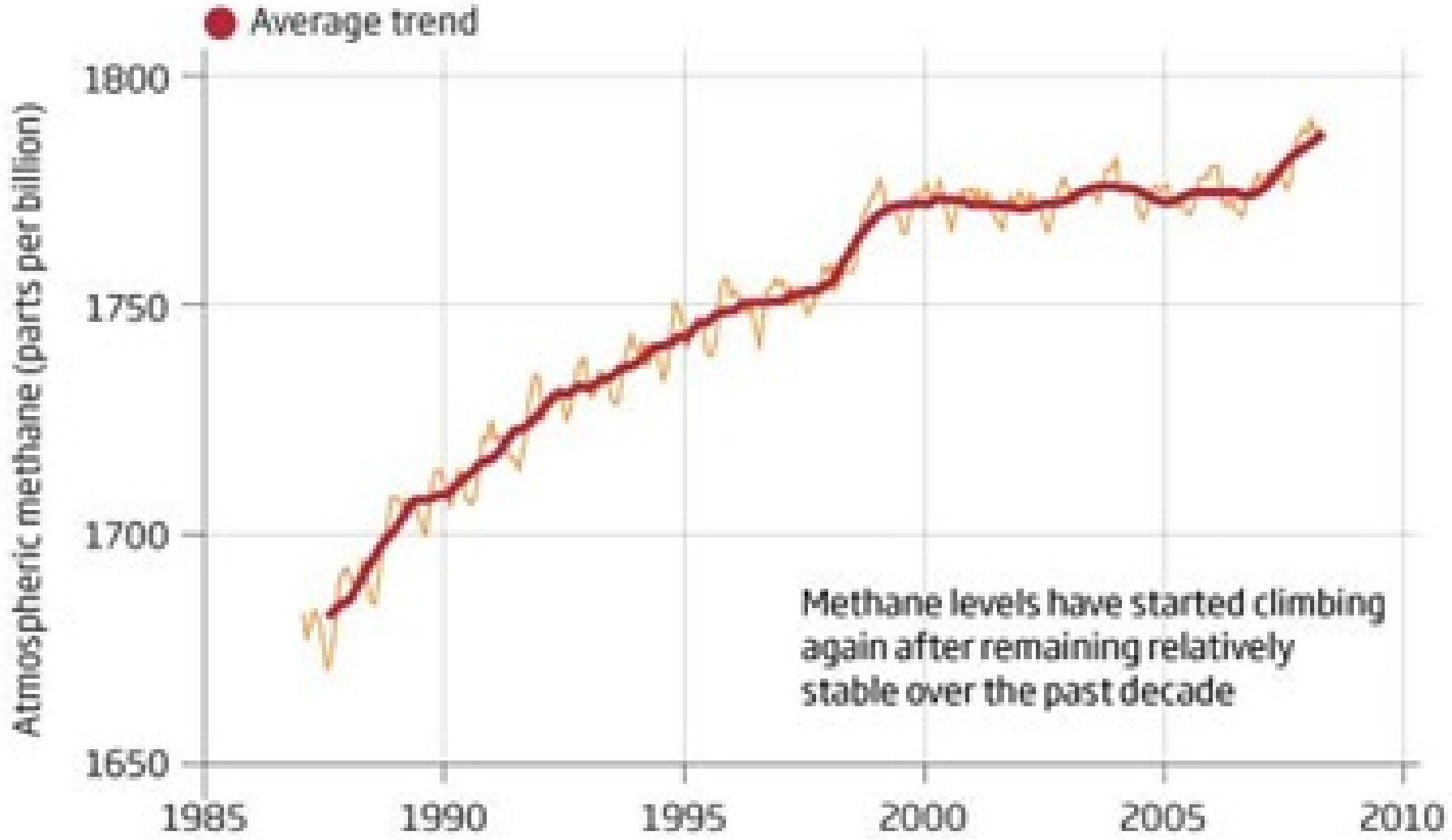
- Methane frozen in the permafrost since the advent of the last great Ice Age, and remaining frozen even after the end of that Ice Age 12,000 years ago… is now thawing.
- Ice-free Arctic Ocean calculated to cause permafrost melt as far as 1500 km south of the Arctic Coastline (
- Greenhouse heating from methane is, pound for pound, 25x higher than that of CO2, averaged over a century

Mostly Due to Livestock So Far, but Arctic Tundra Methane Now Starting to Kick In



Danger signal

In 2007 and 2008, temperatures across Siberia were way above average. At the same time, atmospheric methane levels suddenly increased. Some think the rise in methane is partly due to melting permafrost

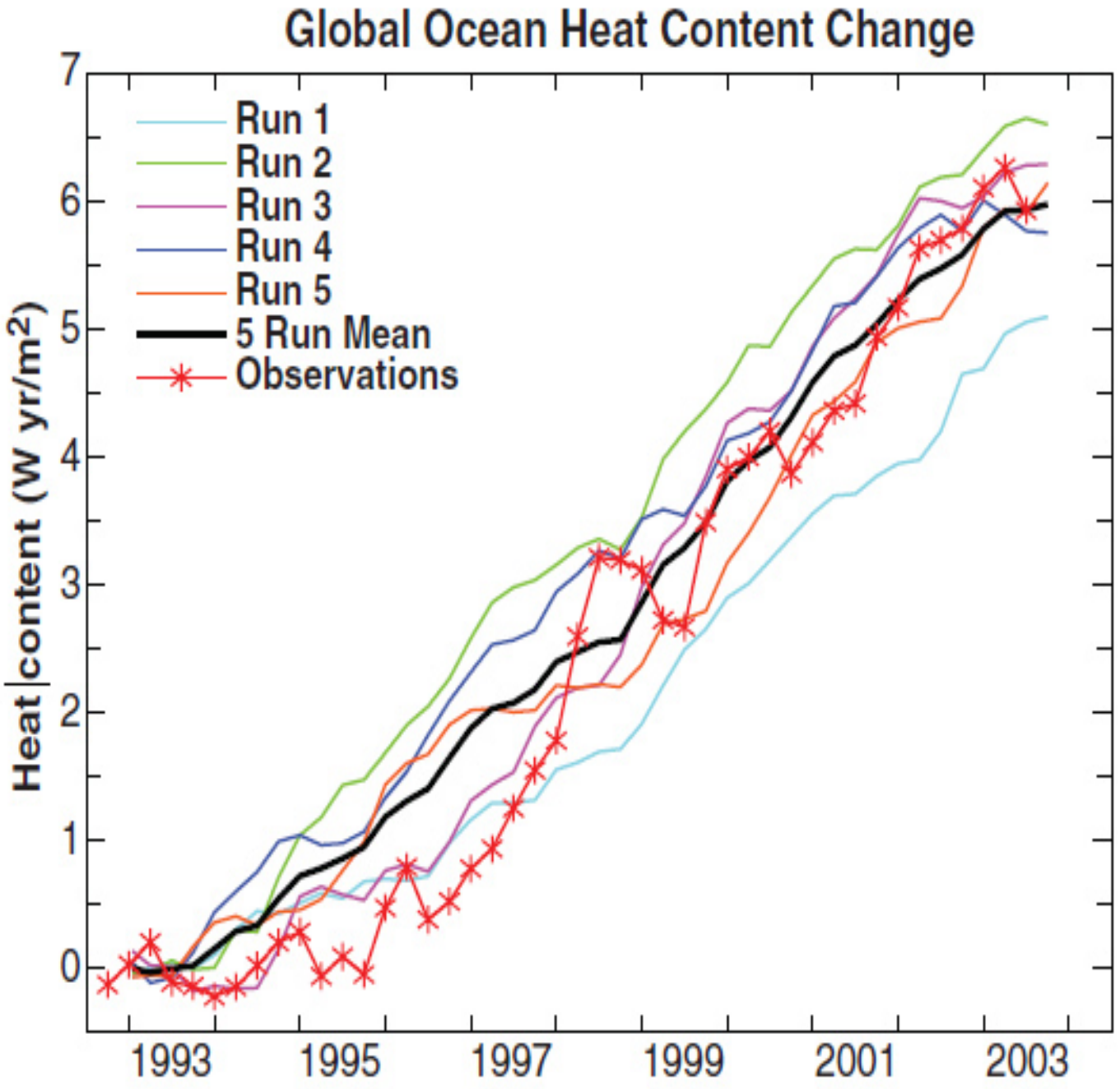


GRAPH COMPILED FOR NEW SCIENTIST BY R. PENN & WAVE AND THE ACACIA TEAM

Positive Feedback #5: Warming Ocean Destabilizes Methane Hydrates?

- This is a leading hypothesis for the cause of the Paleocene-Eocene Thermal Maximum; a (geologically) fast warming of global temperatures 56 million years ago by ~4 C which included a large increase in atmospheric CO2.
- Methane hydrates can be destabilized with higher temperature. Shallow continental shelf deposits may go unstable and outgas methane in large amounts, if the ocean warms sufficiently at their depth
- The danger of this for our future is not well studied yet.
- However, we do know that our Greenhouse warming is slowly penetrating into deeper and deeper layers of the ocean right now.

Fig. 2. Ocean heat content change between 1993 and 2003 in the top 750 m of world ocean. Observations are from (*20*). Five model runs are shown for the GISS coupled dynamical ocean-atmosphere model (*8*, *9*).



Positive Feedback #6: Burned and Blackened Boreal Forest Land

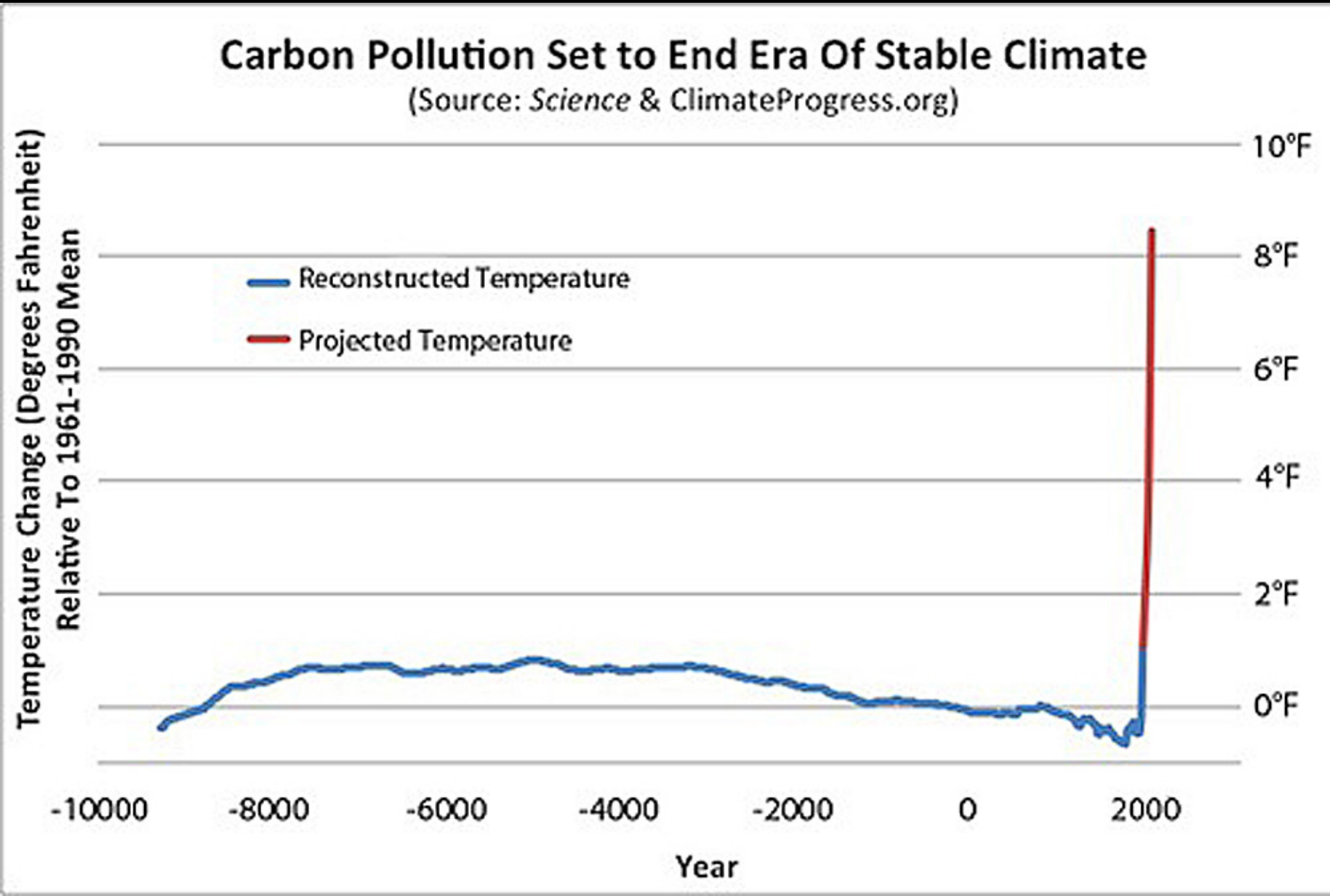
- Kelly *et al.* 2013 show that dying Boreal forests (bark beetle from insufficiently cold winters, climate change, etc) are producing wildfires unprecedented since before the last Ice Age.
- Summer insolation will find lower albedo (darker) surfaces into which this energy will be deposited.
- Re-fertilization from ash will only partly moderate the feedback to some small extent

Positive Feedback #7: Melting Snow has Lower Albedo

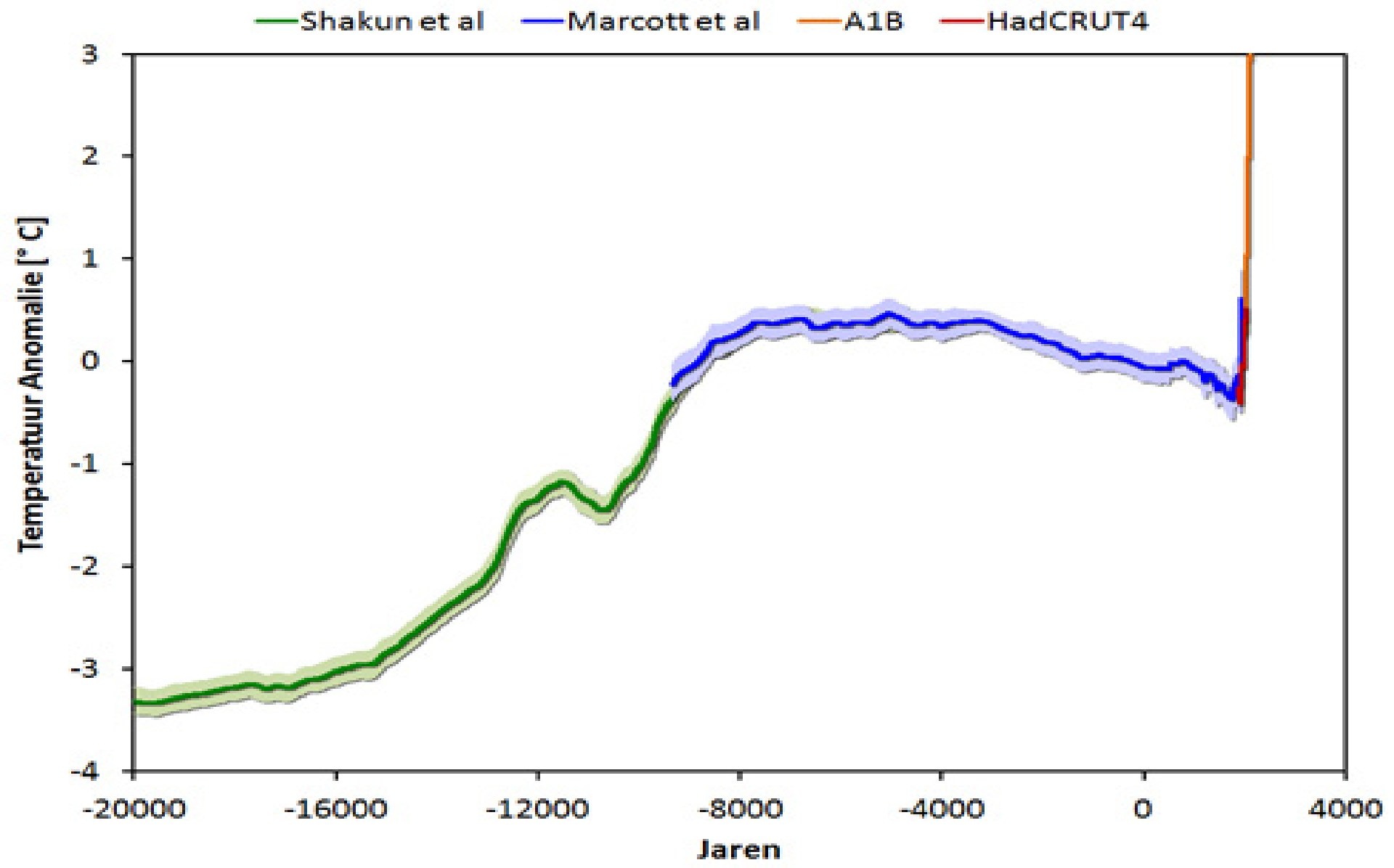
- As snow melts, it is less reflective for two reasons…
- #1: the geometry of the snowflakes lowers albedo
- #2: dark particles (soot, wildfire ash, industrial pollution, cosmic dust, etc.) concentrate on the surface as their underlying snow/ice vanishes

Future Climate: 21st Century and Beyond

In a "Business as Usual Scenario"…Marcott *et al.* (2013)



Global temperatures since the depths of the last Ice Age; Observed (blue), current and predicted (red)

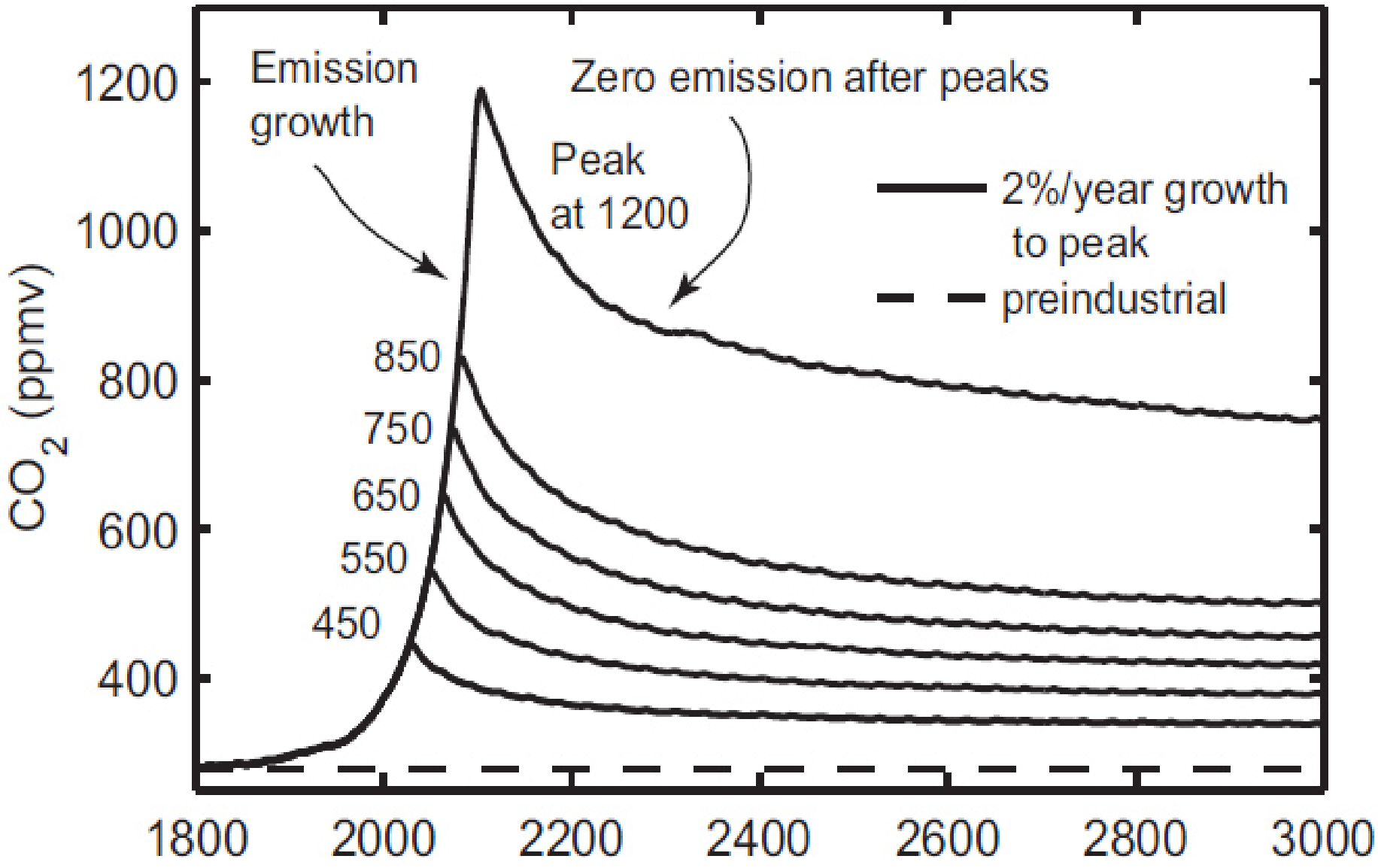


The Future…

- 1. The irreversibility of climate change on human time scales.
- 2. Sea Level Rise. New predictions
- 3. Ocean acidification
- 4. Methane hydrate, permafrost methane stability
- 5. Regional Forecasts, including California
- 6. Societal instability, extinction rates
- 7. Runaway Greenhouse odds

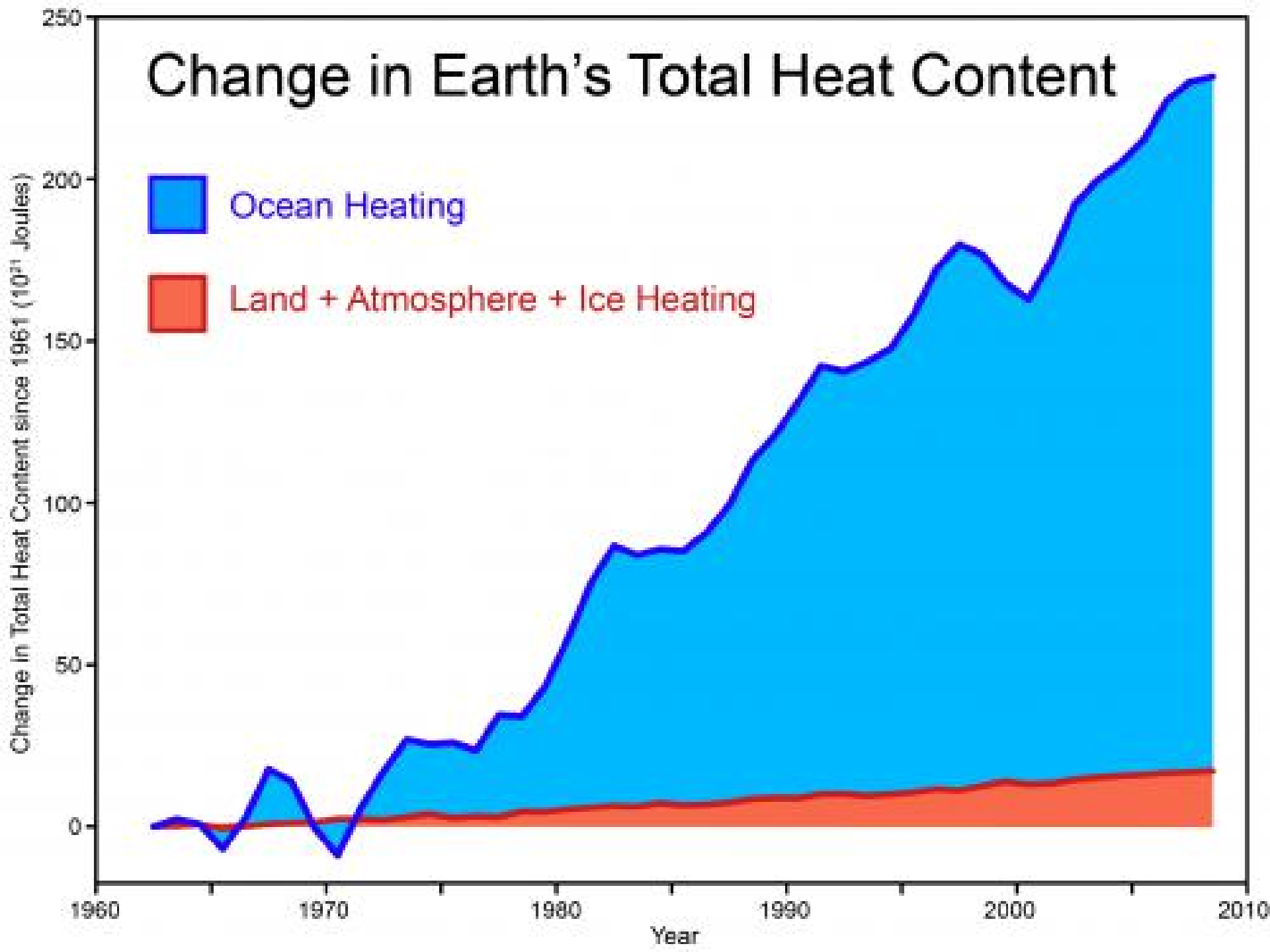
- **Rapidity of the change** is what is so damaging, not just the absolute value of the eventual change. **Ecosystems cannot adapt this fast**. Human society may not be able to adapt either.

Atmospheric CO2 – Next 1000 years. Peaks are Assumed Moments of Zero Further Emissions. CO2 slowly declines over centuries, …but not temperatures (see later slide)



Why don’t CO2 Levels Fall Faster when Emissions Stop?

- **Because on a warmer planet…**
- 1. CO2 does not absorb well into a hotter ocean - a hotter ocean can hold less dissolved CO2
- 2. Marine plants and animals are much less able to convert dissolved CO2 to CaCO3 under rising acidity
- 3. The sheer time scale of mixing CO2 into the ocean. Complete ocean mixing takes ~1000 years.
- 4. Thermal inertia of the oceans. Remember, we saw that **93% of the heat of global warming has gone into the oceans**. That heat hasn’t gone away, it’s still there, and being added to every day.


Change in Earth's Total Heat Content
Ocean Heating
Land + Atmosphere + Ice Heating
Change in Total Heat Content since 1961 (10^{21} Joules)
250
200
150
100
50
0
1960
1970
1980
1990
2000
2010
Year

Oceans Soak Up CO2 Better Early On, Then as it Warms, Not So Much. Note We Don't Achieve Thermal Equilibrium Until ~200 years after CO2 Cessation

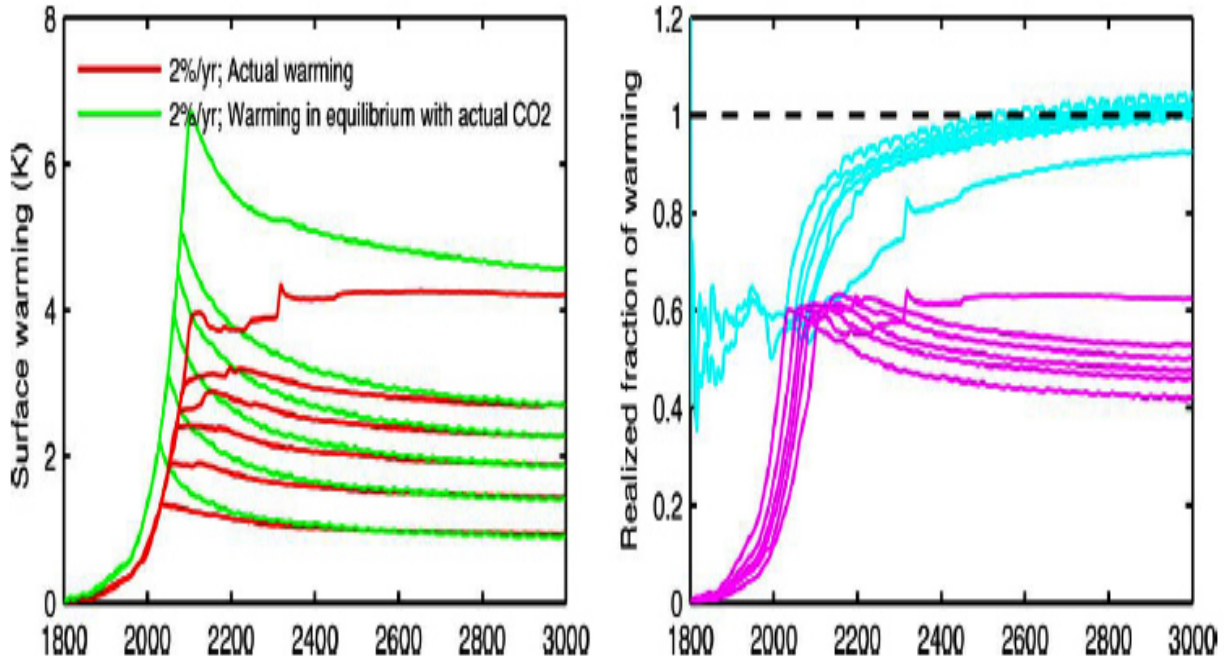
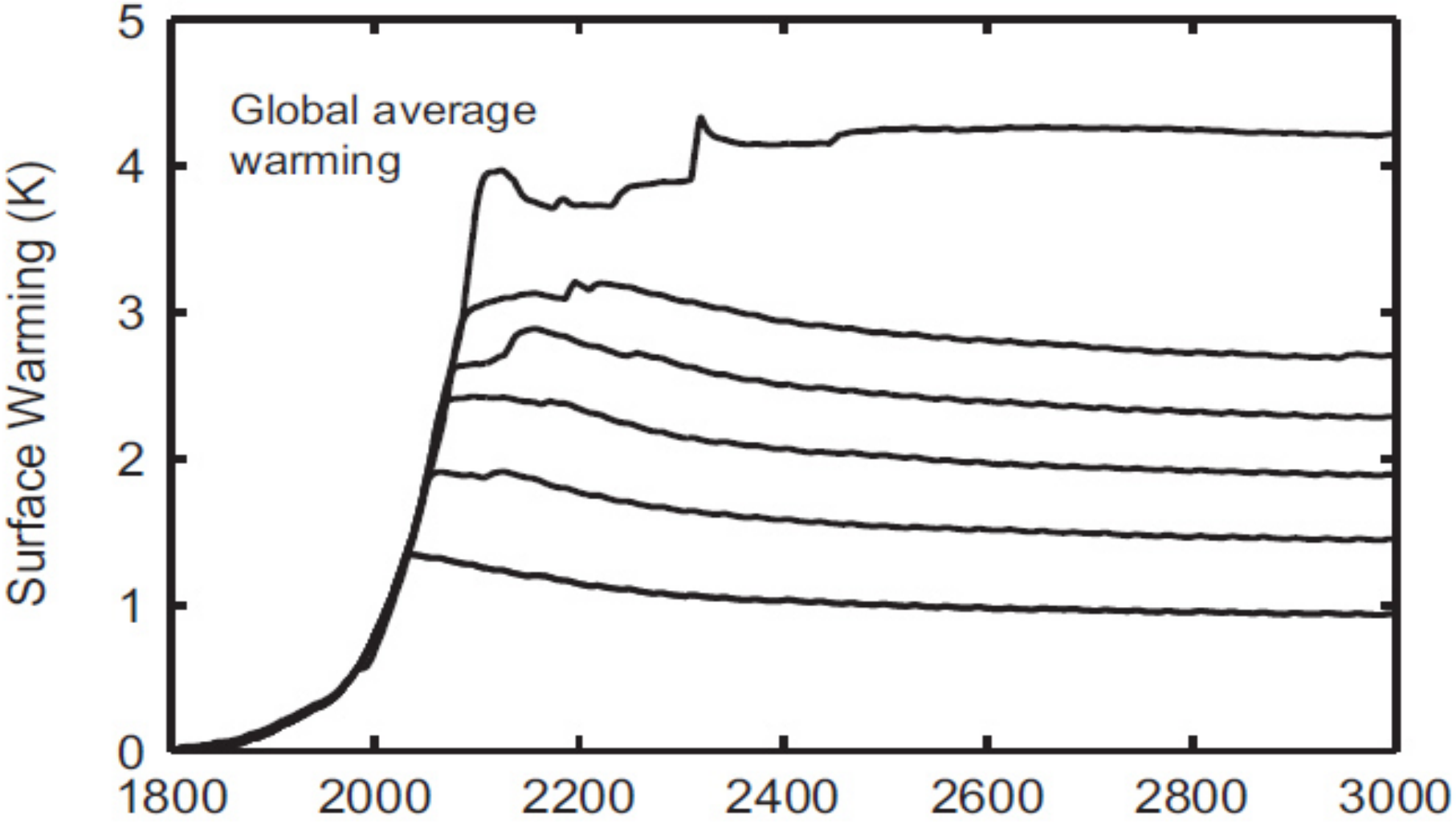


Fig. 2. Comparison between calculated time-dependent surface warming in the Bern2.5CC model and the values that would be expected if temperatures were in equilibrium with respect to the CO_2 enhancements, illustrative of 2%/year emission increases to 450, 550, 650, 750, 850, and 1,200 ppmv as in Fig. 1. (*Left*) The actual and equilibrium temperature changes (based upon the model's climate sensitivity at equilibrium). The cyan lines in *Right* show the ratio of actual and equilibrium temperatures (or realized fraction of the warming for the time-dependent CO_2 concentrations), while the magenta lines show the ratio of actual warming to the equilibrium temperature for the peak CO_2 concentration.

Therefore, Temperatures Don't Fall, Even After CO2 Emissions Halt – for Thousands of Years (Solomon *et al.* 2009).



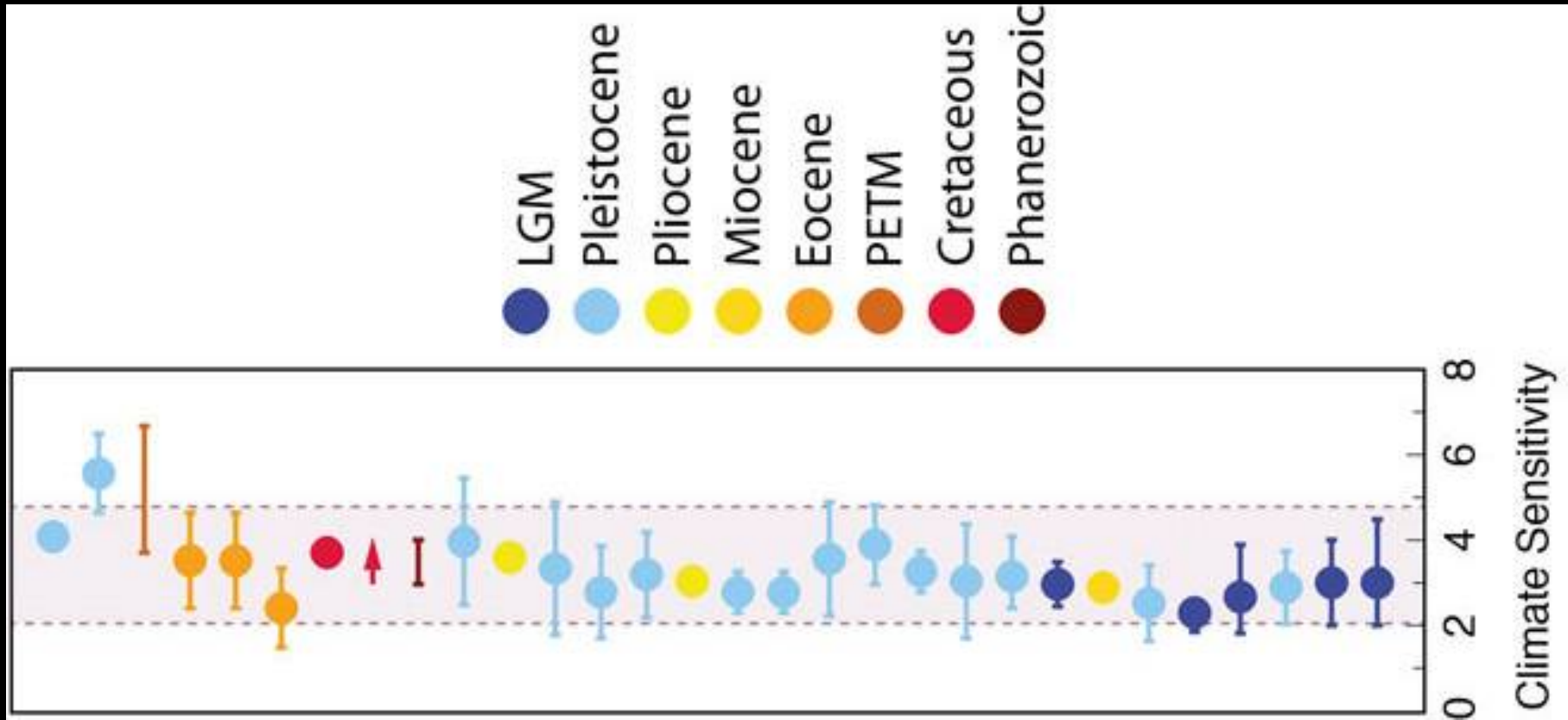
How Long After Stopping CO2 Emissions Will it Take the Earth to Cool Back Down?

- Solomon *et al.* (2009) and Gillett et al. (2011) could only say it was sometime well after a thousand years.
- New work by Zeebe (2013) find even if climate sensitivity is only 3K per CO2 doubling, the long term climate feedbacks will continue to amplify and last **for 23,000 – 165,000 years.**
- Solomon and other climate scientists complain that policy makers are using her work to justify a doing nothing, and ignoring the actual findings, which are that climate change is irreversible, but it is NOT unstoppable, given sufficient action. Denialism morphing into fatalism – with the one constant being a stubborn refusal to DO anything about it, even while action is most urgent and possible

From of Fasulo & Trenberth (2012) (Digest here)

- (my note:“Earth climate sensitivity” = ECS = how much hotter Earth surface temperatures will be, in equilibrium, at double the pre-industrial CO2 levels - a convenient benchmark used to discuss future prospects.)
- *“In short, while FS12 does not provide a specific measurement of climate sensitivity, it does suggest that the climate models with lower sensitivity ('low' here refers to approximately 2 to 3°C surface warming in response to doubled CO2, not the ridiculously low estimates of 1°C or less proposed by contrarians like Lindzen) are not accurately representing changes in cloud cover, and are therefore biased. Climate models with higher sensitivity - in the 3 to 4.4°C ECS range for doubled CO2 - more accurately simulate the observational RH (relative humidity) data and thus the response of subtropical clouds to climate change.” (Fasulo & Trenberth 2012)*
- *(continued on next page)…*

Equilibrium Climate Sensitivity to a Doubling (to 560ppm) of Pre-Industrial Age Atmospheric CO2, from Past Warm Climate Periods (PALEOSENS collaboration, 2012 in *Nature*)



“If climate sensitivity is on the higher end of the likely range, it does not bode well for the future of the climate. As Fasullo told The Guardian, "our findings indicate that warming is likely to be on the high side of current projections."

In terms of warming over the 21st Century, we are currently on track with IPCC emissions scenario A2, which corresponds to about 4°C warming above pre-industrial levels by 2100 if ECS is around 3°C for doubled CO2.

Note that's the warming models expected by the year 2100, but at that point there will still be a global energy imbalance, and thus additional warming will remain 'in the pipeline' until the planet reaches a new equilibrium. An even higher ECS would correspond to even more warming, but anything greater than 4°C would almost certainly be catastrophic.”

But Won't CO2 "Fertilization" Sequester More Carbon, Looking on the Bright Side?

- **Port *et al.* (2012)** model effect on vegetation from predicted CO2 rises under RCP 8.5 Scenario
- They find fertilization due to rising CO2 causes boreal forests to spread north, deserts to slightly shrink.
- By including the rise in carbon sequestered by CO2-fertilized plants, the marginal reduction in greenhouse warming is 0.22 C
- **0.22C drop, however, is only a tiny dent in the net ~6 C rise in global temperatures**
- And new work in 2013 says this is probably far to optimistic, since it fails to include the effect of heating and drying on the soil microbes which fix nitrogen so it is available to plants… most plants are NITROGEN-LIMITED, not carbon-limited

There are a few Plant Species which are more Carbon-limited and will do very well in the Coming Earth…Like Poison Oak

From Port *et al.* 2012

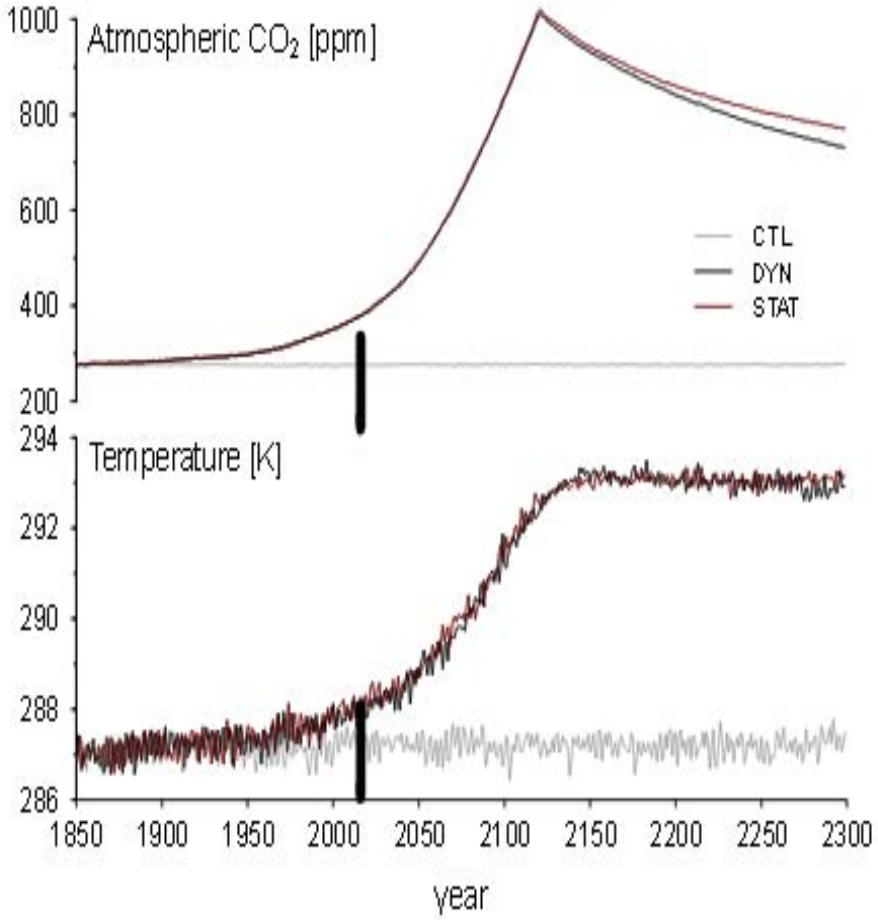


Fig. 2. Time series of annual mean atmospheric CO_2 concentration and global annual mean temperature in the CTL (grey line), the DYN (black line), and the STAT (red line) simulation.

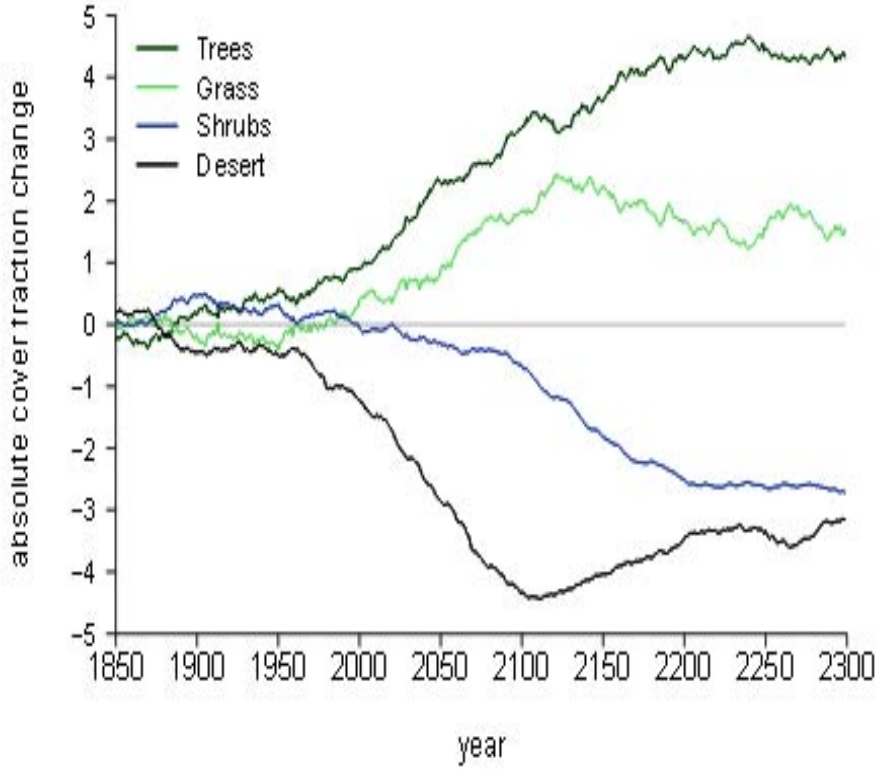
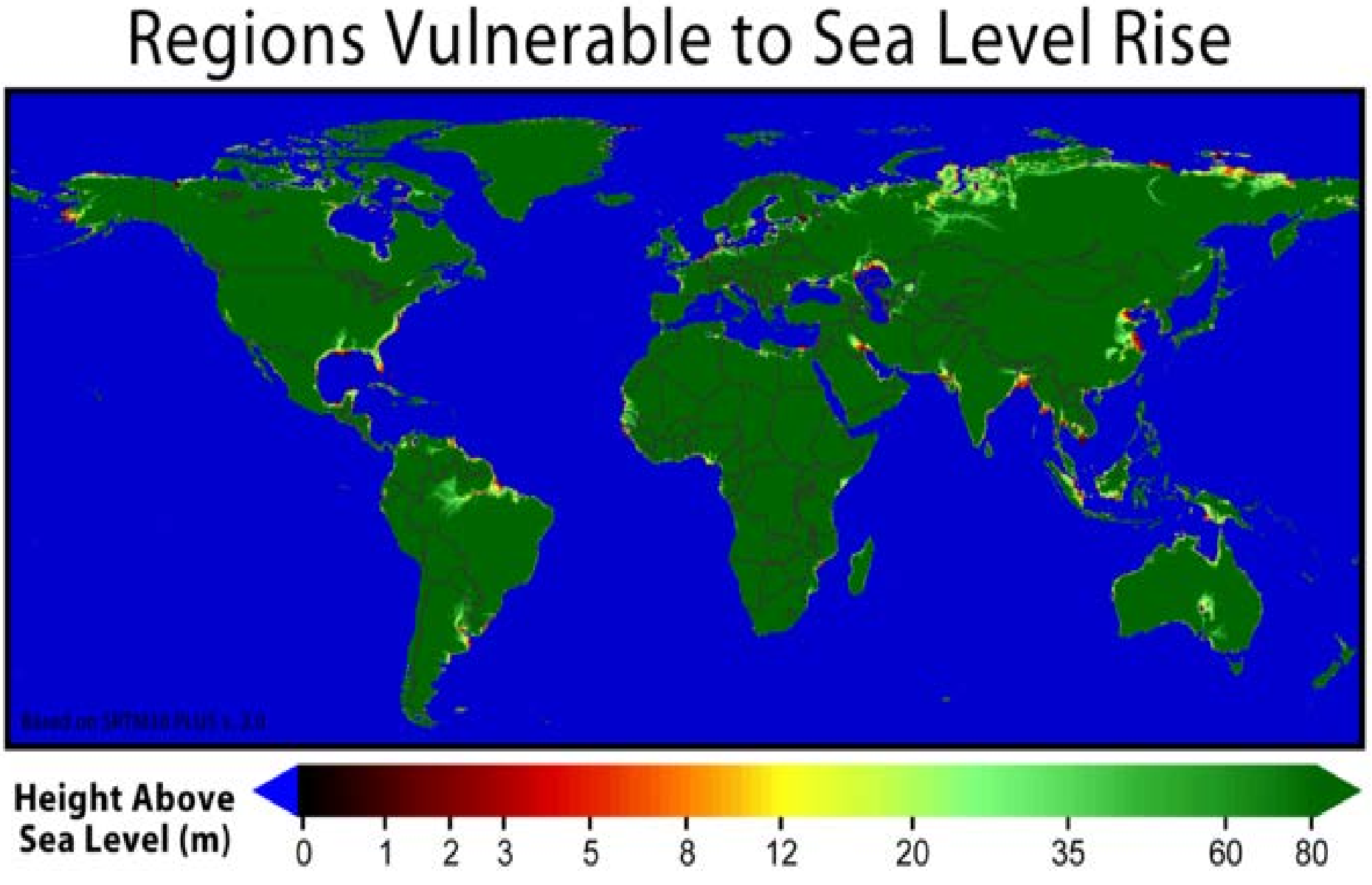
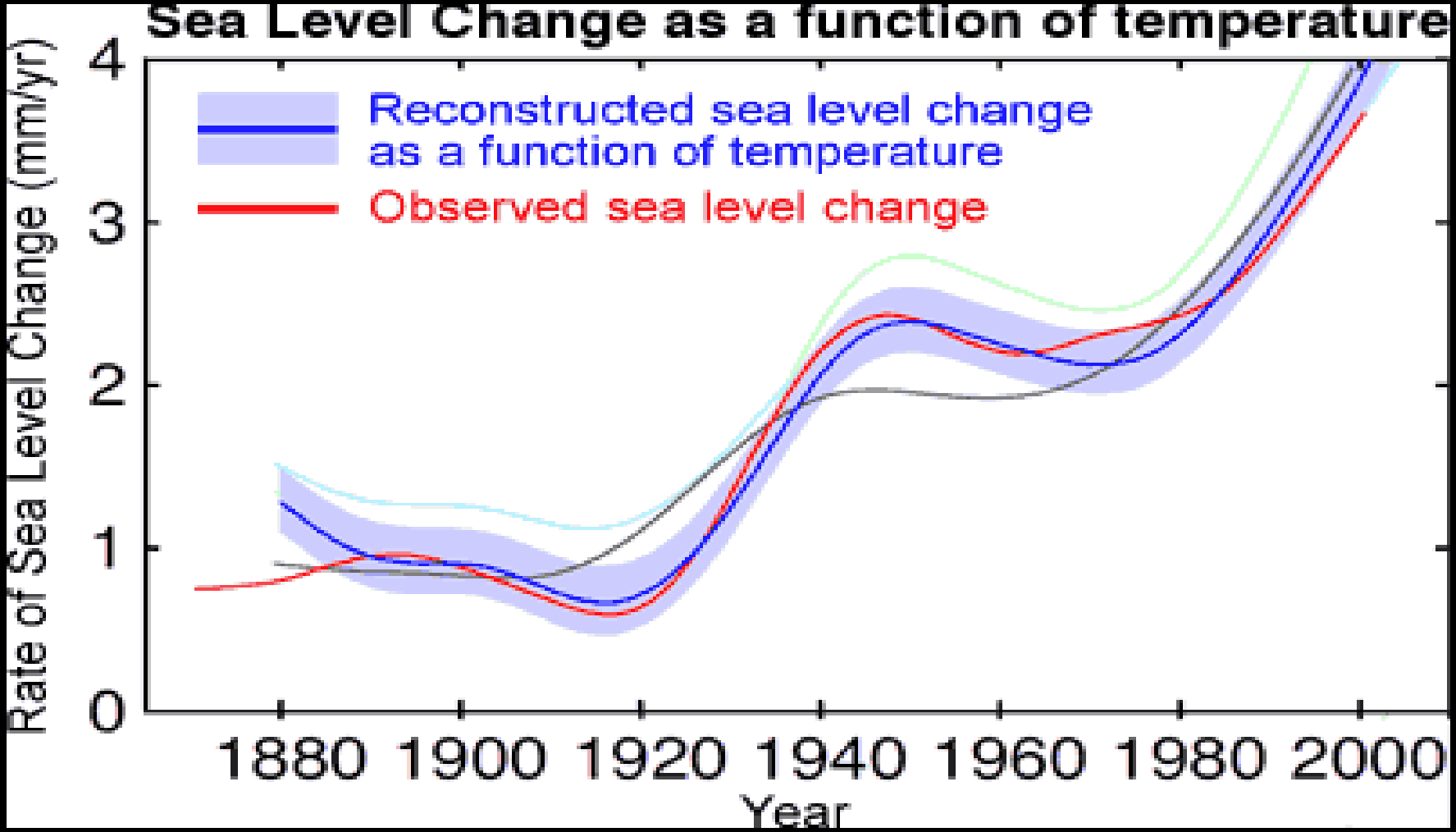


Fig. 3. Time series of changes in absolute global mean vegetation cover (DYN – CTL) in [%]. Forest includes tropical evergreen and deciduous trees as well as extra-tropical evergreen and deciduous trees. Shrubs contain cold and rain green shrubs and grass includes C_3 and C_4 grass.

2. Sea Level Rise

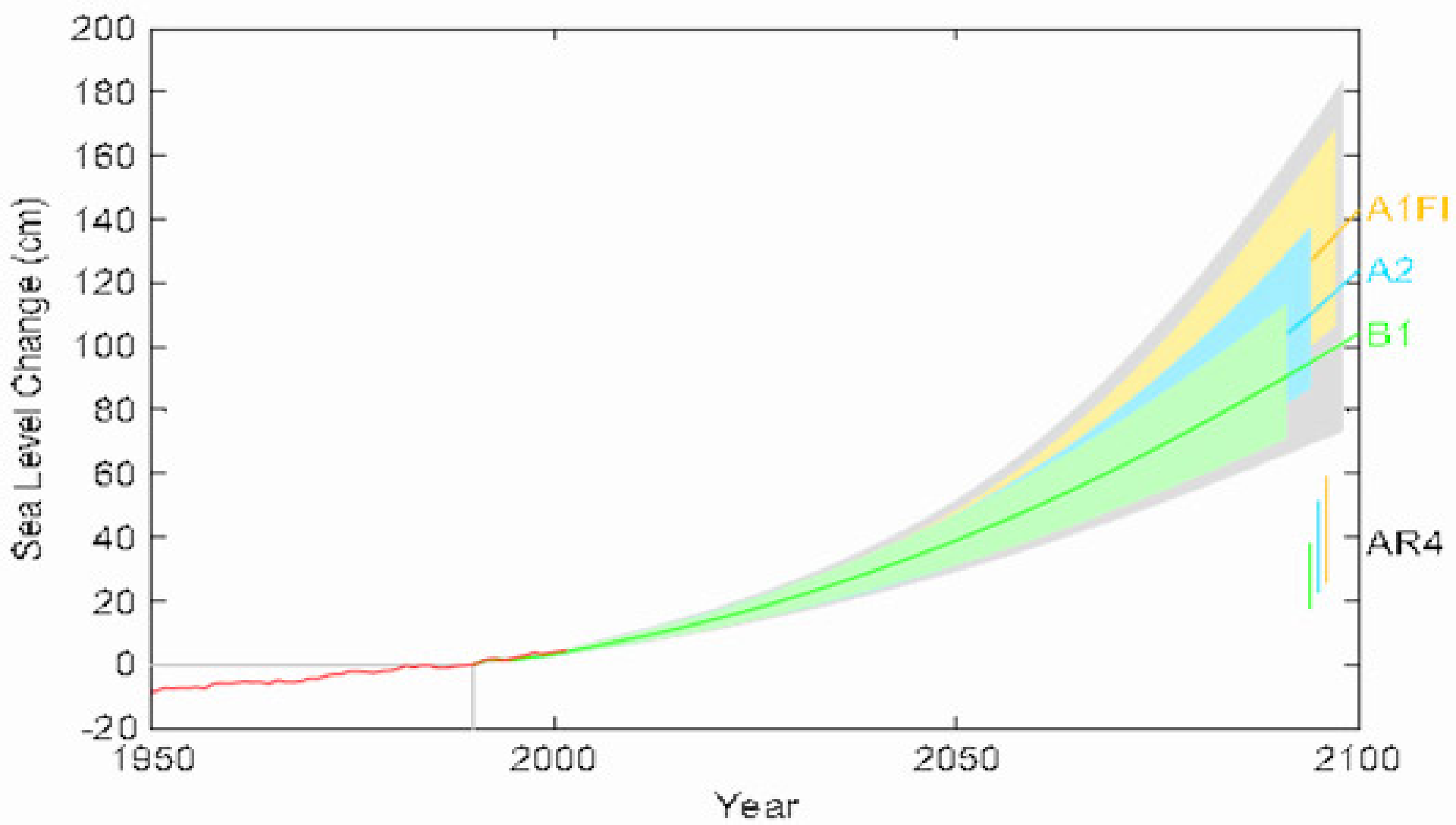


The Rate of Sea level Rise Itself continues to Accelerate as Land Ice Melting Accelerates



Observed rate of sea-level rise (red) compared with reconstructed sea level calculated from global temperature (dark blue with light blue uncertainty range). Grey line is reconstructed sea level from an earlier, simpler relationship between sea level and temperature (Vermeer 2009)

The IPCC AR4 2007 modelling of glaciers did not include the effect of meltwater on lubricating the glacier/bedrock interface. When real-world data is used to include this effect… sea level rise is much worse, and clearly is still accelerating in year 2100 (Vermeer and Ramstorff 2009). And latest (2013)



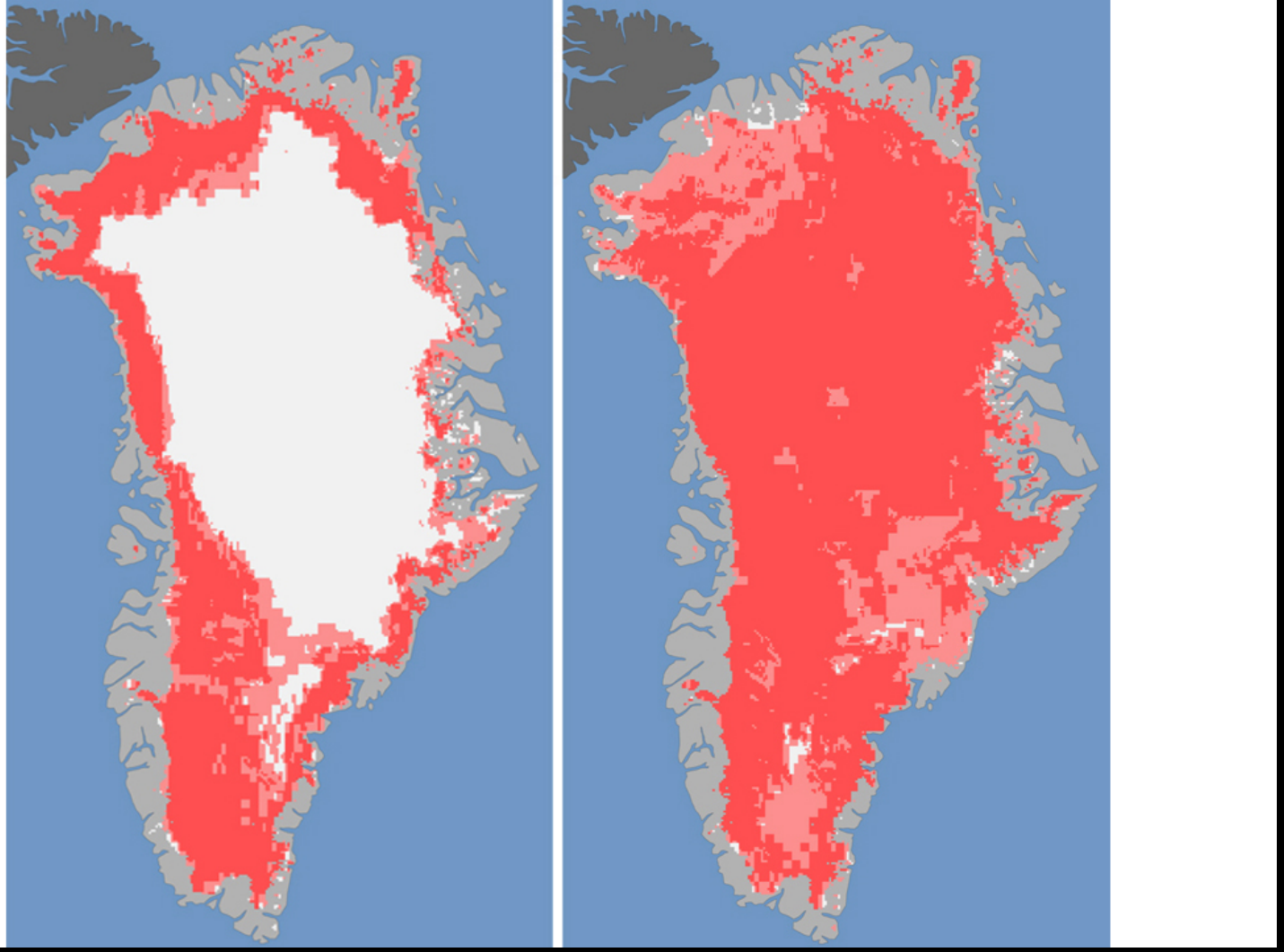
Eventually…. from Raymo *et al.* 2012

- *(from the paper's Abstract) - "… observations of Pleistocene shoreline features on the tectonically stable islands of Bermuda and the Bahamas have suggested that sea level about 400,000 years ago was more than 20 meters higher than it is today. Geochronologic and geomorphic evidence indicates that these features formed during interglacial marine isotope stage (MIS) 11, an unusually long interval of warmth during the Ice Ages*
- *"Here we show that the elevations of these features are corrected downwards by 10 meters when we account for post-glacial crustal subsidence of these sites over the course of the anomalously long interglacial.*
- *"On the basis of this correction, we estimate that eustatic* ***sea level rose to 6–13m*** *above the present-day value in the second half of MIS 11.*
- ***This suggests that both the Greenland Ice Sheet and the West Antarctic Ice Sheet collapsed during the protracted warm period while changes in the volume of the East Antarctic Ice Sheet were relatively minor, thereby resolving the long-standing controversy over the stability of the East Antarctic Ice Sheet during MIS 11."***

- **Given the permanence of the temperature change we are causing, it is likely, that a similar collapse of the Greenland and Antarctic ice sheets is also in our future.**

Summary of Raymo *et al.*

- During interglacial period MIS 11, oxygen-18 data shows global temperatures were ~identical to today's (**source; p 457**).
- Allowing temperatures to remain at today's levels may therefore lead to not just the loss of all permanent Arctic Ocean ice (which has now essentially already happened) but to the melting of all Arctic ice, leading to the large sea level rises seen by Raymo *et al.* in MIS 11.



In 2012 for the first time on record, Greenland had surface melting across its entire surface, even the colder, high altitude inland. It is projected that by next year the clean highly reflective new snow layers in summer will show much larger areas of older and darker (due to wildfire ash, pollution, etc) ice layers, markedly reducing its reflectivity and hence absorbing sunlight with consequent higher melting rate. See **Box *et al.* 2012** for the declining albedo of the Greenland ice cap. If/When Greenland melts entirely, it alone will contribute 7m to global sea level.

Maybe a New Ice Age Will Come to the Rescue?

No

- For the past 8,000 years, the Milankovitch forcing of insolation at the Arctic Circle has been declining. So far during human history we've gotten away, somewhat, with dominating the planet because of this Ice Age controlling offset.

- That period is now over. We are at a local minimum in both summer and annual solar heating at the Arctic Circle. From now on, for ~30,000 years, we have a net warming direction

Milankovitch insolation (middle graph) predicts stable Northern Hemisphere (NH) ice volume (dotted) at pre-industrial 210 ppm CO2. If instead we continue raising CO2 to ~double present values, all NH ice disappears for about 10,000 years until any Milankovitch cooling begins again Source, p. 459 and Milankovich insolation will not be lower than today for over 50,000 years.

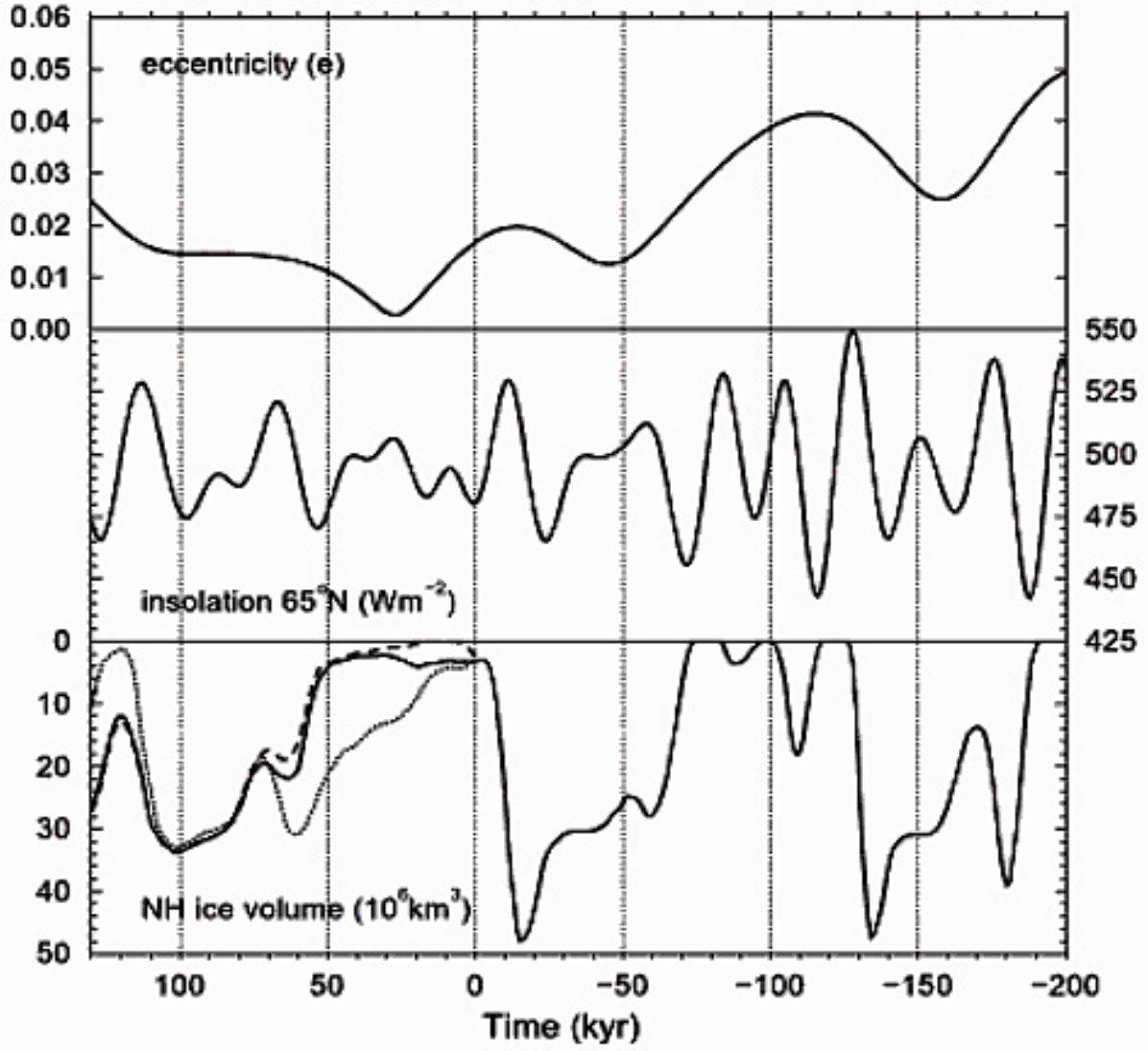
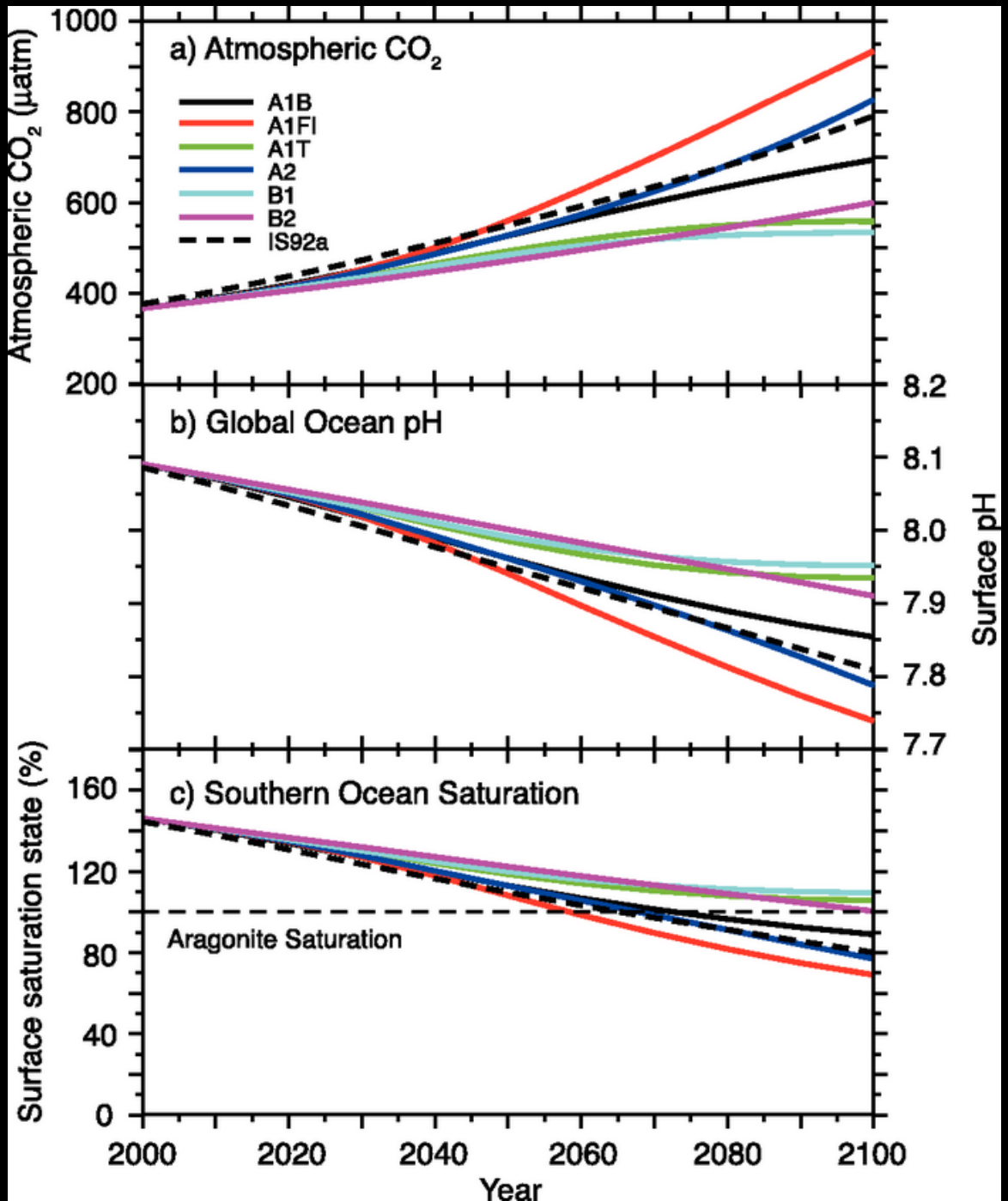


FIGURE 15.16 Long-term variations over the period from 200 ka BP to 130 ka AP of eccentricity (e), June insolation at 65°N (Wm^{-2}) (Berger, 1978), and NH ice volume (10^6 km^3) (Berger and Loutre, 2002). In the panel Ice Volume: the solid line is the ice volume simulated by using the Vostok CO_2 concentration for the past (Petit et al., 1999) and a scenario reproducing the last 120 ka for the future; the dotted line gives the future ice volume if the future CO_2 would remain constant and equal to 210 ppmv; the dashed line is for the future ice volume under a scenario where the CO_2 concentration would reach 750 ppmv within the next two centuries and return to the 'natural Vostok level' 1000 years later.

3. Ocean Acidification



- **IPCC AR4 (2007). Ocean pH *vs.* Emission scenarios**

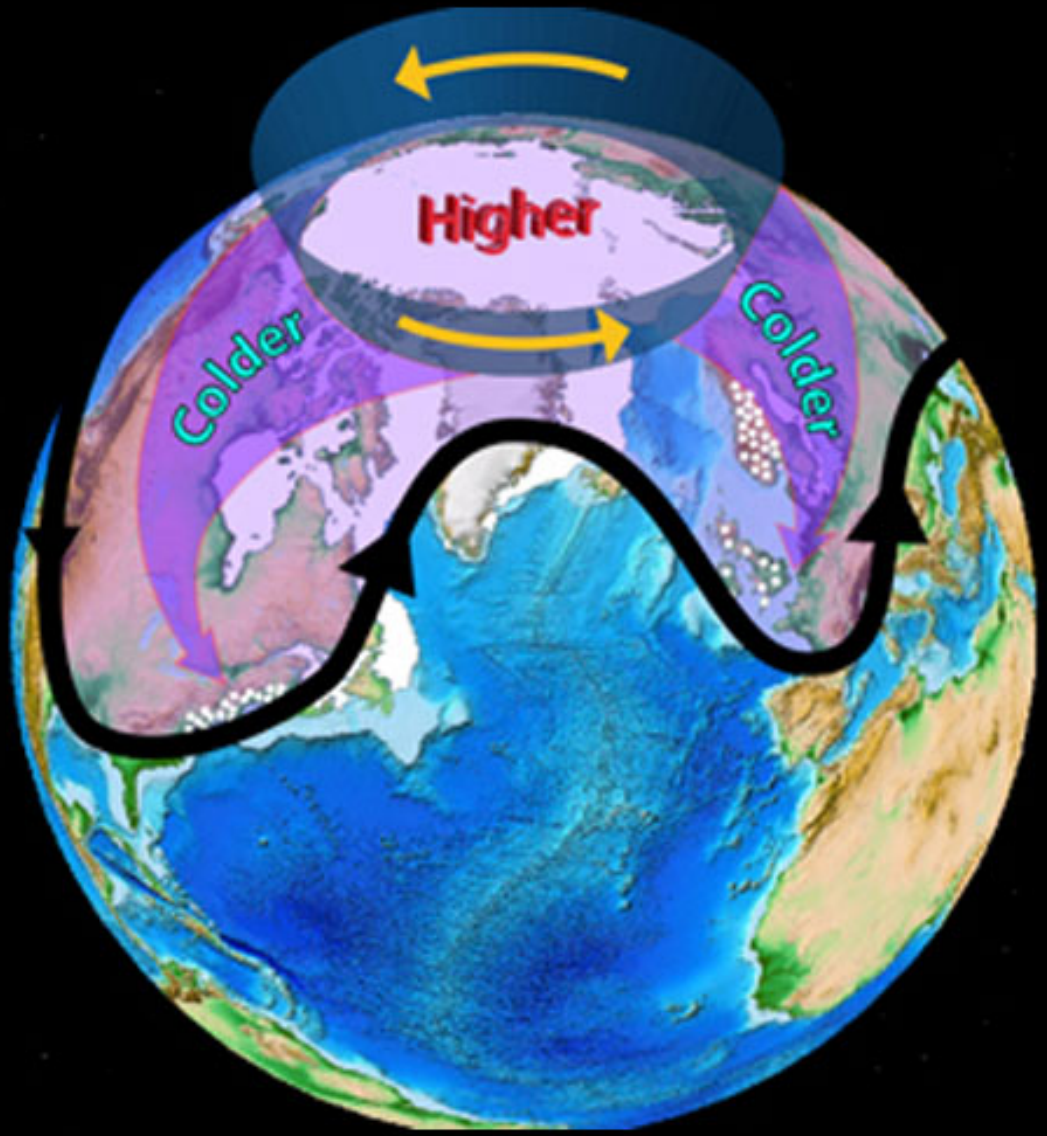
- Below the Aragonite saturation limit, ~most calcarious species disappear (a few, e.g. clams, build with calcite, which survives to more acidic levels)

21st Century Ocean Acidification

- Even using the overly conservative **2007 IPCC scenarios outcomes using overly conservative modellings**, by mid century the oceans will be too acidic for the survival of coral reefs, and they will disappear
- Coral reefs to dissolve when CO2 doubles from pre-industrial levels (**Silverman *et.al.* 2009**)
- **Shellfish reproductive failures** due to acidification have already arrived.
- At higher levels, the **entire food web of the ocean is endangered**, as many species of microbes, plants, and animals use calcium carbonate exoskeletons which cannot be made in too-acidic oceans
- **Loss of calcarious marine life also means drastically reduced ability to fix CO2 into CaCO3 and remove it from the biosphere and atmosphere in during the ocean conveyor.**
- **Already, primary productivity in the oceans has dropped 40%**

4. More Severe Weather

- Melting Arctic Ocean ice -> darker surface -> more solar radiation absorbed -> excess heat released especially in Autumn
- This decreases the temperature gradient and pressure gradient across the jet stream boundary separating the Polar Cell from the Ferrel Cell of mid latitudes
- This means SLOWER moving storms which can park over atypical places, more frequent “blocking patterns”.
- More severe droughts, and more severe storms when they do happen



Negative Arctic Oscillation conditions are associated with higher pressure in the Arctic and a weakened polar vortex (yellow arrows). A weakened jet stream (black arrows) is characterized by larger-amplitude meanders in its trajectory and a reduction in the wave speed of those meanders.

The Good News – More Rain! The Bad News – It's All Over the Poles and Oceans

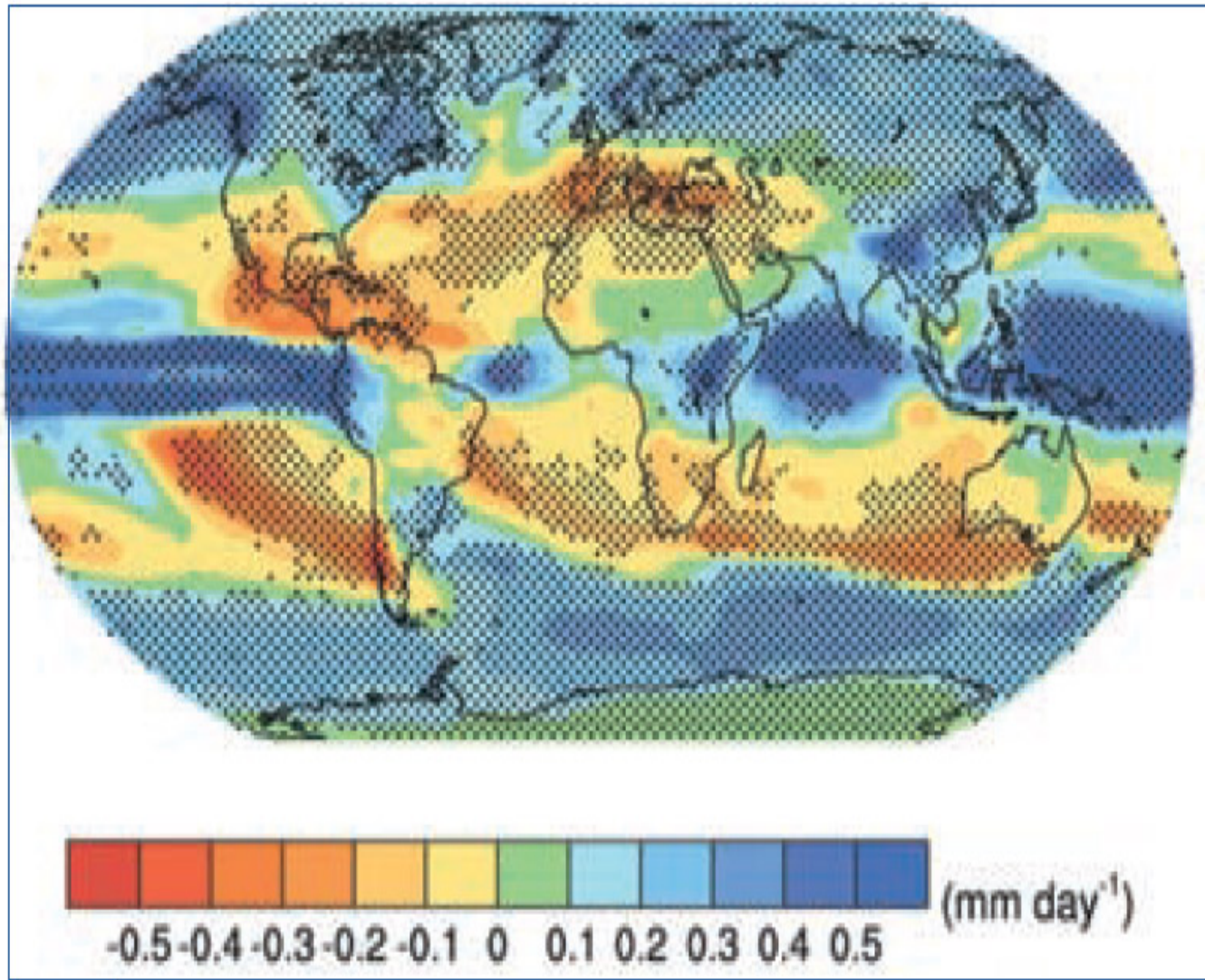
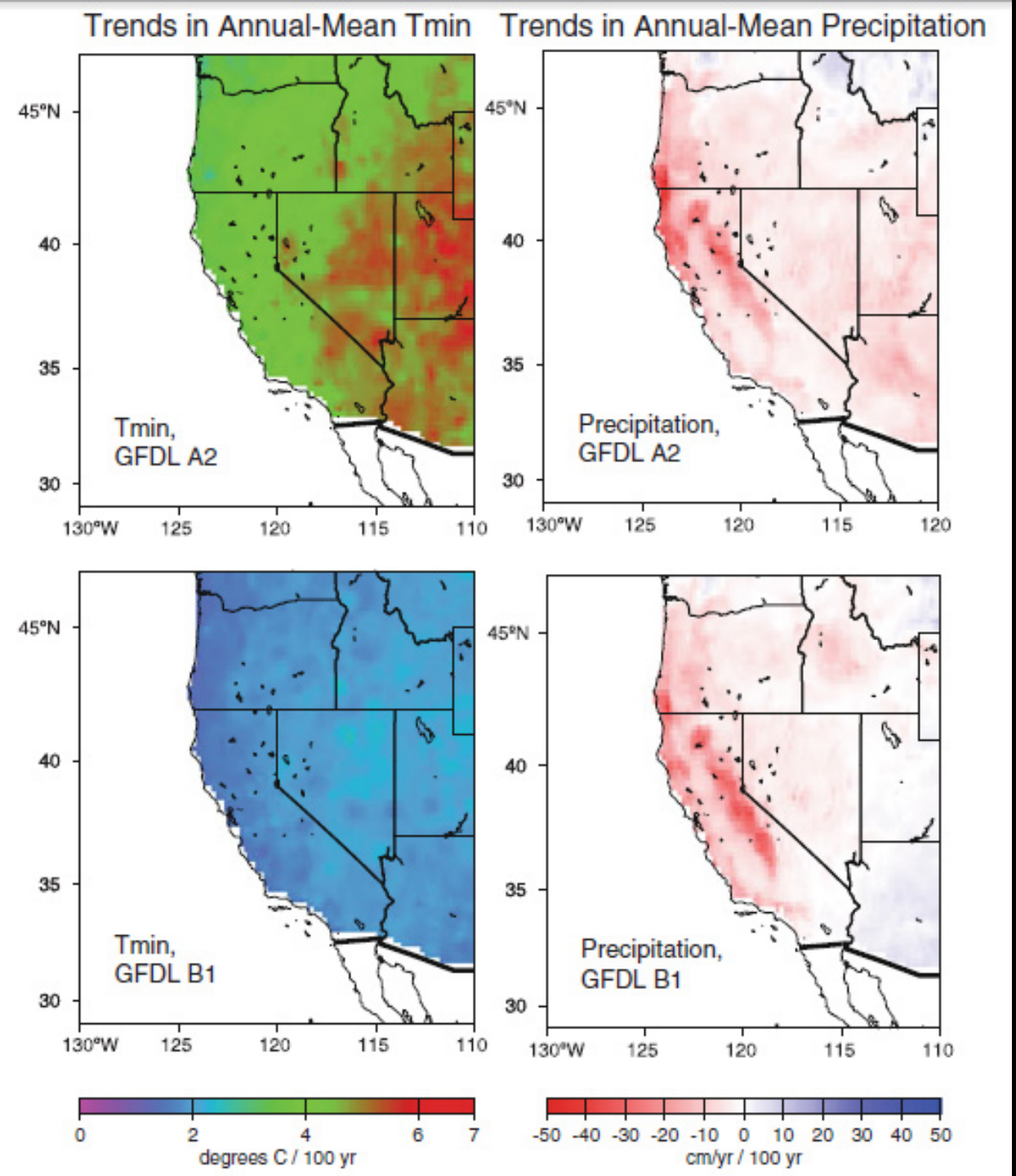
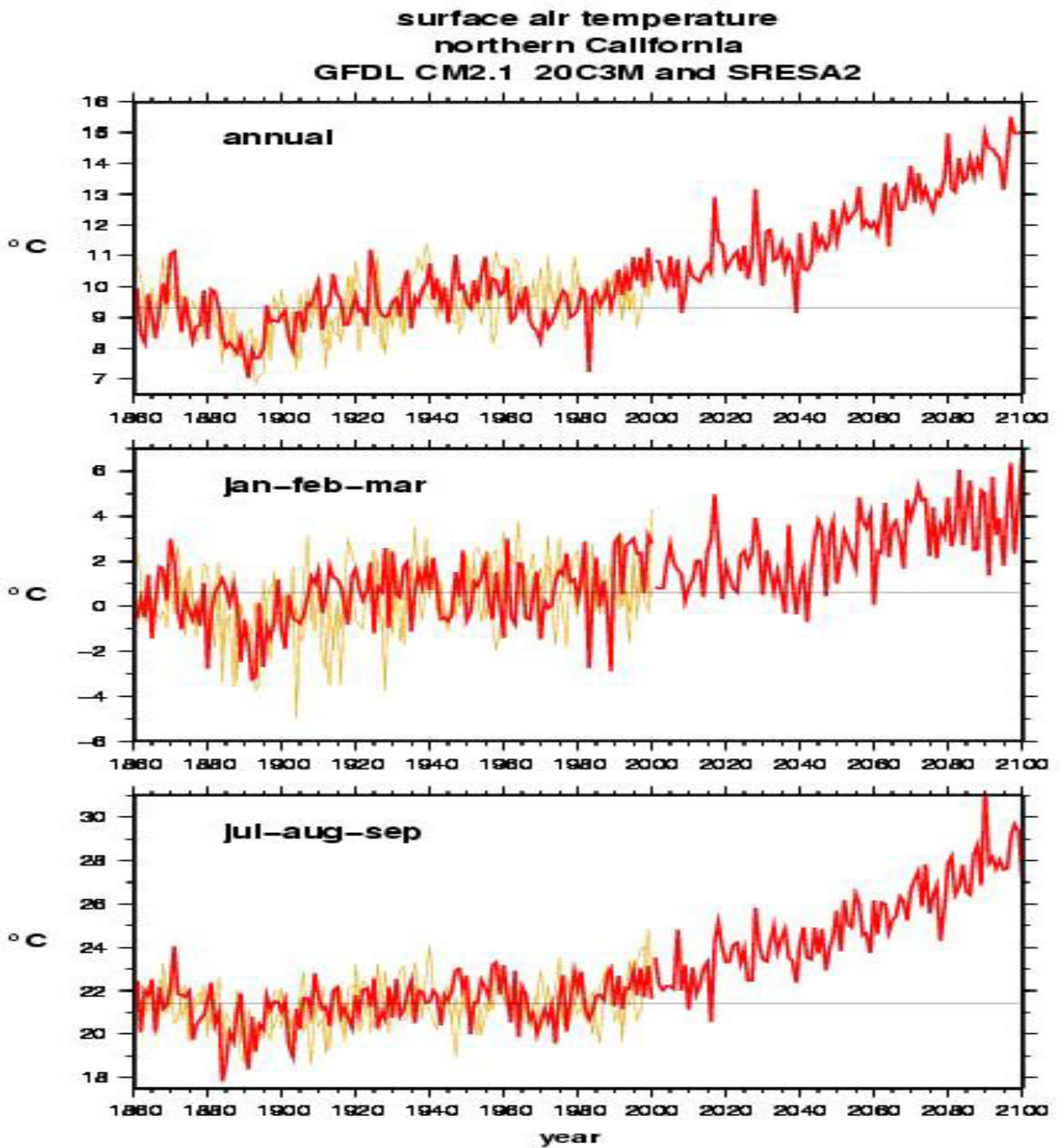


Figure 11: By 2099, precipitation is expected to increase in the Arctic and decrease in temperate zones based on this multi-model mean from the IPCC Fourth Assessment Report. The units are millimeters per day and the changes are annual means for the A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. Stippled areas indicate where at least eight out of ten models agree *(IPCC 2007, Figure 10.12)*.

Regional Climate Forecasts: California and the Bay Area…

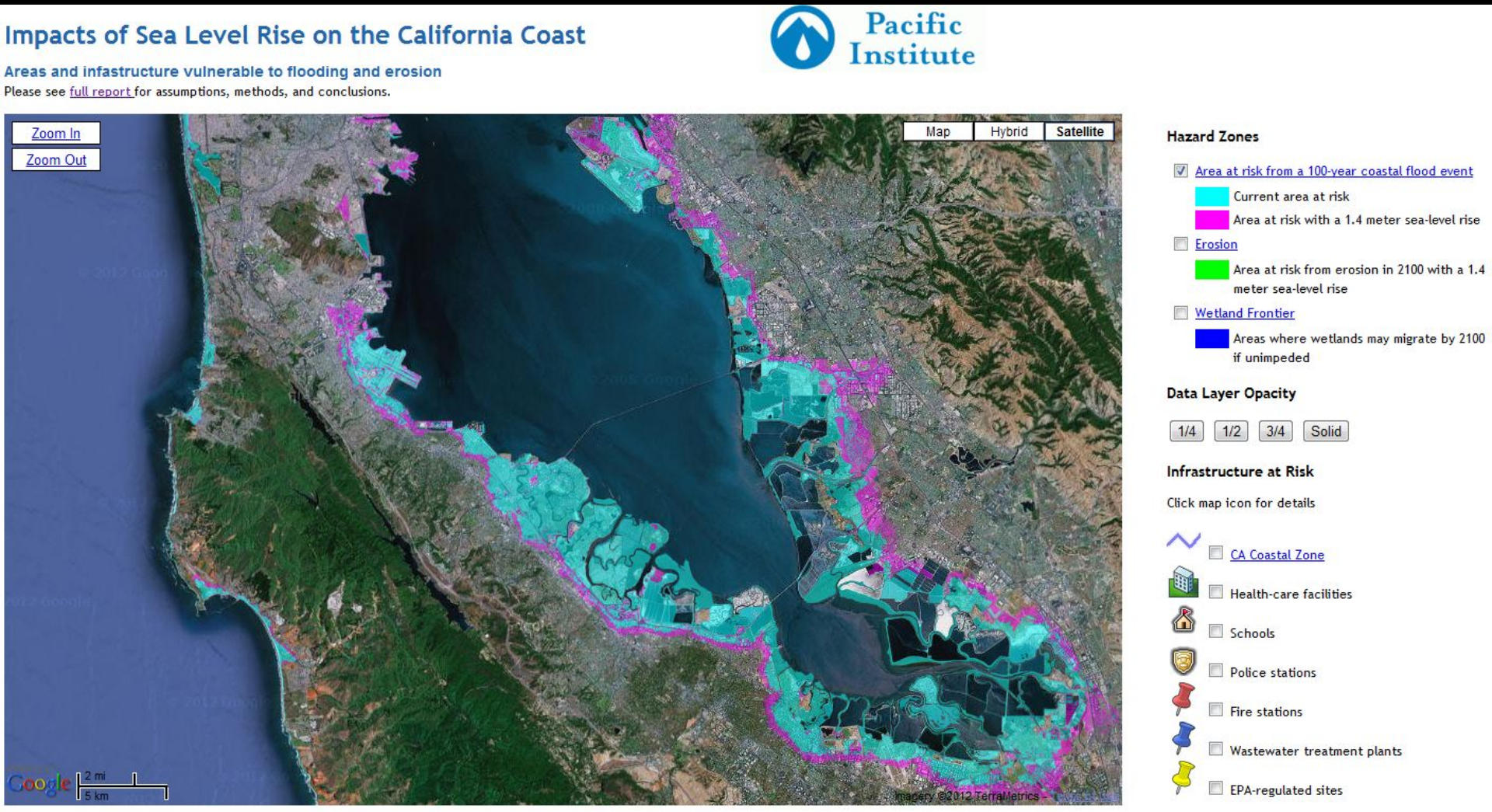


- **Top two panels – A2 Scenario.** Night temps rise by 3-5C near coast, and 5-7C in desert inland. Drought areas focus on Northern California; 30-40cm/yr loss by 2100 in coastal mtns and Sierra. **Bottom two panels – B1 Scenario.** Night temps rise only 1-2C, drought still severe in Sierra, less so in northern coastal mountains vs. A2 scenario
- (Dettinger 2011)



- **IPCC Climate Scenario A2 – Predictions for Us, in Northern California.** Annual mean, and broken up into winter, and summer months. Summer temps rise 8C from early 20th Century (!), and more than winter temps

Bay Area Sea Level Rise. Purple is 1.4m rise prediction, which is quite likely too conservative

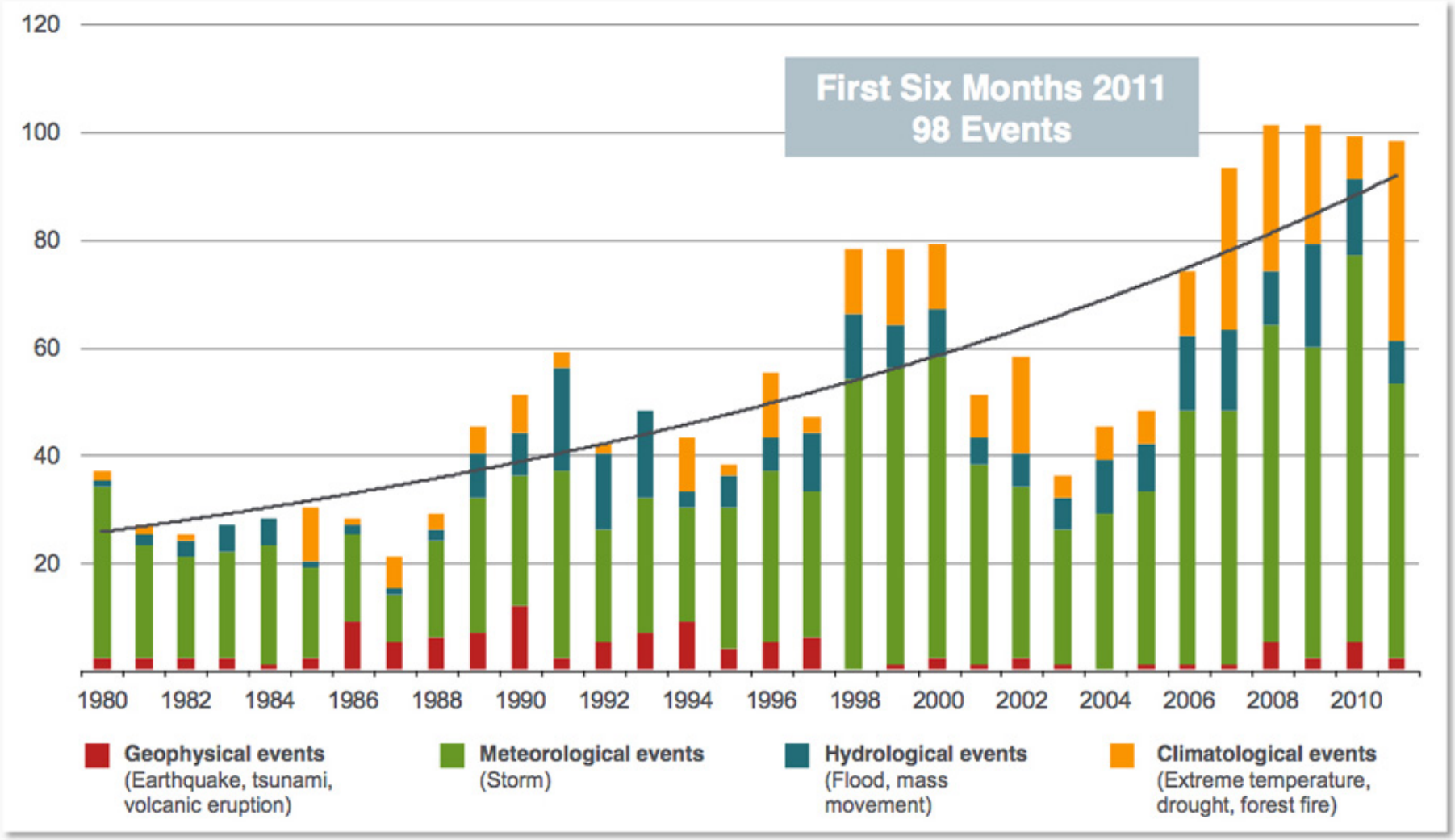


U.S. Natural Catastrophe Update

Natural Disasters in the United States, 1980 – 2011

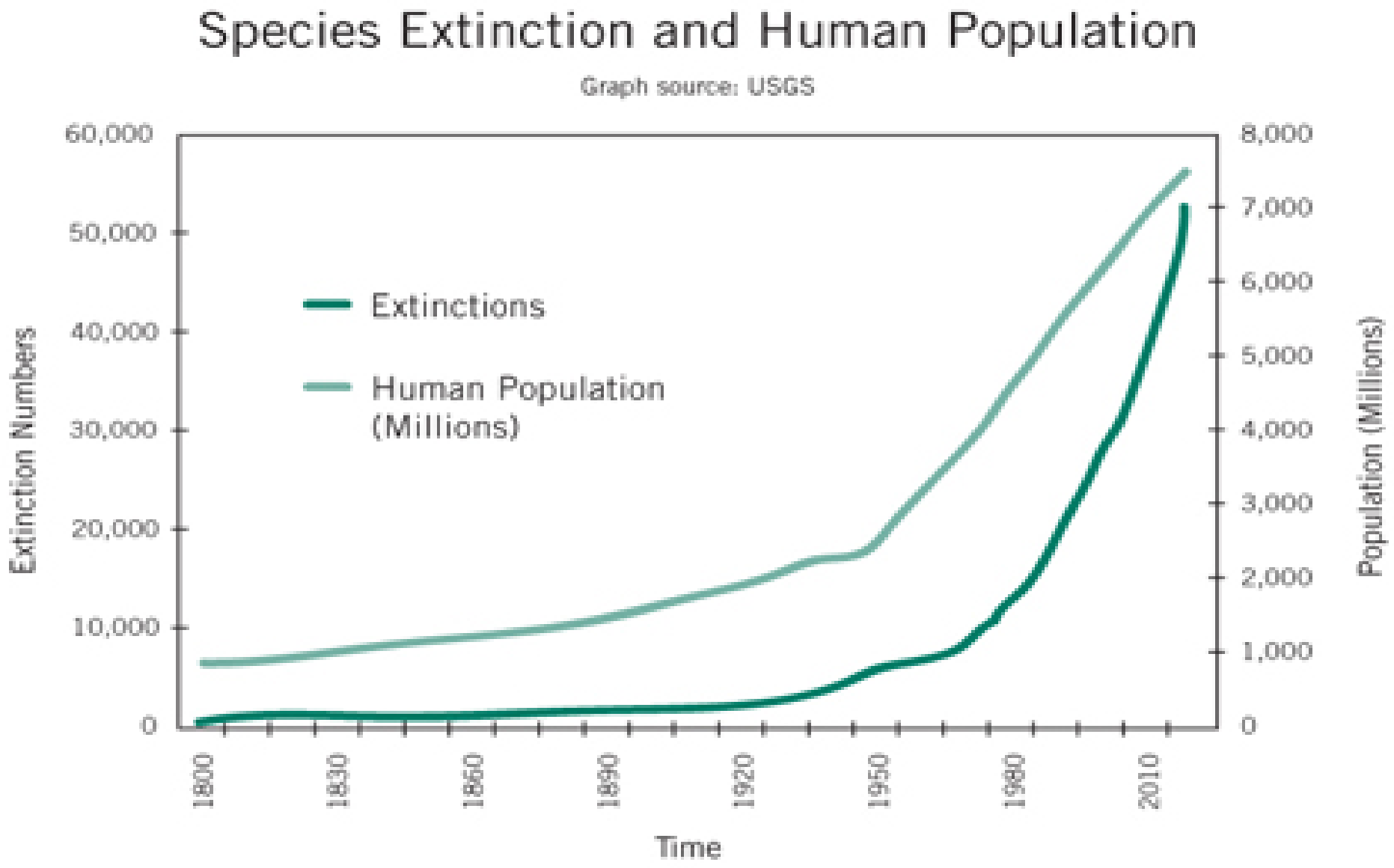
Number of Events (January – June Only)

Munich RE

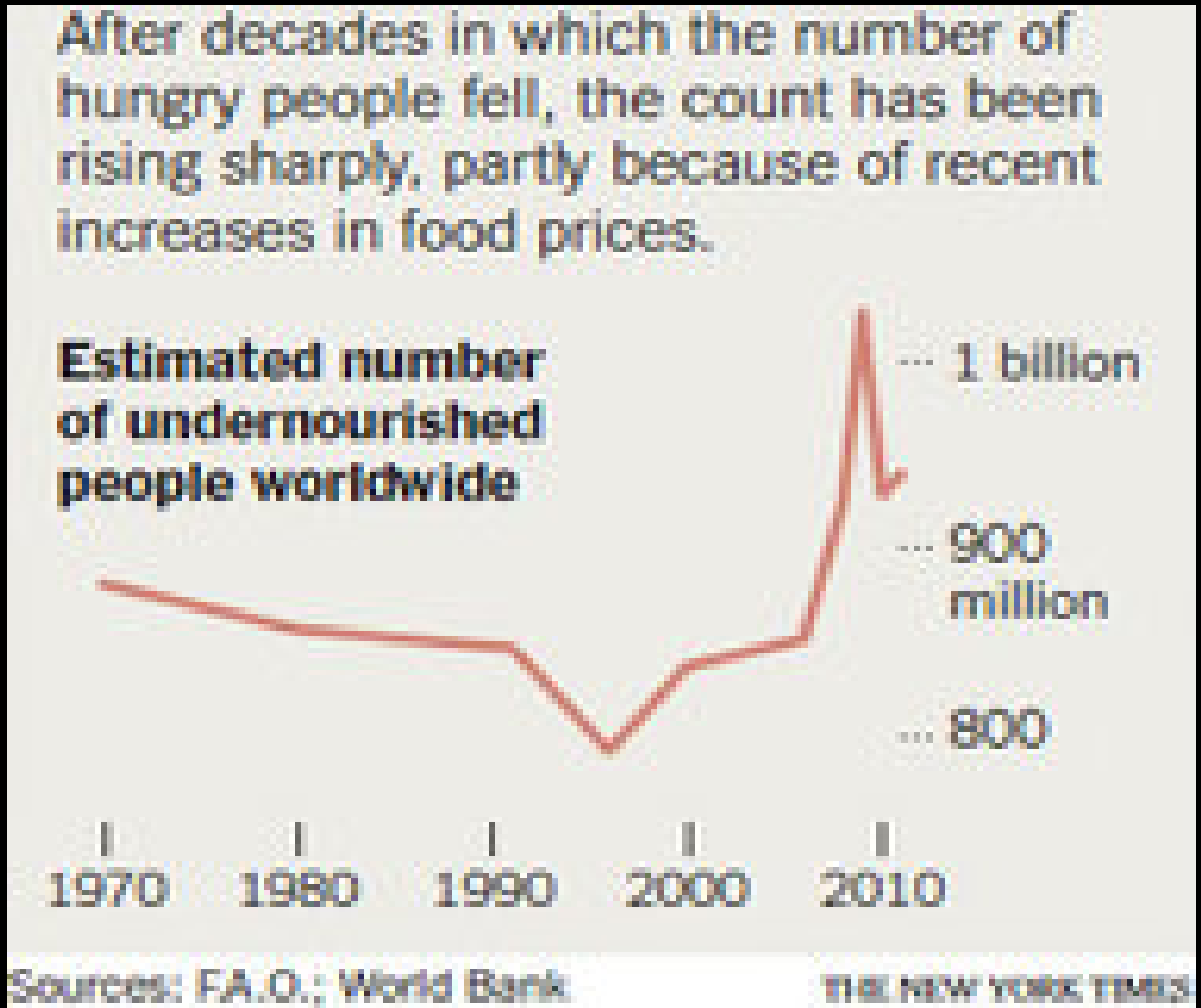


Source: MR NatCat*SERVICE*

Entering the Anthropocene Epoch. Are We Being Welcomed By Our Fellow Species?



Inevitable rising food prices devastate poorer countries, leading to riots and revolutions. We should expect the trend to accelerate as soils deplete



This is all BAD. But, could it be Infinitely Worse Still?

- The ultimate in bad outcomes would be a "Runaway Greenhouse Effect".
- The Runaway Greenhouse would look something like this: We continue adding CO2 to atmosphere, with positive feedback from water vapor, and the steamy climate is further accelerated by increased cirrus clouds, methane release in large quantities, followed by destabilized methane hydrates from the melting Arctic continental shelf, and temperatures accelerate until the oceans boil away, raising water-vapor induced greenhouse warming to maximum extent possible. Water vapor is dissociated by solar UV and water disappears from our planet.
- Venus suffered this fate
- **Runaway Greenhouse means: Extinction of all life on Earth**
- **Do we run this risk?**

Probably Not For a Long Time. But…

- "If we burn all reserves of oil, gas, and coal, there's a substantial chance that we will initiate the Runaway Greenhouse. If we also burn the tar sands and tar shale, I believe the Venus syndrome is a dead certainty." James Hansen, NASA Climatologist (2010); see MIT Review here.
- Goldblatt and Watson (2012) find this is unlikely, but with an important caveat –
- - We do not know how positive are the feedbacks from clouds when temperatures rise substantially. They find it is unlikely, but within possibility that we could trigger a Runaway Greenhouse with continued CO2 release.

Maybe extremely powerful computers later this century will show us how to have our cake and eat it too, so we don’t have to ding our lifestyles?

Or… Maybe Not…

- Note that China, rapidly rising to be the most dominant country on Earth, already has deployed their computerized system of 20 million spy cameras, which they unashamedly call **“Skynet”**
- Except, their air pollution is so bad Skynet is having a hard time seeing through it.
- They COULD try and reduce the 1 new coal power plant per week pace of fossil fuel use… but instead:
- Their solution? Alter Skynet’s wavelength sensitivities to allow it to still monitor and spot dissidents (marked now for “termination” in the “black jails”) effectively.

Strategies

- …Are few so far
- 1. GeoEngineering – Earth Shading. Drop sunlight by 1.7% compensates for 2 C temp rise which would otherwise occur. LARGE
- Largest NEO (Ganymed) could provide enough dust to compensate for the worst(?) case 11F temp rise of 21st century

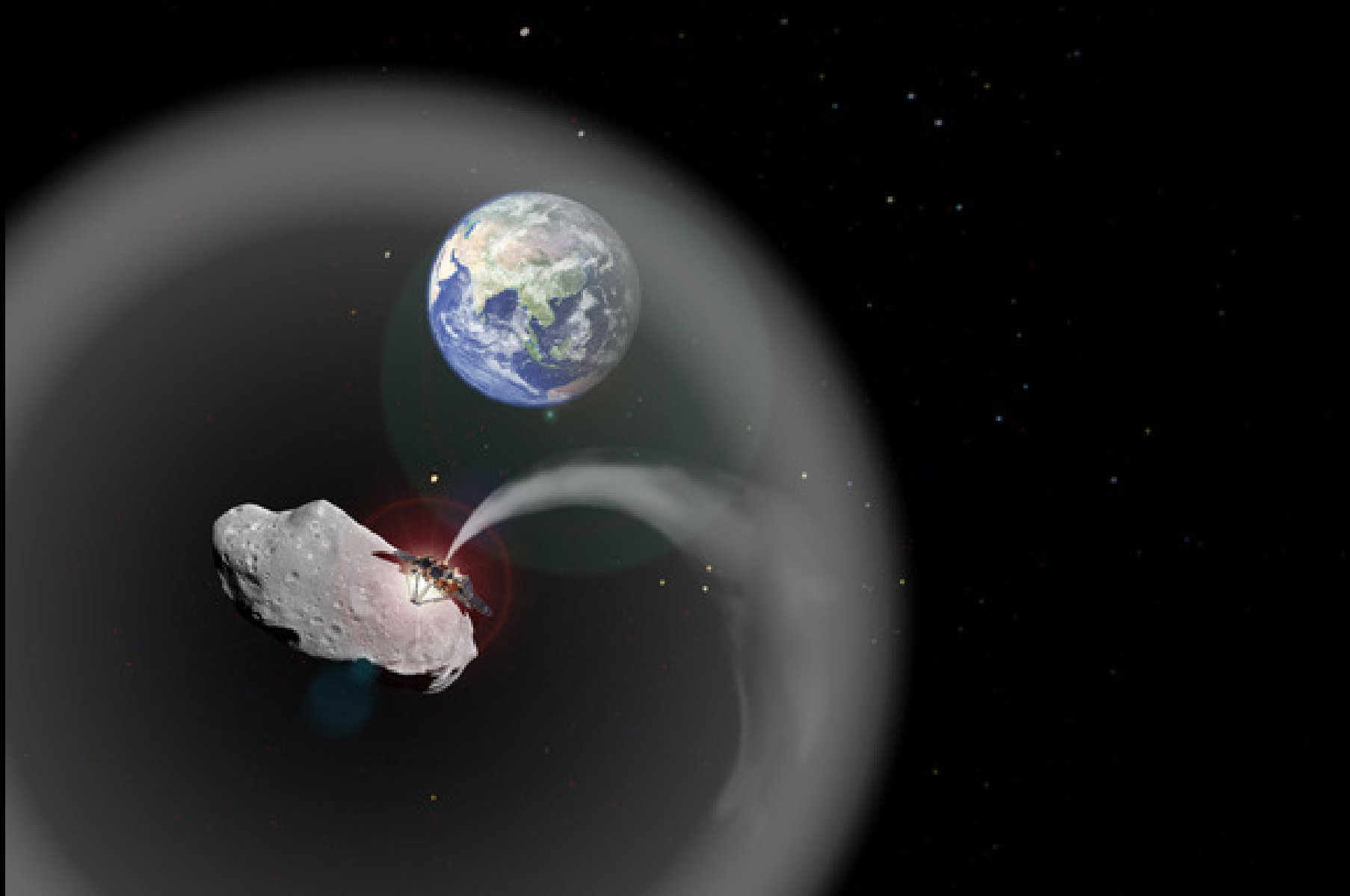
-- very difficult to move and then halt an asteroid to this location. Ganymed too large to move, according to private industry studies

-- and what if we screw up?

-- sunshading will also lower wavelengths needed for photosynthesis and carbon sequestration

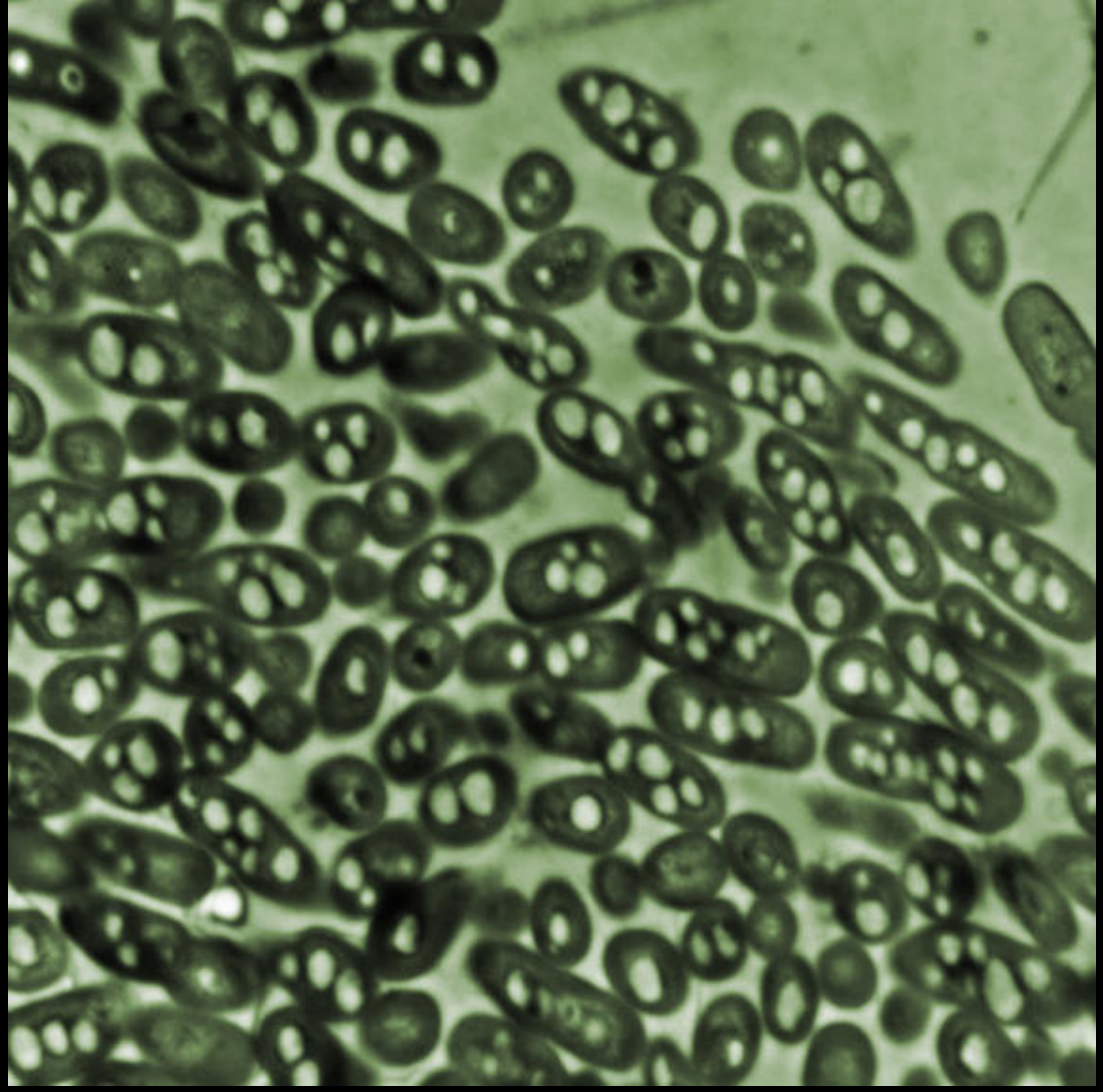
-- won't help with ocean acidification, which is potentially the most serious of all consequences of CO2 pollution

Move one or more asteroids to the L1 Lagrangian point between us and Sun, and sputter dust off of it to attenuate sunlight



Alternative Fuels?

- Make little sense. Photosynthesis is very inefficient, and competes with food production.
- Studies show corn ethanol is actually adding to our CO2 emissions, when the full accounting is done.
- It seems mainly to be a politically motivated favor to farmers



Bioengineered bacteria produce isobutanol (gasoline)

-- can they be engineered to use CO_2 for this?

-- can it be scaled up to industrial size production?

-- carbon-neutral, at best, but might be worth doing

Corn-based Fuels Make No Sense

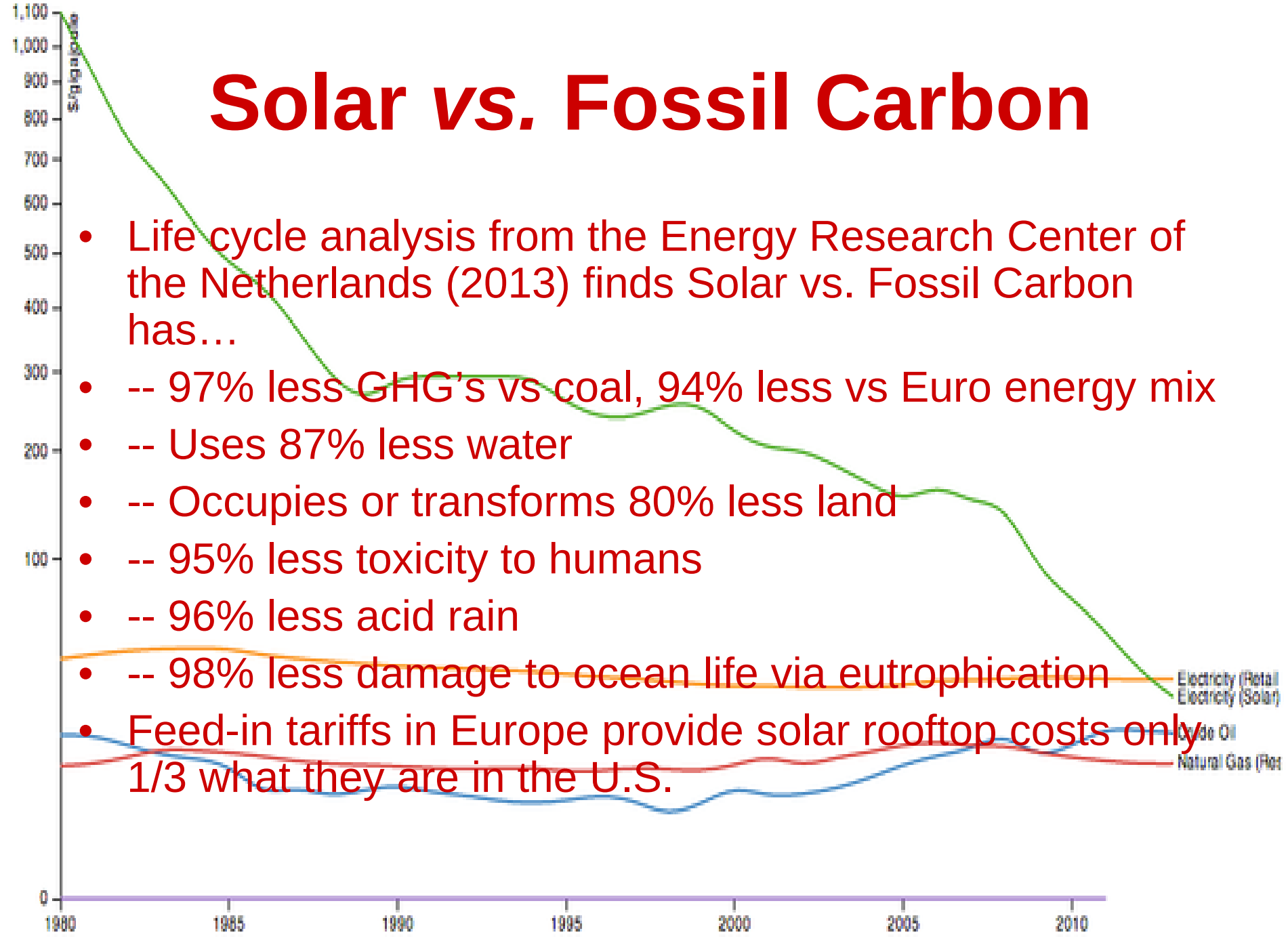
--- Corn-based biofuels consume 30% more energy in growth/manufacture than they give. Other problems:
--- Commandeer valuable farmland which will need to go to food
--- Vast acreage of tropical forests are cleared to produce sugar cane, palm oil, and cereal grains destined for ethanol. Clearing tropical forests adds both heat and CO2 to the atmosphere
--- Biofuels leave soils poorer, are supplemented with artificial fertilizers, which add nitrous oxide (another GHG) and other pollutants to the atmosphere in their manufacture, and are heavy water users.
--- They nevertheless are being pursued, incentivized by lobbied-for government subsidies for growers.
--- Accounting for carbon flows is deeply flawed on the part of the proponents of corn and sugar ethanol biofuels. This strategy is not carbon neutral

Solar PhotoVoltaics - Good…

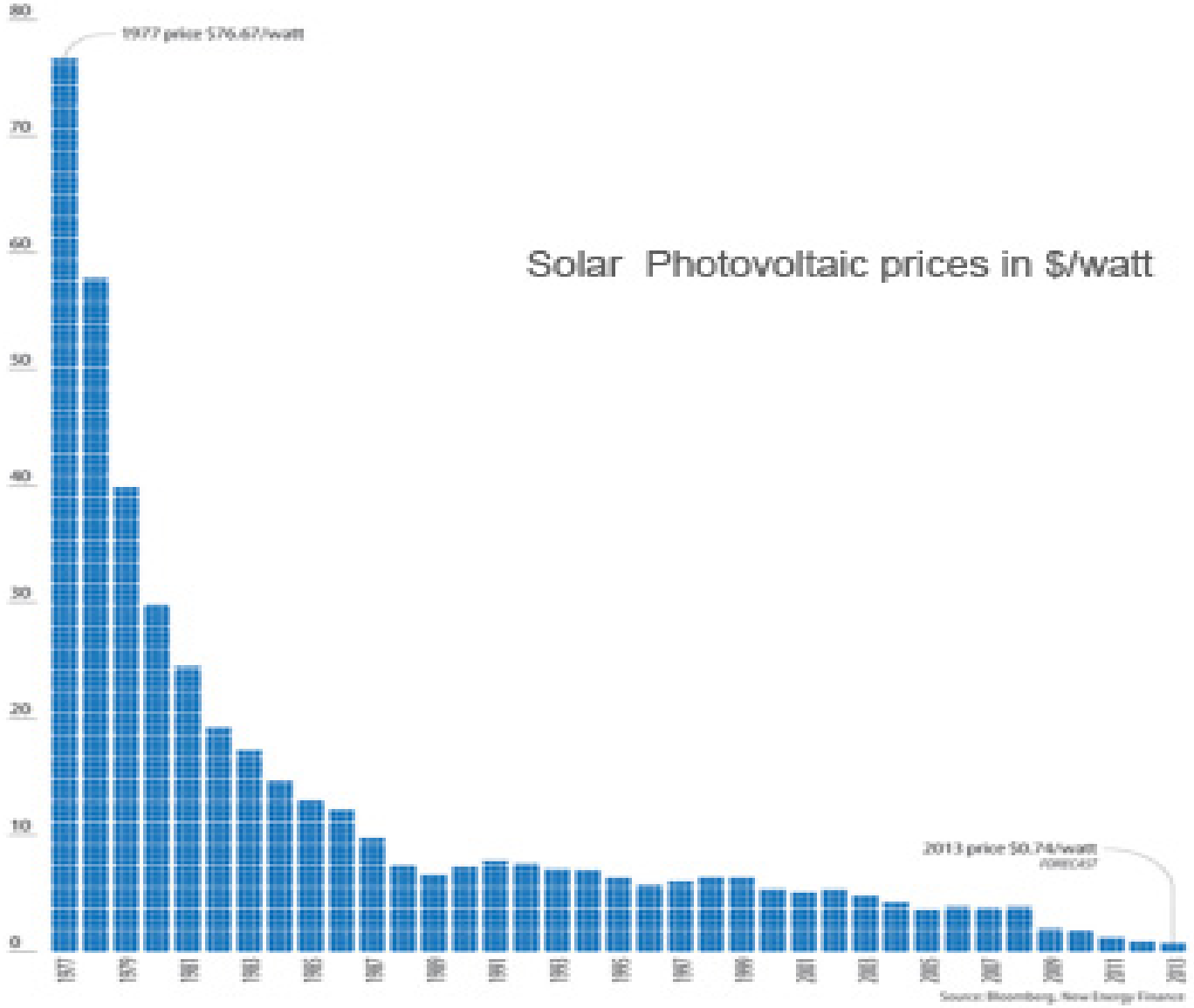
- Some of Solar PV's advantages:
- --- rapidly getting cheaper
- --- carbon nanotube-based solar may provide improved power/cost ratios
- --- rooftop panels allow distributed systems "off the grid" and therefore
- *** provide no easy targets with respect to national security
- *** allow energy independence and are the ultimate in "local", motivating their care by owners
- --- few if any moving parts to break, only occasional further investment (batteries mainly) once purchased
- --- in warm climates, rooftop systems also lower heat load to structures, lowering air conditioning costs. As the Earth warms, more and more of us will be in "warm climates"

Solar *vs.* Fossil Carbon

- Life cycle analysis from the Energy Research Center of the Netherlands (2013) finds Solar vs. Fossil Carbon has…
- -- 97% less GHG's vs coal, 94% less vs Euro energy mix
- -- Uses 87% less water
- -- Occupies or transforms 80% less land
- -- 95% less toxicity to humans
- -- 96% less acid rain
- -- 98% less damage to ocean life via eutrophication
- Feed-in tariffs in Europe provide solar rooftop costs only 1/3 what they are in the U.S.



Solar PV price/watt 1977-2011

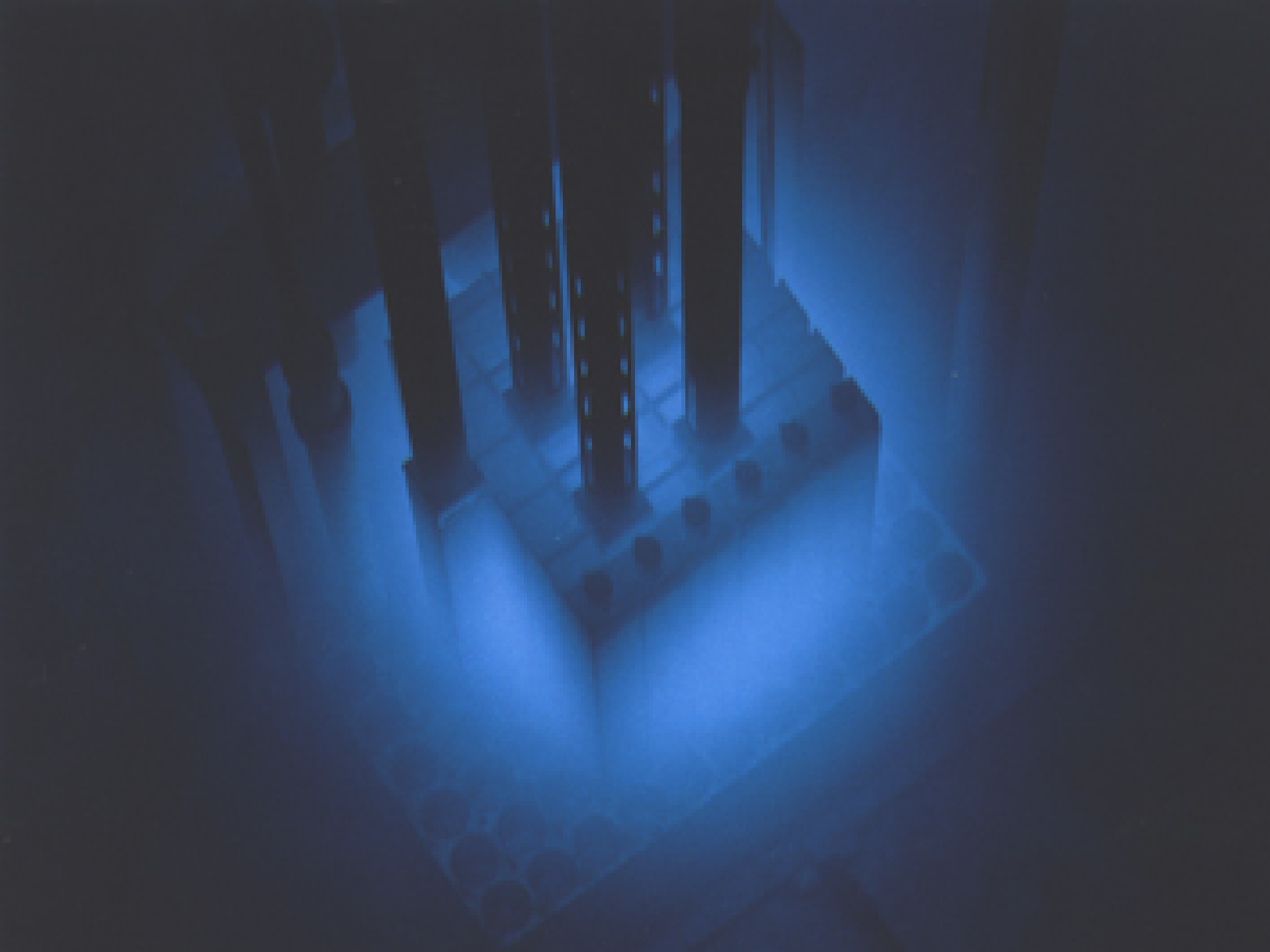


Solar, and Transportation both Require Better Battery Technology

- A recent (**Duduta *et al.* 2011**) **breakthrough in battery technology made at MIT** is a hopeful sign. If it works as hoped, it may double the energy density of current batteries, and also make possible the ability to "fuel up" at the pump with an oil-like rechargable electrolyte much like we do with gasoline cars at the moment. Read about it **here.**
- A new **all-liquid-metal battery** technology is also promising very high storage densities at relatively low cost.

The Nuclear Option

- Nuclear reactors, to describe, are just steam engines that use something other than wood or coal to stoke the boiler. They use the heat generated by nuclear fission reactions of certain heavy elements.
- Nuclear has some advantages:
- --- it’s “always on”, unlike solar
- --- its carbon emissions are minimal (even including mining the uranium or thorium currently)
- --- it’s very energy dense and can supply a lot of power in a small area, so is intriguing for use in technologies for pulling CO2 out of the atmosphere.



Nuclear – the Disadvantages

- All reactors are necessarily big and very expensive. No car-sized "Mr. Fusion" is on anyone's horizon
- Safety - When they go wrong, they can go VERY wrong. Remember, in the real world, bad engineers get jobs too.
- They were economically viable only when the government stepped in to insure them. Are they economically viable when they must be privately insured? Any libertarian wanting to support nuclear should consider that. Is no private company willing to insure a nuclear power plant? If there's premiums to be collected over/above the claims to be payed out, why are private insurance companies not looking to exploit this opportunity? Is it ignorance, stupidity, or have they in fact run their own risk/reward numbers and decided it's not worth it? (this is not sarcasm, I'm genuinely wondering).
- There may be solutions to some of these…

Breeder Reactors – The Solution?

Breeder reactors convert long-lived radioactive by-products into power and into (relatively) short-lived radioactive by-products – requiring storage for ~several centuries, rather than thousands of years as with conventional reactors. They produce nuclear fuel as they run, and so are also fuel-efficient.

- Capital costs are ~25% higher than for conventional reactors. With the abundance of Uranium, they were not thought economical, however with the worries about radioactive waste storage, they are now more interesting.
- Supplies will exhaust with current designs in a matter of decades, but with breeders and intelligent design using Thorium, could last for well over 1000 years at current power needs (Shu 2011)
- Require a large starter of U^{235} to provide fast neutrons for fissioning other nuclei. U^{235} is rare (0.7% of natural uranium is U^{235}), but available.
- For the waste to be safe after just a few centuries, requires very high grade separation of actinide series chemical elements.
- From the Yale 360 forum, this article argues in favor of Breeder technology, and this is a rebuttal

Should we give Nuclear another chance?

- It was, at one time, hailed as a clean and low-cost new power source…. before Chernobyl
- Chernobyl killed only 31 people directly, but estimates of excess cancer deaths from the radiation cloud range from 9,000 (U.N. and Atomic Energy Commission) to 25,000 (Union of Concerned Scientists) to ten times higher (Greenpeace) - it's easy to see the correlation with "green"ness, but I myself am not in a position to say who's most correct.
- Japan's Fukishima disaster in 2011 is still being assessed, but was the only other "Level 7" nuclear disaster. Direct excess cancer deaths here are expected in the hundreds, although many argue this is too conservative.
- Mining of Uranium involves radon left in the tailings seeping into ground water, and according to the International Atomic Energy Agency, and here, this adds about 40,000 excess cancer deaths per year, worldwide.

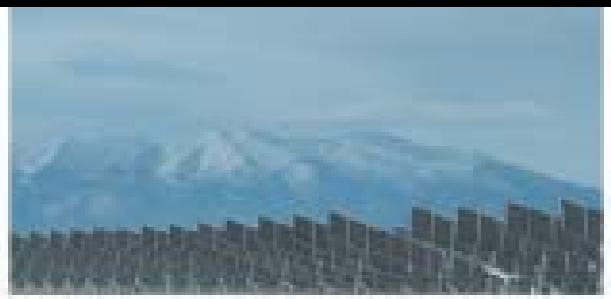
However ALL these death rates ***Pale…***

- … in comparison to deaths caused by fossil fuels, even without global warming's eventual casualties
- Black lung, emphysema, cancer, heart disease, air pollution's many other health effects.
- 13,000 deaths per year in the U.S. alone from coal dust
- Even hydroelectric has a worse record than nuclear… A string of dam failures in China once killed 230,000 people.
- **Fossil Fuels kill 320 times more people per unit power produced than solar + nuclear combined…**
- **Add in the deaths global warming will cause show that arguments about nuclear safety, by comparison, are a non-issue**

Energy Source	Death Rate (deaths per TWh) CORRECTED	
Coal (elect, heat,cook -world avg)	100	(26% of world energy, 50% of electricity)
Coal electricity - world avg	60	(26% of world energy, 50% of electricity)
Coal (elect,heat,cook)- China	170	
Coal electricity- China	90	
Coal - USA	15	
Oil	36	(36% of world energy)
Natural Gas	4	(21% of world energy)
Biofuel/Biomass	12	
Peat	12	
Solar (rooftop)	0.44	(0.2% of world energy for all solar)
Wind	0.15	(1.6% of world energy)
Hydro	0.10	(europe death rate, 2.2% of world energy)
Hydro - world including Banqiao)	1.4	(about 2500 TWh/yr and 171,000 Banqiao dead)
Nuclear	0.04	(5.9% of world energy)

- Fossil Fuels (all) = 164 deaths/TWh
- Solar = 0.44 deaths/TWh
- Nuclear = 0.04 deaths/TWh

But – a Big Problem with Nuclear is Rapidly Escalating Cost:



Solar is Less Expensive Than New Nuclear

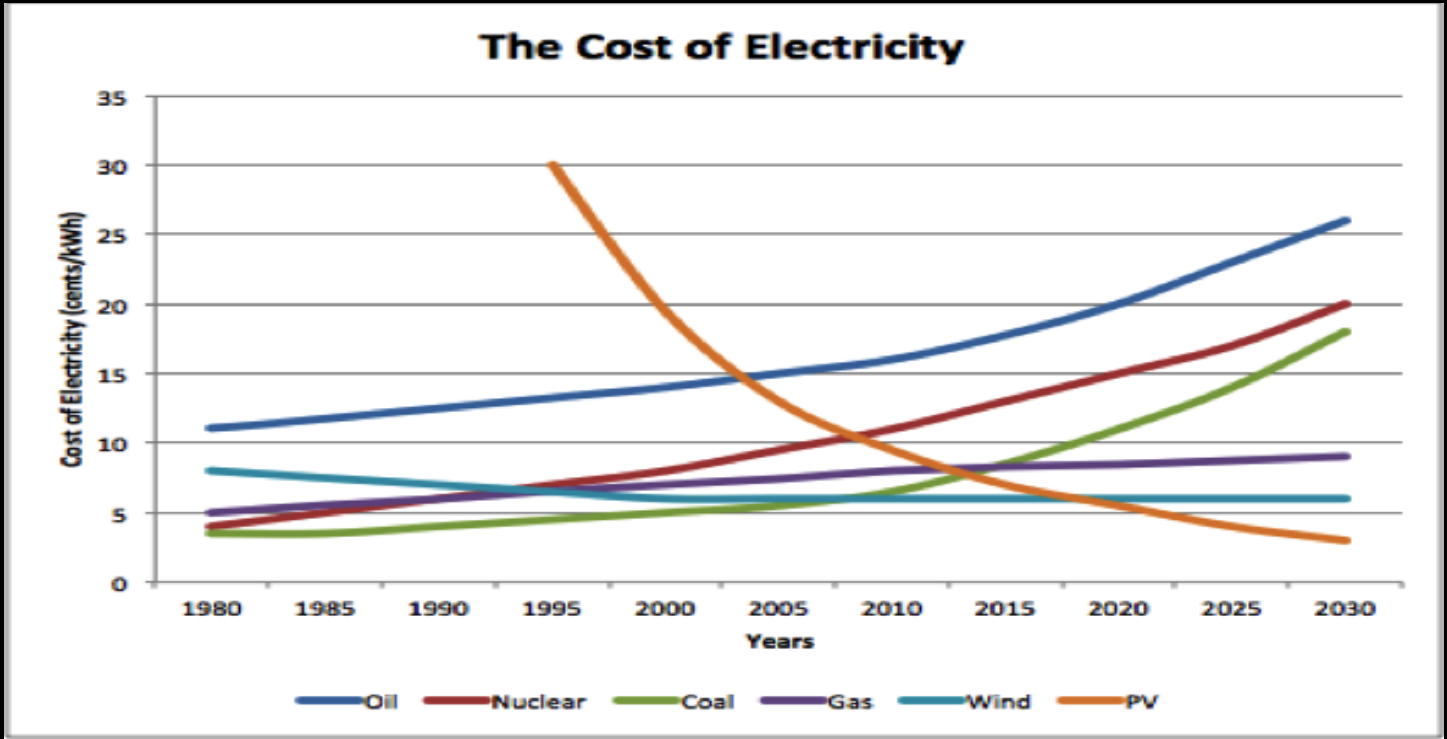
Average time to permit and build a nuclear 1 GW power plant – 13 years.
Average time to permit and build 1 GW solar – 1 year.

The last nuclear power plant completed in the US, Watts Bar 1 in Tennessee, took 23 years 7 months to construct.

Sources: 2011 nuclear price is the mid-point of the LCOE range given by Lazard, version 5.0. 2020 nuclear price is illustrative, calculated assuming 0.5% annual escalation; 2011 & 2016 PV Prices from DOE, Advanced Research Projects Agency – Energy, $1/Watt Photovoltaic Systems, May 2011; 2020 PV price illustrative, assuming 4% annual cost reduction from 2016 (further subsidized by prices bid by solar developers into the California market).

The time to permit a 1 GW power plant: 13 yrs for Nuclear *vs.* 1 yr for solar. Then construction after that.

- Time we do not have.
- During that time-to-permit, solar costs are projected to continue falling



Sobering as Nuclear's Rising Costs Are…

- …They don't include the cost of insuring of the power plants against disaster
- Is Nuclear Uninsurable?
- Yes, says a study commissioned in Germany in 2011 (here)
- Finds that insurance would cost as much as the electricity produced ($0.20/KwH), at a minimum, on up to 15 times the price of the electricity produced ($3.40/KwH) (!)

Other Technologies

- Lackner's artificial trees for pulling CO2 out of the atmosphere. How to sequester?? But $600/ton of CO2 to make, then more to sequester somewhere. Good, but expensive. Saves geo-Engineering land surface where we all live!
- Scrubbing CO2 from existing power plant flues (Rau 2011)
- Perhaps using this same chemistry for scrubbing CO2 from the atmosphere, dumping bicarbonate to the oceans?
- But, to drop atmospheric CO2 from 400ppm today to 350ppm which is considered long-term safe, would require manufacturing a limestone cube the height of Mt. Everest, and an additional 8,000 ft mountain every year to balance the current rate of CO2 emissions.

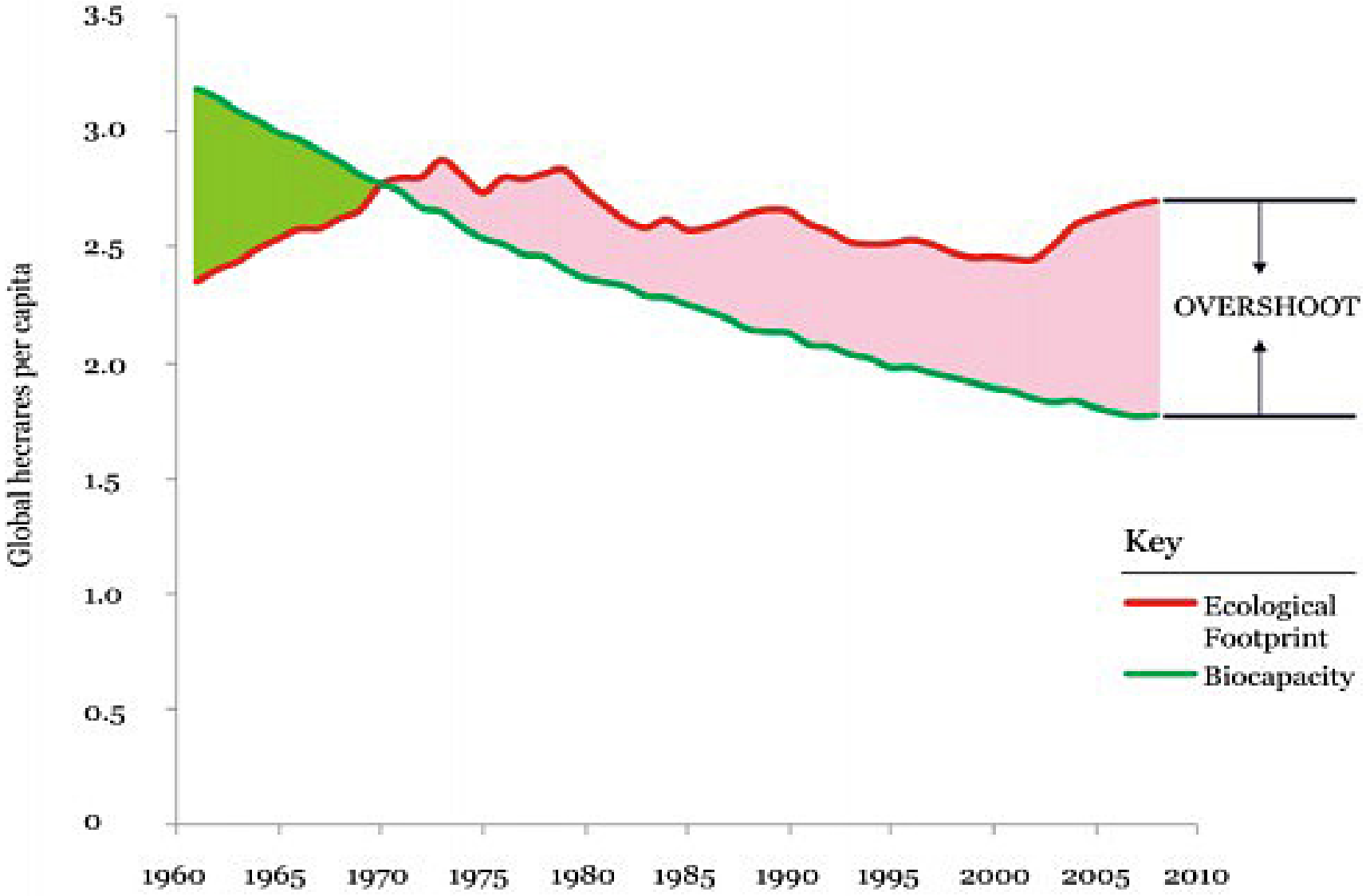
Should We Count on Technological Fixes?

- Or is the system itself broken?
- What is the goal of human action? **Happiness and well-being**
- Does a system built on rewarding short-term unlimited, unchecked growth on a finite planet provide this, given physics-built-in delays between action and consequence?
- Climate change is absolutely insoluable within this context

Technological Fixes Do Not Fix

- History demonstrates that whenever technology creates savings, those savings are simply spent on ever greater consumerism elsewhere.
- Technological fixes are not the answer, (although we probably need them in the short term)
- We need to question the equation we've assumed: Consumerism = Happiness
- Already, 98% of the vertebrate biomass on Earth is humans and their livestock. Lions, tigers, bears… have all been ~eliminated. Are we happier?
- **Recent U.S. study finds that beyond an annual income of $70k, there is very little correlation between wealth and happiness.**

There are Simply Too Many People Clamoring for Too Many Dwindling Resources



It’s Not About the Science

- ***One more study showing dire consequences will do nothing towards spurring action.***
- It was never about the science, it is about ideology, and Naomi Klein has been eloquent in researching this, as one example.
- **Libertarians are correct** – Governments are incompetent, corrupt, and morally thieving of goods created by one and then given to another. Since governments have a legal monopoly on the use of Force, and are elected by a majority of voters regardless of voter qualifications to cast an intelligent vote, **this very unlikely to change**.
- **Environmentalists are correct** – Corporations have demonstrated they care only about their own wealth, and give zero care about our children or grandchildren, for tens of thousands of years into the future… a startlingly appalling truth that is now obvious to all.
- ***The system is broken.***
- As a reformed former Libertarian, I claim we desperately need a new political/economic system which is genuinely long-term human well-being oriented, and morally responsible to our fellow species and future generations. Such a system has not been invented, so far as I can tell.
- I would LOVE to get out from under the increasing public school onerous bureaucratic paperwork and have long hours to ponder a solution to this.

“Induced Demand”

- If we cut insolation with asteroids, will we simply then raise fossil fuel use because now we can “get away with it”?
- If we go nuclear, will that be a license to cut more trees because we don’t need their carbon sequestration?
- **What, really, are our values as one species on a planet of millions of other species?**

Game Theory: We're Doomed

- A study using Nash Equilibria applied to real life experiments in climate talks, finds that as long as there is any uncertainty in the exact extent of future climate-induced damage, nations will always "chisel", trying to get the other guy to pay more than his fair share, and the talks are doomed, and so is Earth climate (Barrett *et al.* 2012 in PNAS).
- This has indeed been the case in the past, and continuing to the present.

Why Policy Solutions?

- Right-wing ideologues attacking climate science know the real stakes:
- Climate knows no national borders; it requires global political solutions, it requires strong government legal action because individual and corporate individual motivations are to strip the Earth as rapidly and efficiently as possible, before the competition beats you to it.
- Our atmosphere is an open sewer free to all to dump their CO2, methane, and other man-made GHG's.

The Fatal Flaw in *Laissez Faire* Capitalism…

- …is that, to the individual or corporation, the marginal benefit of polluting is far higher than the marginal cost of enduring the pollution
- Why? Because the benefit accrues strictly to the individual or corporation, while the cost is diluted across the entire world.
- Right wing ideologues who posture on the high moral ground do not acknowledge this.

Tax-And-Dividend: The Most Direct and Effective Policy to Align Financial Motivations toward Climate Health

- Tax every ton of carbon coming from the ground or crossing our borders. This tax money goes into a fund from which every person in the country gets a monthly or quarterly check. Simple, no arguing or lobbying about how to spend the tax money. Even libertarians agree this is a good idea, those who've gotten beyond the knee-jerk anti-climate science position.
- Tax-and-Dividend thereby involves all of us - millions -will be involved in solving the problem, rather than foot-dragging an uphill battle as we're doing now.
- Tax must be STEEP to provide powerful motivation. BIG tax means BIG checks in the mail, motivating you to bike, walk, buy an electric car, solarize your roof, draw heat from geothermal systems, etc.
- Must be instituted world-wide, or at least in the Carbon Countries: U.S., China, Europe, India. For competitive reasons, corporations would insist if it happens at all, it must be world-wide – which is fine.

Tax Code: Child tax credit?

- We should instead consider a child tax penalty
- Could be a graduated tax, so that the “rich” cannot buy their right to children while the poor cannot.
- At sustainable current technology, the world can only support 7 billion people at a standard of living (measured by per-capita GDP) equal to that in Ethiopia – a place of wide-spread grinding poverty.

I've Been Trying During The Past Few Days to End This on a Hopeful Note

…. But, having a very hard time doing so.

Maybe you have ideas?

My best is **OCCUPY DC** and resist leaving until policy demands are met. Would require 100,000 or more to make jailing them all impractical, and insure all media MUST cover it, so we're not just "disappeared"