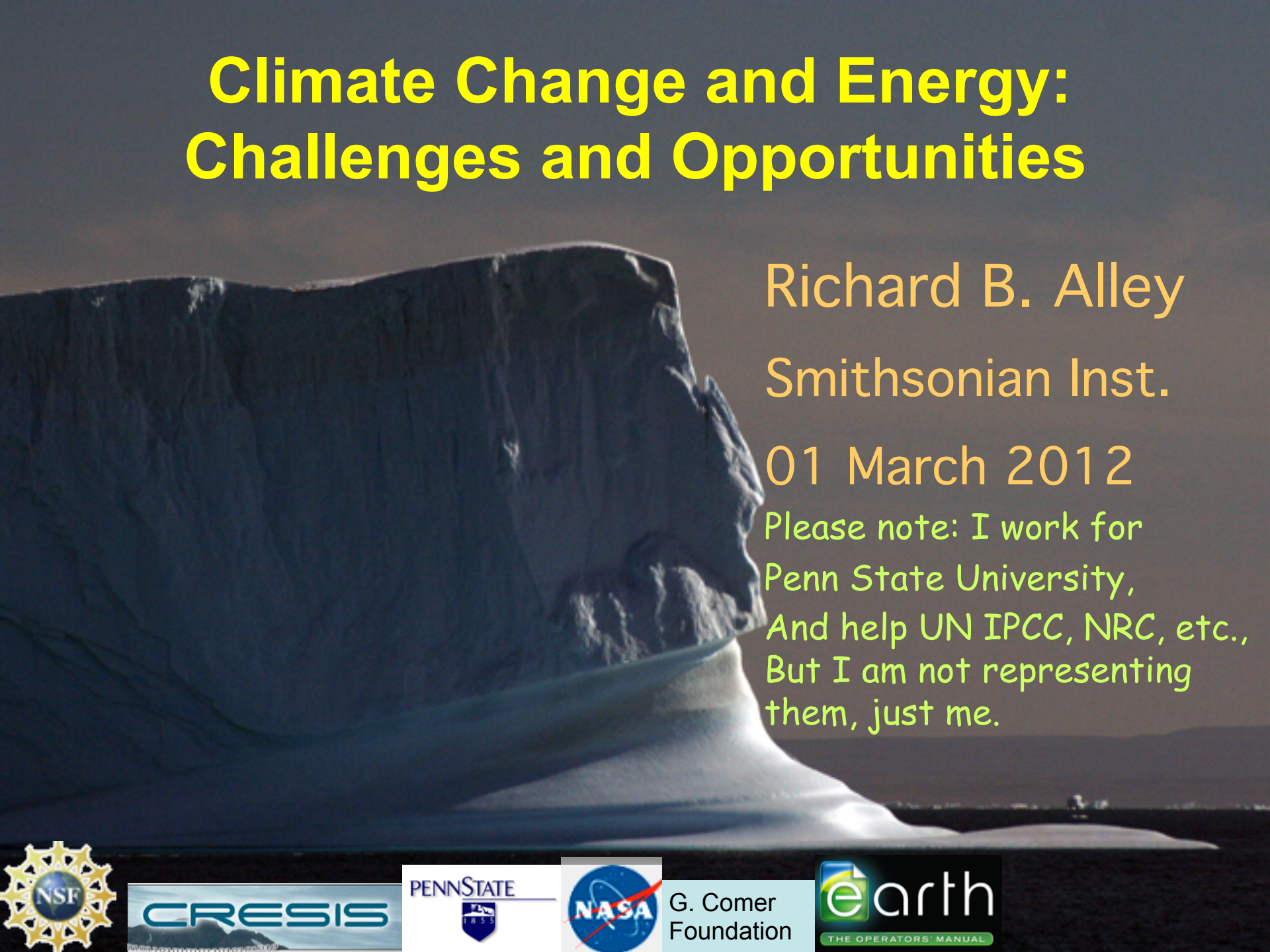
Climate Change and Energy: Challenges and Opportunities



Richard B. Alley

Smithsonian Inst.

01 March 2012

Please note: I work for Penn State University, And help UN IPCC, NRC, etc., But I am not representing them, just me.

NSF CRESIS PENNSTATE NASA G. Comer Foundation earth THE OPERATORS' MANUAL

Sustainability

- Oversimplifying a lot, people choose to have enough kids to replace themselves if, and only if, those people:

→Are confident the kids will survive;

→Have choices about what to do in life.

- If we succeed in supplying these, Earth's population is projected to stabilize at 9 or 10 billion within a few decades;
- If we don't supply these…?????

Sustainability

- With about 7 billion of us on Earth, we are supporting only about 5-6 billion of us well
- So sustainability requires doubling the number of people with choices in life and confidence their kids will survive. But…
- Much we do now unsustainable, using things nature is not replacing fast enough to help
- Many issues (soil, groundwater, phosphorus for fertilizer); energy may be the biggest (with enough energy, can beat the others)

Energy

- You eat ~2000 Calories per day (~100 W);
- You use over 240,000 Calories per day;
- Like having over 100 serfs doing your bidding;
- Driving, heating, cooling, pumping, plowing, trucking, flying, cooking…
- Almost all (~85%) from oil, coal and natural gas (fossil fuels).

http://www.smithsonianmagazine.com/multimedia/rich-media/0206-forgotten-forest/index.php

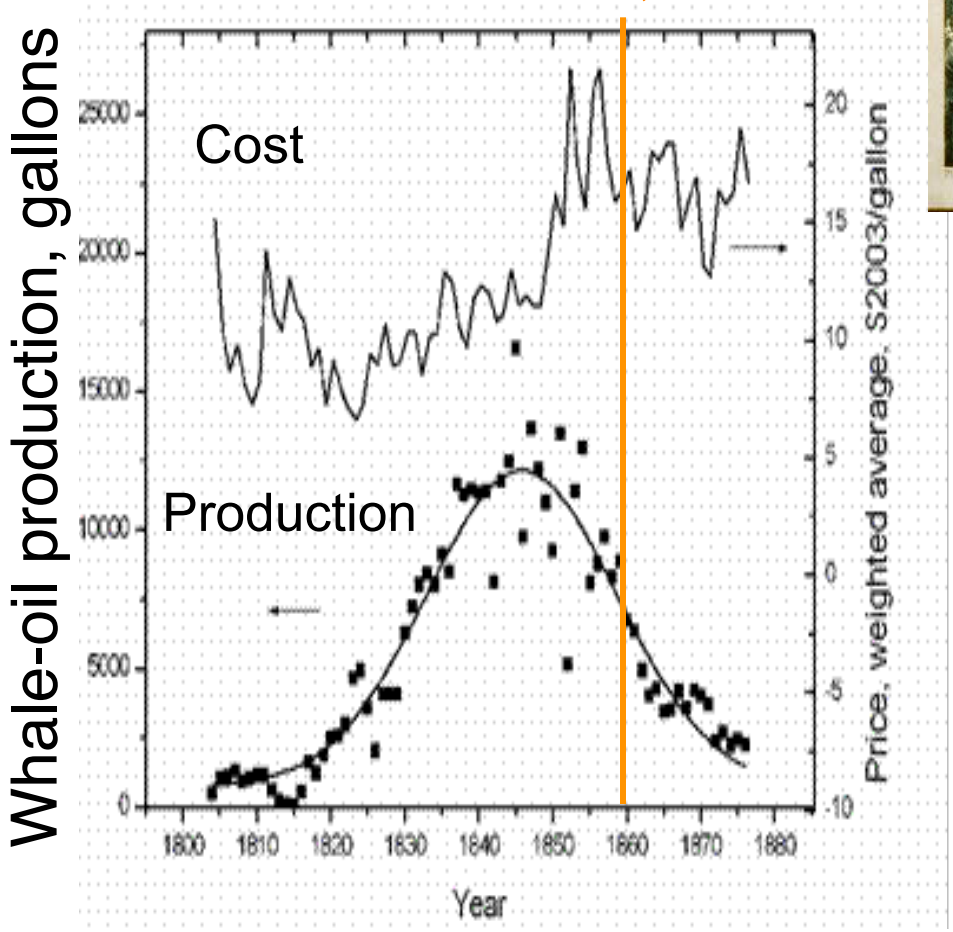
http://www.explorepahistory.com/ (Pennsylvania State Education Association)

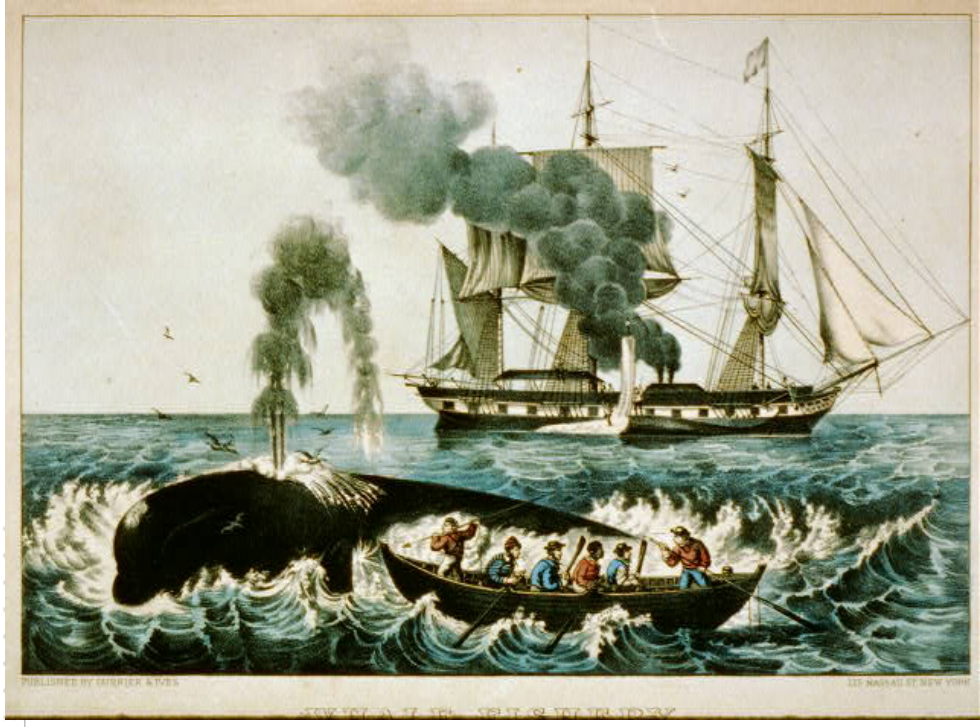
Settlers cut almost all Pennsylvania trees, often for fuel, losing all (elk, bison, fisher, mountain lion), or almost all (deer, turkey) large wildlife.

Penn's Woods-->Pennsylvania "Desert" (**and not just Pennsylvania!**)

Not enough whales to light the evening, so, we drilled for oil…total US whale-oil production in century of 1800s about 1 week of modern US oil imports!

Drake Well, 1859





http://www.loc.gov/pictures/item/2002698808/

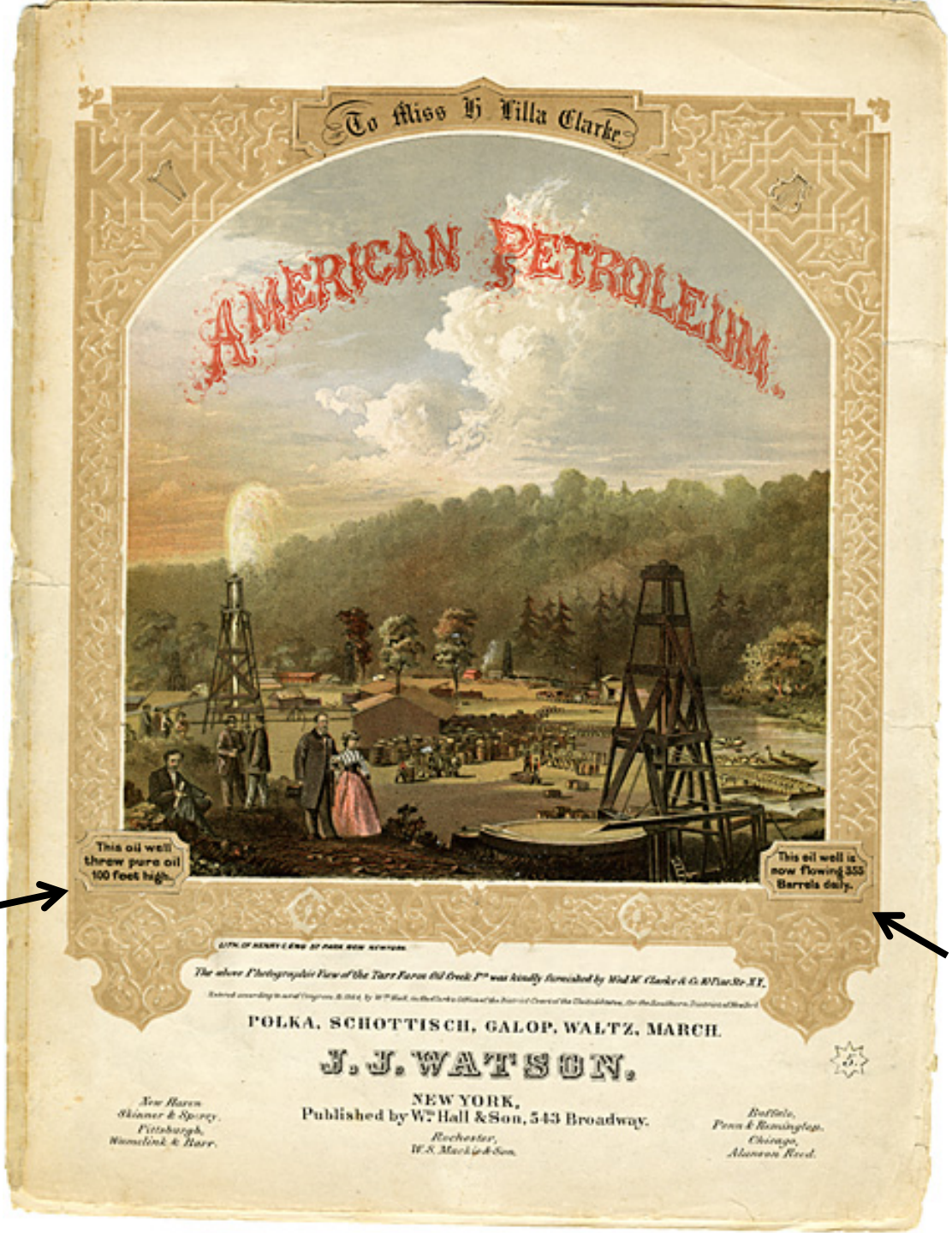
Currier and Ives, Whale Fishery: Attacking a right whale, Library of Congress

Whale oil production. Prices and Production over a complete Hubbert Cycle: the Case of the American Whale Fisheries in 19th Century, Aug 2004, Ugo Bardi, ASPO: The Association for the Study of Peak Oil and Gas, and Dipartimento di Chimica - Universita di Firenze,Via della Lastruccia 3, Sesto Fiorentino (Fi), Italy. bardi@unifi.it This document is published in the #45 issue of the ASPO newsletter. (www.peakoil.net) The present version appears at http://www.aspoitalia.net/aspoenglish/documents/bardi/whaleoil/whaleoil.html Data from A. Starbuck, History of the American whale fishery, Seacaucus, N.J. 1878, reprinted 1989

“GRAND BALL GIVEN BY THE WHALES IN HONOR OF THE DISCOVERY OF THE OIL WELLS IN PENNSYLVANIA”, VANITY FAIR, 1861

www.nps.gov/nebe/historyculture/upload/timeline.pdf

The **AMERICAN PETROLEUM POLKA**, 1864. Pennsylvania wells.



Library of Congress, http://www.loc.gov/pictures/item/2001702308/

"This oil well threw pure oil 100 feet high."

"This oil well is now flowing 355 Barrels daily."

Energy companies supply lots! Consider transportation:

- Typical U.S. driver buys almost 100 pounds of gasoline per week (45 kg)
- And burning adds O_2 to make about 300 pounds of CO_2 (135 kg)
- *(1 gallon of gas weighs about 6 pounds, so 16 gallons is nearly 100 pounds, and each pound of gasoline yields 3.1 pounds of CO_2)*

If CO_2 came as horse ploppies

- ~1 pound/mile driven (1/4 kg/km);
- US drivers would cover every road in the country an inch deep every year (2.5 cm/yr);
- And you would smell it everywhere.
- Don't even THINK about airplanes…

Photo http://www.fort.usgs.gov/resources/spotlight/horse/Idform_large.asp

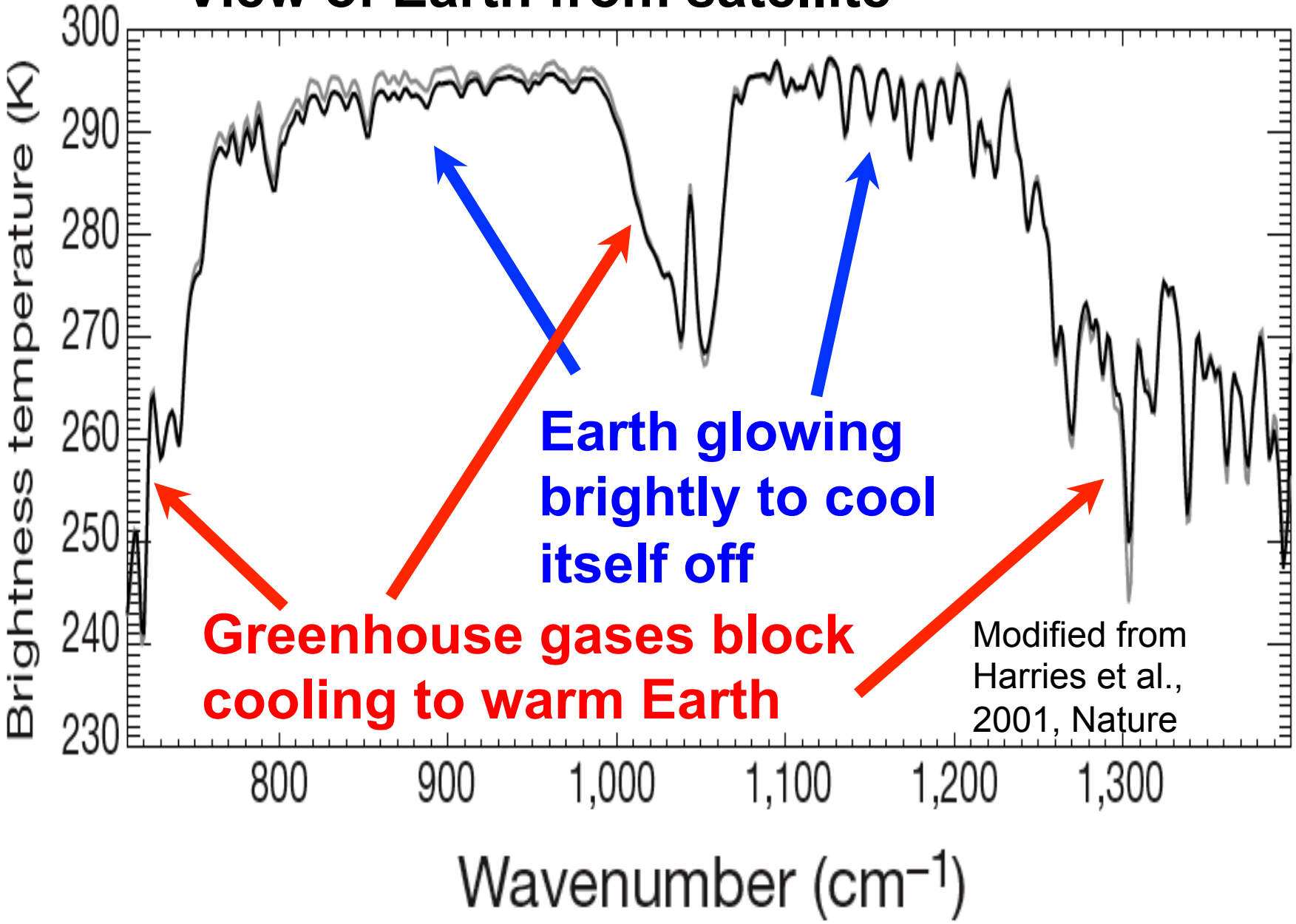
Fossil Fuels Will "Run Out":

- They are finite—easy ones going fast
- Use is rising rapidly--other people want 100 "willing workers", too!
- We are using them ~1 million times faster than nature saved them for us
- At $100/barrel for oil, poor people cannot afford the benefits of the energy (and getting harder for us…at $100/barrel, oil imports ~$1,000 per year for each person in USA).

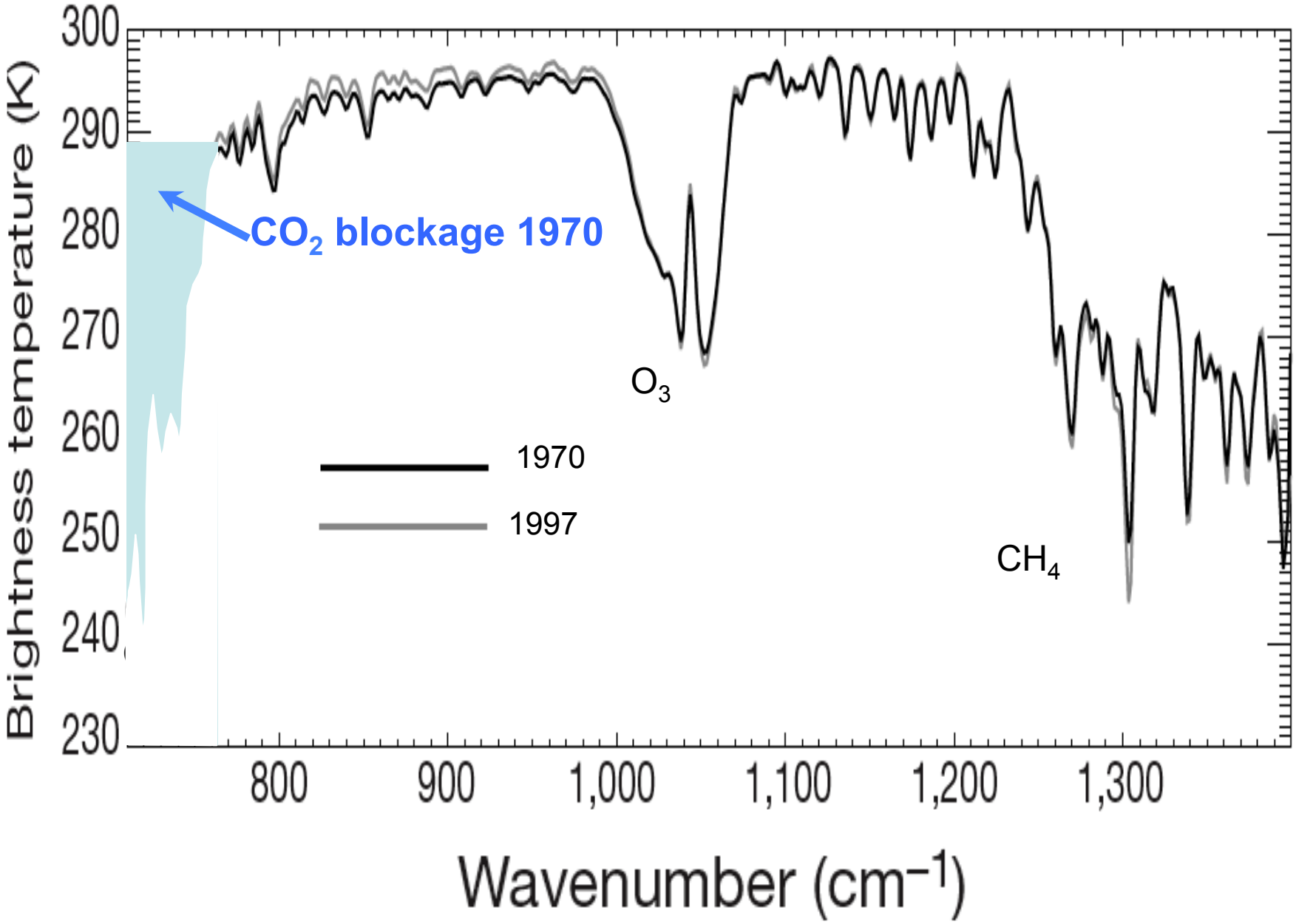
Now to global warming:

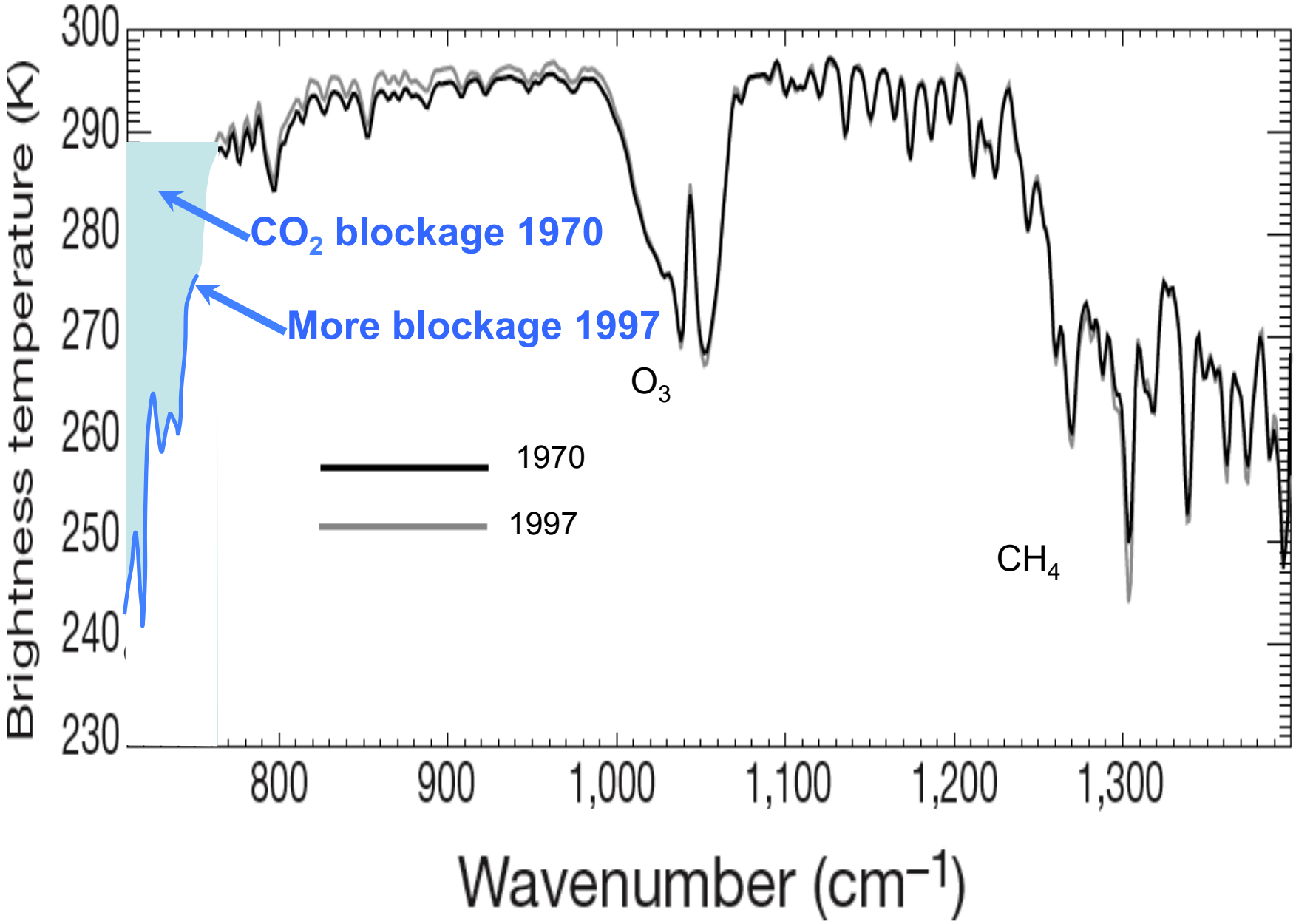
- IF we burn all the fossil fuels before switching to other energy
- AND we put the CO_2 into the air
- THEN we are confident we will change world in ways we don't like;
- Nice to burn and then learn, but for sustainability we must learn faster.

View of Earth from satellite



← Think of different colors, although all in infrared →


Brightness temperature (K)
300
290
280
270
260
250
240
230
800
900
1,000
1,100
1,200
1,300
Wavenumber (cm⁻¹)
CO2 blockage 1970
O3
CH4
1970
1997


Brightness temperature (K)
300
290
280
270
260
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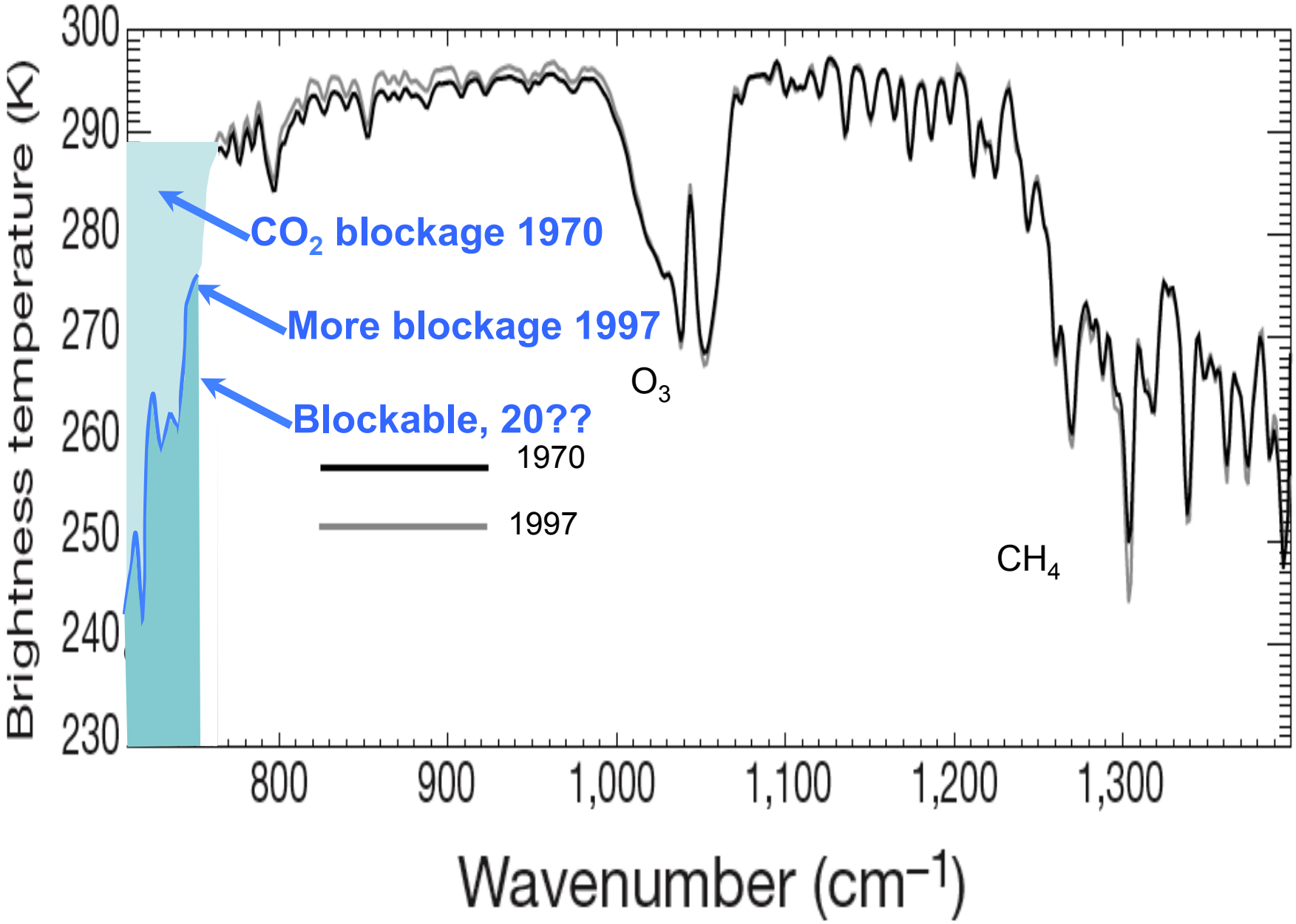
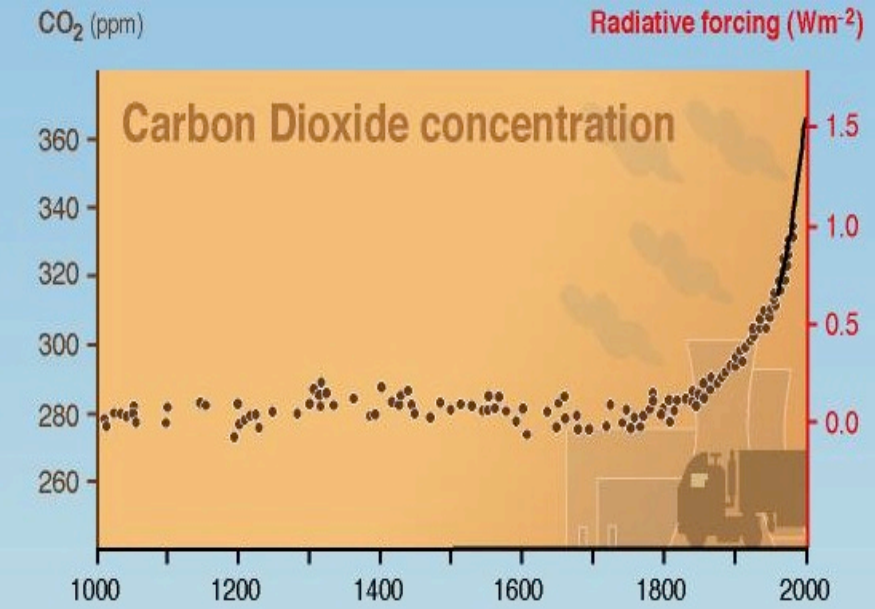
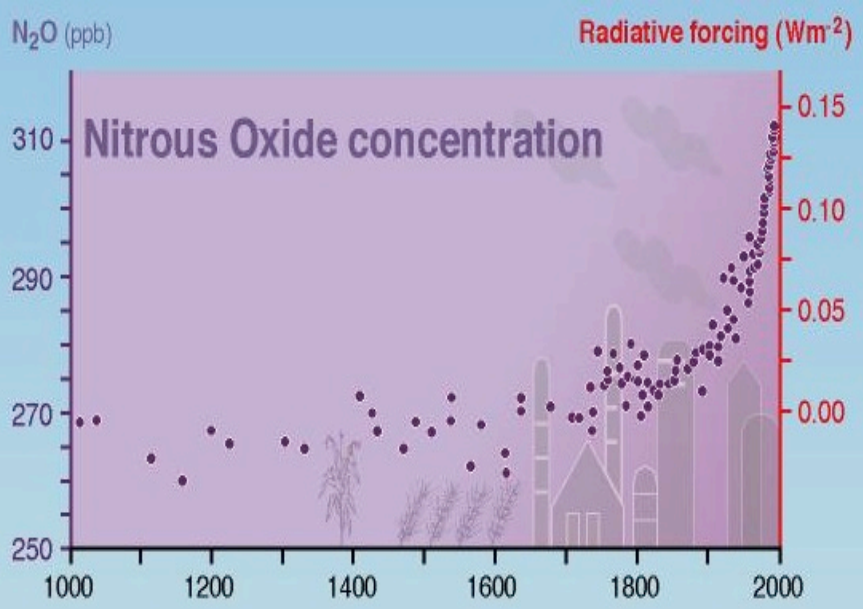
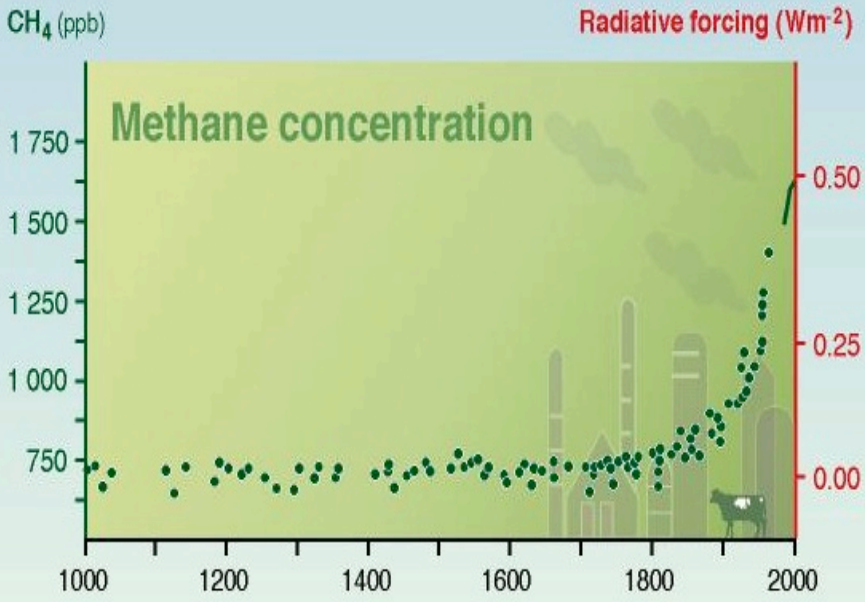
240
230
800
900
1,000
1,100
1,200
1,300
Wavenumber (cm⁻¹)
CO2 blockage 1970
More blockage 1997
O3
CH4
1970
1997

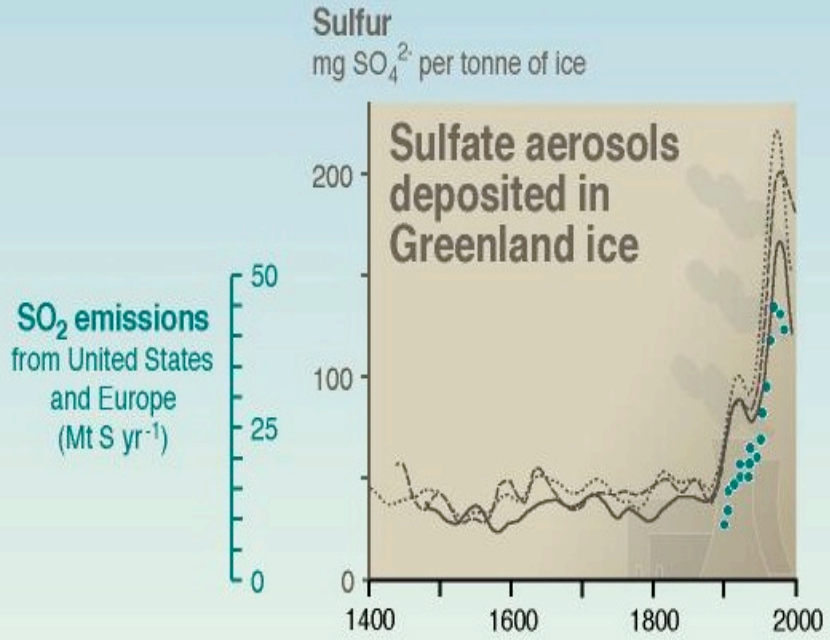

Brightness temperature (K)
300
290
280
270
260
250
240
230
800
900
1,000
1,100
1,200
1,300
Wavenumber (cm⁻¹)
CO2 blockage 1970
More blockage 1997
Blockable, 20??
1970
1997
O3
CH4


CO_2 (ppm)
Radiative forcing (Wm^{-2})
Carbon Dioxide concentration
360
340
320
300
280
260
1.5
1.0
0.5
0.0
1000
1200
1400
1600
1800
2000


N_2O (ppb)
Radiative forcing (Wm^{-2})
Nitrous Oxide concentration
310
290
270
250
0.15
0.10
0.05
0.00
1000
1200
1400
1600
1800
2000

IPCC, 2001


CH_4 (ppb)
Radiative forcing (Wm^{-2})
Methane concentration
1 750
1 500
1 250
1 000
750
0.50
0.25
0.00
1000
1200
1400
1600
1800
2000


Sulfur
mg SO_4^{2-} per tonne of ice
Sulfate aerosols deposited in Greenland ice
200
100
0
1400
1600
1800
2000
SO_2 emissions from United States and Europe ($Mt\ S\ yr^{-1}$)
50
25
0

Is it our CO_2? Yes

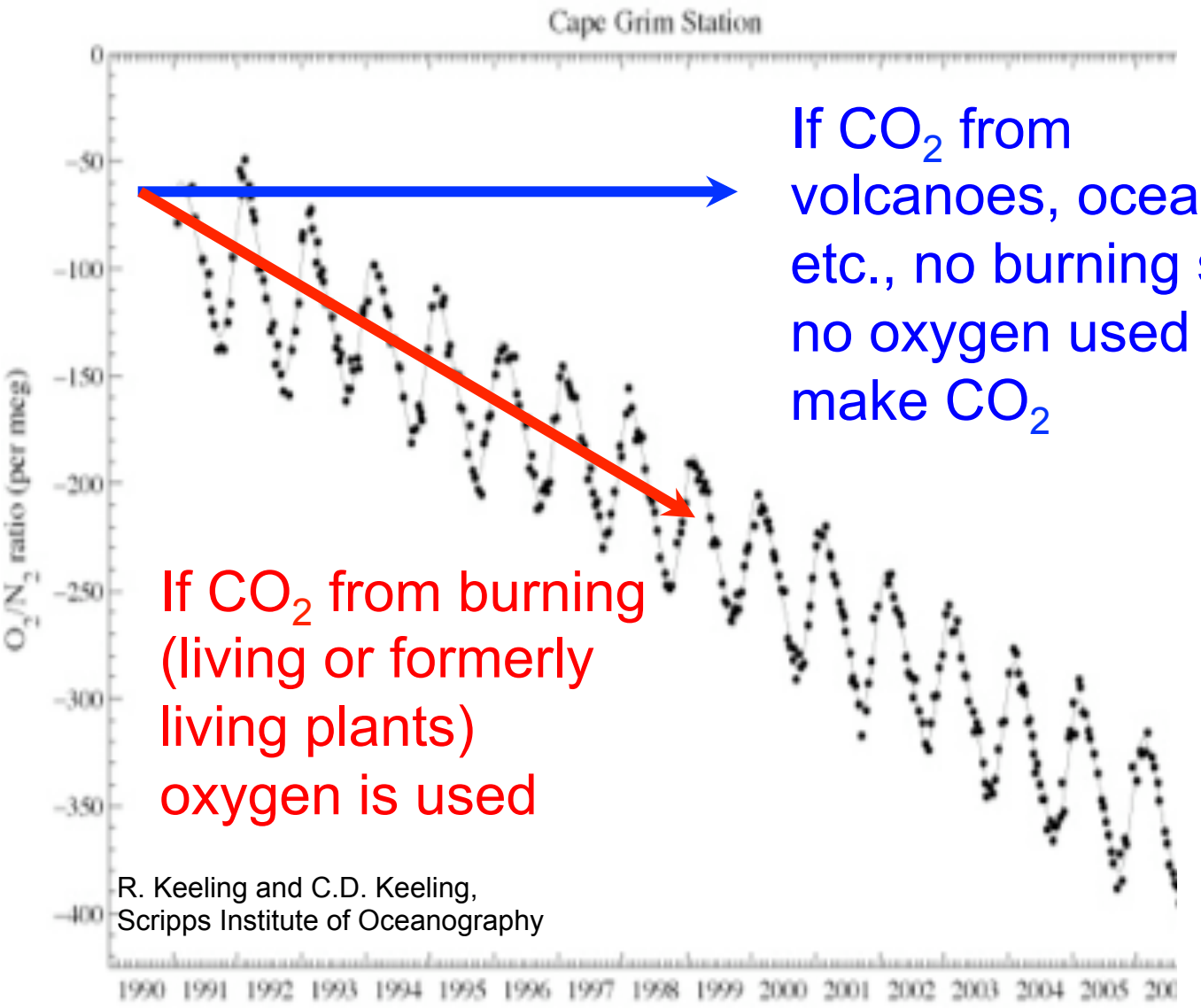
- Bookkeeping: quantitative match between known burning and observed extra CO_2 in system;
- No other possible explanation adequate (volcanic source 1-2% of ours…);
- Air shows fossil fuels responsible:

→Atmospheric ^{13}C dilution—extra CO_2 is or was living (not volcanic, dissolved in ocean, etc.)

→Atmospheric ^{14}C dilution--extra CO_2 is from old source (not from modern plants)

→Atmospheric O_2 drop--excess CO_2 is from burning (not from ocean or volcanoes)

It really is our CO_2. What we burn is in the air and the ocean. Tracers in the air confirm this. For example, burning fossil fuels uses oxygen, but volcanoes don't. The drop in oxygen is clear.



(We'll still be able to breathe!)

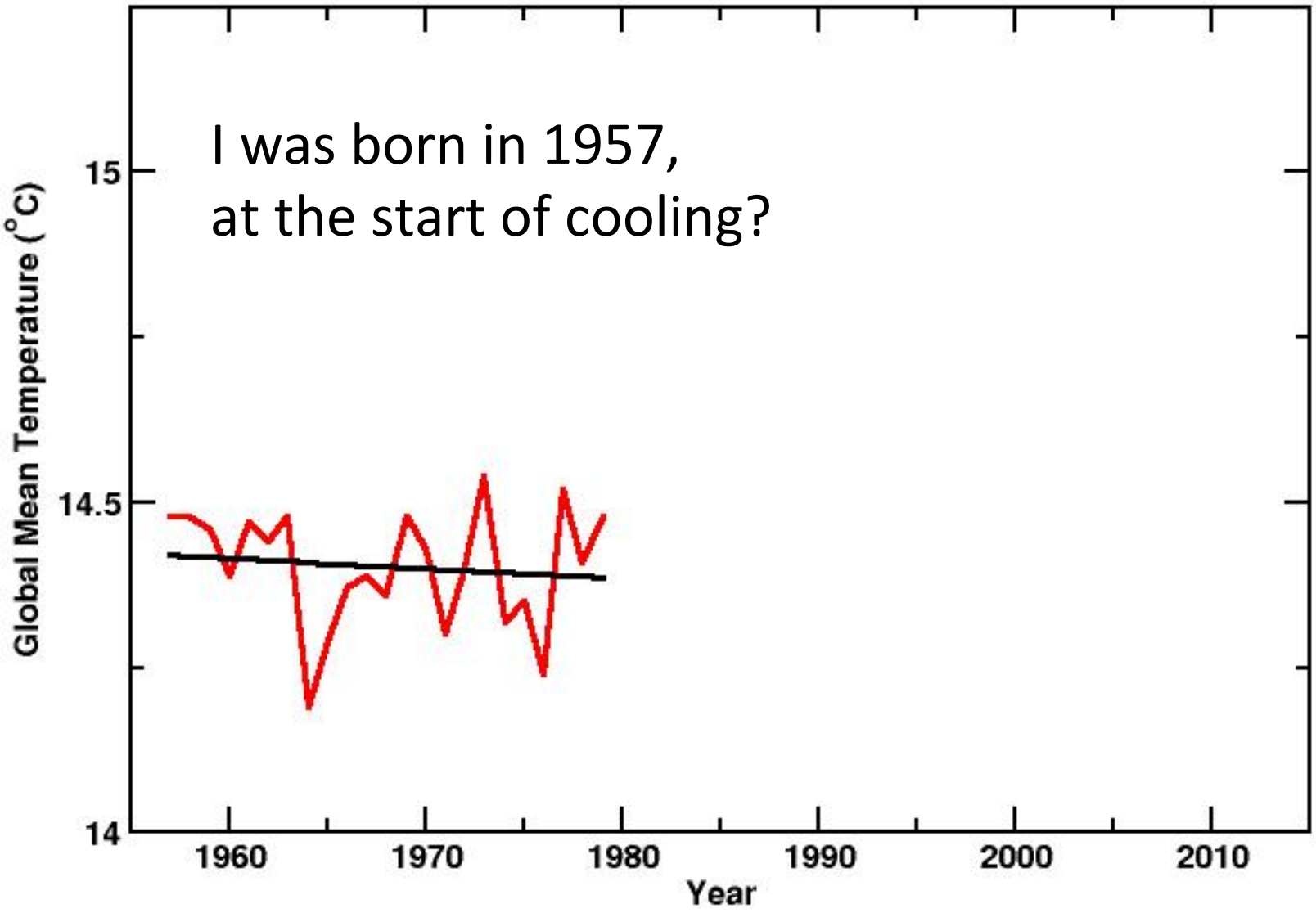
On Google, November 2, 2011, "Global warming stopped in 1998" yielded "About 155,000 results". First is:

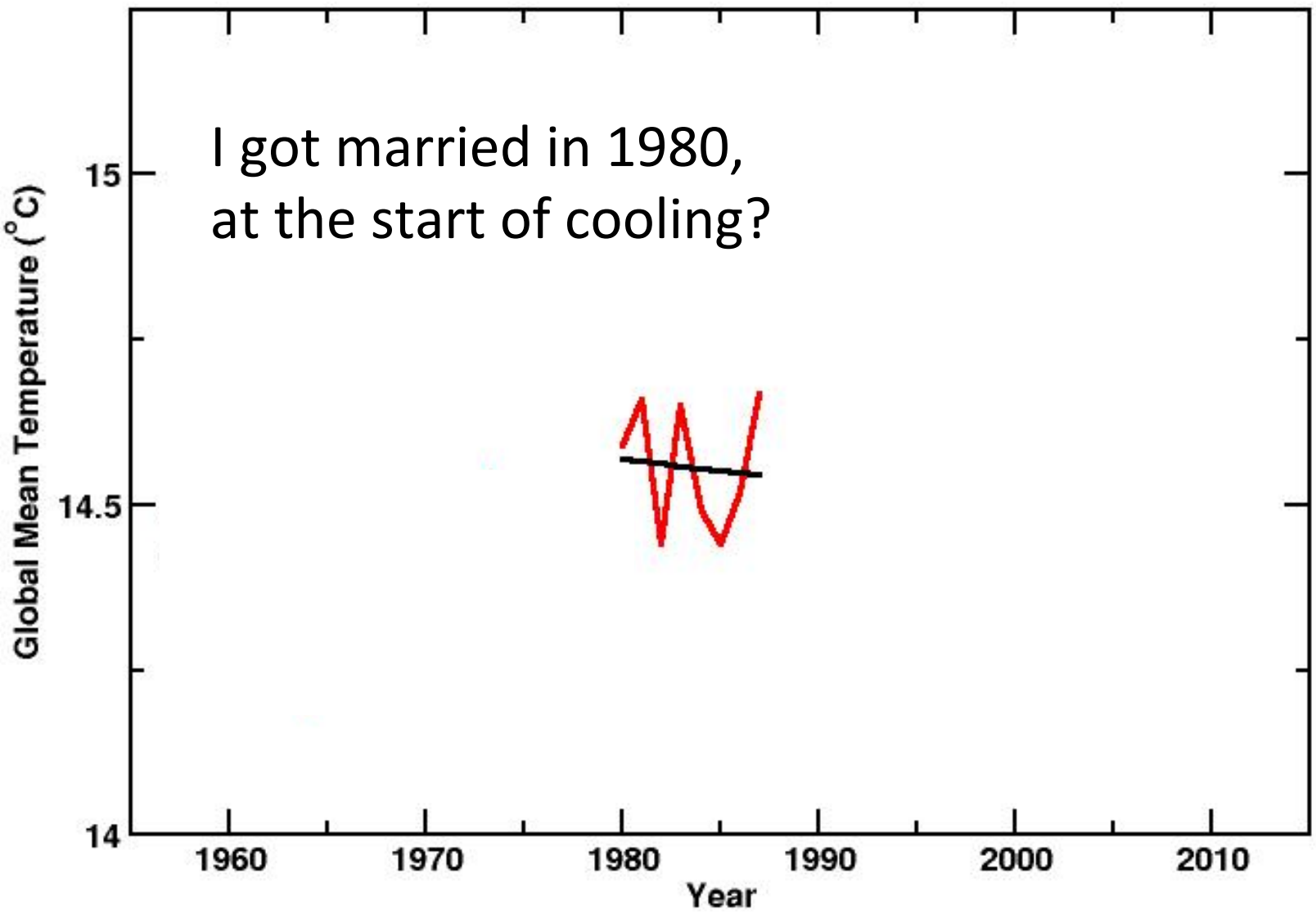
" There IS a problem with global warming... it stopped in 1998 ...
www.telegraph.co.uk/.../There-IS-a-problem-with-global-warming...-...
Apr 9, 2006 – We have more to fear from another ice age, argues climatologist Bob Carter, yet scientific brainwashing is keeping the truth from both public…". More-recently…

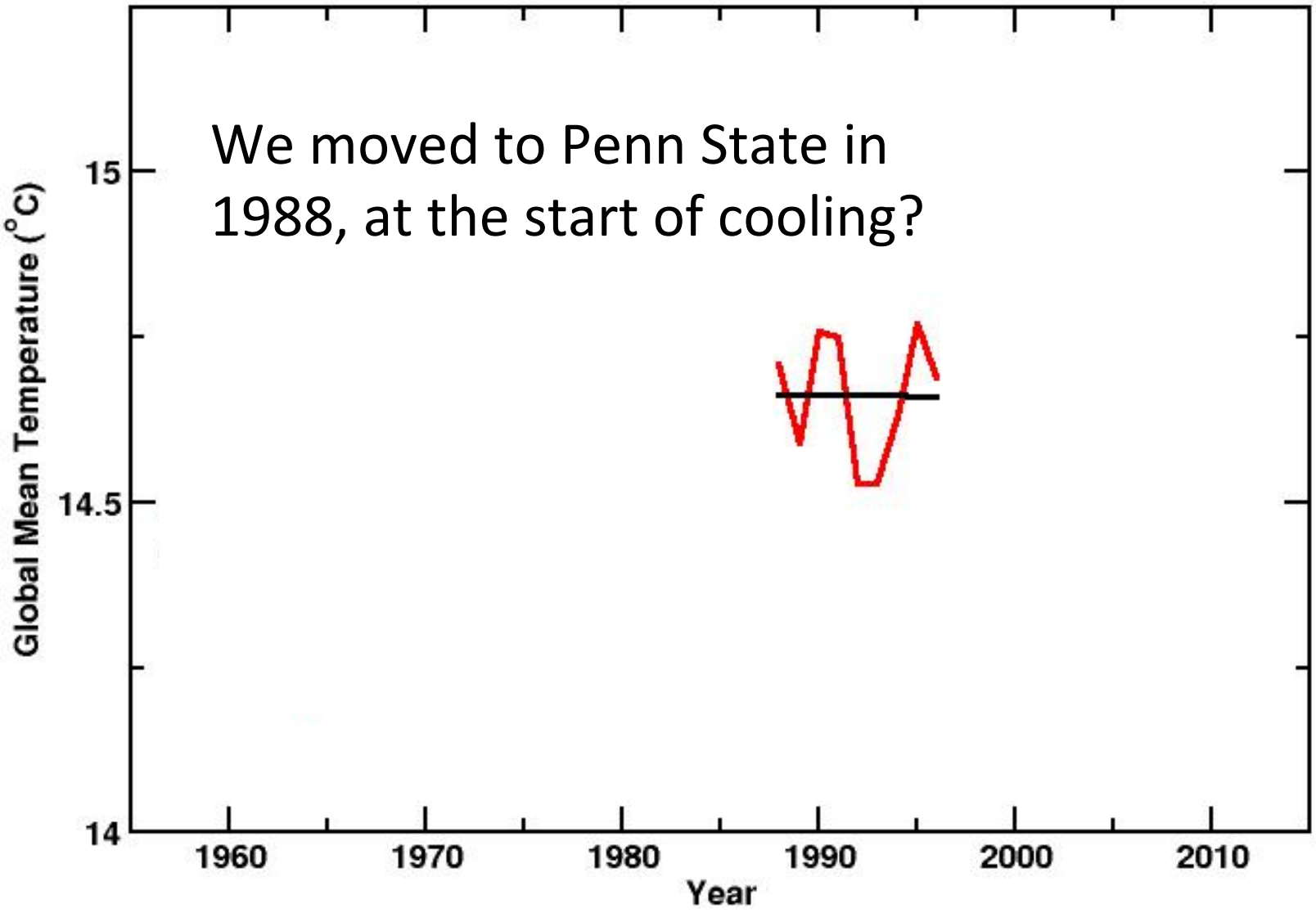
"Perhaps the most inconvenient fact is the lack of global warming for well over 10 years now." –Wall Street Journal, Jan 27, 2012
http://online.wsj.com/article/SB10001424052970204301404577171531838421366.html?mod=WSJ_hpp_RIGHTTopCarousel_1

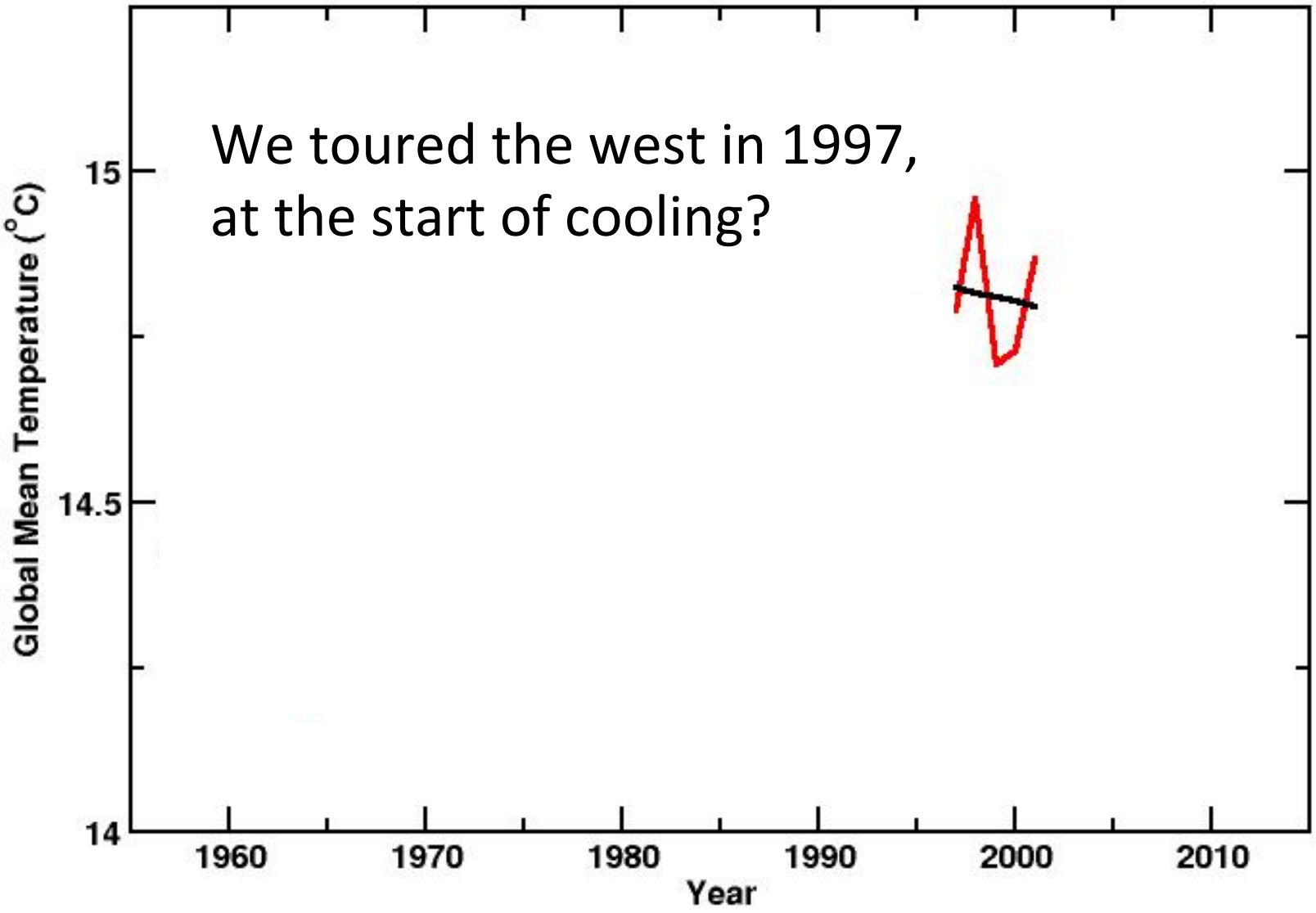
"…the planet has not warmed for the past 15 years…"—Daily Mail, 29 Jan 2012
http://www.dailymail.co.uk/sciencetech/article-2093264/Forget-global-warming--Cycle-25-need-worry-NASA-scientists-right-Thames-freezing-again.html#ixzz1kyUw8KE9

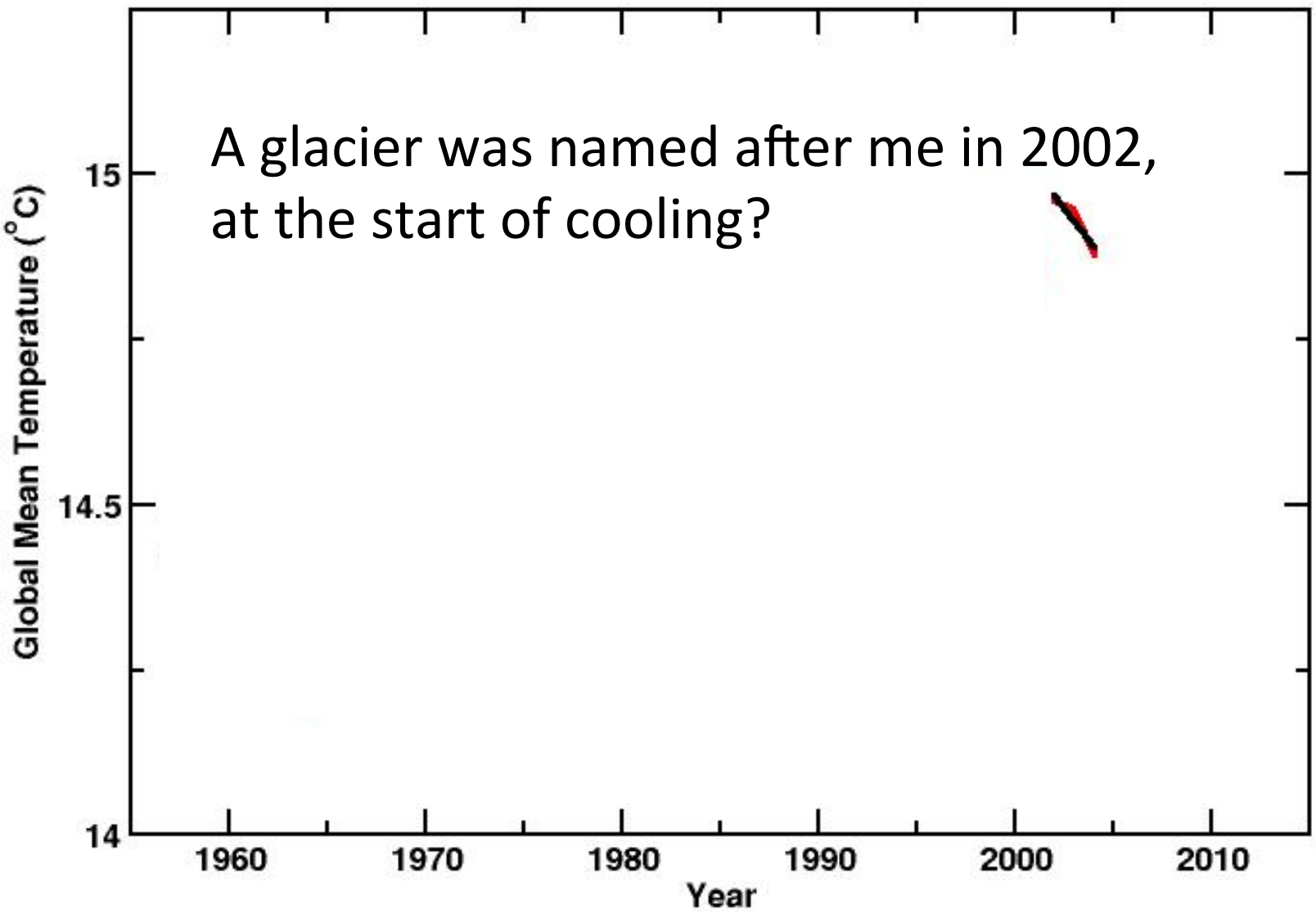
Let me use NASA GISTEMP to show you how they turn warming into cooling

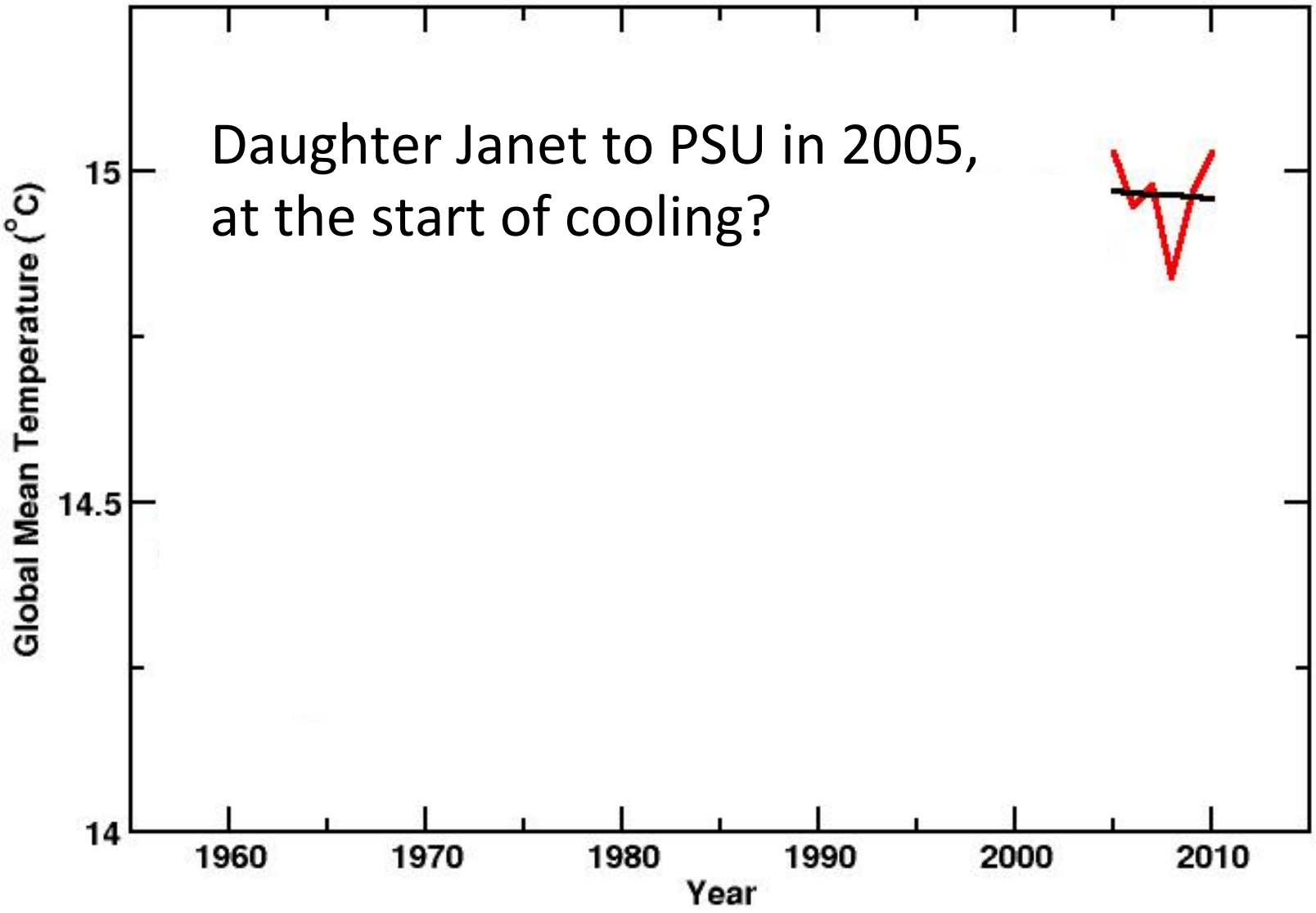

I was born in 1957,
at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year

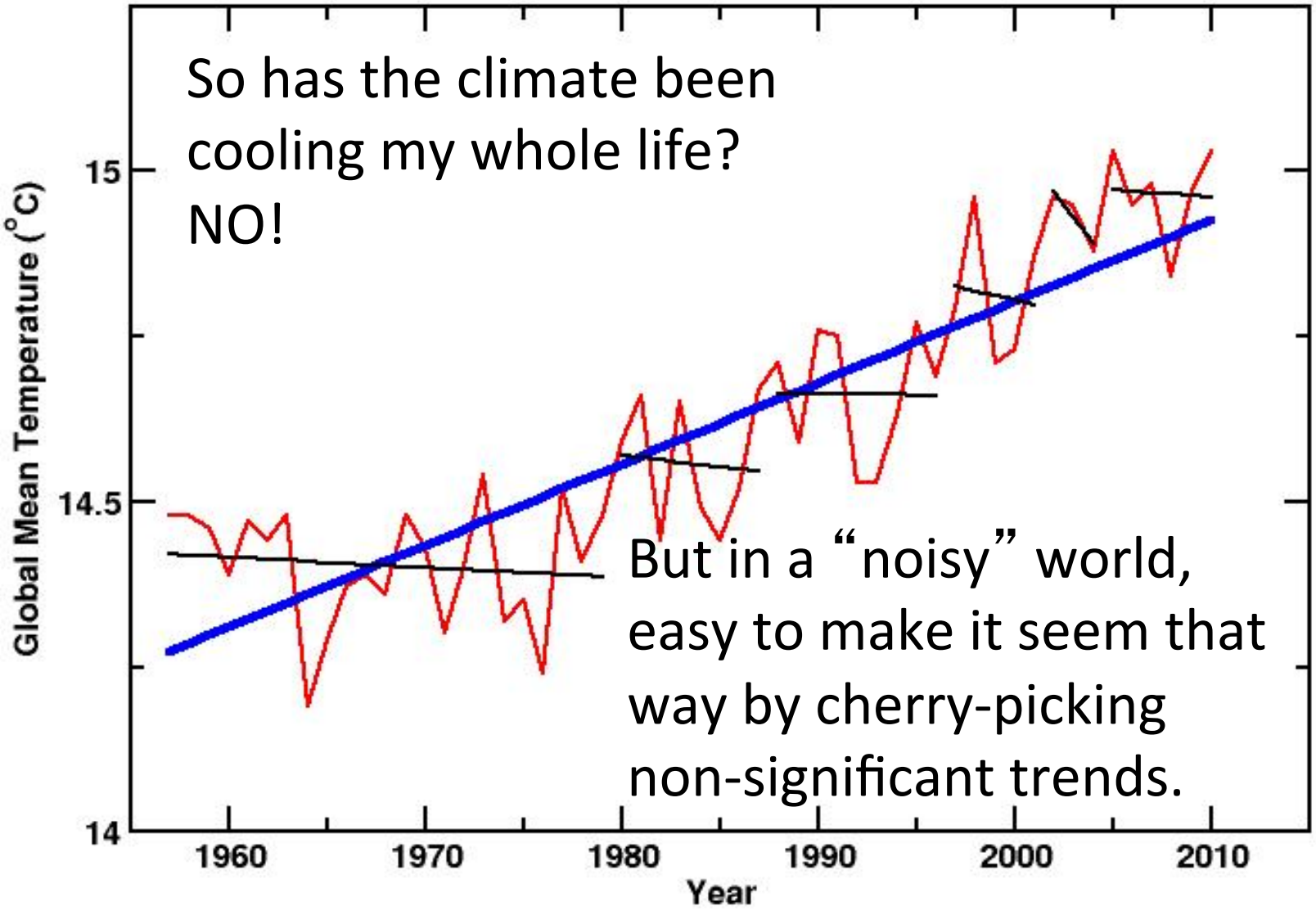

I got married in 1980,
at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year


We moved to Penn State in 1988, at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year


We toured the west in 1997,
at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year


A glacier was named after me in 2002,
at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year


Daughter Janet to PSU in 2005,
at the start of cooling?
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year


So has the climate been cooling my whole life?
NO!
But in a "noisy" world, easy to make it seem that way by cherry-picking non-significant trends.
Global Mean Temperature (°C)
15
14.5
14
1960
1970
1980
1990
2000
2010
Year

World is warming…

- 1899 Guinness brewery hired mathematician W.S. Gosset

→ To learn to separate signal from noise

→ 7 years growing many barleys in various places and conditions to find the best type

→ Published in 1908 by "Student"—Guinness considered use of statistics a trade secret

→ How many people have ignored Gosset and lost big at stocks or gambling?

→ In all the main temperature data sets, all the highly significant trends are now up.

Warming over last century:

- **UNEQUIVOCAL, from cautious IPCC**
- Direct thermometer measurements:

→ In air (including far from cities);

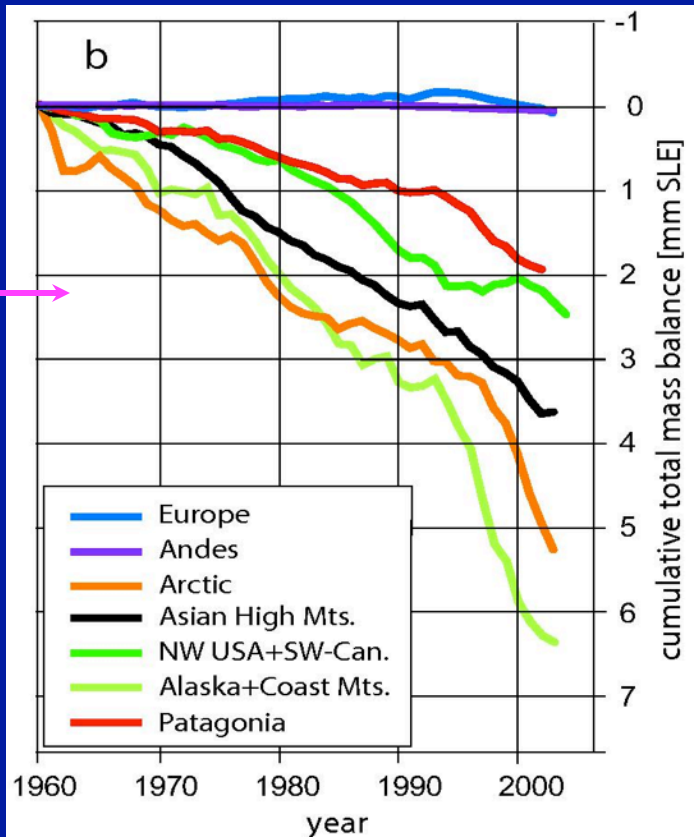
→ In ocean water;

→ In ground;

→ On balloons;

→ From satellites;

- Mass loss from almost all glaciers, including those getting more snow;
- Great majority of biology shifts in direction expected for warming;
- (There still is weather--some people who should know better look at a cool day, week or year and claim warming stopped. Silliness.)



Muir Glacier, Alaska, August 13, 1941, photo by W.O. Field

http://nsidc.org/data/glacier_photo/special_high_res_muir.html

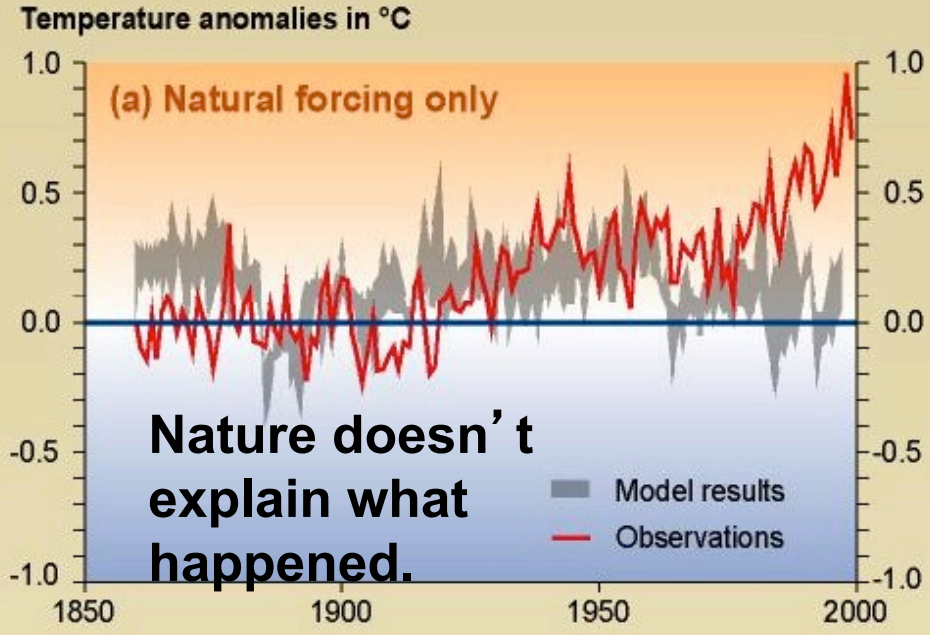
Muir Glacier, Alaska, August 31, 2004, photo by B.F. Molnia

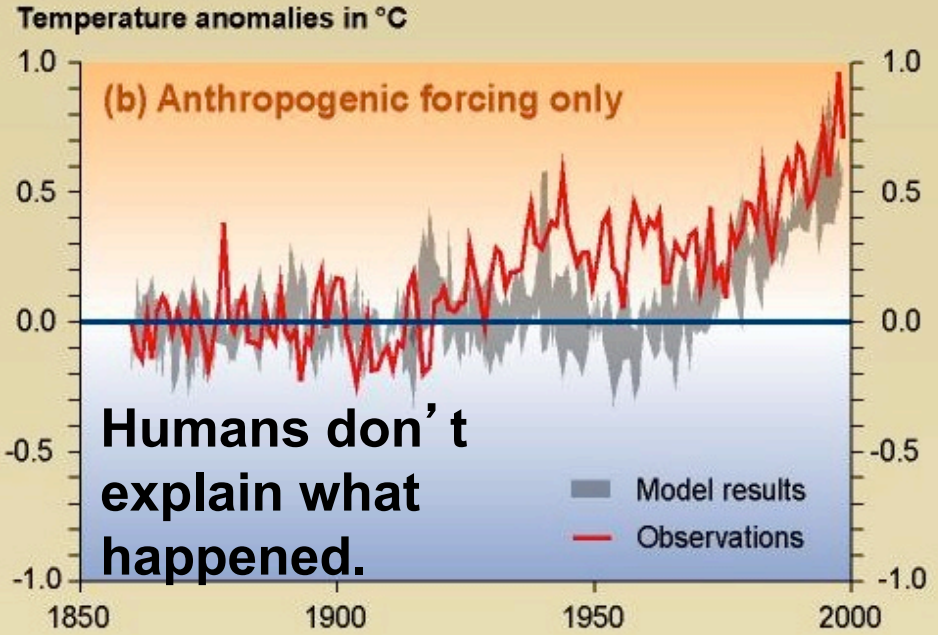
http://nsidc.org/data/glacier_photo/special_high_res_muir.html

High confidence warming from our CO_2

- PHYSICS: warming influence of rising CO_2 is unavoidable, observable physical reality;
- FORCINGS: Nothing else pushing warming (sun not brightening, cosmic rays not changing, etc.);
- FINGERPRINTS: Quantitative match between modeled and observed warming in time and space if and only if CO_2 included, with mismatch for any other possible cause of warming.

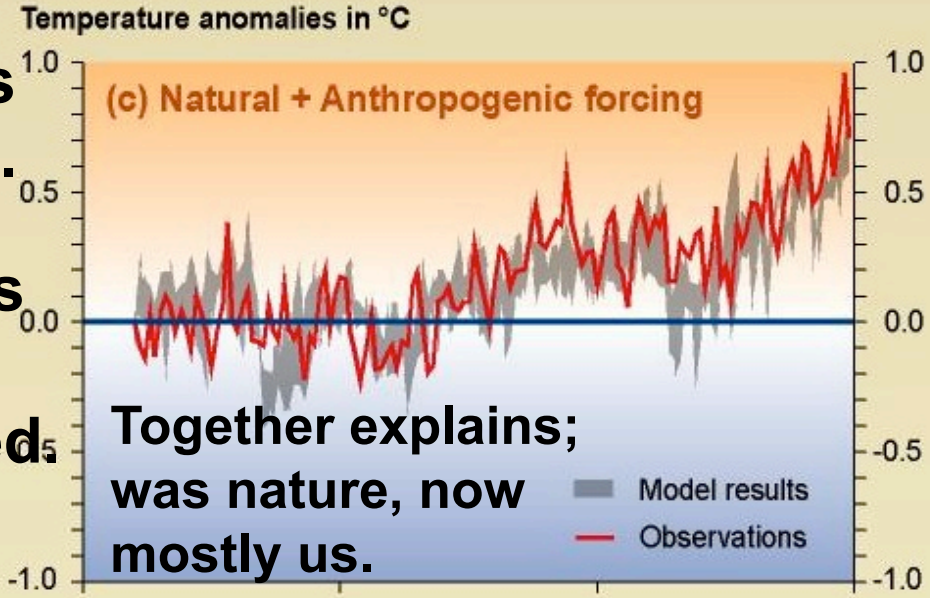
Comparison between modeled and observations of temperature rise since the year 1860



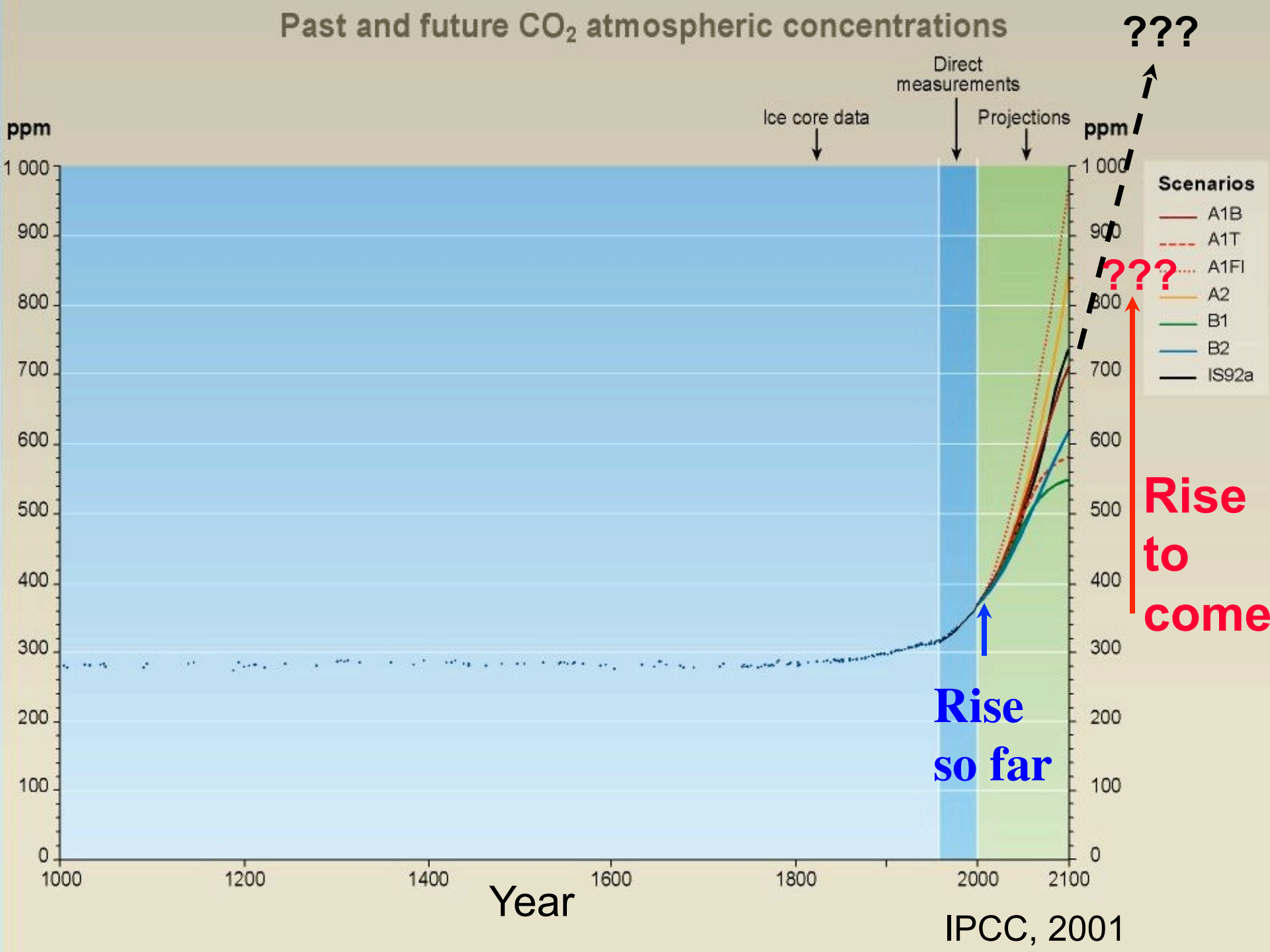


Red shows what happened.

Gray shows what model thinks happened.



IPCC, 2001


Past and future CO_2 atmospheric concentrations
???
Direct measurements
Ice core data
Projections
ppm
ppm
1 000
900
800
700
600
500
400
300
200
100
0
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
???
Rise to come
Rise so far
1000
1200
1400
1600
1800
2000
2100
Year
IPCC, 2001

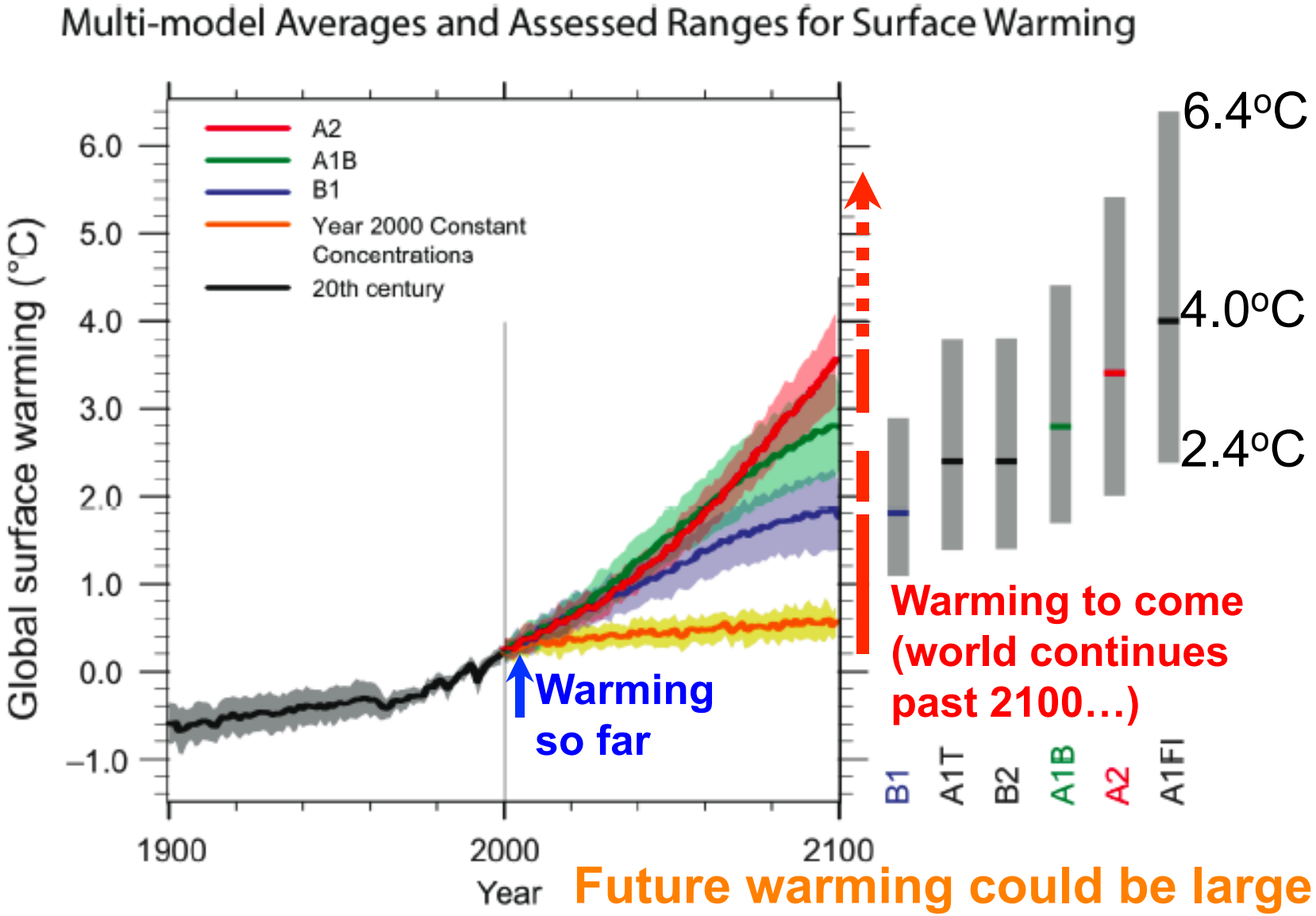


FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}

Likely impacts

→Grain-belt drying and crop heat stress

→Sea-level rise

→Tropical diseases no longer frozen

→Loss of unique ecosystems, especially with humans in way of migration

→Tropical cyclones that form likely to become larger (more energy/fuel)

→More floods and more droughts (more water in air; faster drying)

Economics

- Over decades, damages grow to few % of world economy per year (1%≈$600 billion);
- Fix ≈1% of world economy per year, after a few decades of serious effort and investment in learning how;
- Economically best to start investing now to head off warming, then ramp up;
- (Well, economically best to start a while ago, but too late for that now…

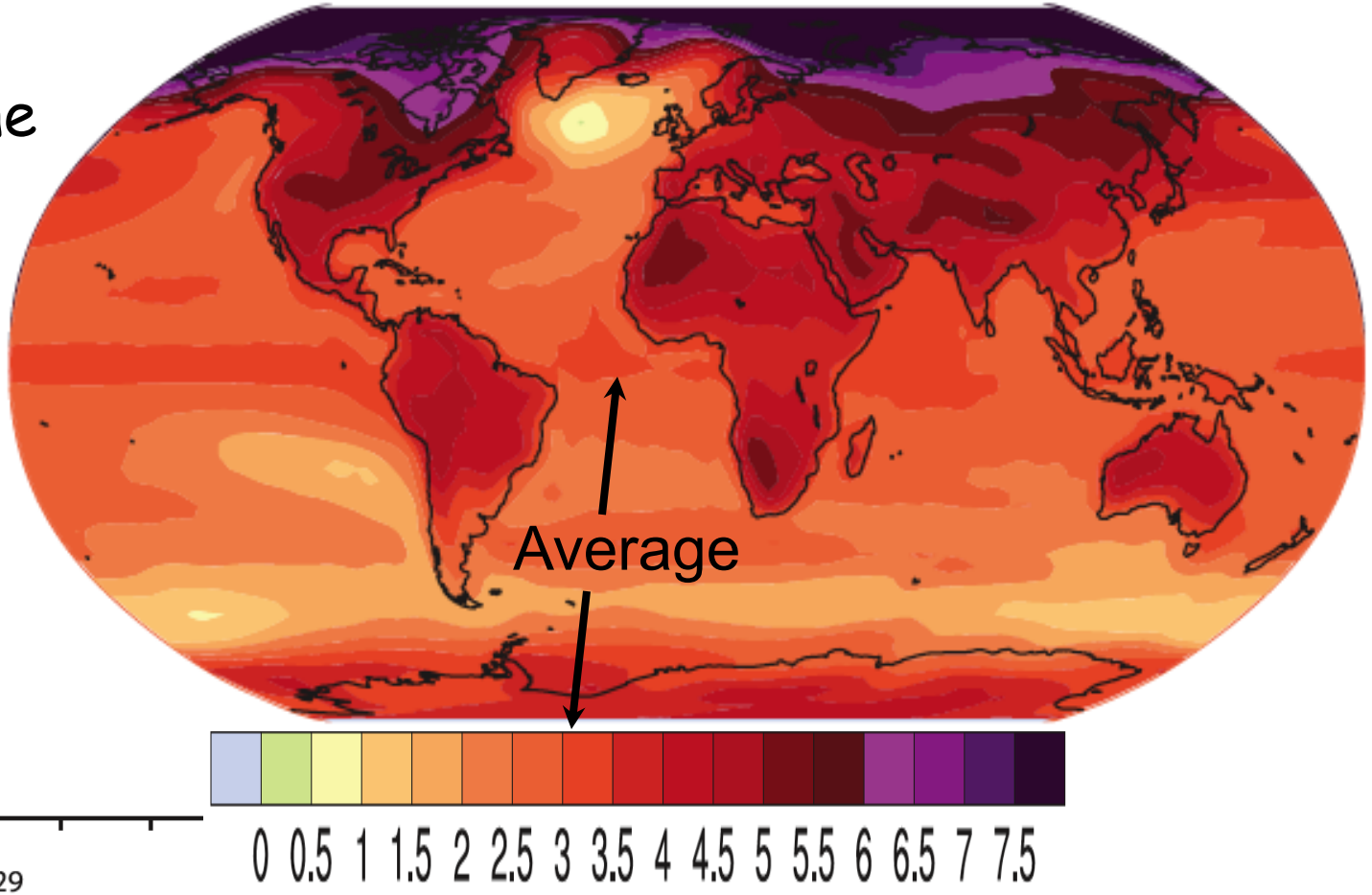
An issue of fairness?

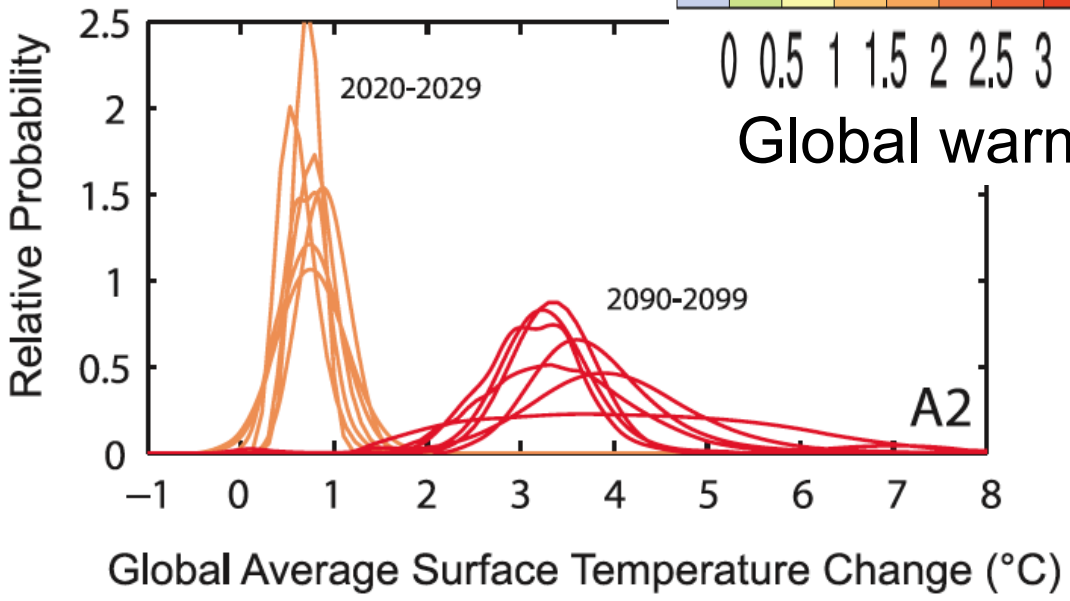
- If you have winter, air conditioners, and bulldozers, a little warming not too costly and may even help economy (too much hurts); if any missing, warming hurts;
- Most warming being caused by people with winter, air conditioning and bulldozers;
- Our emissions hurt others more than us;
- We legally must clean up toilets and some things from smokestacks so others can drink and breathe…

If this picture is wrong, it probably is optimistic:

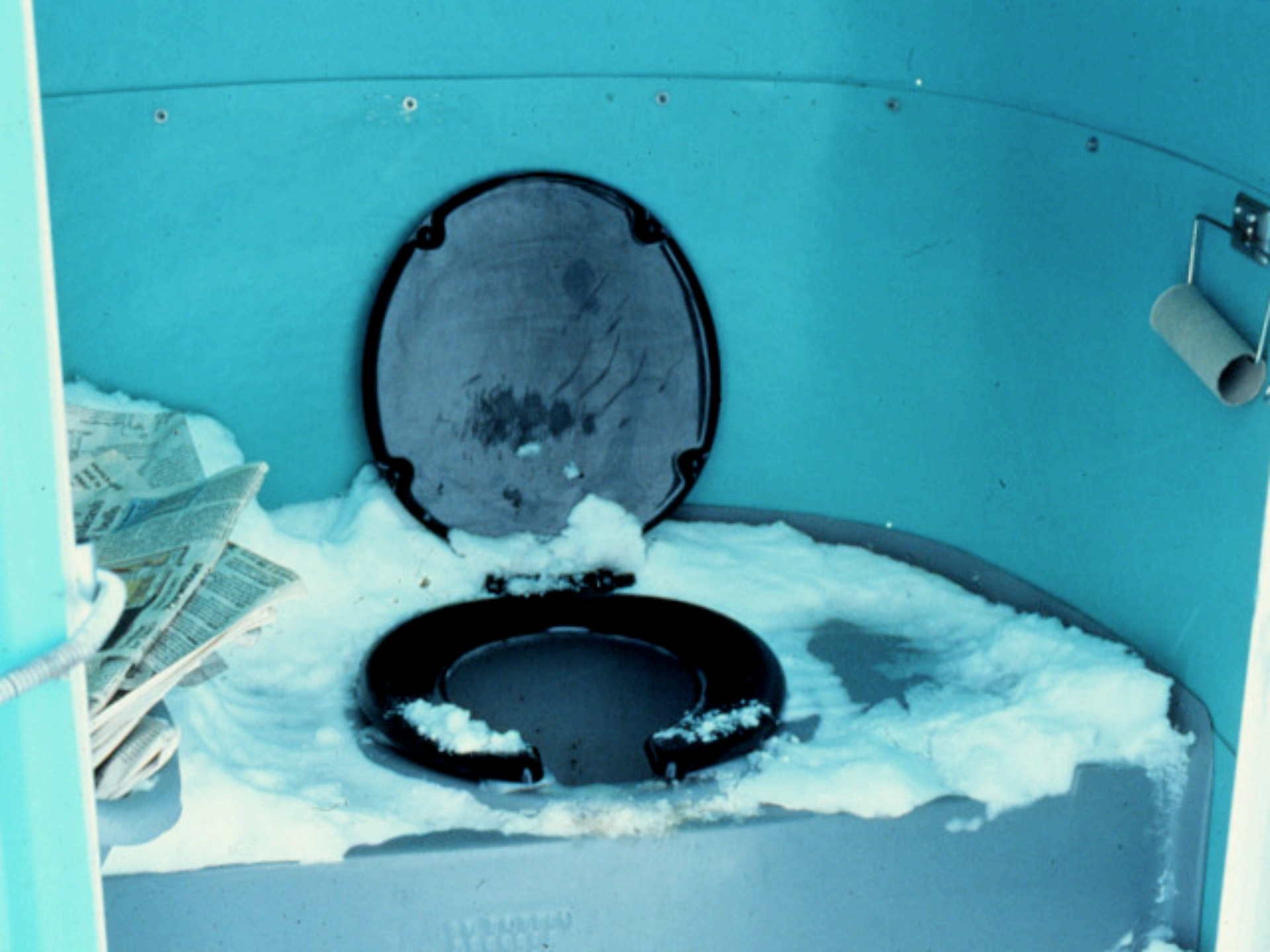
- Models more often underestimate than overestimate past changes (my view of science);
- Projections smooth but world isn't; abrupt changes harder to handle (north Atlantic shutdown, droughts, ice-sheet collapses, etc.);
- Skewed climate sensitivity (typically, estimates of warming give central estimate, possibility of slightly better, slightly worse, or much worse);
- Economically, uncertainties motivate MORE action now, not less (buy insurance against the unknown).

Lake Wobegon: Almost everyone experiences above-average warming (most people live on land, which warms faster than global average).

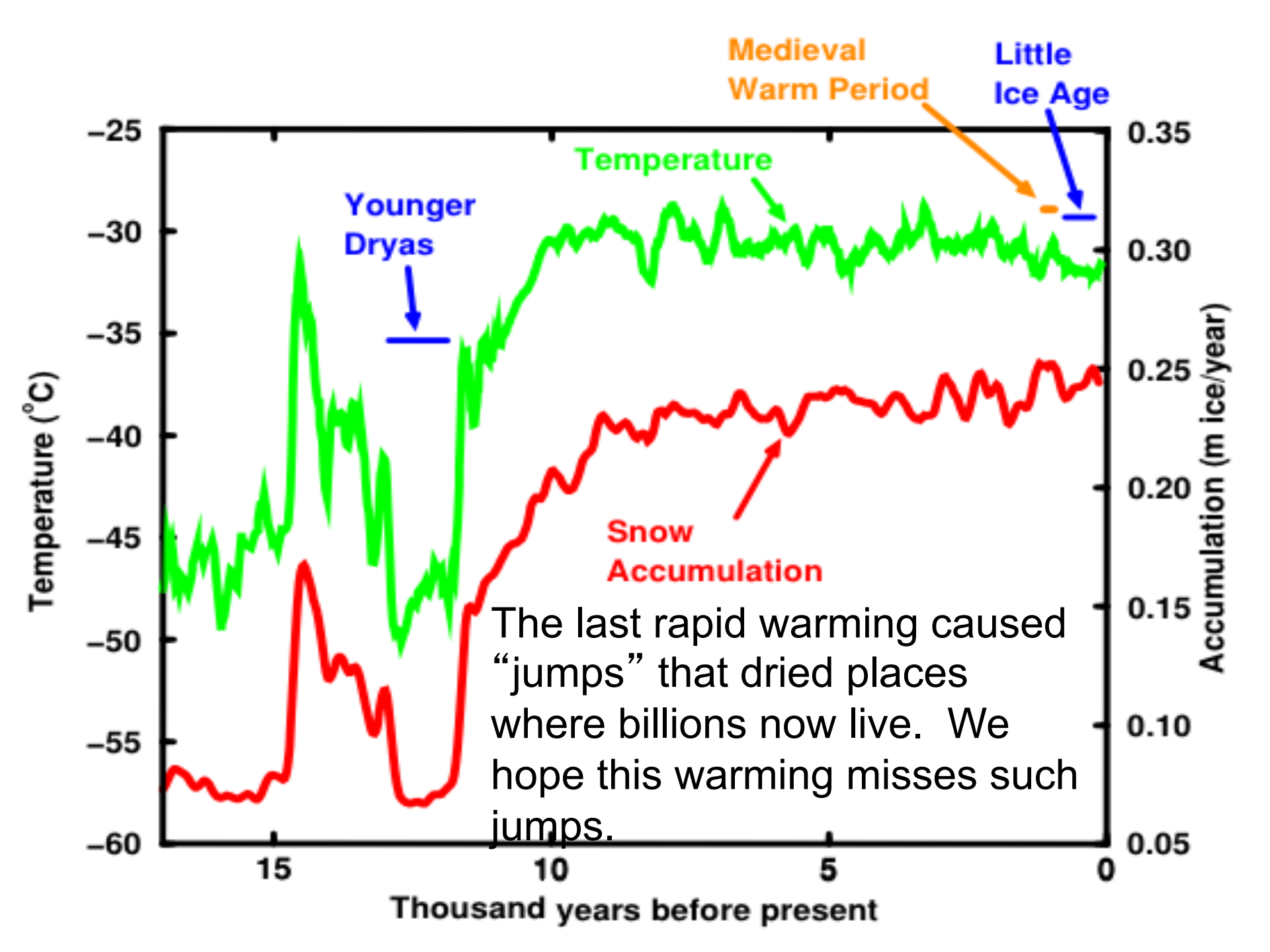




With chance of a little better, a little worse, or a lot worse.



Penn Staters Kurt Cuffey, Wanda Kapsner studying ice cores, central Greenland (NSF-sponsored GISP2 project)


Medieval
Warm Period
Little
Ice Age
Temperature
Younger
Dryas
Snow
Accumulation
The last rapid warming caused "jumps" that dried places where billions now live. We hope this warming misses such jumps.
Temperature (°C)
Accumulation (m ice/year)
Thousand years before present
−25
−30
−35
−40
−45
−50
−55
−60
0.35
0.30
0.25
0.20
0.15
0.10
0.05
15
10
5
0

NSF US Antarctic Program (Penn Staters Don Voigt, Huw Horgan, Sridhar Anandakrishnan CReSIS

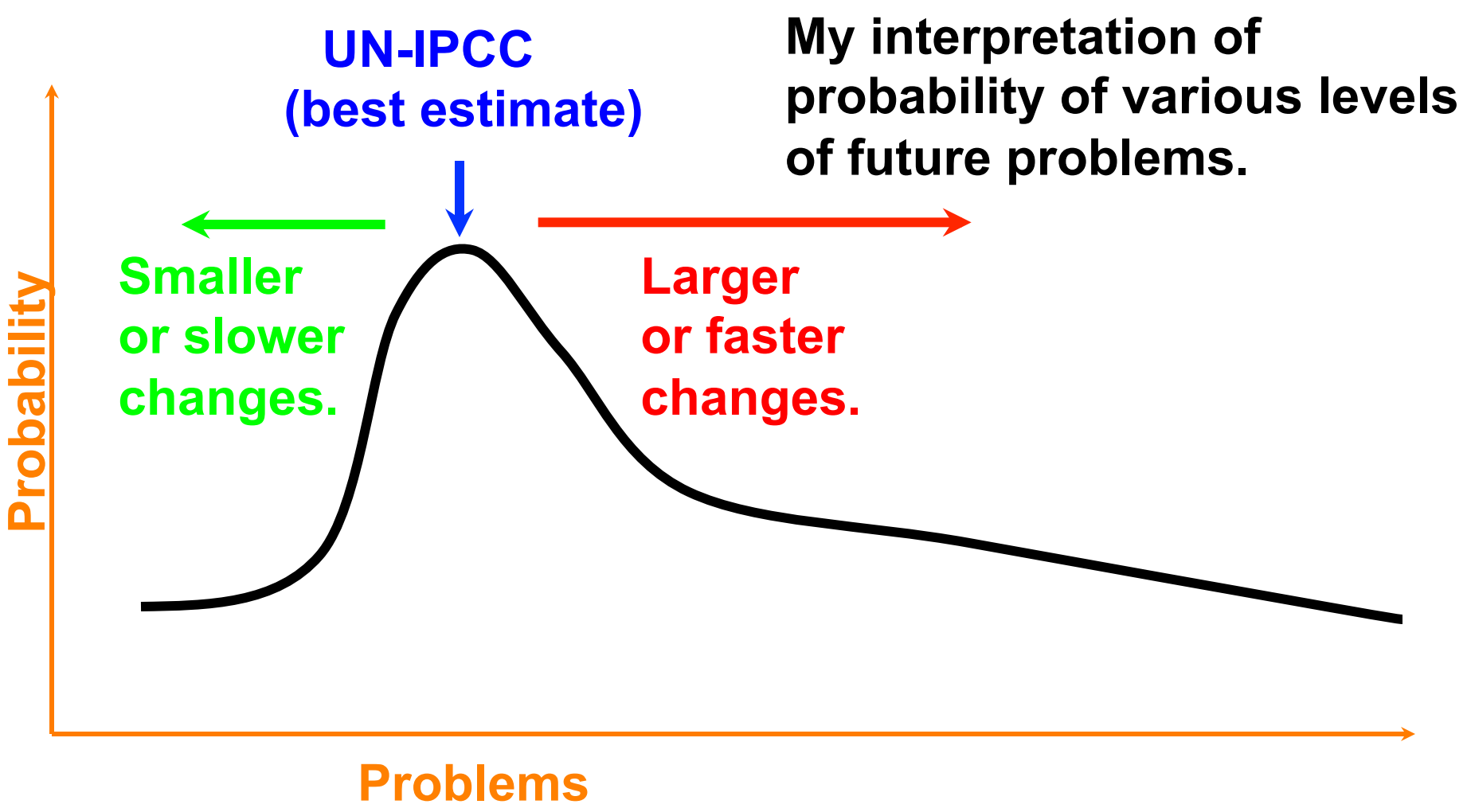
IPCC on ice sheets:

- 2001: much uncertainty, but expected snowfall to rise more than melting, little change in flow, net growth 21st century;
- Then: ice sheets responded to warming by shrinking, with ice-flow accelerations;
- 2007: **"Models used to date do not include…the full effects of changes in ice sheet flow, because a basis in published literature is lacking… understanding of these effects is too limited to… provide a best estimate or an upper bound for sea level rise."**

No agreed-upon worst case; maybe 3-4x this rise?
Don't believe this could happen faster than centuries, but we might in decades reach the level that would commit us to this over centuries. Generally NOT in cost/benefit projections.

Scary thought

"…the wetbulb temperature...today…never exceeds 31 °C. Any exceedence of 35 °C for extended periods should induce hyperthermia in humans and other mammals, as dissipation of metabolic heat becomes impossible…this …would begin to occur with global-mean warming of about 7 °C, calling the habitability of some regions into question. With 11–12 °C warming, such regions would spread to encompass the majority of the human population as currently distributed. Eventual warmings of 12 °C are possible from fossil fuel burning." Sherwood & Huber, PNAS, 2010



Most US debate seems to pit “UN-IPCC best estimate” against “smaller or slower changes”; most of the room seems to be in “larger or faster changes”.

For Global Warming:

- Physics, history show warming effect of raising CO_2
- This is not opinion or politics, there is no serious alternative to this, it is not called into question by anyone's emails, it is simply science
- Best science says that ignoring this will be more costly than dealing with it
- And, the uncertainties are primarily on the "bad" side—the less you trust climate science, the more you should be worried by global warming
- But, there are lots of ways to deal with it
- If we burn then learn, we will have made life harder for modern poor people and most future people.

For Energy :

- Our modern energy system is grossly unsustainable, and probably the most unsustainable part of our lifestyle;
- Energy really does help us, but a whole lot of people can't afford that help now, with prices likely to rise (perhaps a lot!) unless we improve our technologies;
- More than enough energy is available that we haven't learned how to use economically in large enough quantities;

Maximum Available Energy:

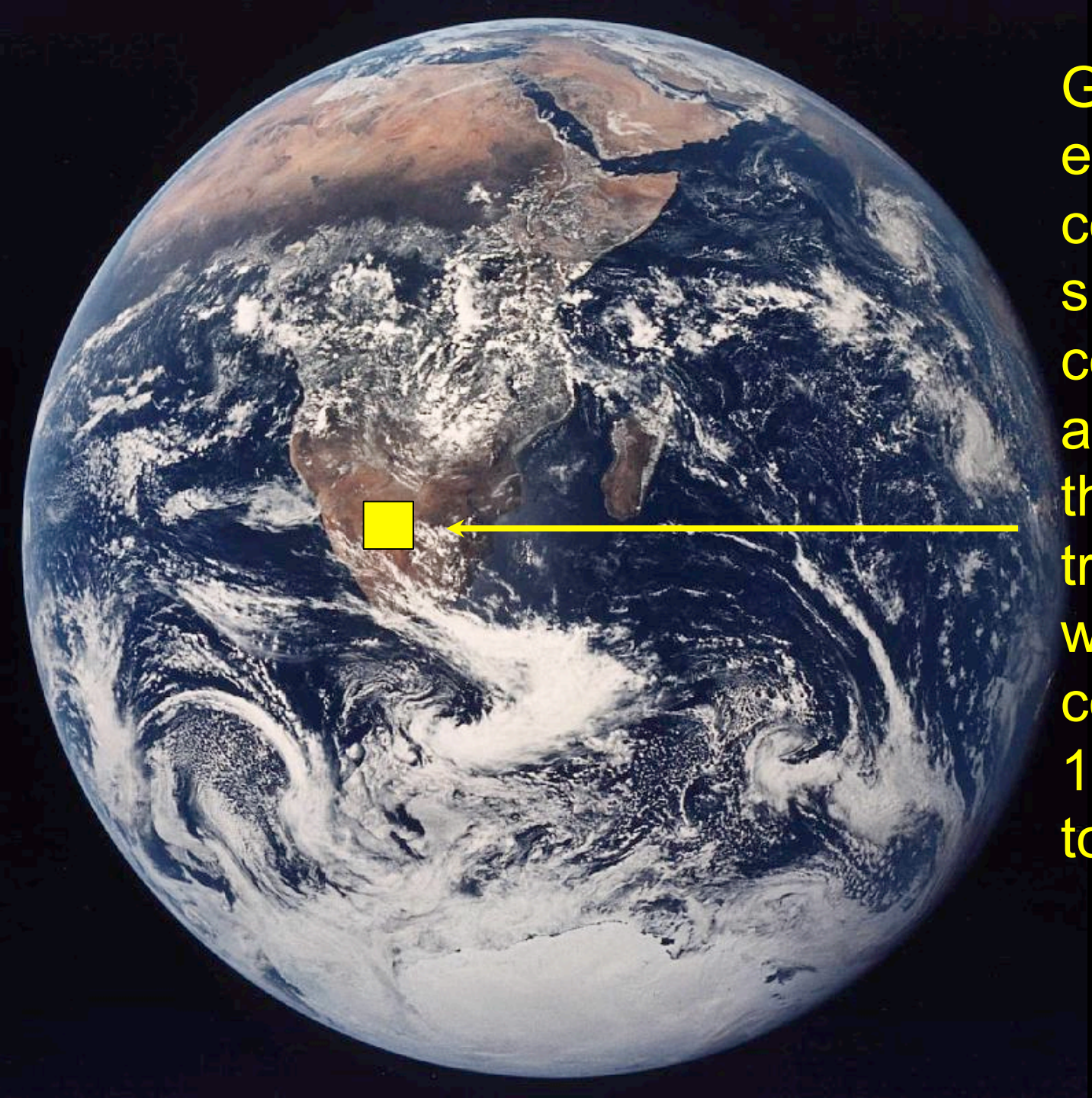
- Sun 173,000 TW
- Wind 1220 TW
- Plants 166 TW
- Waves & currents 65 TW
- Geothermal 44 TW
- Human use today 15 TW
- Tides 4 TW
- Hydroelectric 1.9 TW

For Energy :

- Building a wind farm on windy parts of deserts and plains would generate ~5x more energy than world use (On land that is not city, forest or ice, with enough wind to run at >20% capacity; Lu, McElroy and Kiviluoma, 2009, Global potential for wind-generated electricity, Proceedings of the National Academy of Sciences of the USA 106, 10,933-10,938)
- Some issues with batteries if a lot of wind is used, but wind is generally competitive now
- Modern price ~$1 trillion/year for 30 years to install windmills to power world—U.S. alone spends over $1 trillion/year on energy
- HUGE challenge but surely NOT impossible

The US rate of windmill installation a century ago, if repeated today with modern wind turbines, would supply 1/3 of WORLD energy use from wind in 30 years.

Photo by Geoffrey Haines-Stiles for Earth: The Operators' Manual, Texas



Global human energy use could be supplied by covering approximately this area of a tropical desert with solar cells converting 10% of sunlight to electricity.

For Energy :

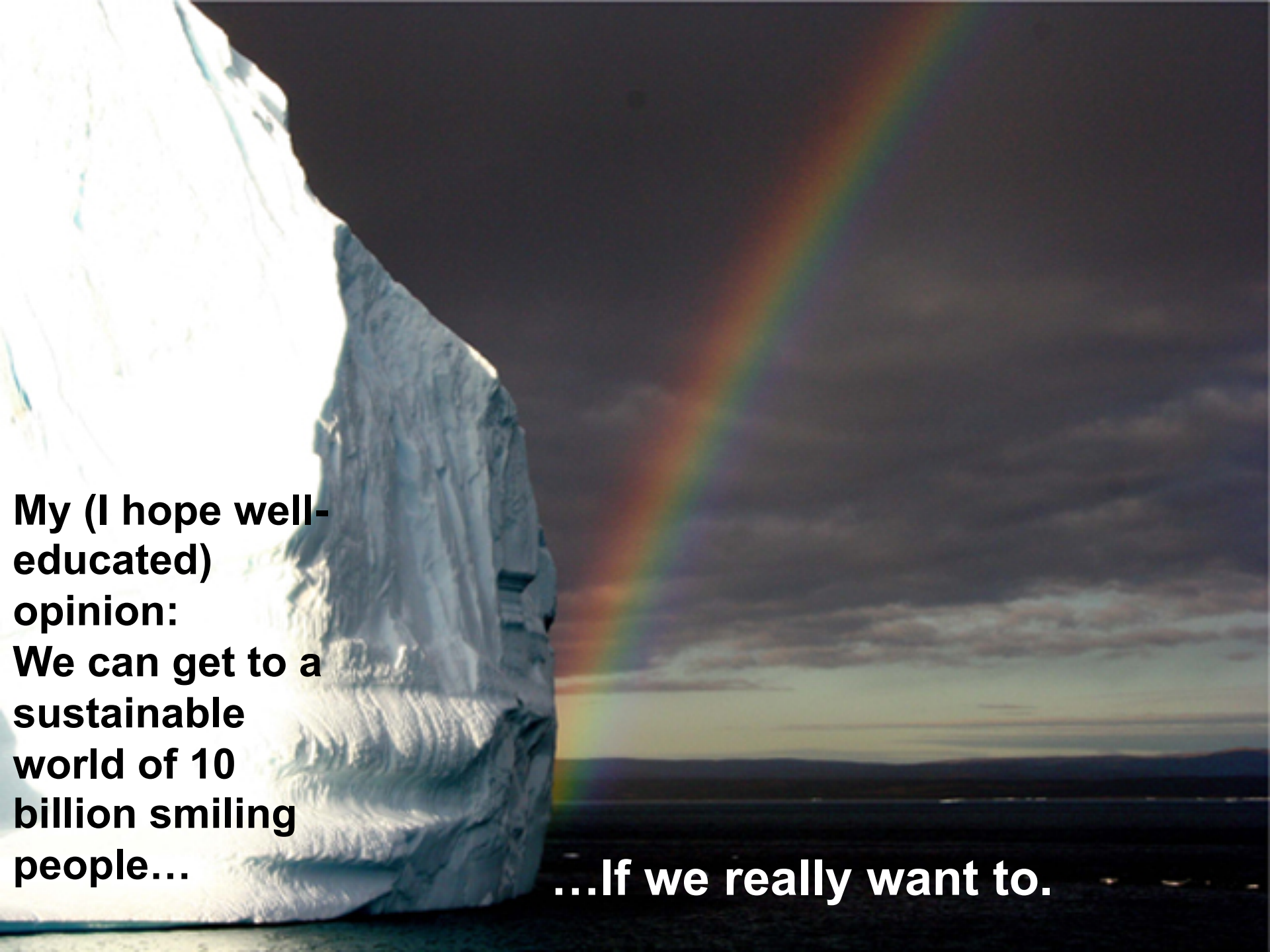
- Surely lose good jobs in fossil-fuel industries if we move to other sources
- But, available scholarship says alternatives (wind, sun, nuclear, conservation, wave…) make as many or MORE jobs than fossil fuels
- Note "asymmetry"—job losers know who they are, but larger group of job gainers don't
- Pentagon's ***Quadrennial Defense Report*** notes national-security gains from response
- And, essentially all available scholarship shows global economic gains from responding

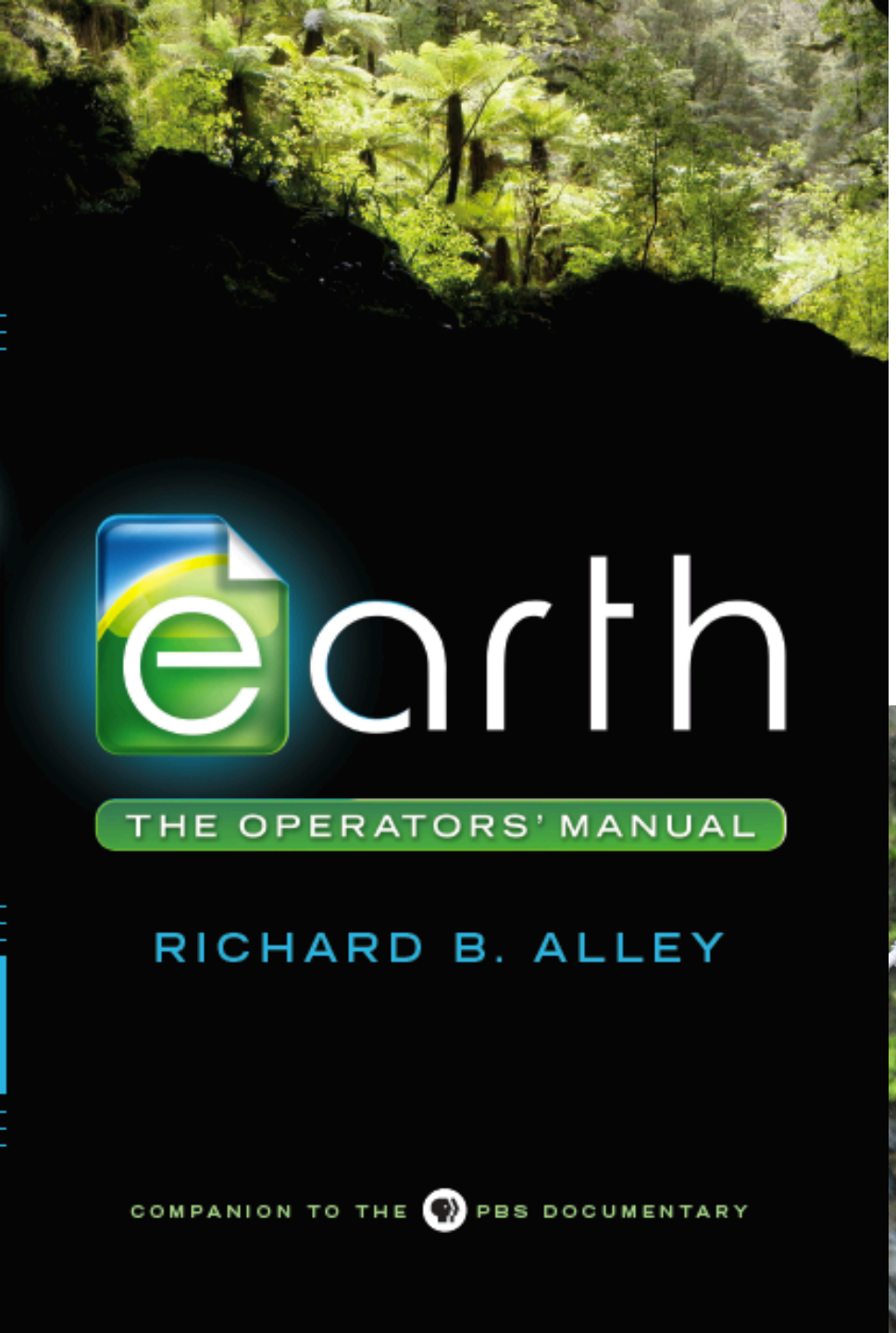
Economic Disaster? Scenario 16…

- We tax tobacco to reduce smoking, and alcohol to reduce drinking, and then we tax wages…
- Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009, H.R. 2454, in the 111th Congress, Appendix, 1/29/10;
- Scenario 16–Revenue recycling to reduce labor taxes; all allowances modeled as being returned to households by lump sum in Scenario 2 are instead auctioned and the revenue used to reduce taxes on labor;
- Economy grows faster for next few decades than under business as usual;
- Up to some limit, taxing things we don't want (climate-changing carbon emissions) rather than things we do want (labor) makes economy grow faster.

This does not tell you what to do!

- My thoughts: many people learned their science from those favoring certain policies, causing others to adopt "science" that supports their policies;
- Some problems can be solved individually or by small groups, and others can be solved by large institutions without much help from individuals—energy is so large that a solution will require institutions and individuals;
- We 've done bigger things (WWII, or the switch from chamber pots and outhouses to sewer and clean water);
- We' ve never agreed to solve something this big;
- Decisions involve values, politics, jobs, taxes, security, and more—but we are arguing in public about well-established physics rather than the big questions.


My (I hope well-educated) opinion:
We can get to a sustainable world of 10 billion smiling people…
…If we really want to.



Earth—The Operators' Manual **TV, web, museum tour, book

**Accessible, apolitical, authoritative, and a lot of fun

**Streaming at PBS, www.earththeoperatorsmanual.com