

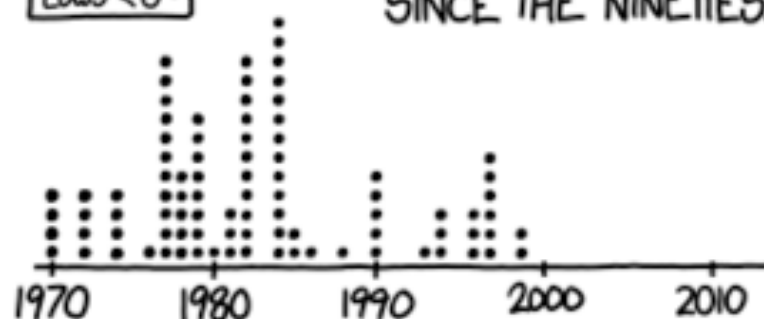
IT IS **BRUTAL** OUT. SO MUCH
FOR GLOBAL WARMING, HUH?

WHAT?
SIGH
THIS USED TO HAPPEN
ALL THE TIME.



YOU'RE FROM ST. LOUIS, RIGHT?
ON AVERAGE, IT USED TO GET BELOW 0°F
THERE A HANDFUL OF DAYS PER YEAR.

DAYS WITH
LOWS < 0°F



BUT YOU HAVEN'T
HAD A DAY LIKE THAT
SINCE THE NINETIES.

SOURCE: RCC-ACIS/CLIMATECENTRAL

THEN, IN 2014, WHEN THE FIRST
POLAR VORTEX HIT, IT DIPPED
BELOW ZERO FOR TWO DAYS.
AND EVERYONE FREAKED OUT



BECAUSE WHAT USED
TO BE NORMAL
NOW FEELS TOO COLD.

IT IS TOO COLD!



THE FUTURE:

LOOK AT THIS—
ICE! IN **ST. LOUIS!**
SO MUCH FOR
GLOBAL WARMING.



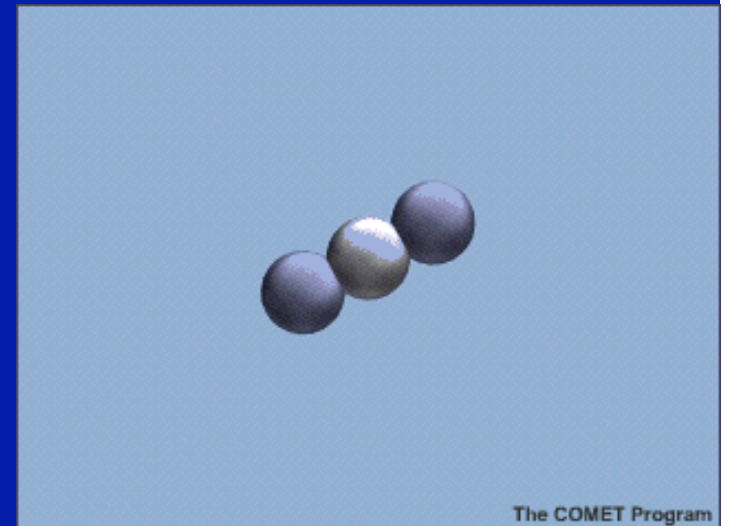
Capitalism vs. the Planet
Class 2: The Science
Facilitator: Gary Wyngarden

Jonathan F. Ormes

JFOrmes@comcast.net

Apr. 5, 2016

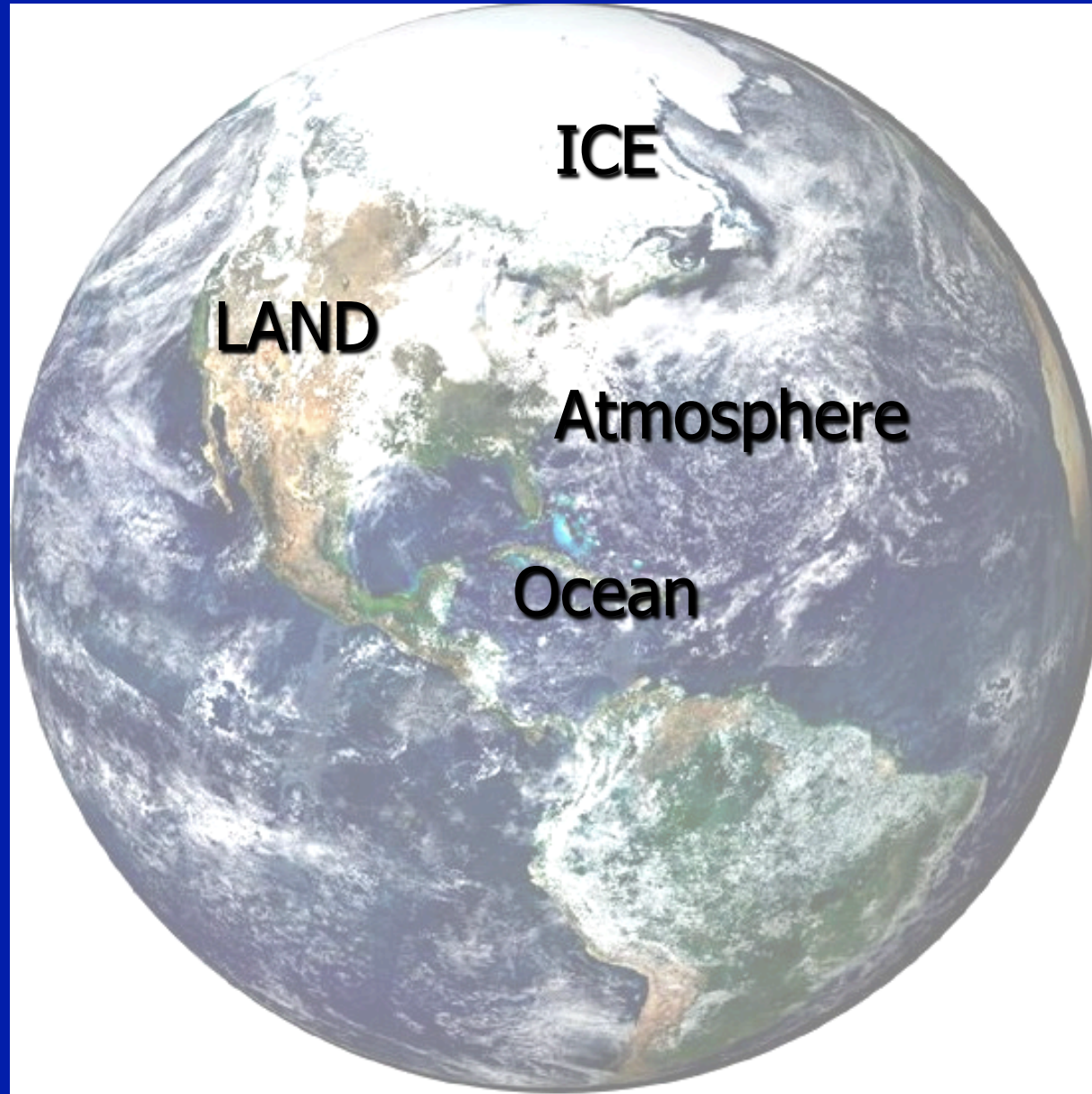
<http://portfolio.du.edu/OurClimate>



Outline: Part 1

- Climate vs. Weather
- The greenhouse effect
- How to answer deniers (on science questions), not that this will change their minds

The climate system



Climate: Long-term Average Weather

- If you don't like the weather, go indoors and wait
 - Icelanders say: "There is no such thing as bad weather, only bad clothing."
- If you don't like the climate, move

**“Climate is
what you expect;
weather is
what you get.”**

Climate must average over

- **Day-night**
- **Seasons**
- **Multi-year, even decades long,
Atmospheric and oceanic
oscillations**



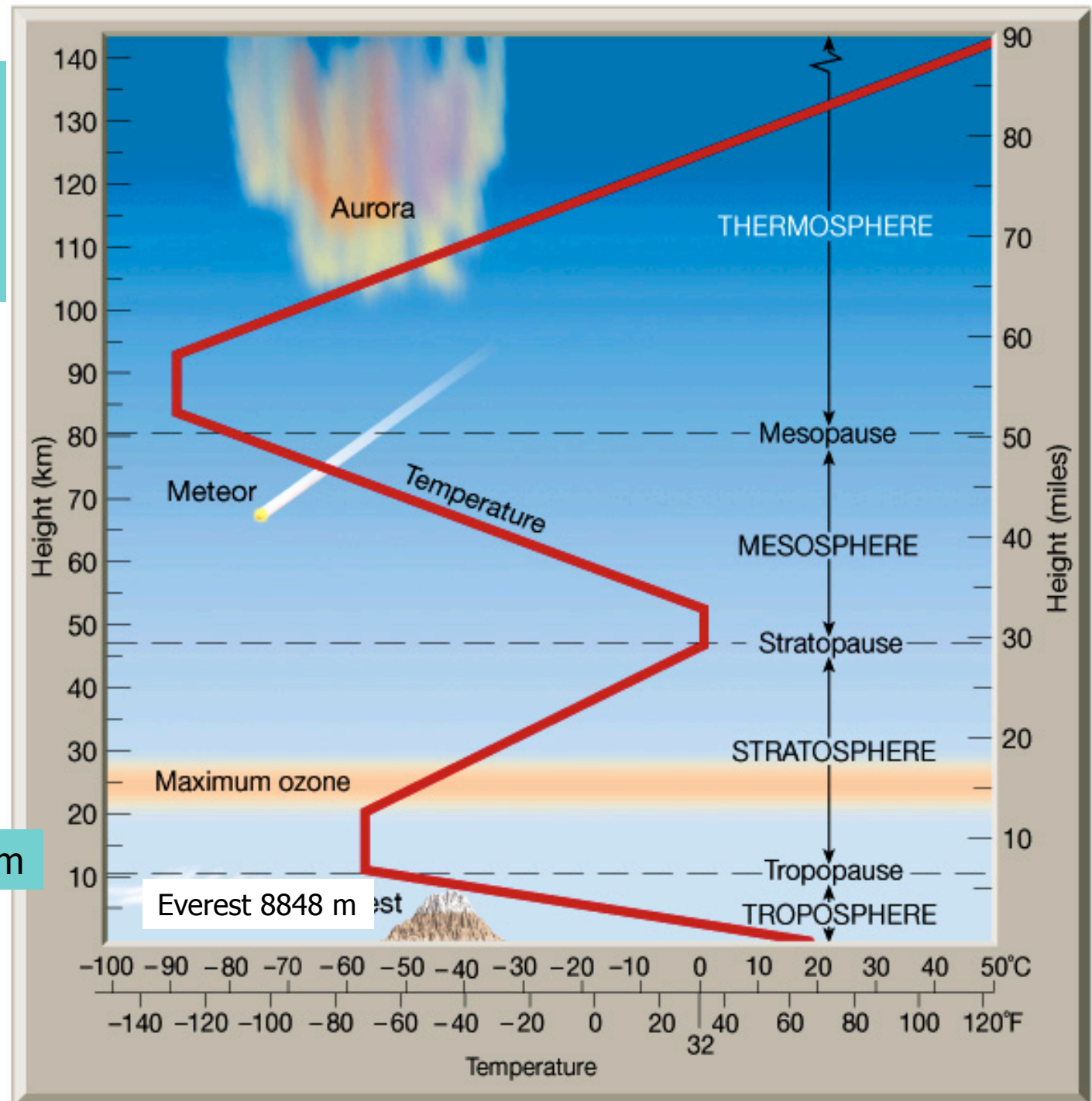
www.extremeinstability.com

collisions not
important
energetic particles
from sun
determine T

solar uv
breaks oxygen
makes O_3

radiative surface 10 km

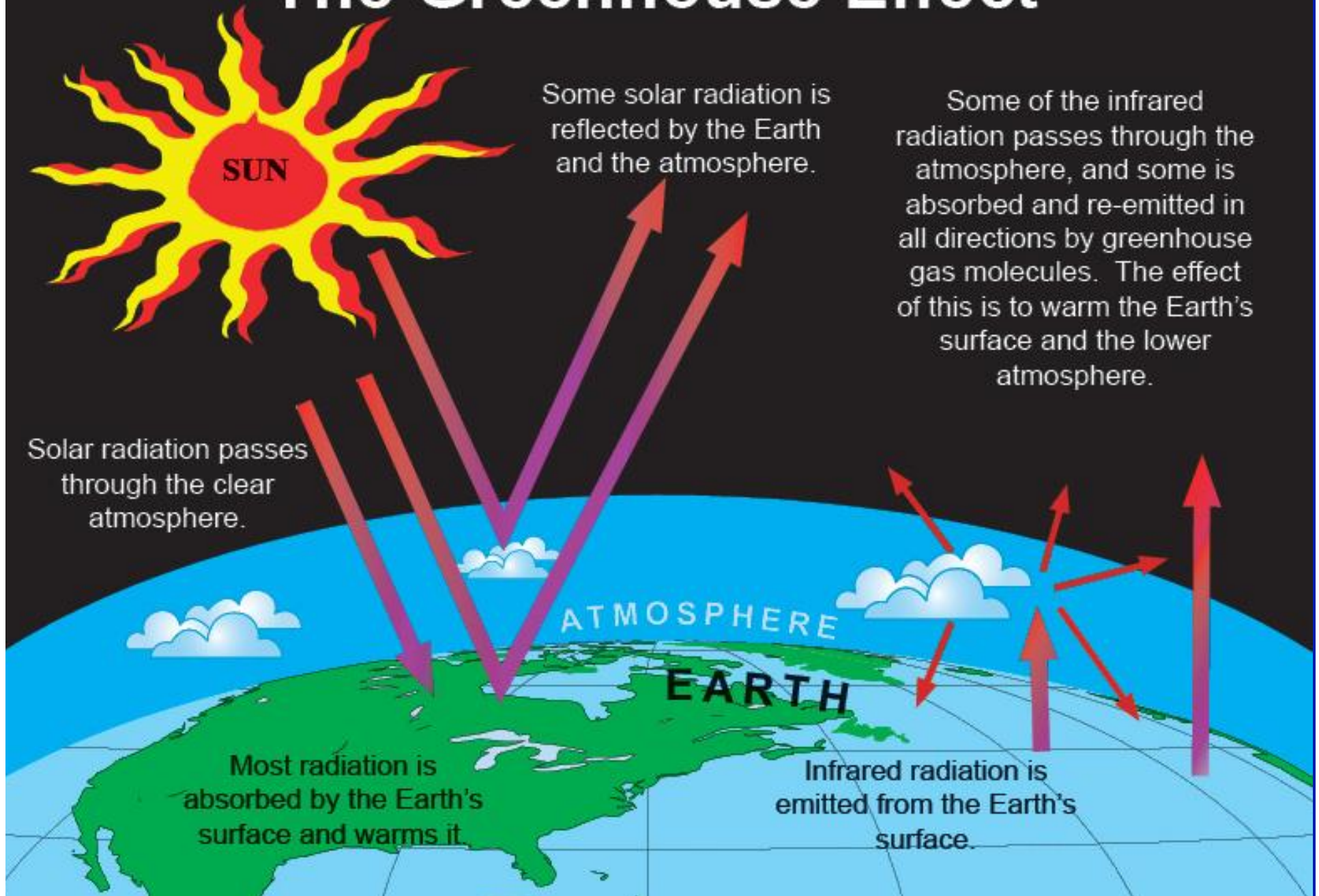
Weather &
greenhouse



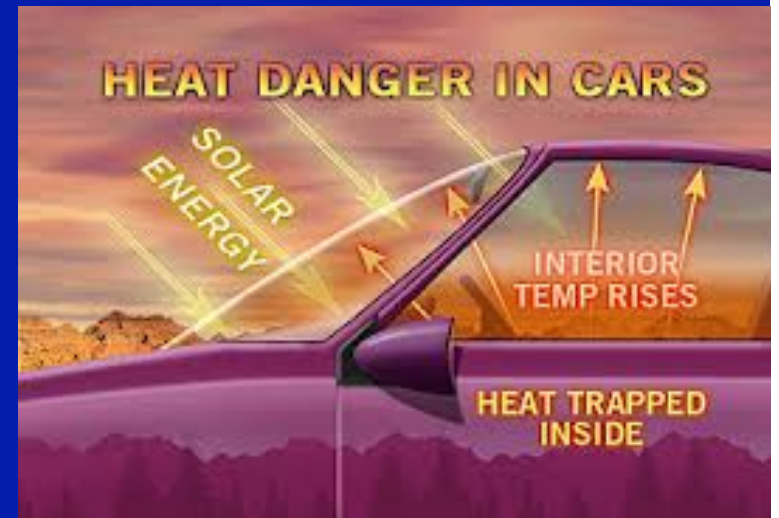
Some science

**CLIMATE CHANGE,
INFRARED RADIATION
AND CO₂**

The Greenhouse Effect



The Greenhouse Effect keeps the planet warm

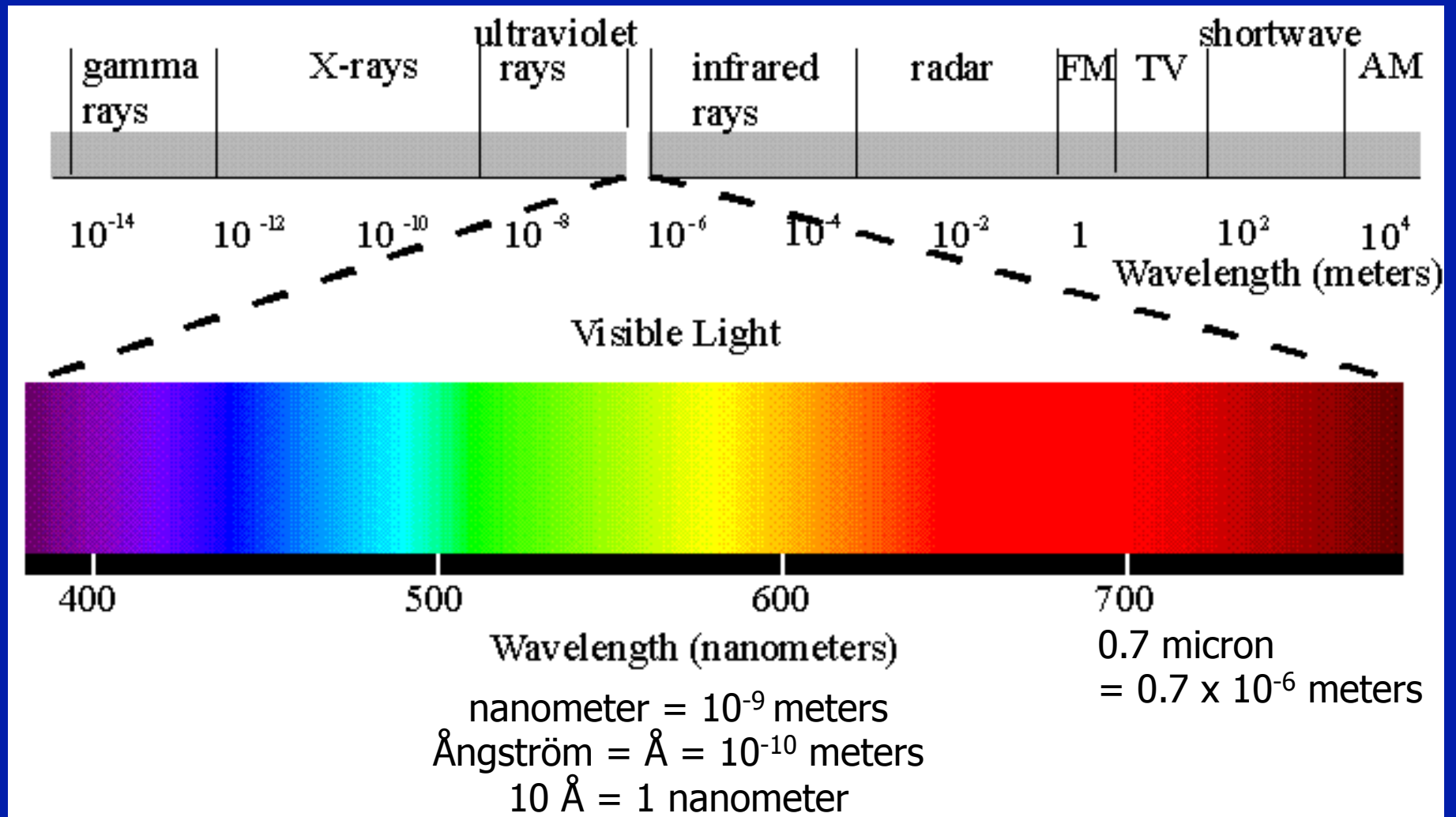


I have had a window blown out of my car left at an airport parking lot.

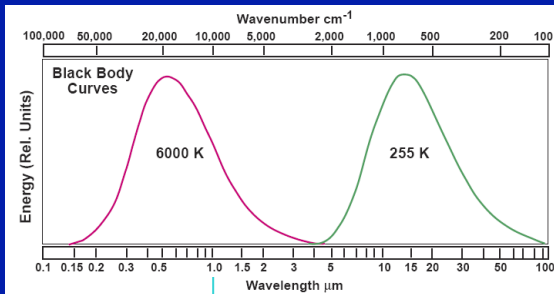


You DO know about heat radiation. Scientists call it infrared radiation.

Electromagnetic Spectrum



Sun



Earth

X-rays

ultraviolet
rays

infrared
rays

radar

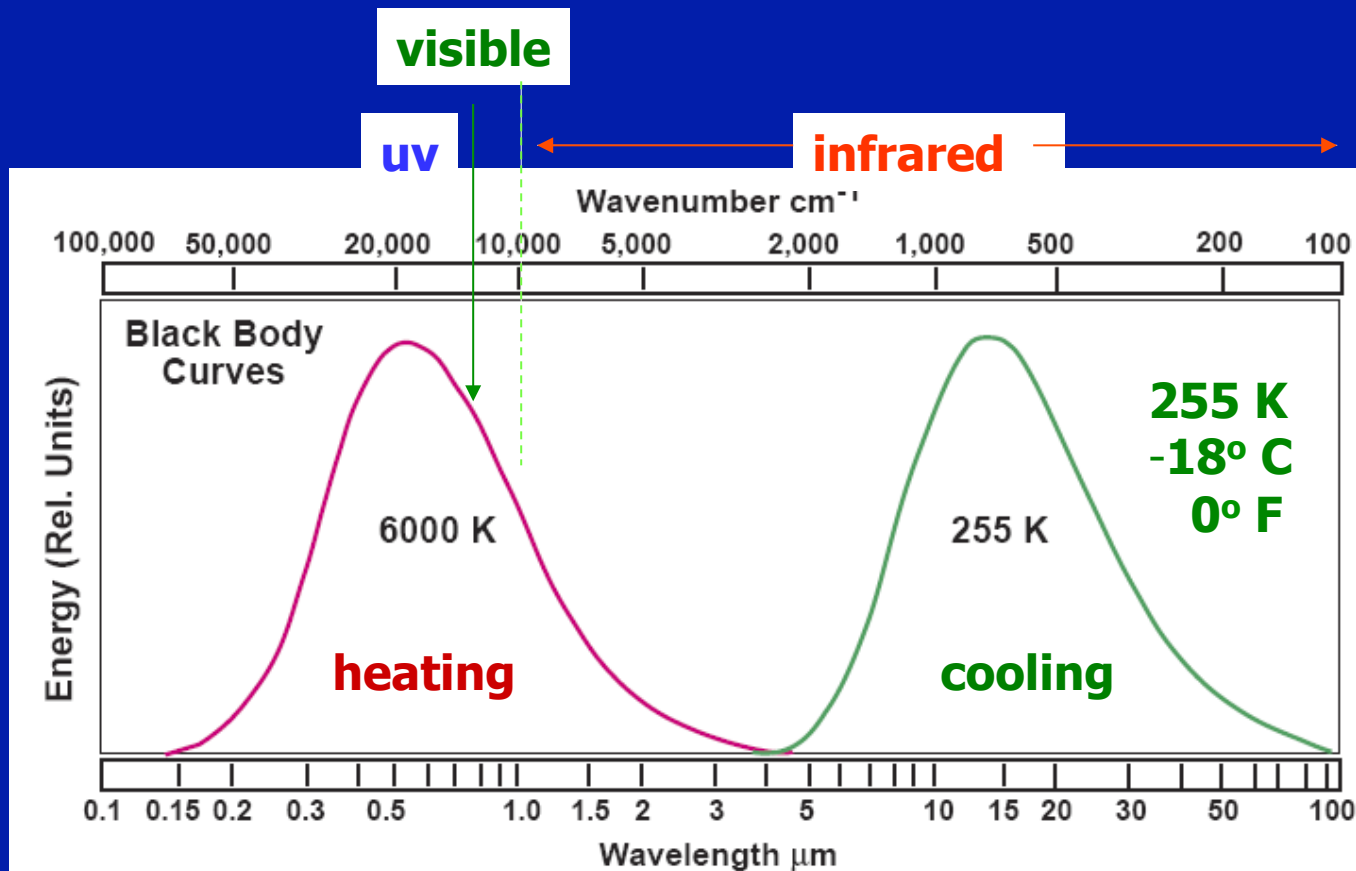
FM

10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1

Visible Light



Radiative equilibrium of the Earth

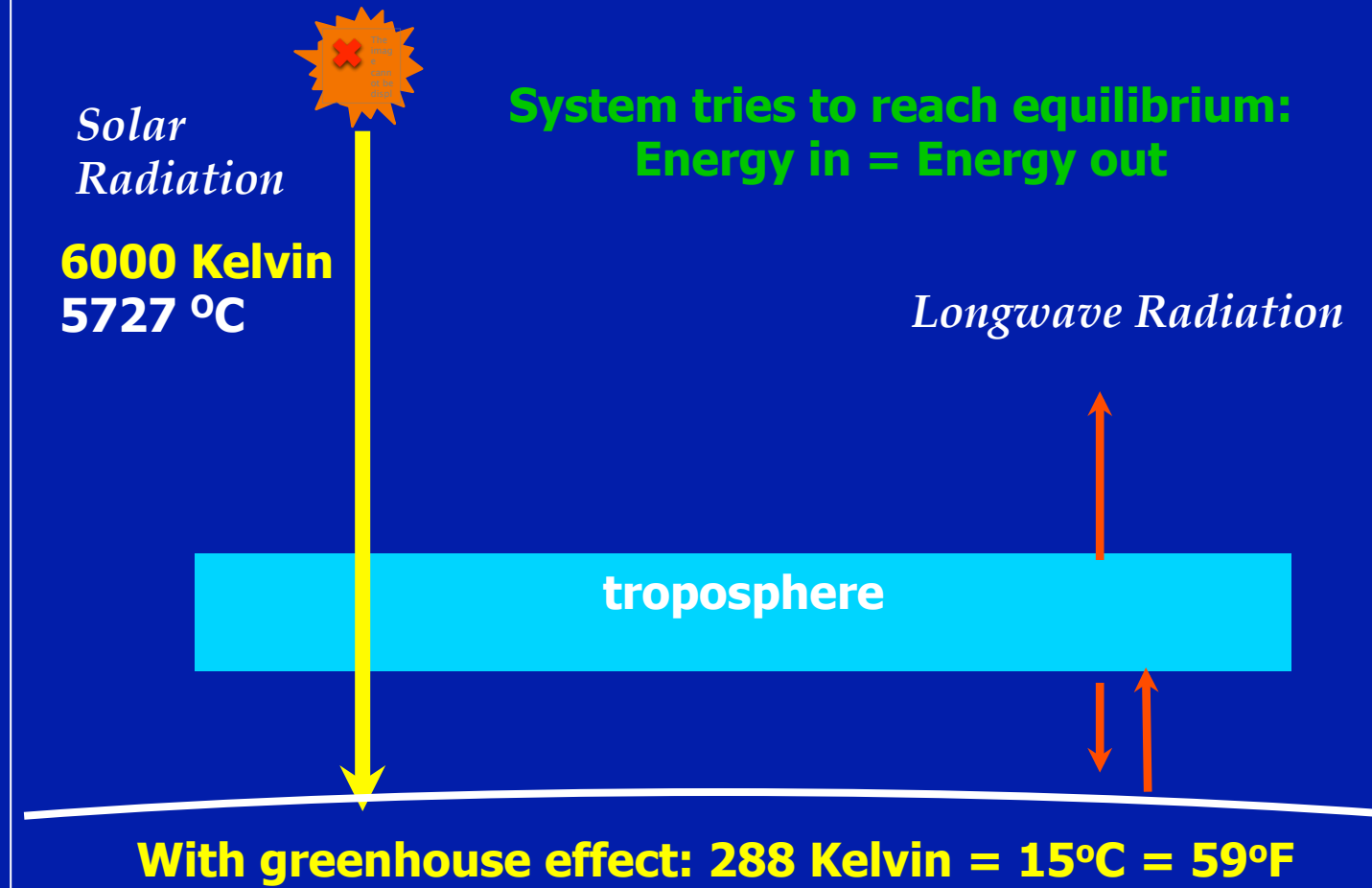


Wavenumber
 $\tilde{\nu} = 1/\lambda$

Figure 1. Blackbody Curves for 6,000 K and 255 K
(from Luther and Ellingson 1986)

Earth is 33 °C (59°F) warmer than it would be without the current greenhouse effect. The effect is real.

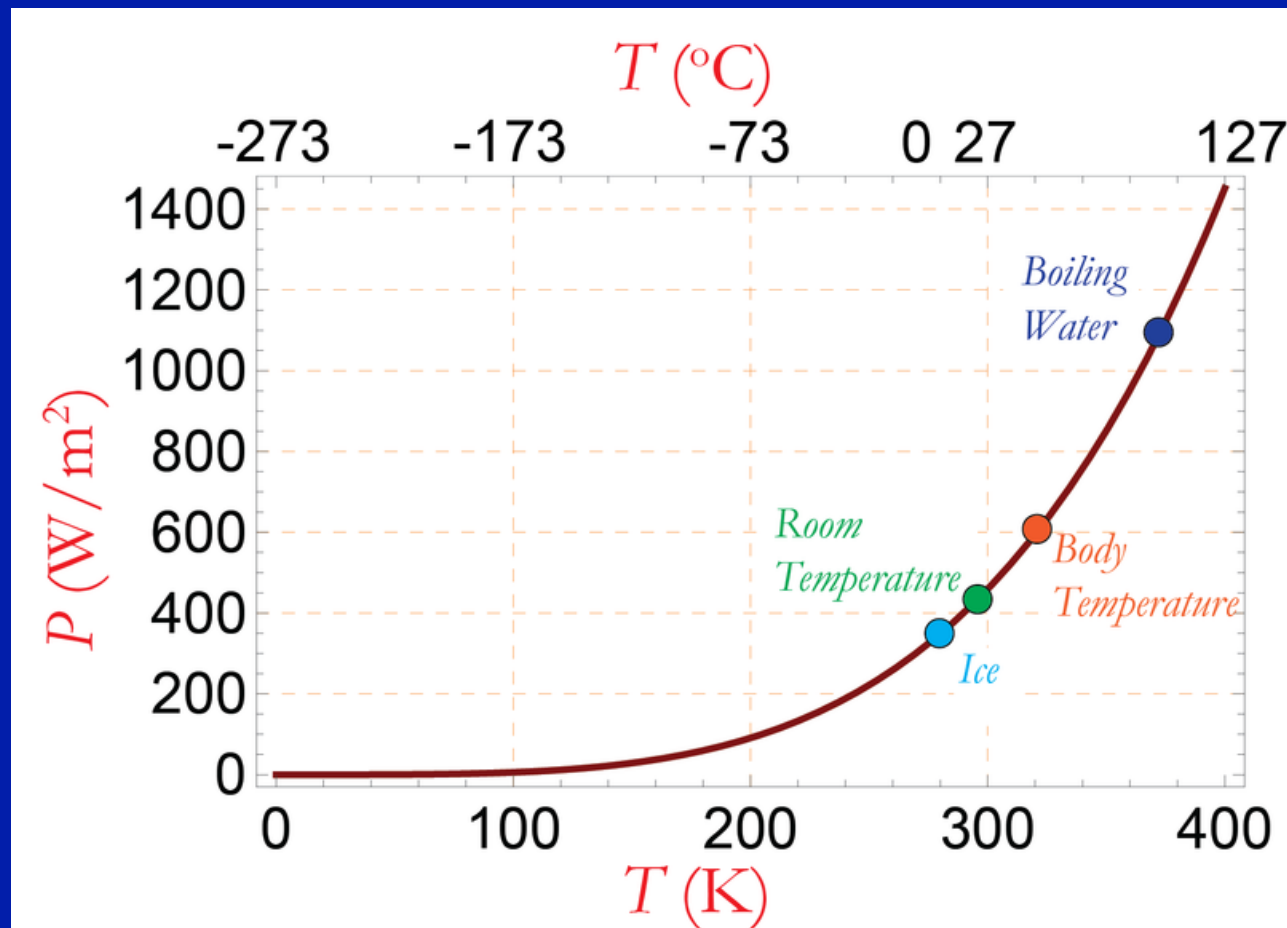
The Greenhouse Effect



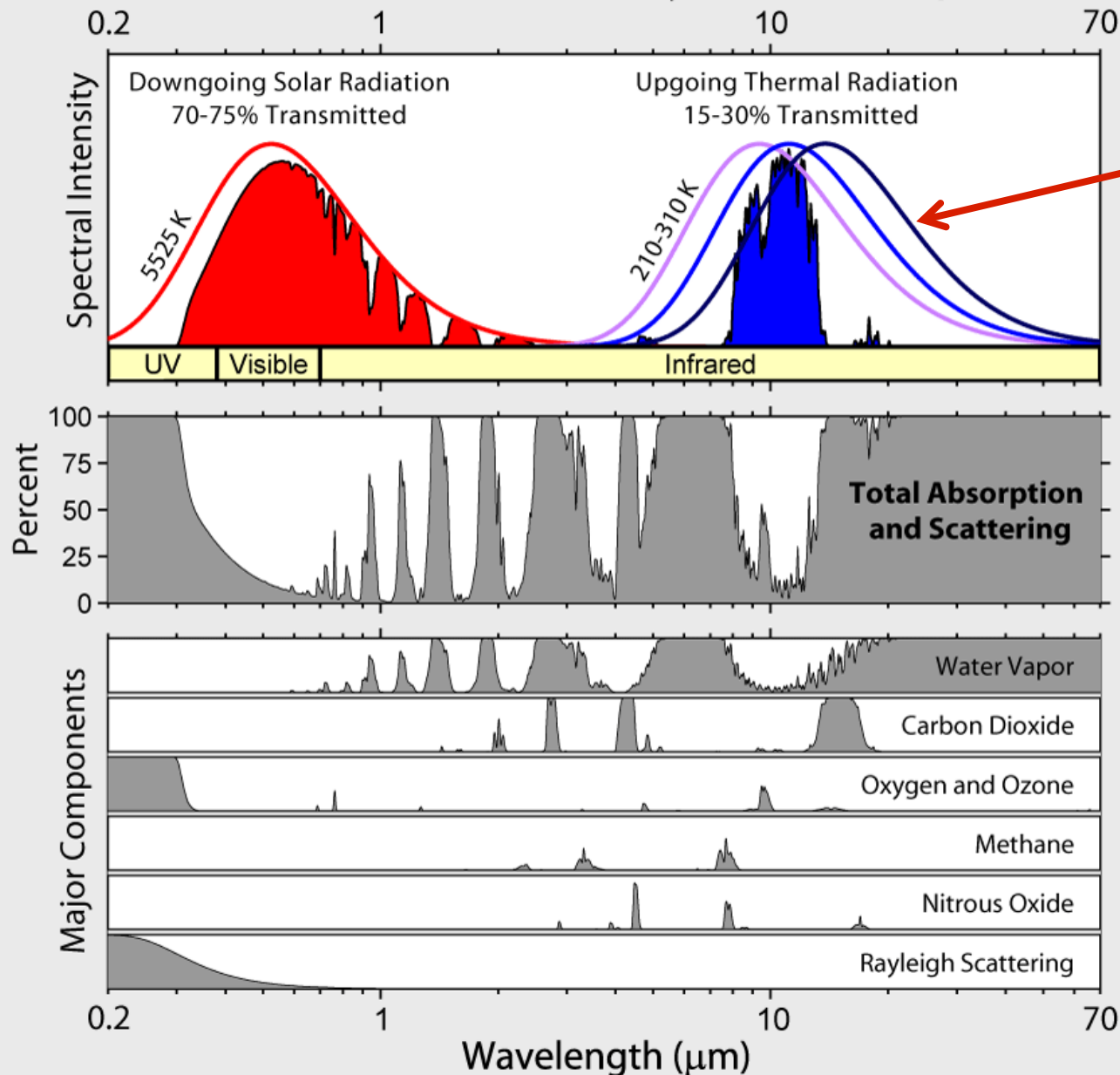
Without greenhouse effect: 255 Kelvin = -18°C = 0°F

The human zone

$$\text{Power emitted} = \sigma T^4$$



Radiation Transmitted by the Atmosphere

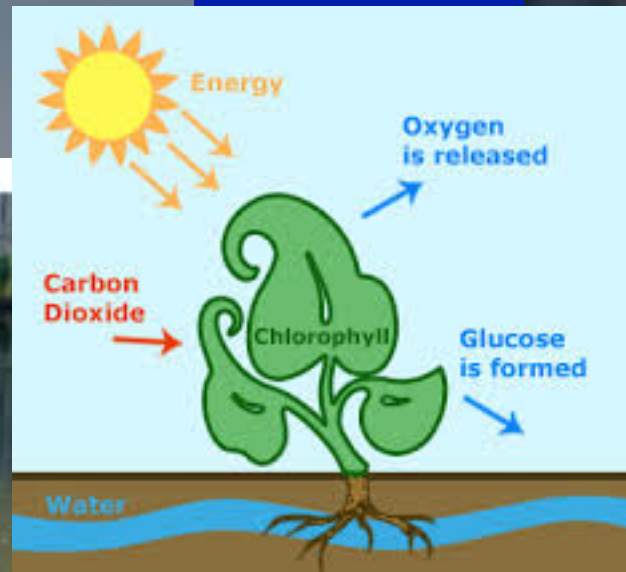


Emission spectra for a range of temperatures.

210 K or -63°C is the winter temperature at the south pole.

I would have put the maximum temperature slightly higher, 45°C or 318 K.

CO_2 is a natural gas.
It is released by breathing fauna and taken
up by plants during photosynthesis.
All life depends on it.



CO₂ is a colorless, odorless gas

How the heck can it control the climate?



Frozen CO₂ is dry ice



**You see it on your breath on a cold day.
It makes the bubbles in your soda.**

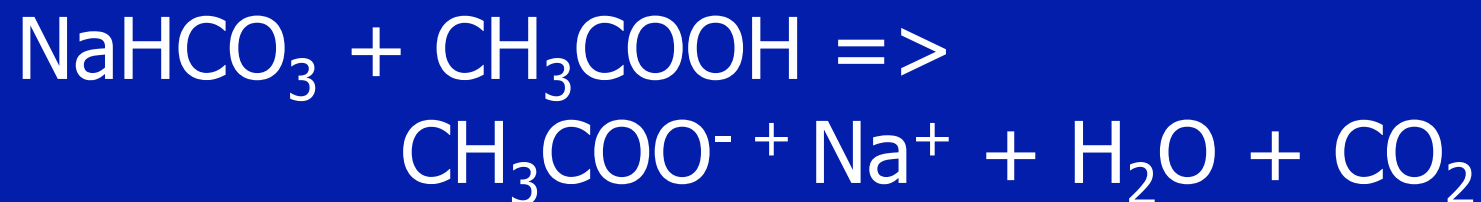
It is not “clear” or colorless to heat radiation.



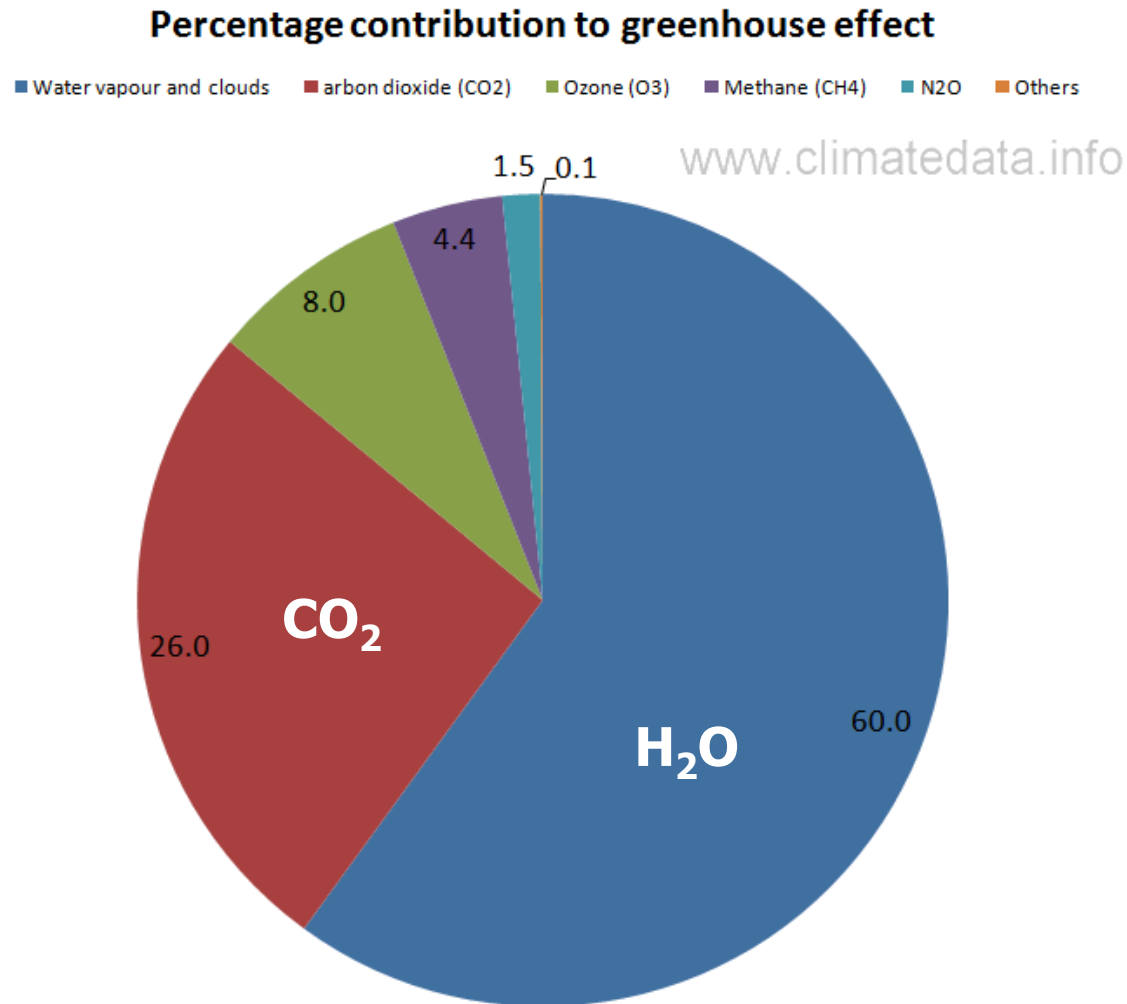
Experiment

vinegar – acetic acid (CH_3COOH)

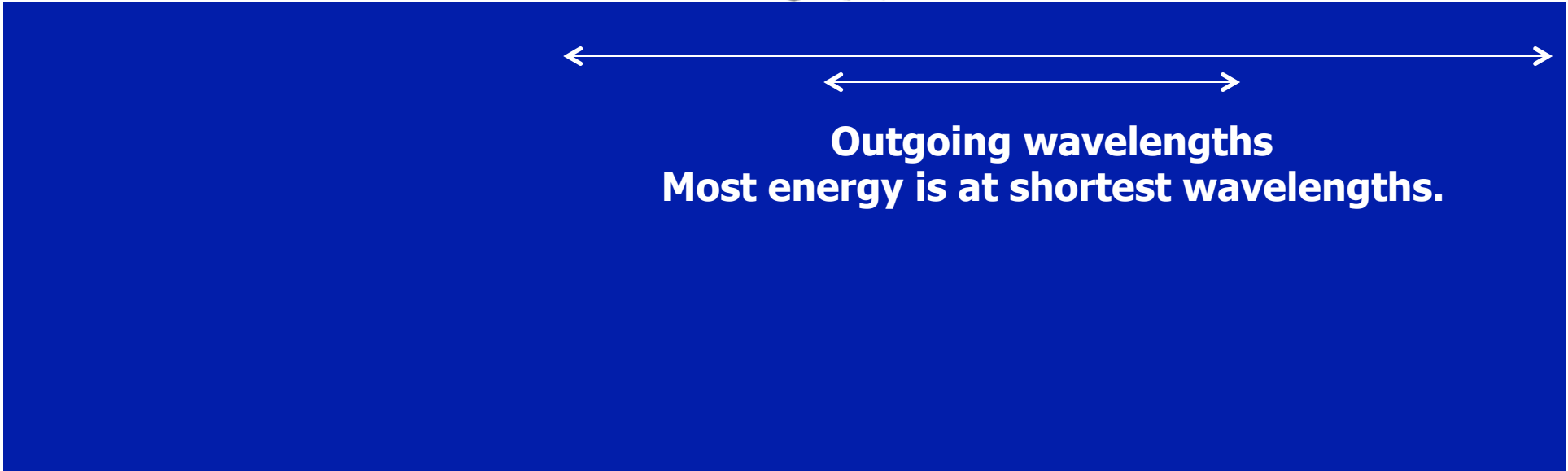
baking soda – sodium bicarbonate – (NaHCO_3)



Water contributes a lot



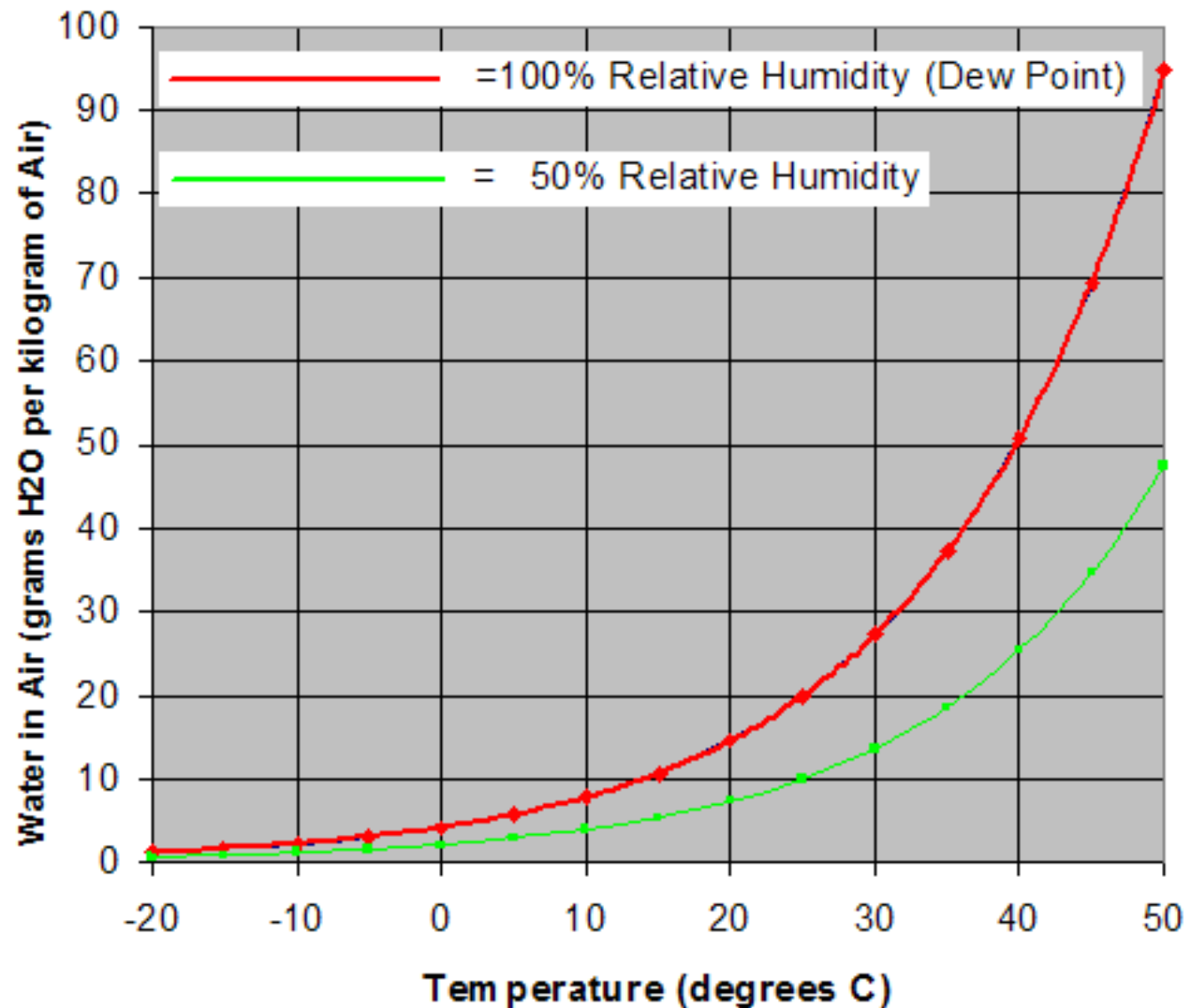
H₂O or CO₂?



Outgoing wavelengths
Most energy is at shortest wavelengths.

Amount of Water in Air at 100% Relative Humidity Across a Range of Temperatures

Calculated with tool at <http://www.lenntech.com/calculators/relative-humidity.htm>

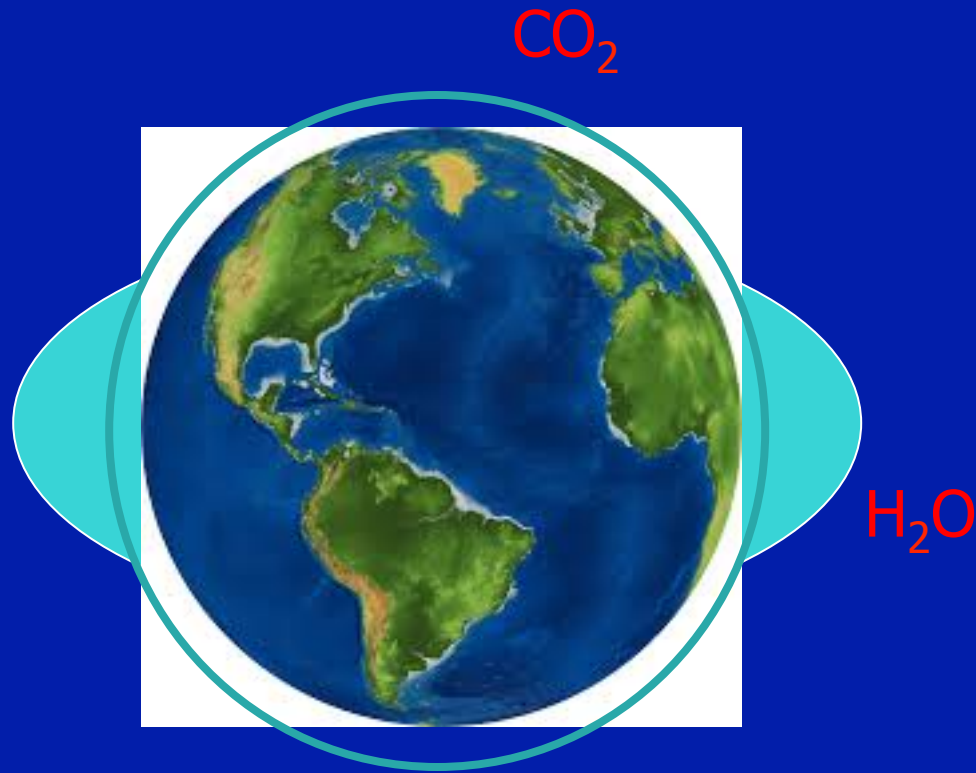


Warmer air
holds more
H₂O

Water is a greenhouse gas

- Water stays in atmosphere only a few days.
- When CO₂ goes up, atmosphere gets hotter and holds more water. The water vapor does not cause the rise in T, but it amplifies the effect of the CO₂.
- Water in atmosphere is least abundant and most variable in cold dry polar and high altitude climates.

Distributions of Greenhouse gases

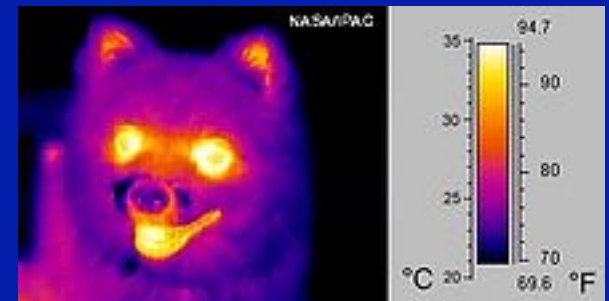
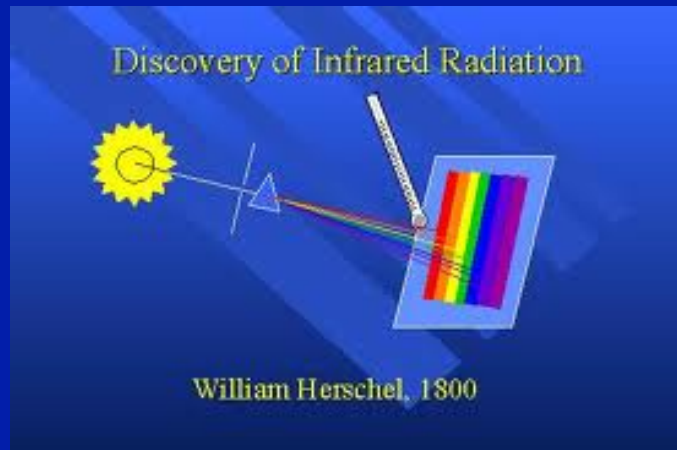




Sir Frederick William Herschel

Discovery of thermal radiation 1800

- In an 1800 experiment, Herschel used a glass prism to spread sunlight into a rainbow of colors.
 - measured the temperature of each color of visible light and noted differences.
 - readings when the thermometer bulb was placed just beyond the red portion of the visible spectrum.
- He had discovered thermal radiation, which has come to be known as infrared. [The prefix "infra" means "below."]

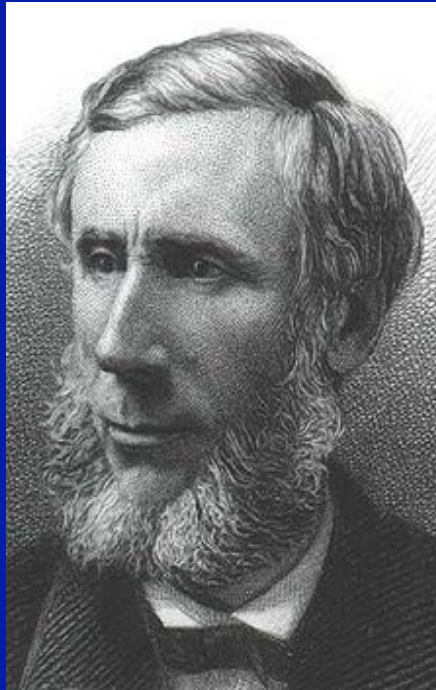


The physics of the 'misnamed' greenhouse effect has been known for almost 200 years.



Joseph Fourier computed that the Earth should be much colder than it is (1824, 1827)

+ 30 °F = 18 °C



John Tyndall, January 1863

Measured the absorption and emission of radiation by CO₂ in air.



Svante Arrhenius, 1896

Calculated in detail effect of CO₂ on Earth's temperature.

The physics is well understood and straightforward.
Does not depend on models.

When did scientists get alarmed?



Sounding the alarm on CO₂ began in the late 1950s. The first was Gilbert Plass¹.

Scientists were morally obligated to sound the alarm, even if they were ill suited to carry a message many people didn't want to hear.



Earthrise photo 1968.

First Earth Day 1970.

First IPCC Report commissioned in 1988.

Scientific consensus is 97% in 2015.

Plass, G.N., 1956, Carbon Dioxide and the Climate, American Scientist **44**, p. 302-16.

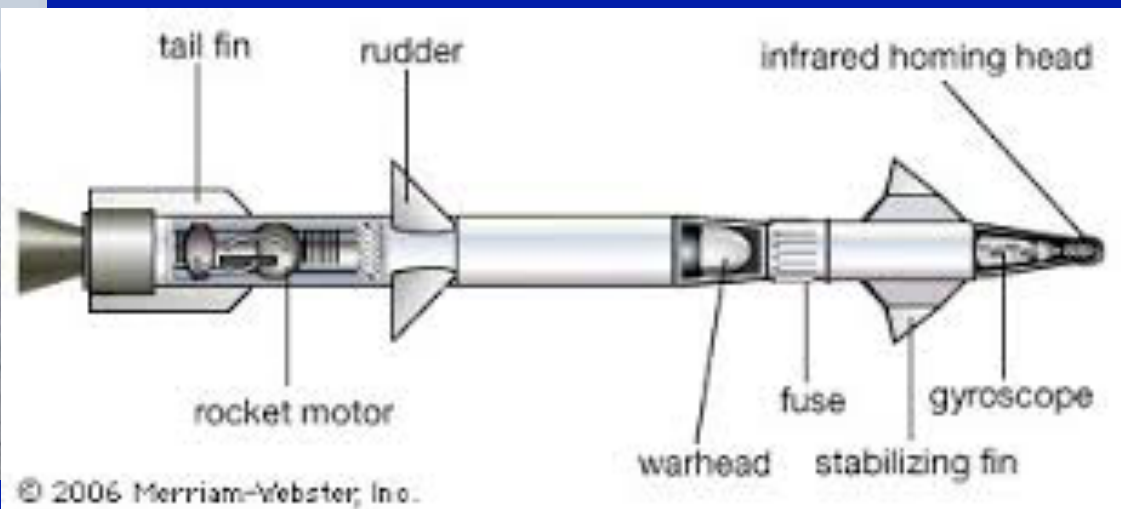
Plass, G.N., 1956, Effect of Carbon Dioxide Variations on Climate, American J. Physics **24**, p. 376-87.

Plass, G.N., 1956, The Carbon Dioxide Theory of Climatic Change, Tellus VIII, **2**. (1956), p. 140-154.

Heat seeking missiles were developed in the early 1950s by the military.



They learned all about the absorption of infrared by atmospheric CO₂.

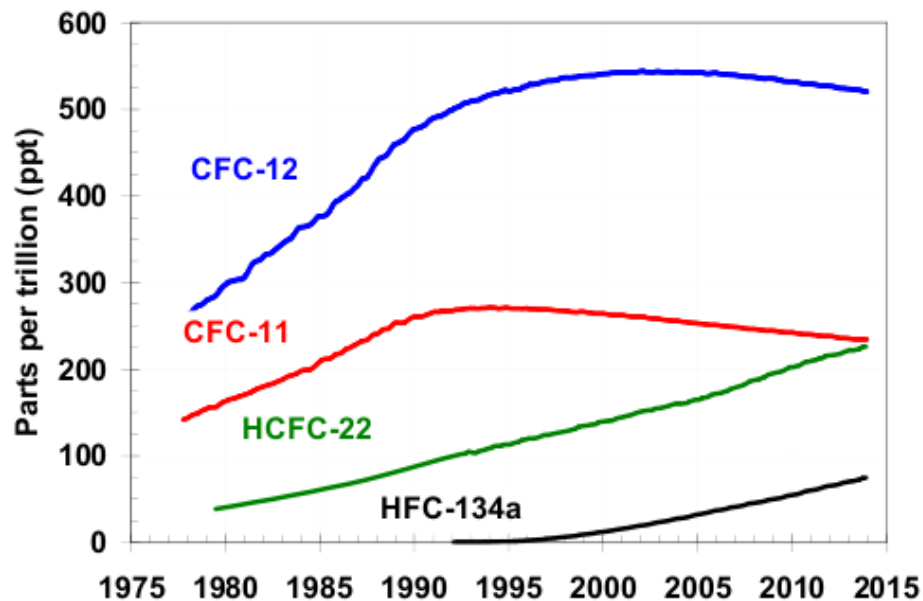
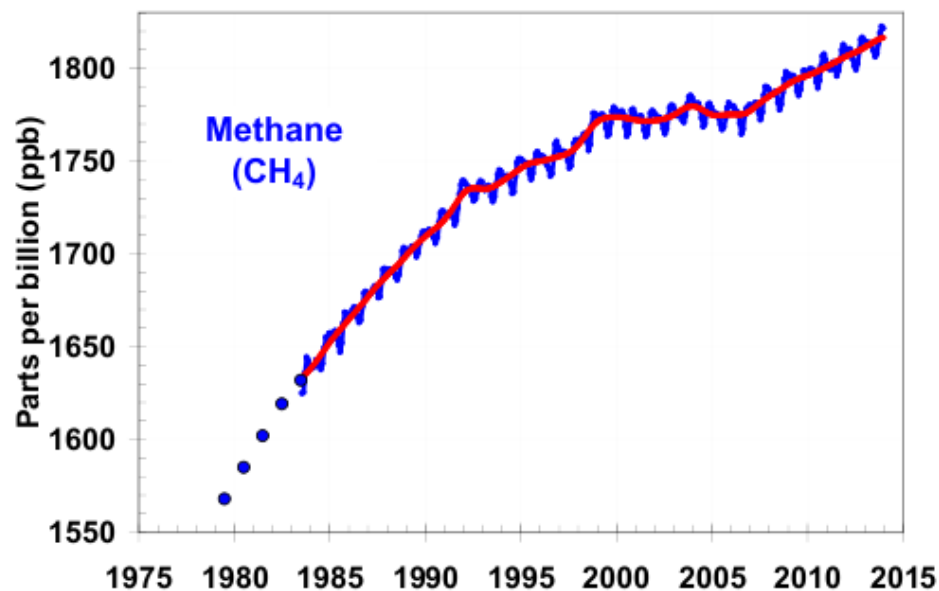
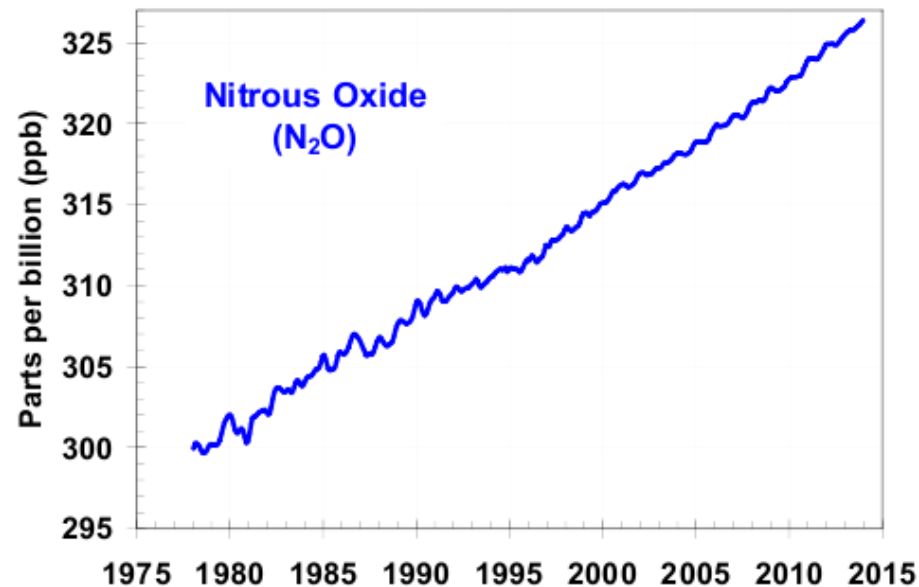
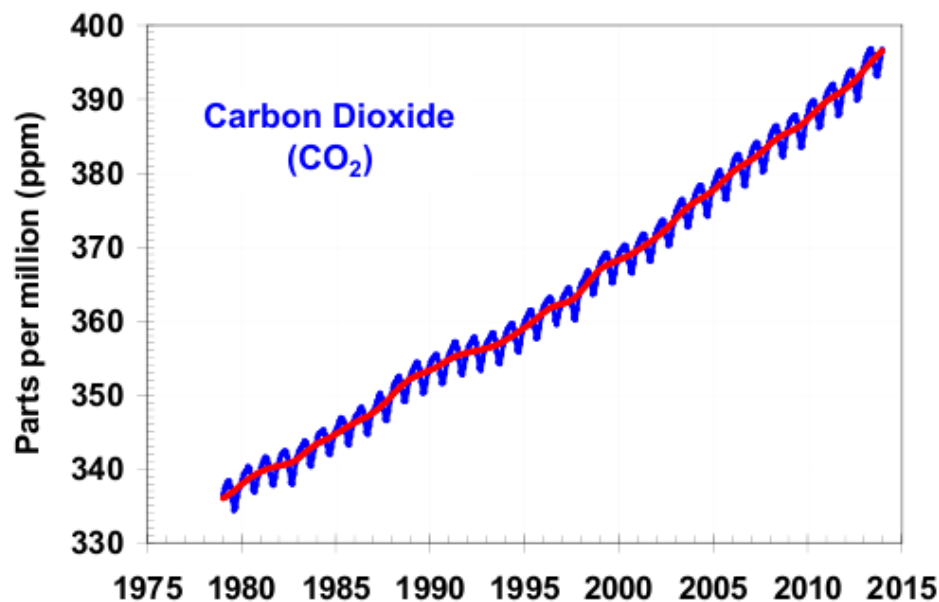


The planet's temperature is controlled
by this very thin layer of atmosphere!

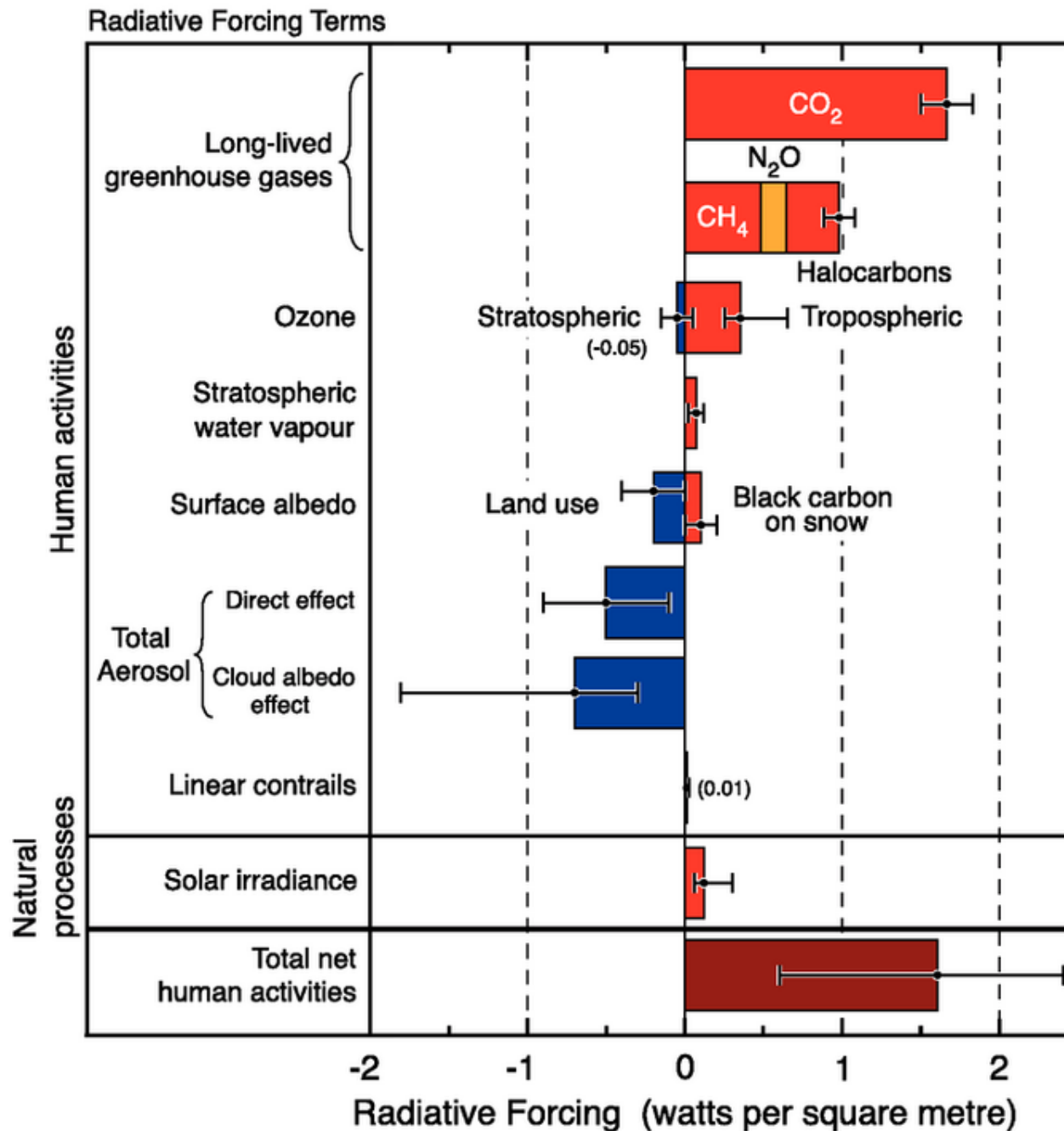


The Greenhouse Effect keeps the planet warm and habitable.

Greenhouse gas (GHG) trends



Radiative forcing of climate between 1750 and 2005



What is the relative contribution of human-induced and natural variations?

Another way is to compare the driving forces.

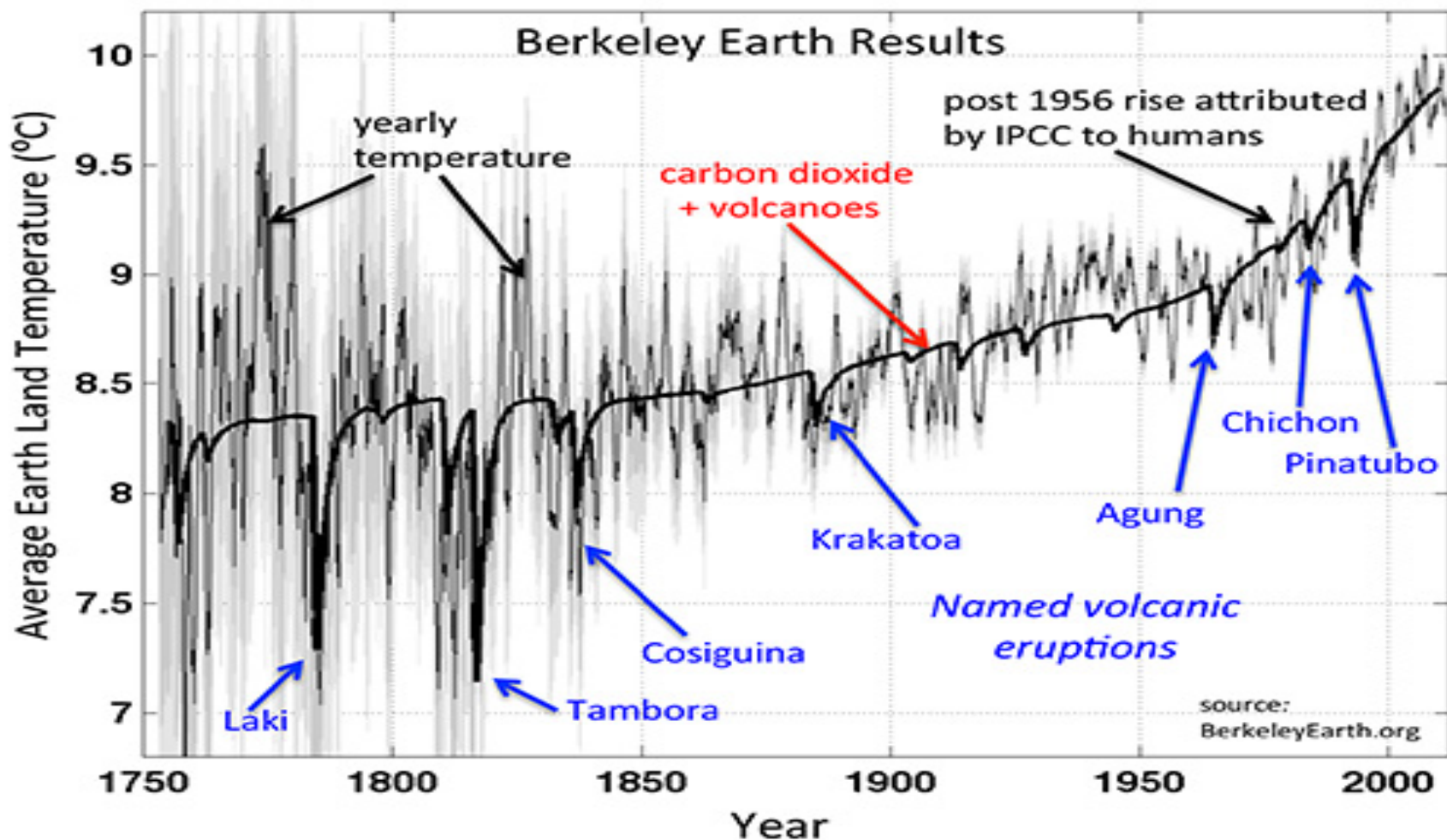
10:1 CO₂:solar

10 net human/1 solar with large uncertainty

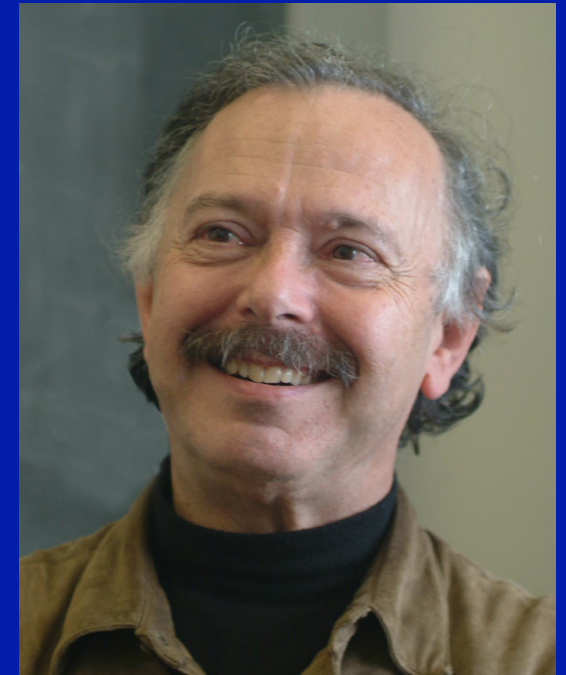
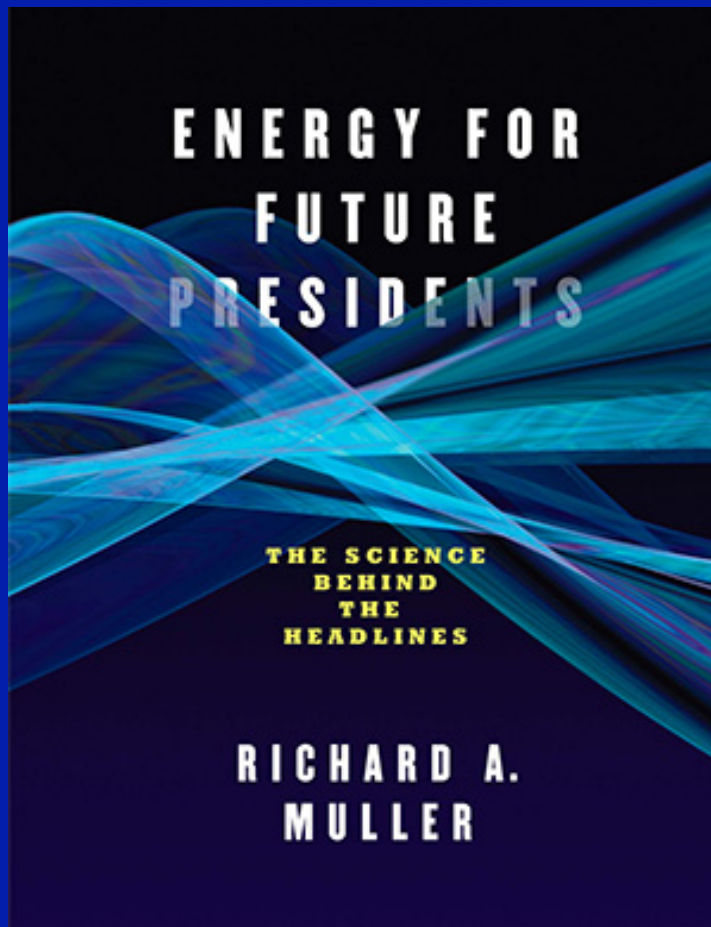
Reanalysis by "Berkeley Earth"

Average Land Temperature

Log(CO₂ abundance)
+ dust from volcanoes



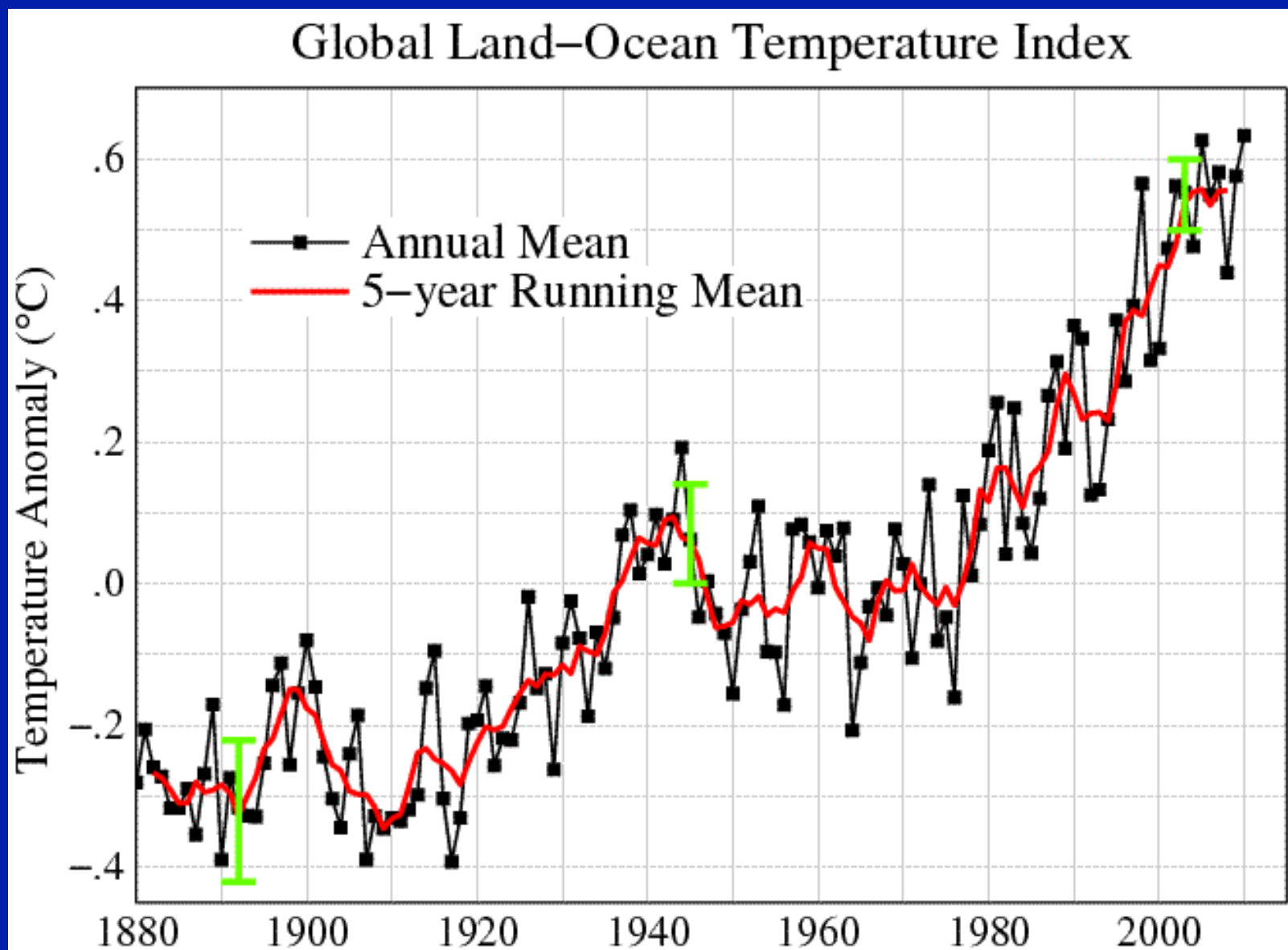
Analysis done by a physicist, a converted skeptic



Richard A. Muller

Work on previous slide was
partially funded by the Koch
brothers.

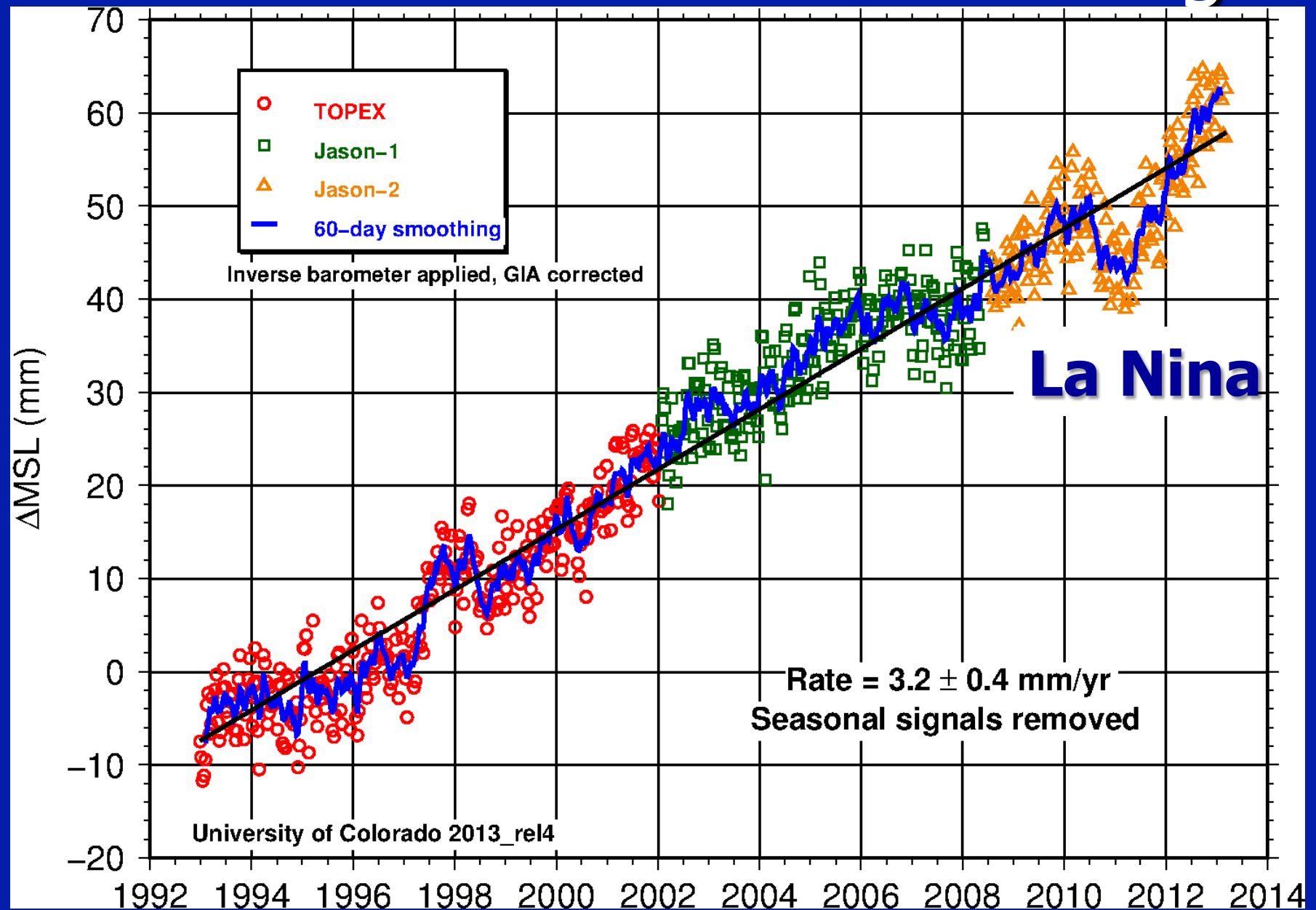
Net result: global warming



More energy – more instability

- Expect climatic instability
 - Droughts and floods
- Expect rising sea levels (time to adapt)
 - Sandy, Katrina
- Expect heat waves
 - France 2003 - 70,000 deaths
 - Dehydrated the grapes
 - Tropical diseases
 - Fires (Australia now typically above 40 °C in summer – 104 °F)

This measurement is amazing



Where did the water go?

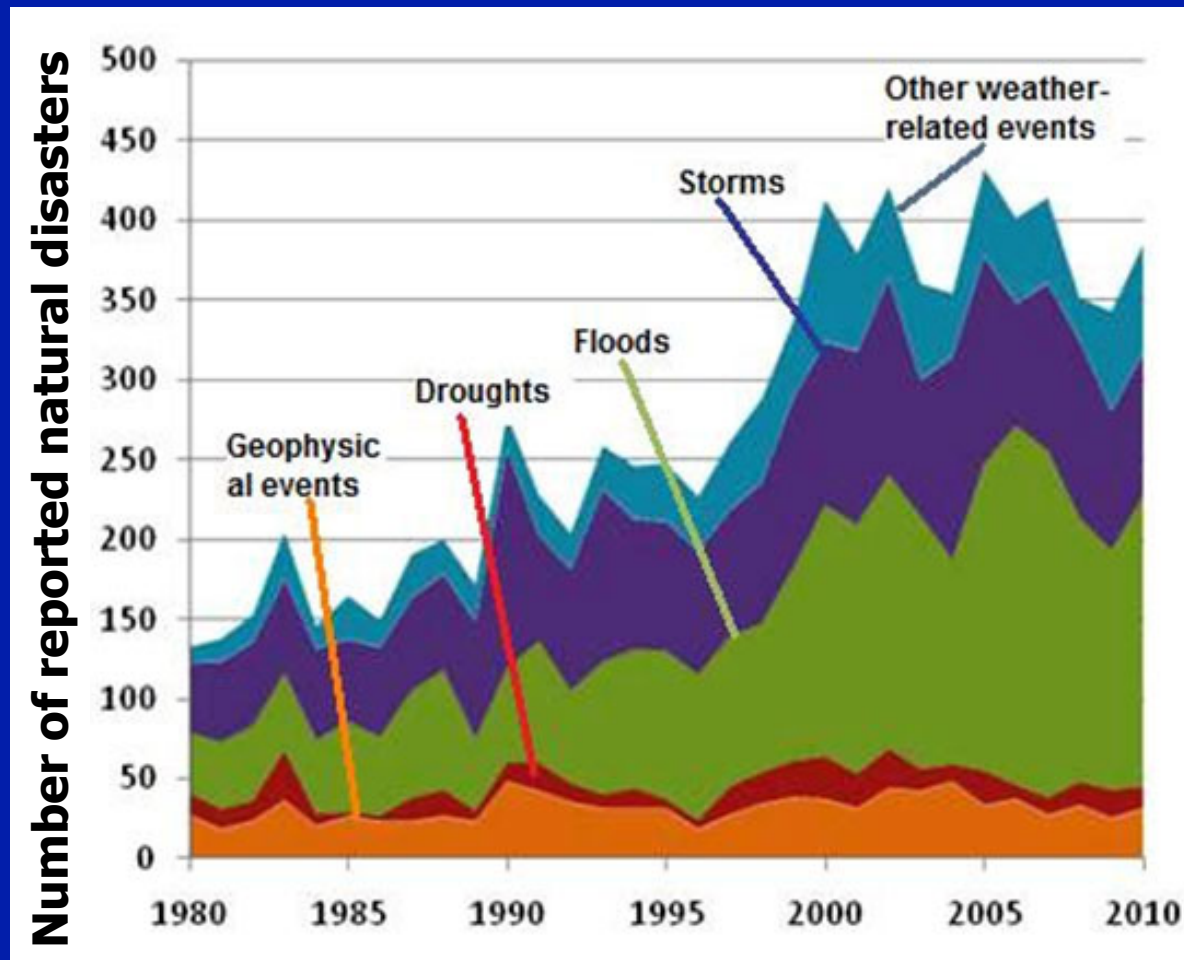


Bangkok, Thailand



Australia

Too much water



Trends in number of reported natural disasters

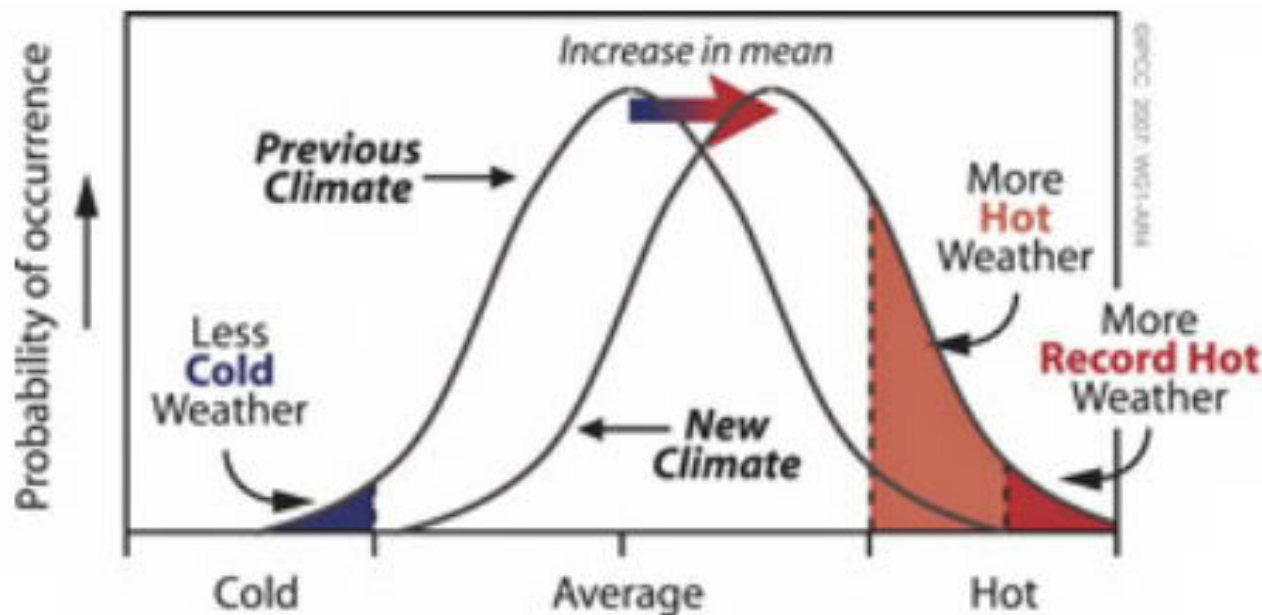
World meteorological organization:

http://www.itu.int/net/newsroom/wrc/2012/features/natural_disasters.aspx

Global warming cannot be “blamed” for any individual storm.
Weather happens.

However, warming can be indicted for shifting the distribution and increasing the probability of storms of a specific intensity.

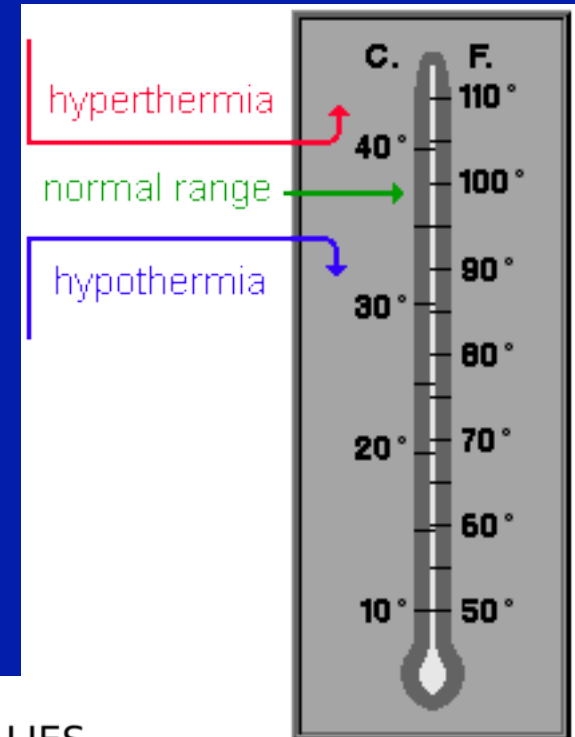
Climate Change Shifts the Odds for Extreme Weather Events



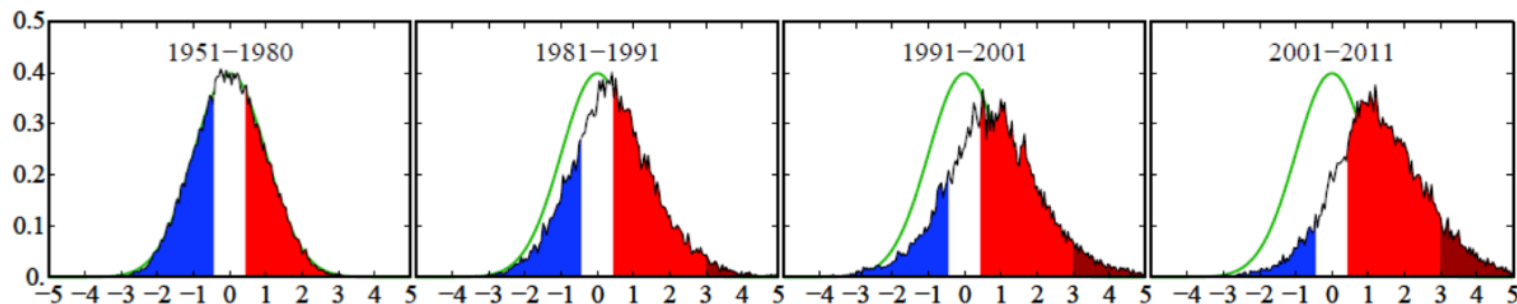
Solomon et al. 2007

Danger to human life!

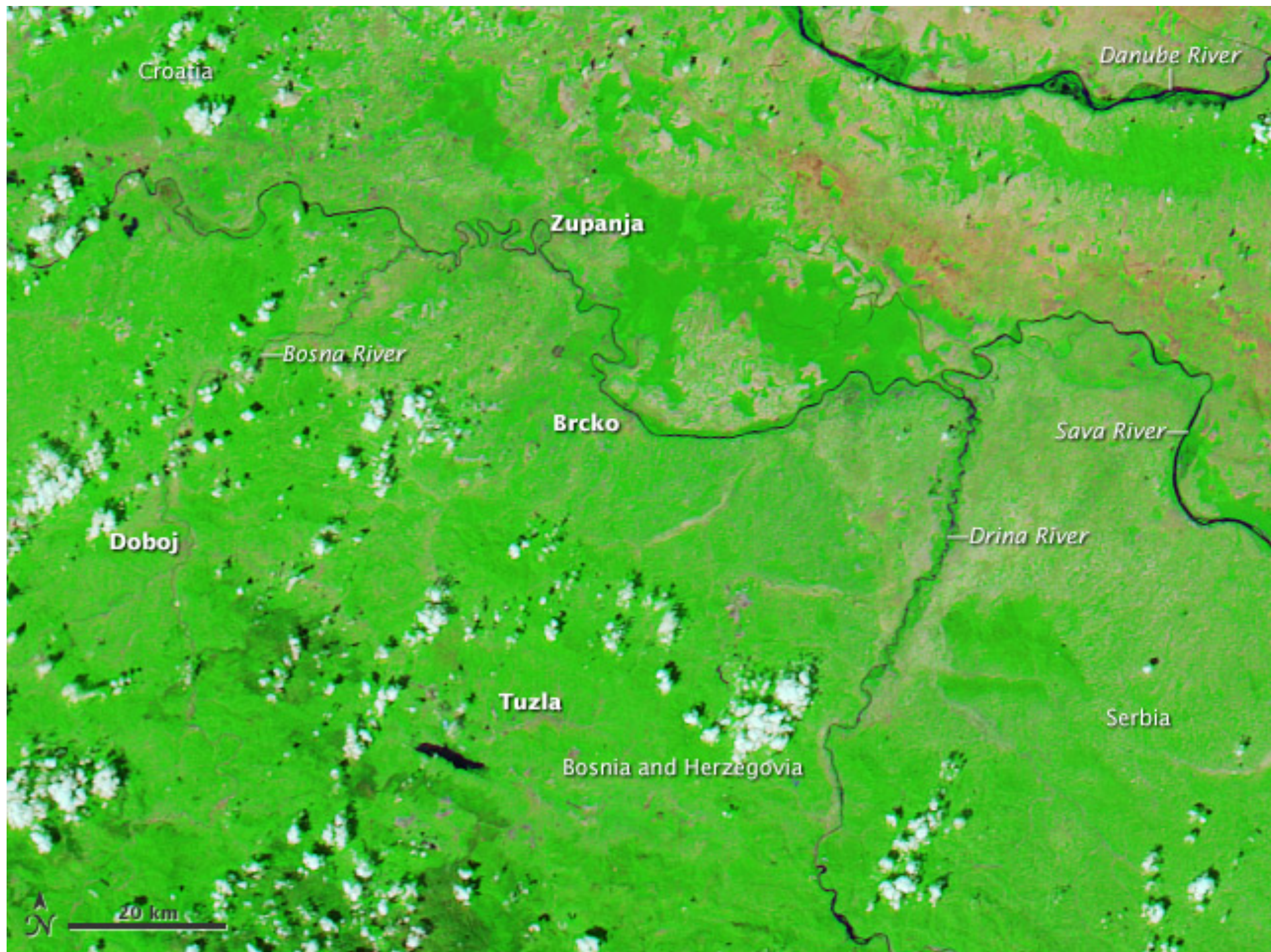
- E.g. Heat wave Europe 2003
- health crises; death toll 70,000
 - heat
 - crops/drought
- Among most lethal weather

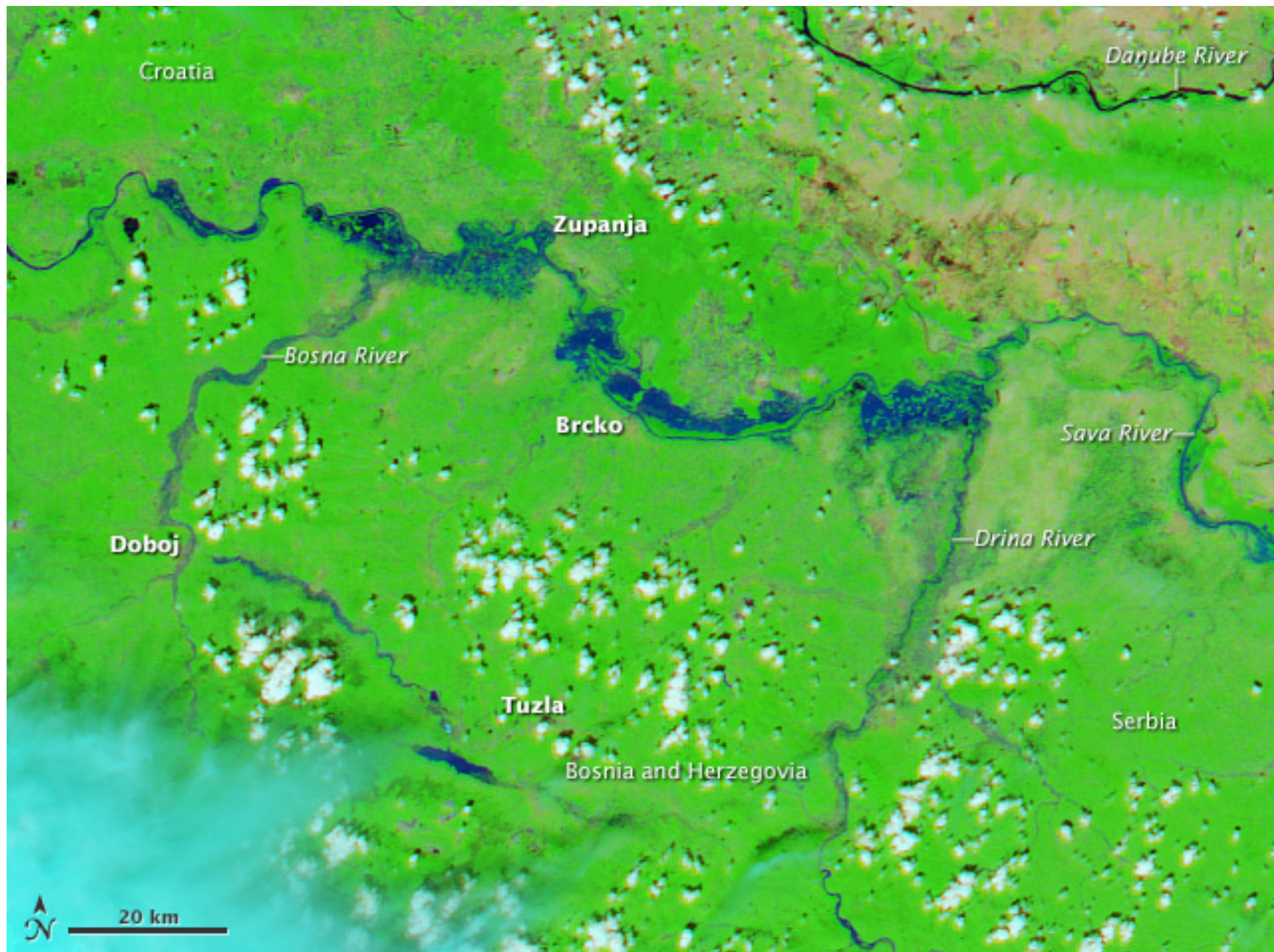


SHIFTING DISTRIBUTION OF SUMMER TEMPERATURE ANOMALIES



Credit: James Hansen, NASA Goddard Institute for Space Studies





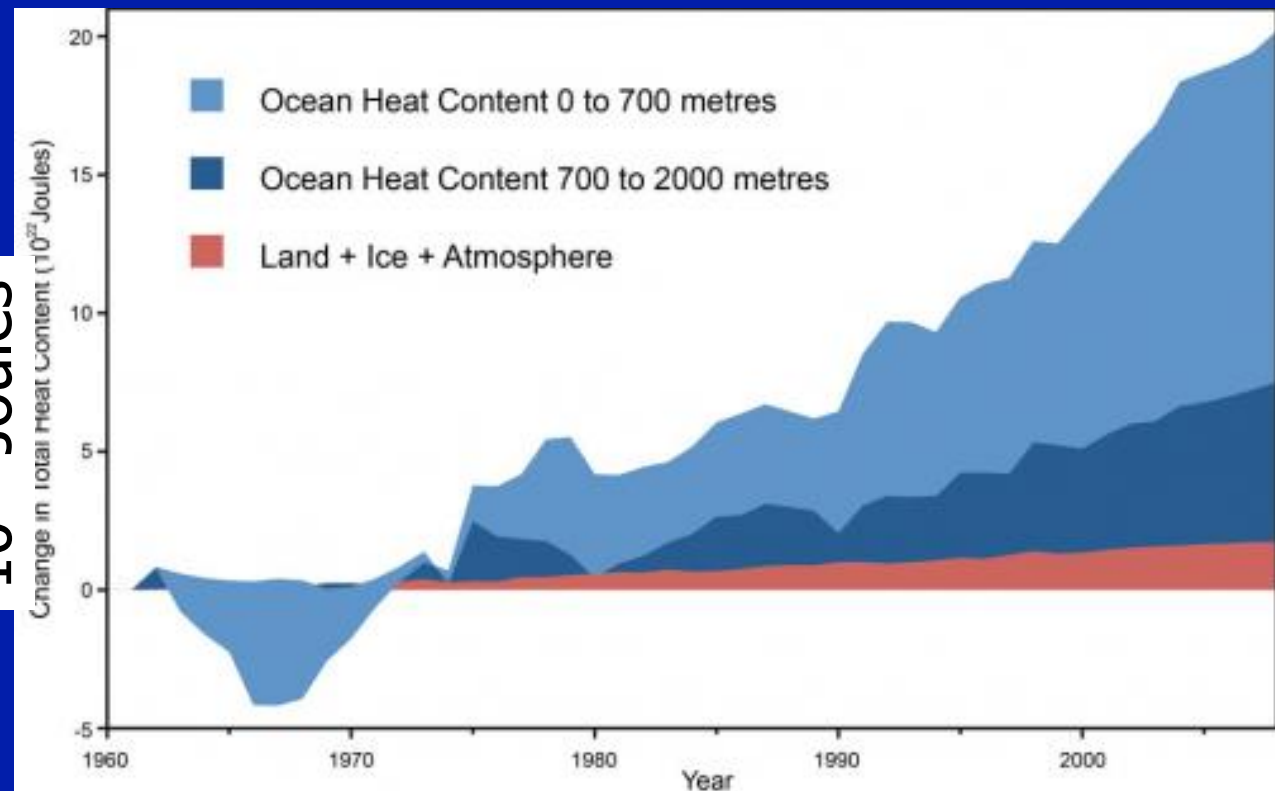
Excess heat is prodigious

Our climate is accumulating
4 Hiroshima atomic bombs
worth of extra heat every second.



90% of the
energy is
going to heat
the oceans;
the rest
heats the
land and air.
A few % is
melting ice.

10²² Joules



What is 2×10^{23} Joules

- Comparable to the energy contained in all the remaining fossil fuels
 - not surprising because we have used about half of the energy made over the history of the planet
- 20% of the solar energy hitting Earth in one year
 - This tells us that the sun provides plenty of energy
- 2000 times the World's annual energy consumption

The precipitation paradox

As global temperatures rise, both drought and heavy rains are increasing.

How can this be?

Over land: warmer air rises, sucking moisture from dry land, intensifying drought



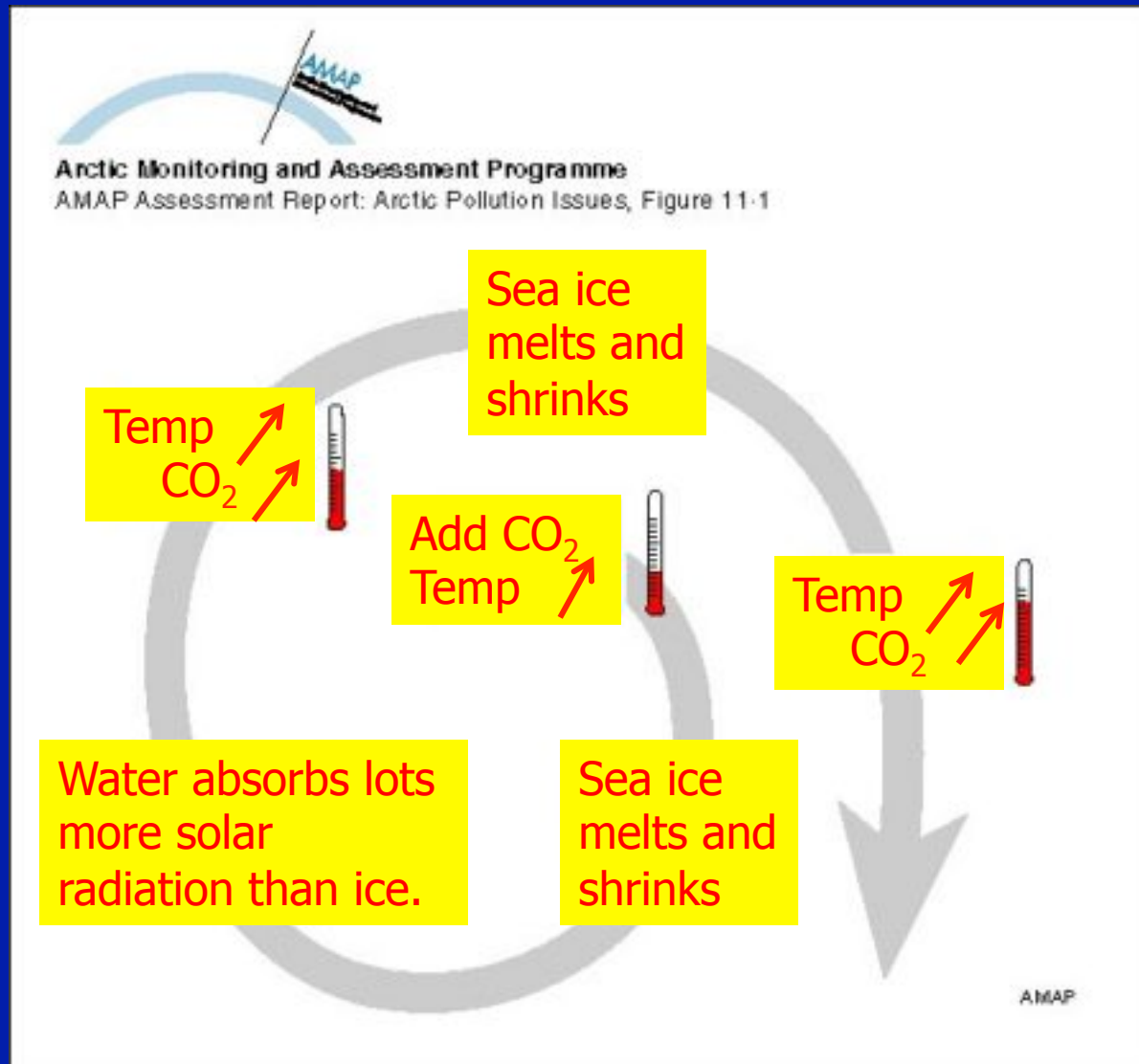
UCAR

Over the oceans: more water evaporates into warmer air, helping increase precipitation intensity worldwide



UCAR

Positive Feedback is most serious in the Arctic.



**Many indifferent, ignorers and outright
special interest contrarians.**

**WHAT DO YOU SAY WHEN THE
SCIENCE IS CHALLENGED?**

What to say

when someone argues that warming is caused by the sun

- Yes, you're right. The sun does vary.

- Ans:

- The sun varies with an 11 year cycle
- There is no evidence for an 11 year variation of the climate
- Global warming is more pronounced at night than in the day, and in the winter than the summer.
- The measured effect of the sun is about 5% of the total forcing (see IPCC slide)

What to say

when someone says climate always changes!

The implication being “no worries”, it’s nothing new

- Ans:

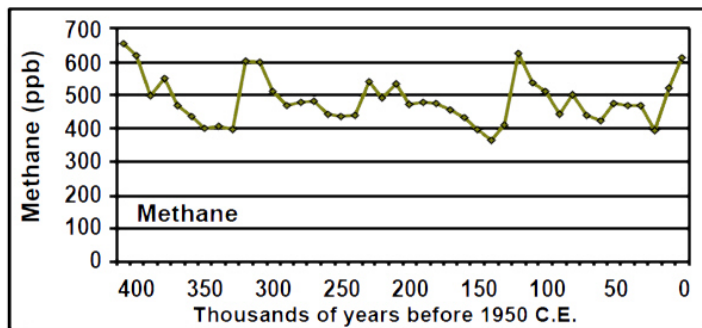
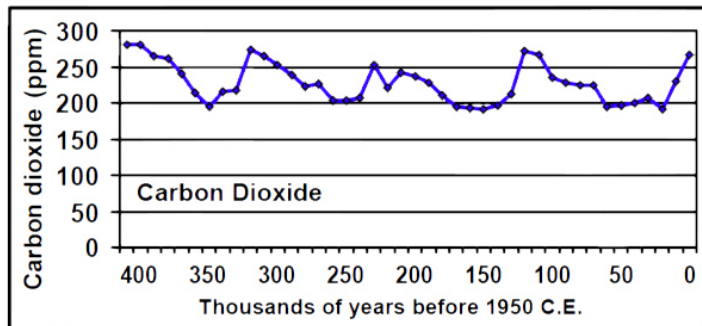
- Yes it does.

- That does not mean this change isn’t caused by humans.

National Ice Core Laboratory

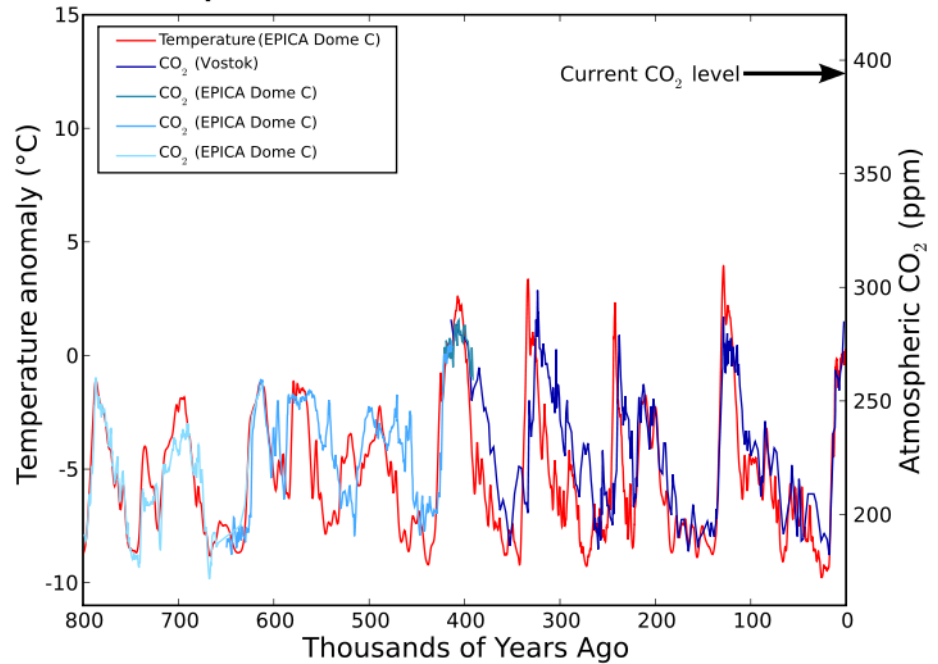


Ice core Temperatures and CO₂

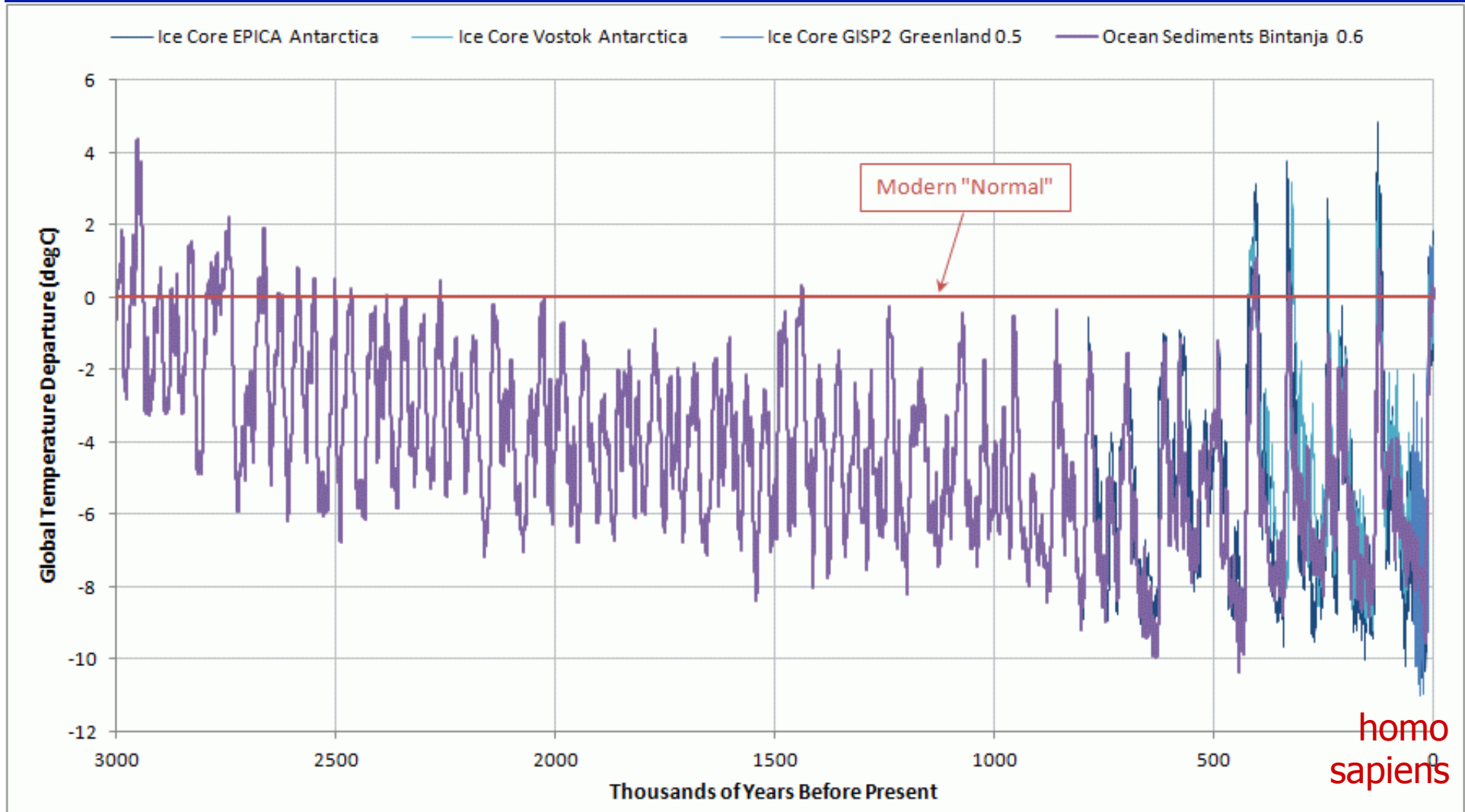


Atmospheric carbon dioxide (CO₂), and methane (CH₄) derived from air bubbles trapped in ice at Vostok Station, Antarctica. Units are parts per million (ppm) for CO₂ and parts per billion (ppb) for CH₄. Year zero is 1950 of the Christian Era (C.E.)

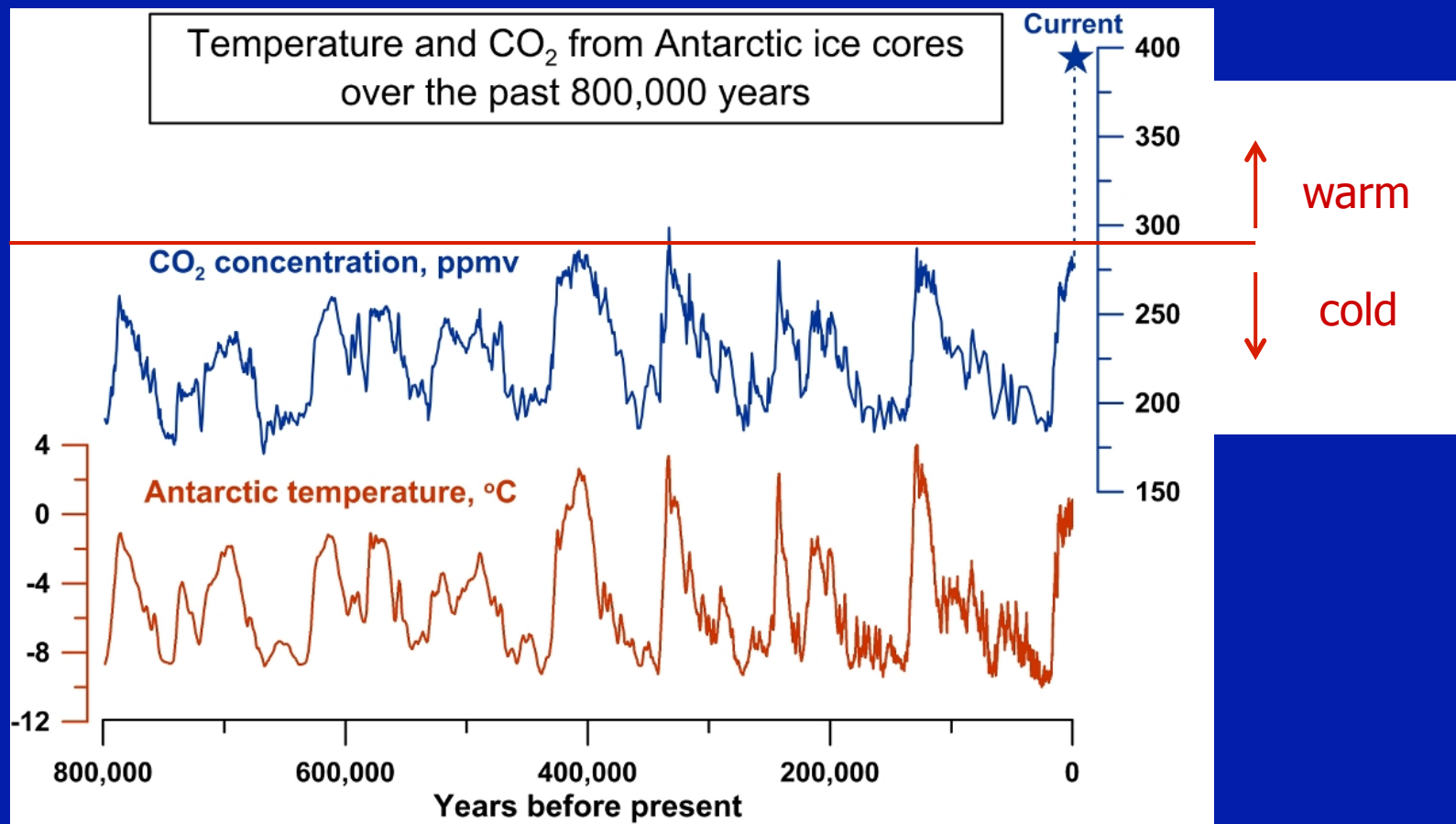
Temperature and CO₂ Records



The climate changes all the time.
The plot shows average planetary temperature
for the last 3 million years.



This plot compares temperature and CO₂ abundance for the last 0.8 million years. Now it's way higher than this (400 ppm) and rising very fast.



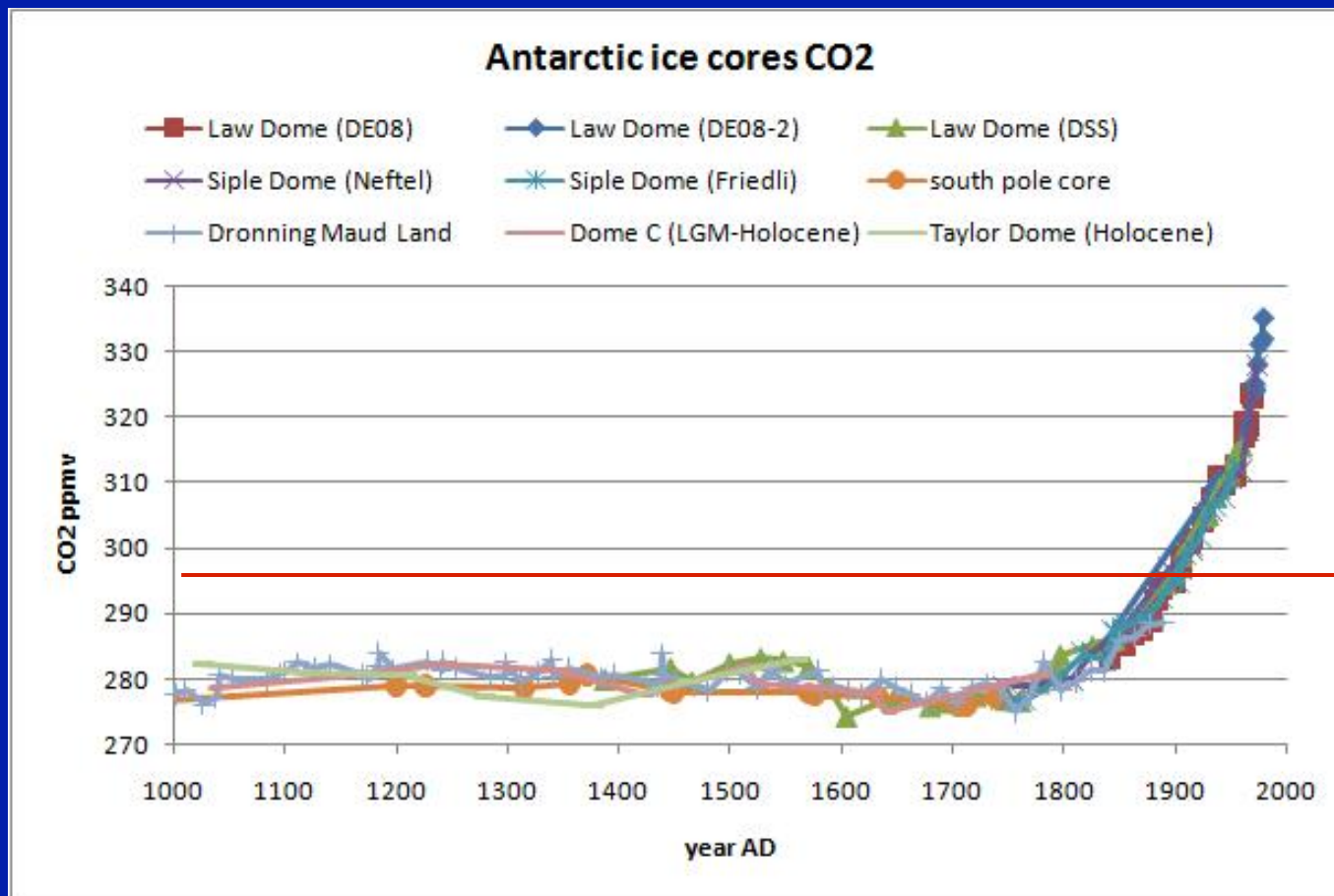
Way too much CO₂!!

Atmospheric CO₂ rates

Volcanoes: 0.13 to 0.44 billion tons per year

Human activities: 35 billion tons (2010)

It's not volcanoes!



red lines indicate
maximum for last
1/2 million years

Who is doing the burning? Apes, ants, elephants?

Where do humans fit in?

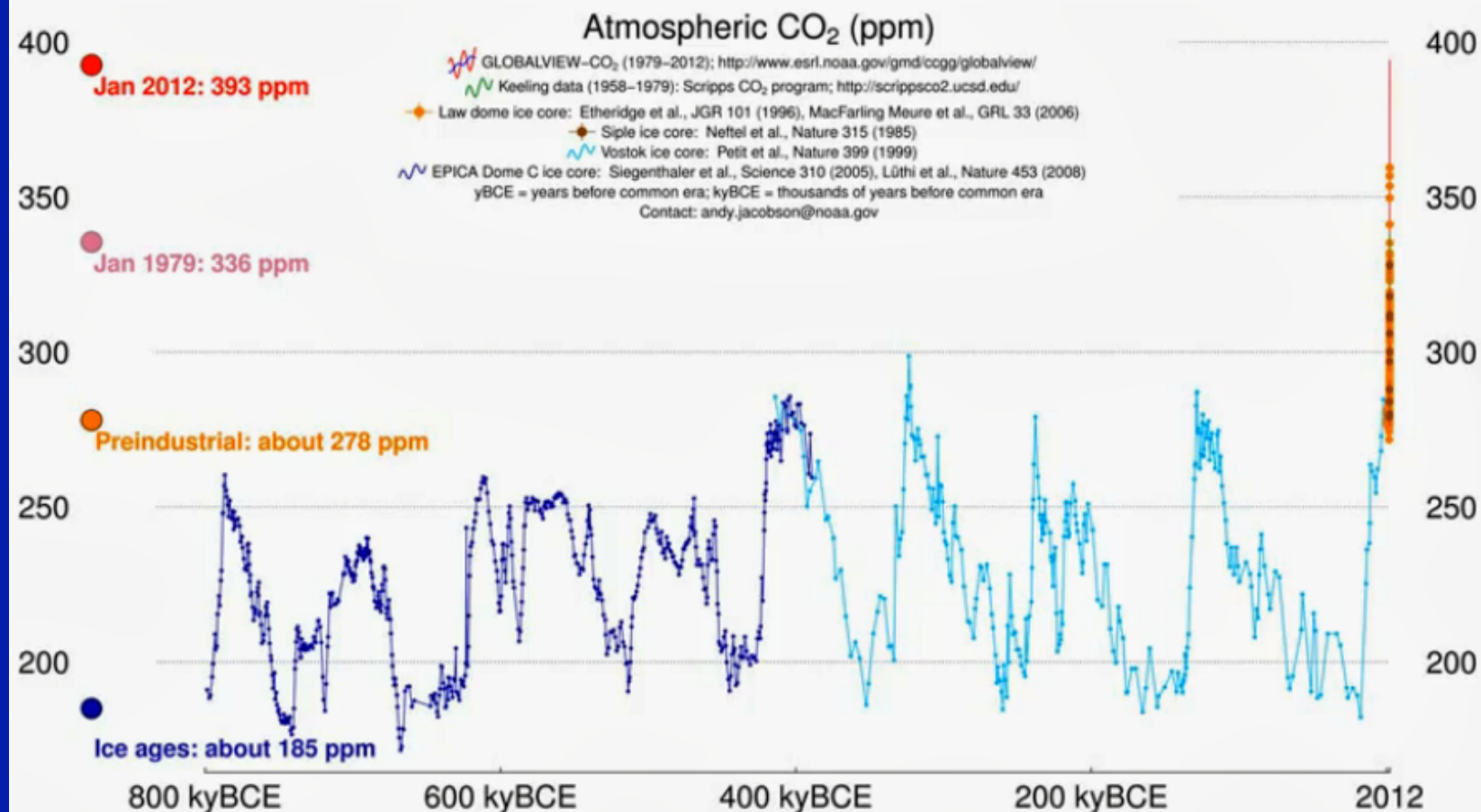
Last few million years, hominids evolved.
Earth cooling, highly fluctuating climate.
Few million years ago CO₂ at 400 ppm.

Last 500,000 years:
Earth in cool period (ice ages), archaic humans.
Neanderthal's extinct about 40,000 ya.

CO₂ levels at 200-280 ppm (from ice cores)
We evolved in the preindustrial climate.

Yes, Virginia, the climate does change over geologic times scales. CO₂ for the last 0.8 million years

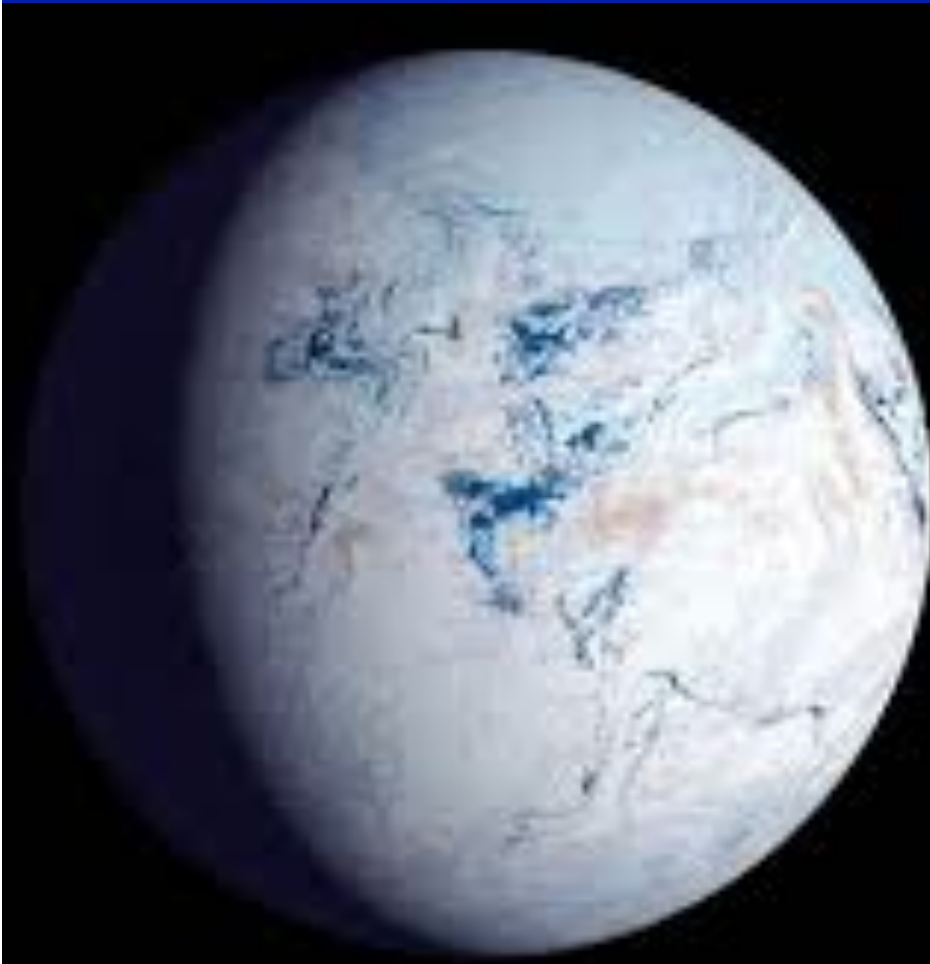
Time history of atmospheric carbon dioxide from 800,000 years ago until January, 2012.



Pretend this slide covers 800 years. Warm periods happen every 100 years or so. The planet is kept habitable by about 2 billion metric tons of CO₂. Then we are attacked by aliens who in a month long attack dump another billion tons of CO₂ in the atmosphere and then retreat to their home planet. They come back in a year and find their attack has worked as planned. They have caused massive disruptions; floods, fires, droughts, massive food shortages, refugees everywhere running from rising seas. Satisfied that their attack is working well they retreat and wait another few years for it to cool down before occupying the planet permanently.

Snowball Earth

Glacial deposits near equator: 635MYA and 710 MYA



Google "Snowball Earth"

Caused by reduced CO₂?

- Equatorial continents
 - Increased albedo
 - More rain on continents, increased weathering
- Other effects possible
 - Orbital changes
 - Dimmer sun
- Once ice starts, feedback can tip the global climate, and trap CO₂ under the ice.

Earth's climate is delicately balanced.

What to say

when someone says climate always changes!

The implication being “no worries”, its nothing new

- Ans: Yes it does
 - Natural geologic processes of weathering, volcanoes, etc. have controlled the Earth's atmosphere for 4.6 billion years
 - What's new is the ***rate of change*** of the injection of GHG into the atmosphere.
 - We are tipping the delicate balance

What to say

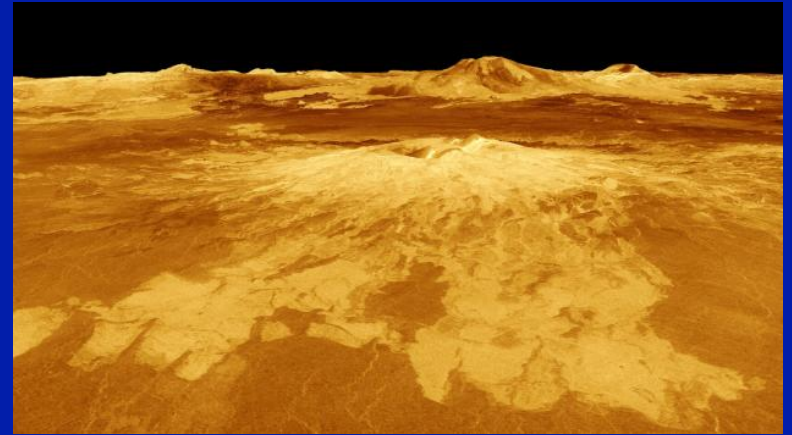
when someone argues climate change is caused by something besides CO₂ (& other GHG)

- Some folks like to blame the internal electromagnetic circuits of the sun-Earth system

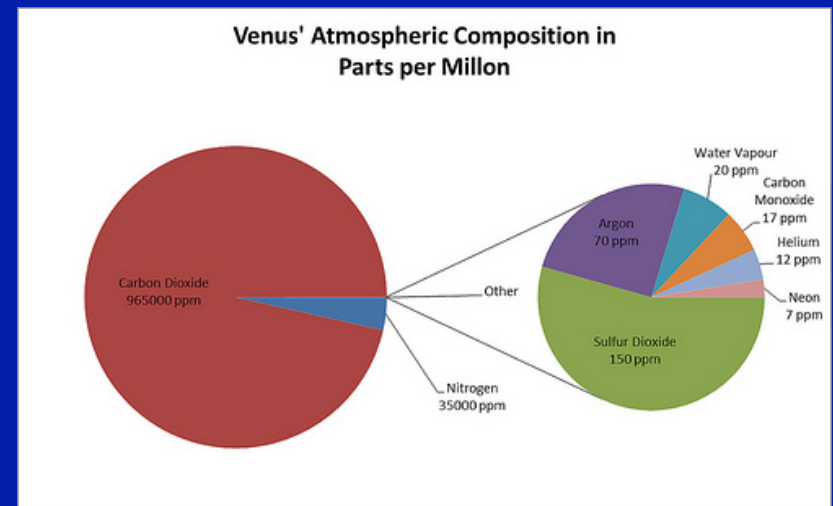
- Ans:

Consider Venus

- Almost 2 x higher heat input from the sun (1.91 x Earth)
- Surface temperature highest in solar system at 462 °C (860 °F), hotter than Mercury
- Big effect is CO₂ atmosphere



Radar image of the surface of Venus from the Magellan Spacecraft



What to say

when someone argues climate change is caused by something besides CO₂ (e.g H₂O)

- Some folks like to blame the internal electromagnetic circuits of the sun-Earth system

- Ans:

- Yes, H₂O is a greenhouse gas – it cooperates with CO₂ (feedback CO₂ rises, causing H₂O to rise)
- We have known the physics of CO₂ since ~1860
- It's what makes Venus so hot
- It's what keeps Earth from freezing over

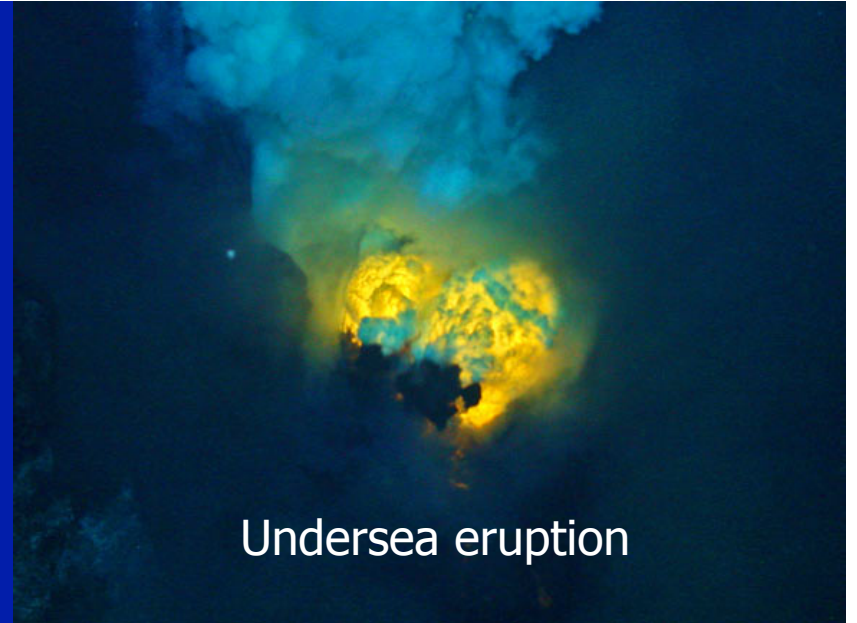
What to say

when someone argues the CO₂ is from volcanoes

E.g. Some people like to blame undersea volcanoes

- Ans:

The facts



Undersea eruption

- Emitted mass
 - Volcanoes: 0.13 to 0.44 billion tons per year
 - Human activities: 35 billion tons/yr (2010)
- Rate of change in atmosphere
 - Cenozoic Average (65 M yrs): 0.0001 ppm/yr
 - Ice age change (50,000 years): 0.002 ppm/yr
 - Anthropogenic rate: ~ 2 ppm/yr (1000 x faster)

What to say

when someone argues the CO₂ is from volcanoes

E.g. Some people like to blame undersea volcanoes

- Ans:

- Yes, there is some uncertainty in the volcanic contribution (maybe x3), but not a factor of 100!
- The volcanic contribution would be there all the time and not start coincident with the industrial revolution.
- The added CO₂ is consistent with the amount of burning and forest removal.

What to say

when someone argues the CO₂ is not from fossil fuels (i.e. *humans* didn't do this).

- Some folks say we don't have a smoking gun

- Ans:

Reduced $^{13}\text{C}/^{12}\text{C}$ in plants and fossil fuels.

- Plants find it easier to use the lighter isotopes (^{12}C) when they convert sunlight and CO_2 into food.

Young plants



300Myr old plants



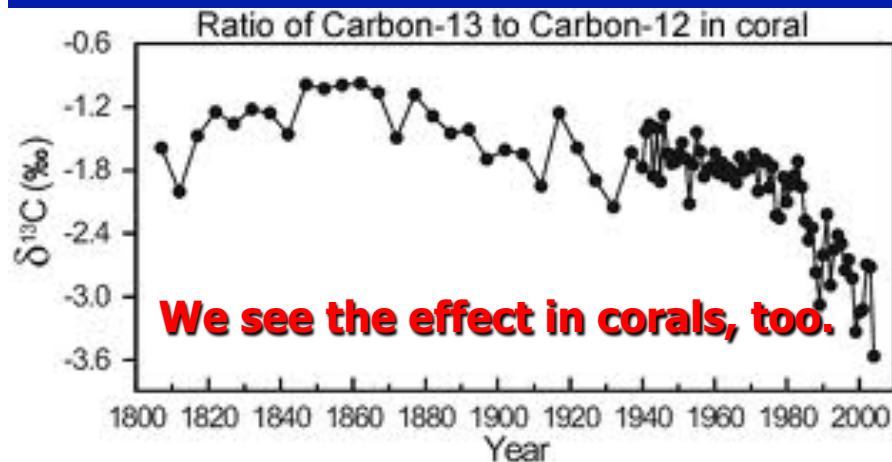
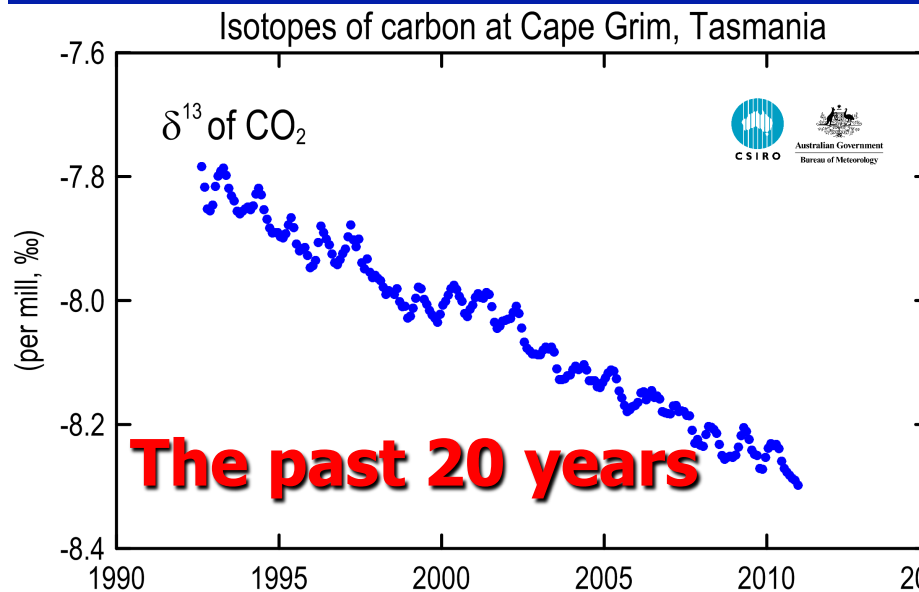
150Myr old plants



The $^{13}\text{CO}_2/^{12}\text{CO}_2$ story

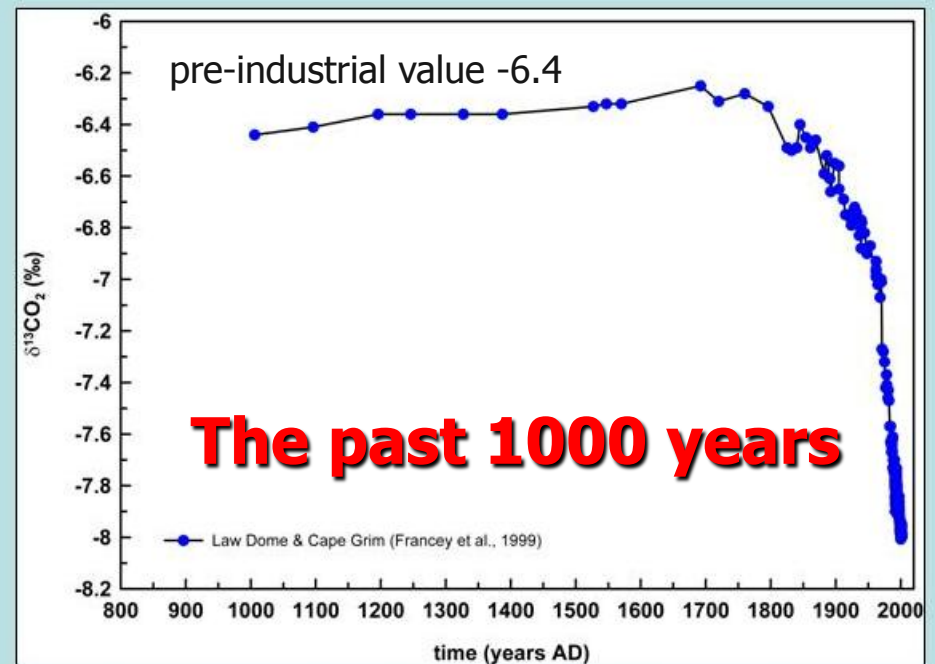
- There is now 400 ppm of CO_2 [$^{12+13}\text{CO}_2$] in the atmosphere (after contamination by the burning of fossil fuels became significant – our hypothesis, 280 ppm).
- So $(400-280)/400 = \mathbf{30\%}$ of the CO_2 (in the air now) comes from burning fossil fuels.
- Outgassing of C from volcanoes has the “natural” or universal abundance.
 - Ratio of $^{13}\text{CO}_2/^{12}\text{CO}_2$ in the air was the “natural” abundance when coal & oil were formed.

http://www.cmar.csiro.au/research/capegrim_graphs.html



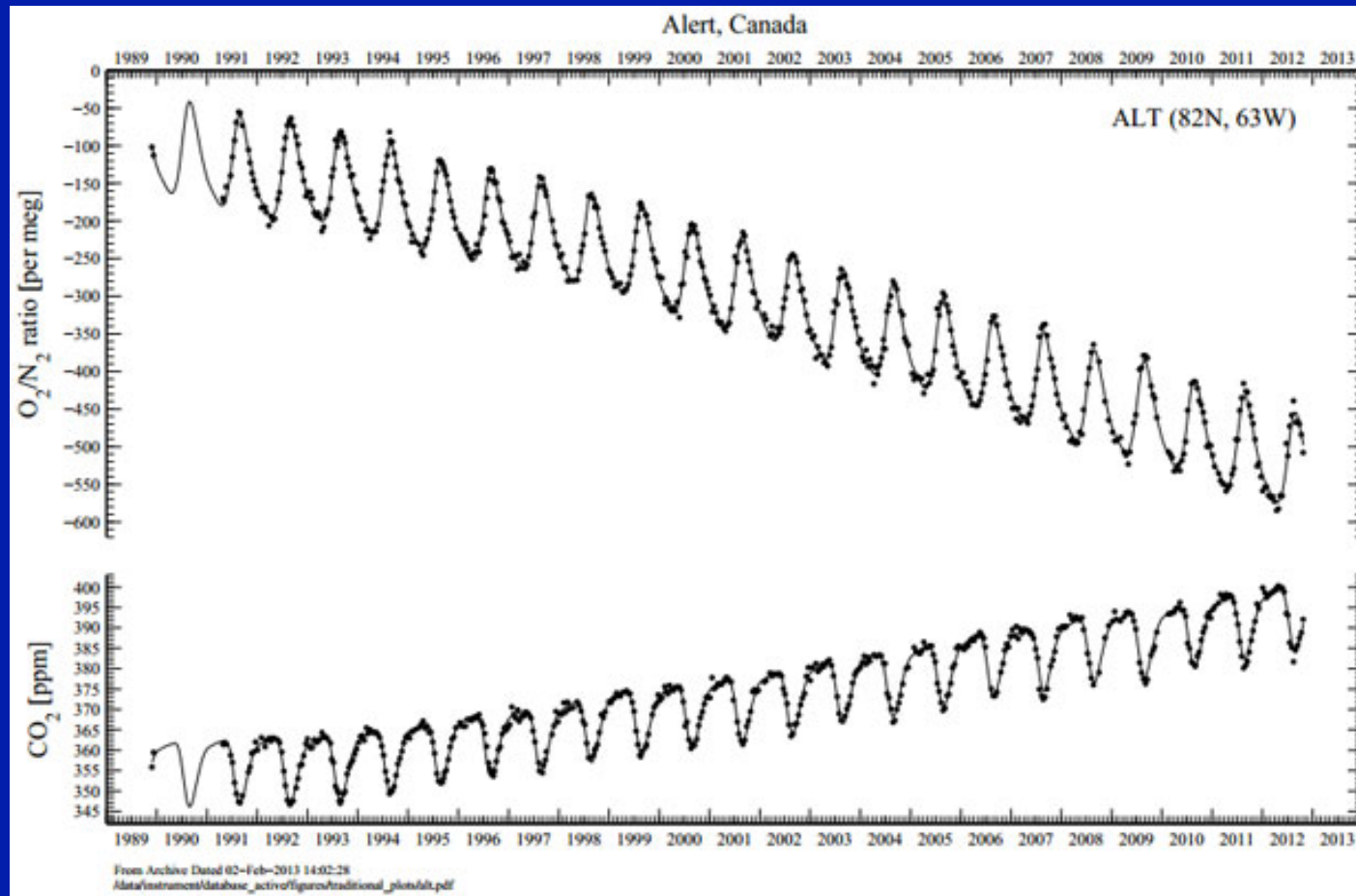
“Evidence for ocean acidification in the Great Barrier Reef of Australia”, G. Wei et al. 2009, *Geochimica et Cosmochimica Acta*, **73**, 8, 15 April 2009, Pages 2332–2346

<http://www.bridge.bris.ac.uk/projects/pcmip/experiments.html>



Reconstruction of the carbon isotope (C-13) of atmospheric CO_2 from the Law Dome ice core (Francey et al., 1999) and the Cape Grim ambient air measurements (Allison et al., 2003).

Oxygen used by burning



The observed downward trend is 19 'per meg' per year. This corresponds to losing 19 O_2 molecules out of every 1 million O_2 molecules in the air/year.

<http://scripps2.ucsd.edu>

What to say

when someone argues the CO₂ is not from fossil fuels (i.e. *humans* didn't do this).

- Some folks say we don't have a smoking gun
- Ans: "Yes we do, and there's powder on our sleeves."
 - We know the CO₂ comes from ancient hydrocarbons because of the decreasing isotopic composition of the ¹³CO₂/¹²CO₂
 - Changes all align with the *burning* of fossil fuels.

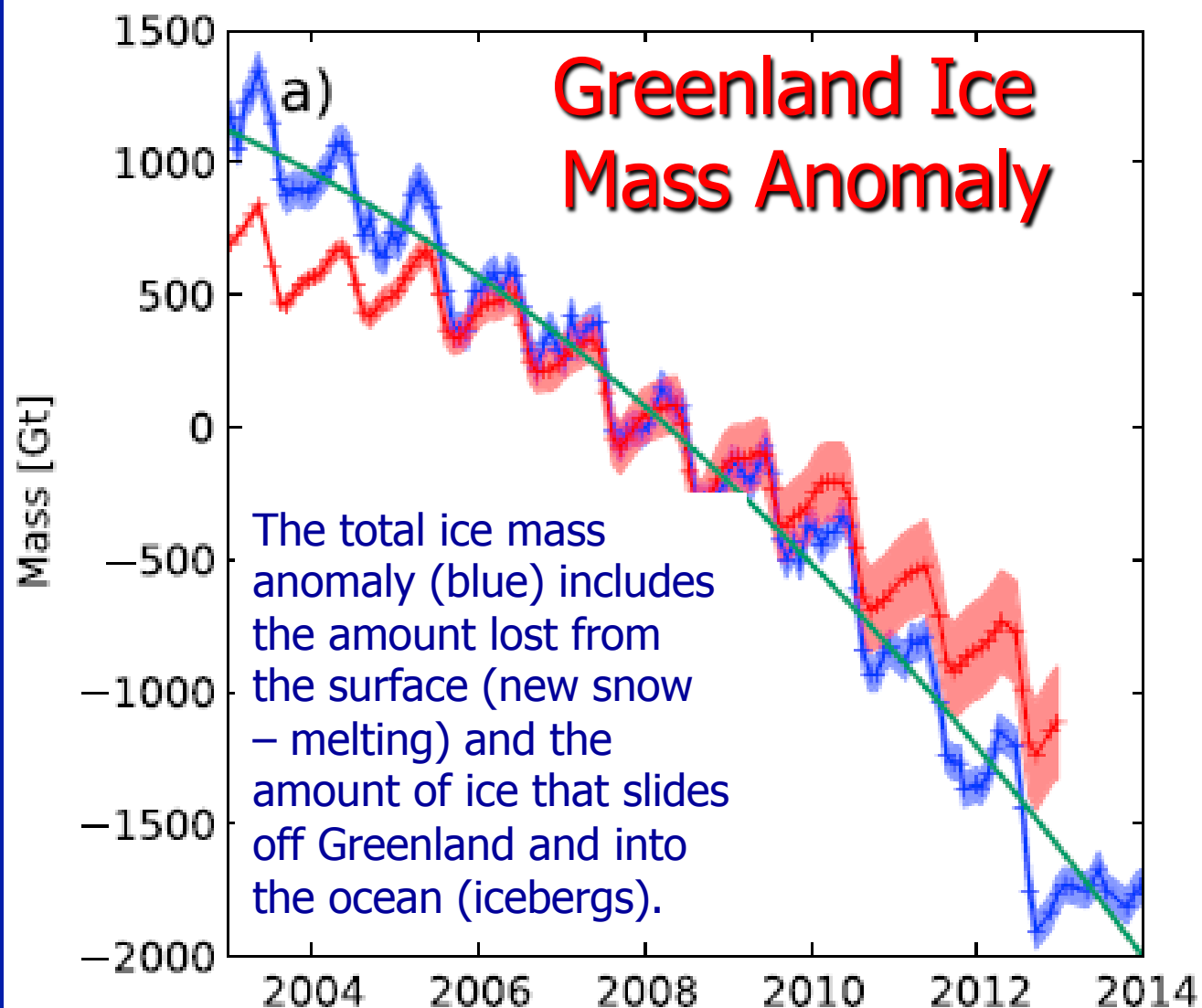
What to say

when someone argues about ice in Antarctica

This friend had a trip to Antarctica and his pilot told him that "ice is increasing in Antarctica"

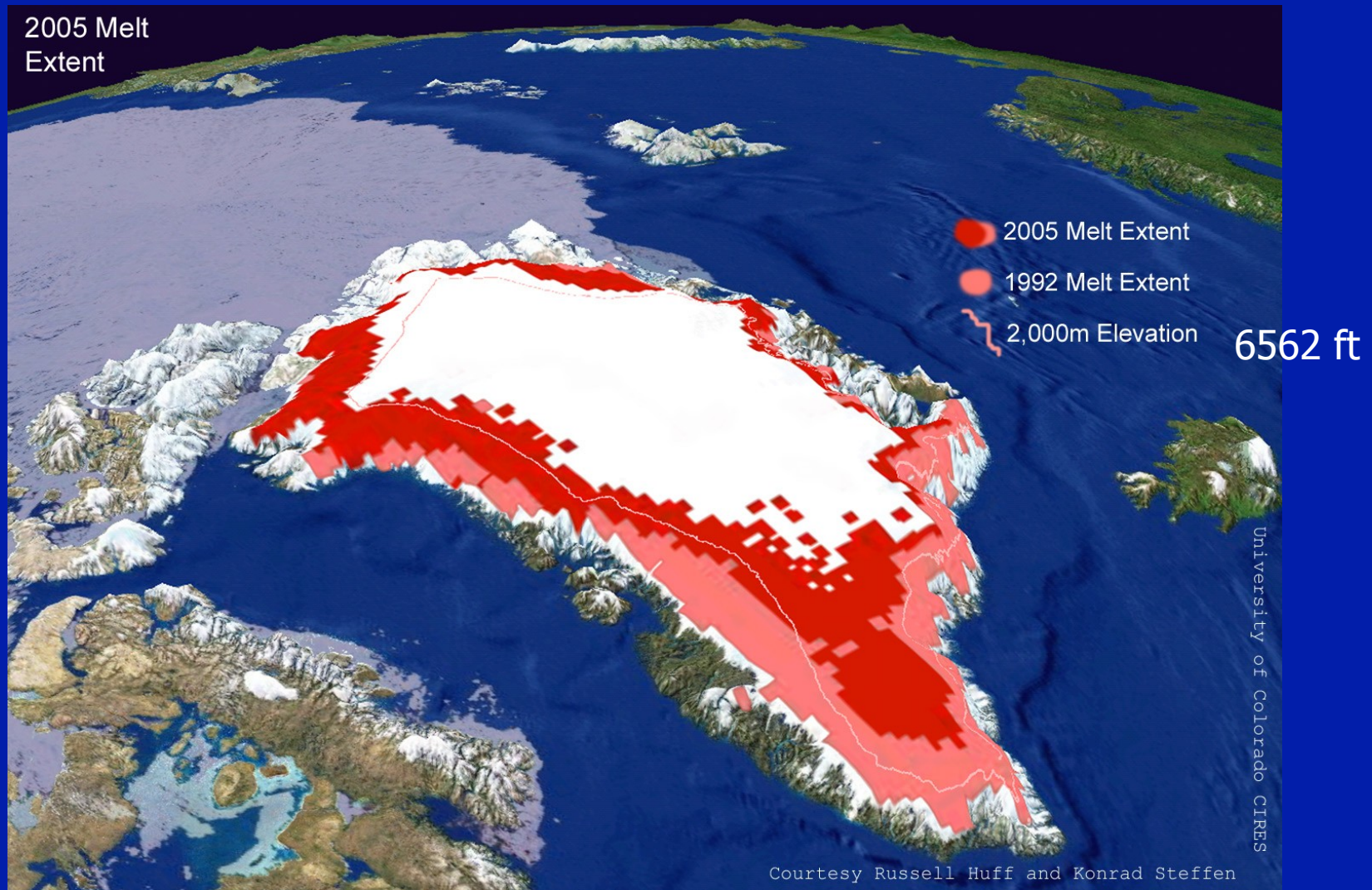
- Ans:

Velicogna, I., T. C. Sutterley, and M. R. van den Broeke (2014), Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data, *J. Geophys. Res. Space Physics*, 41, 8130–8137, doi:10.1002/2014GL061052.



Time series of ice mass, $M(t)$, in Gt (Gigatonne) for (a) the entire Greenland ice sheet (GIS),
Blue: GRACE Total Mass Anomaly
Red: Cumulative Surface Mass Balance (New snow - surface melting)

Greenland's accelerating melt



Cumulative Ice Mass Loss: Greenland

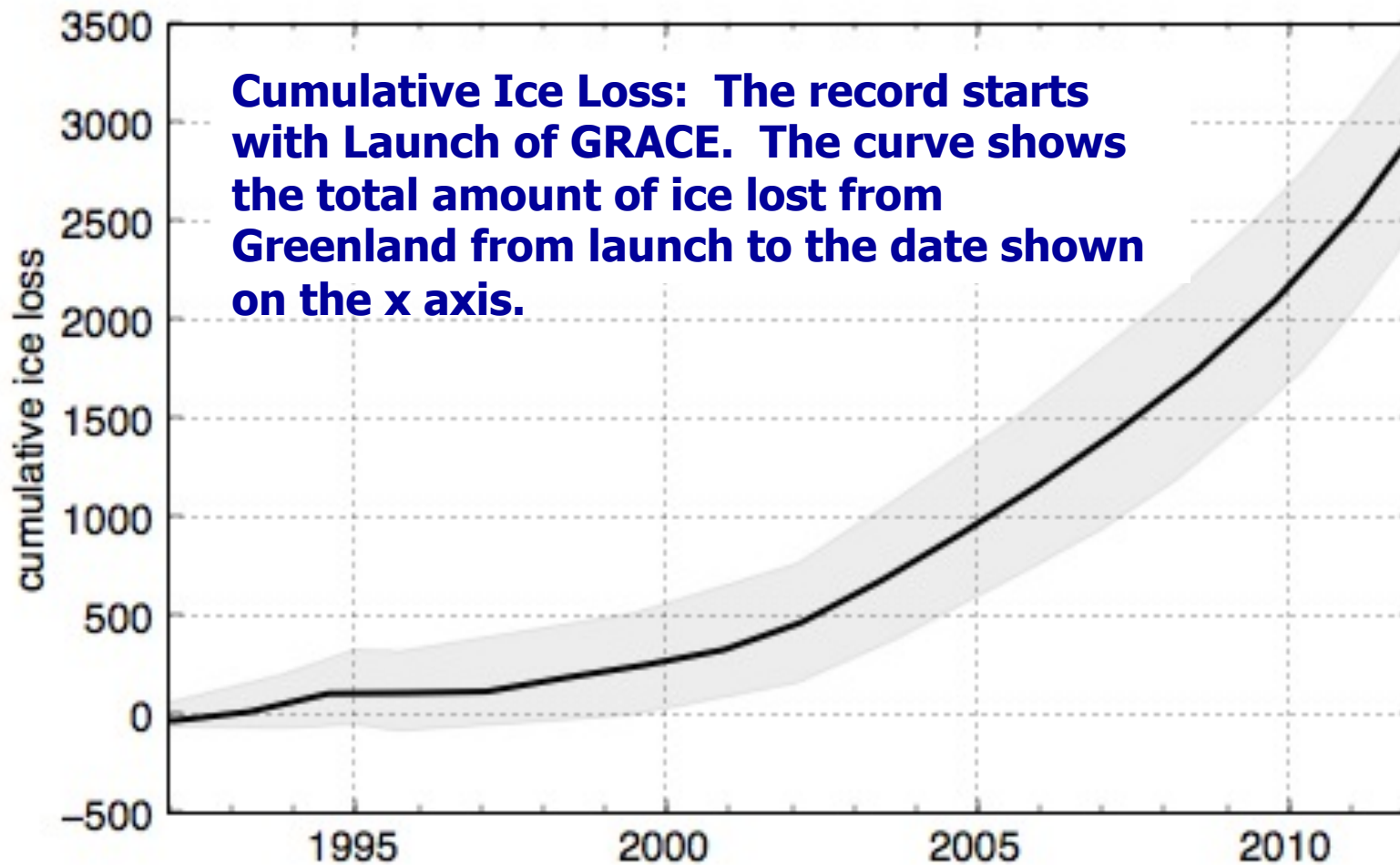


Fig. 2.8 (Dessler). Cumulative Ice Loss in gigatonnes (billions of metric tons. 1 metric ton = 1000 kg). Seasonal variation removed.

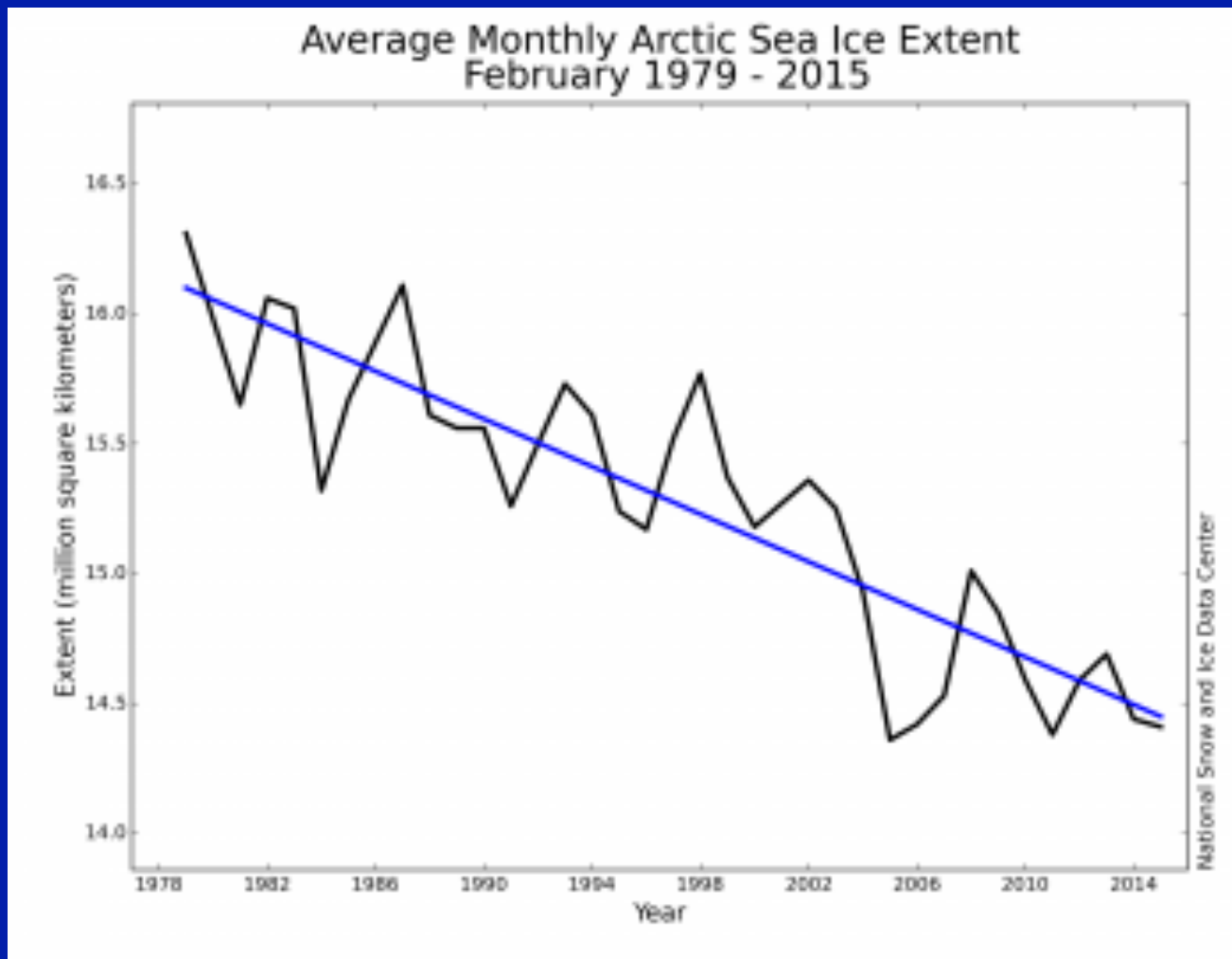
Glacier melt

- Can fresh water from melting ice counteract the increased acidity of the ocean? Not much, because the ocean has much larger volume. However, fresh meltwater can have big effects in the nearby ocean.

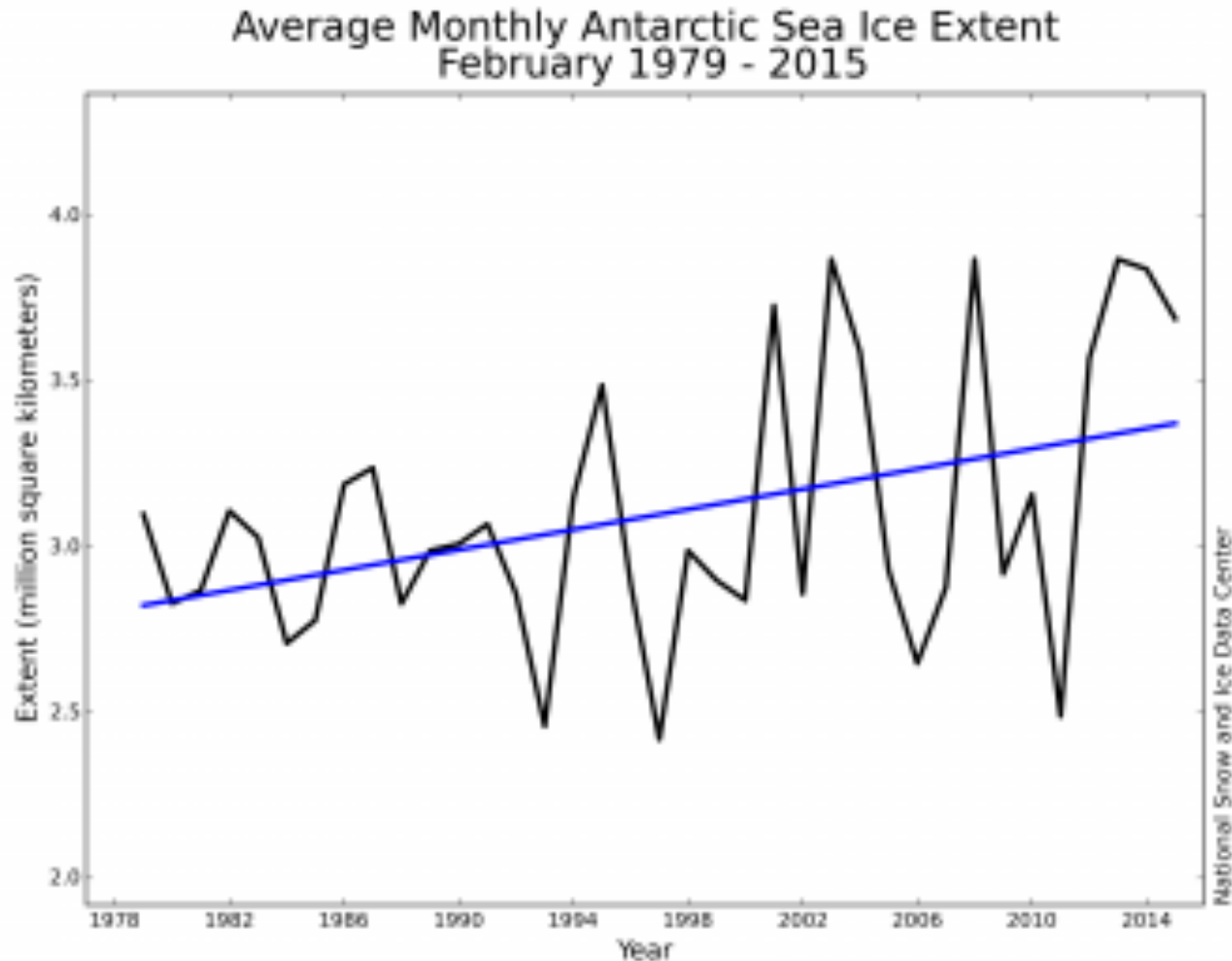
A river of meltwater on Greenland.



Arctic Sea Ice for Feb.



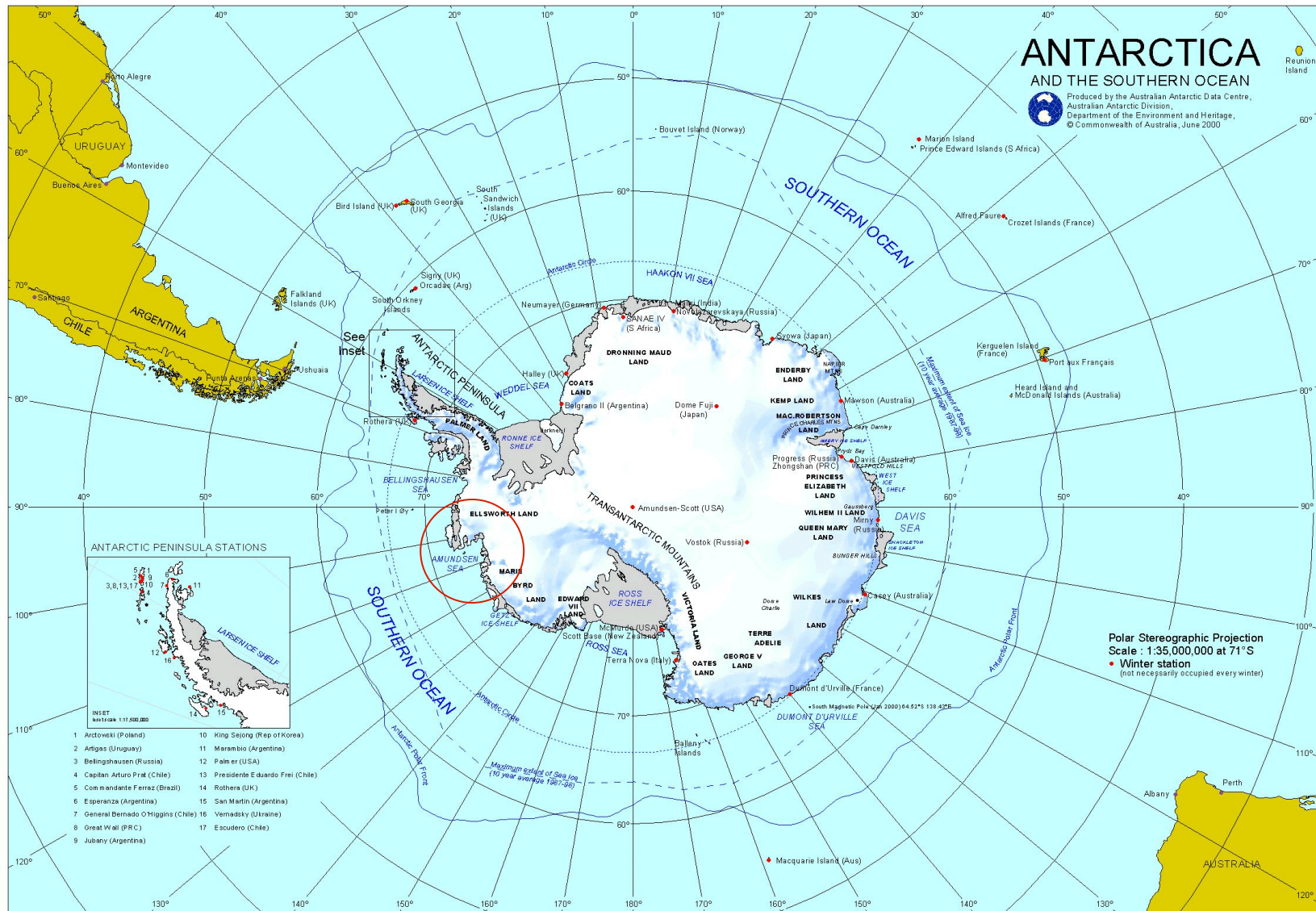
Antarctic Sea Ice for Feb.



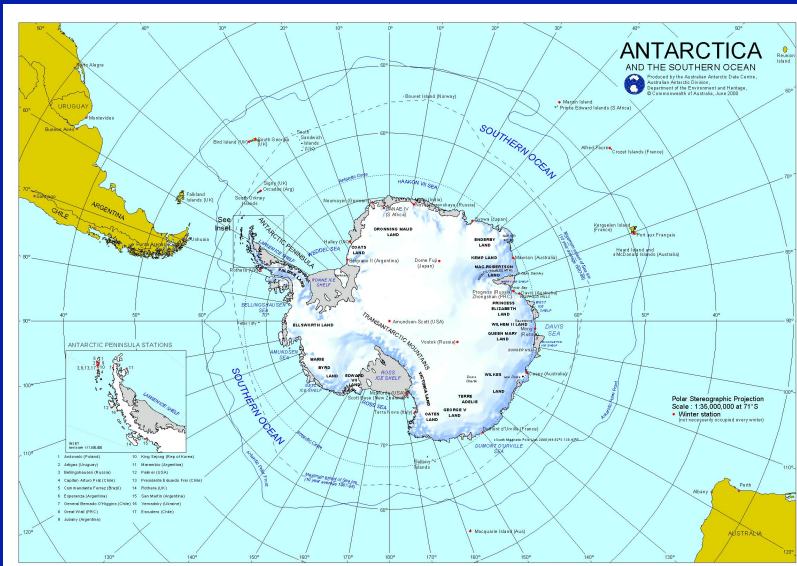
Why?

- Weather and ocean circulation patterns around Antarctica are changing
- Freshwater melt from the Antarctic continent freezes more easily than salty sea water
 - More freshwater melt, more sea ice
- Decreasing ice in the Amundsen Sea where the West Antarctic glaciers are

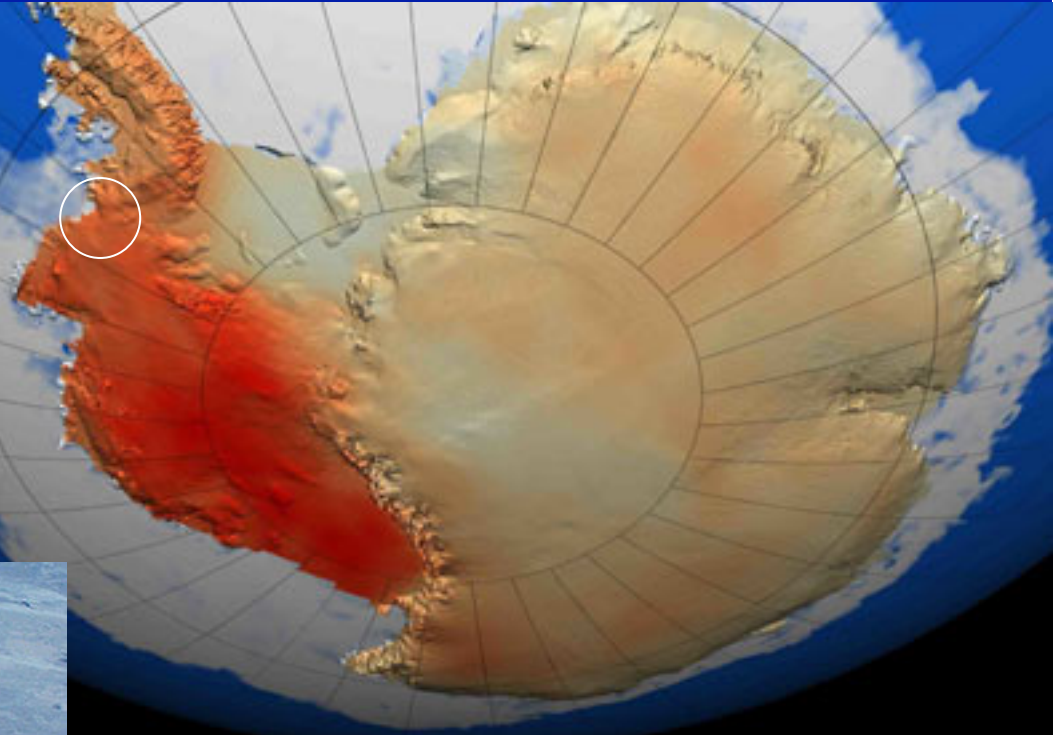
West Antarctic Ice Sheet



West Antarctic Ice Sheet



Thwaites Glacier, Amundsen Sea



Temperature change: red = $0.25^{\circ}\text{C}/\text{decade}$

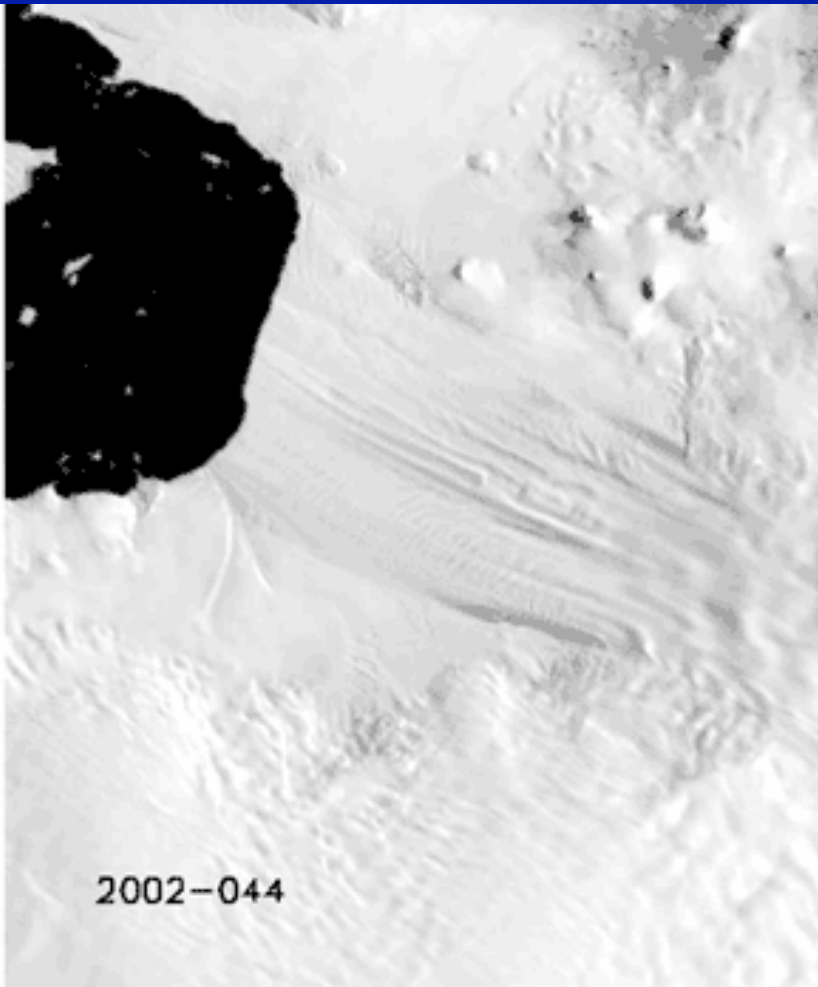


Thwaites and Pine Island Glaciers have become ungrounded from sub-surface rock, allowing free flow of the glacier into the sea. Data only, no modeling involved!

Thwaites Glacier: 2002-2014

<http://www.jpl.nasa.gov/news/news.php?release=2014-147>

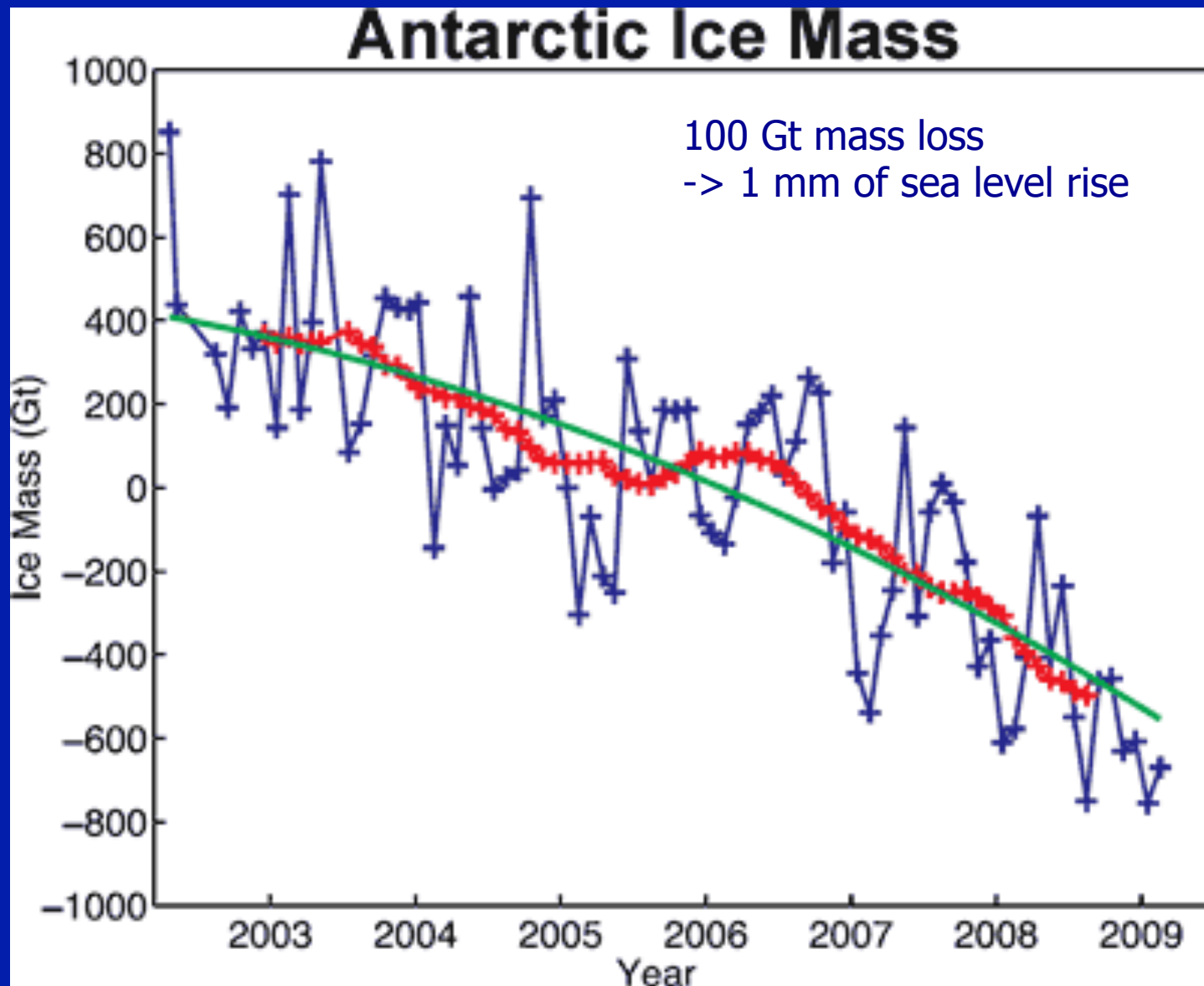
Two independent and important new papers!



May 12: "A new study by researchers at NASA and the University of California, Irvine, finds a rapidly melting section of the West Antarctic Ice Sheet appears to be in an **irreversible** state of decline, with nothing to stop the glaciers in this area from melting into the sea."

Thwaites contains enough ice to raise global sea level by 4 feet (1.2 meters) and is melting faster than most scientists had expected.

These findings require an upward revision to current predictions of sea level rise.



<http://takvera.blogspot.com/2014/01/antarctic-ice-mass-accelerating.html>

What to say

when someone argues about ice in Antarctica

This friend had a trip to Antarctica and his pilot told him that “ice is increasing in Antarctica”

- Ans: Everything is happening as predicted
 - *Sea Ice* at the North pole is decreasing
 - *Sea Ice* is slightly increasing around Antarctica
 1. Melting continental ice has no salt and freezes more easily.
 2. Currents and winds are changing on the continental shelf due to climate change
 - *Land Ice* mass on Antarctica is decreasing

What to do

when you don't know how to answer

- “Maybe you're right. I'll need to check the facts on that question.”

- Sources:

- <https://www.skepticalscience.com/argument.php>
 - Skeptical Science
- <http://www.ipcc.ch/report/ar5/>
 - IPCC Fifth Assessment Report (AR5)
- <http://www.realclimate.org>
 - Real climate

Denier sites

- <http://wattsupwiththat.com>
- <http://www.climate-skeptic.com>