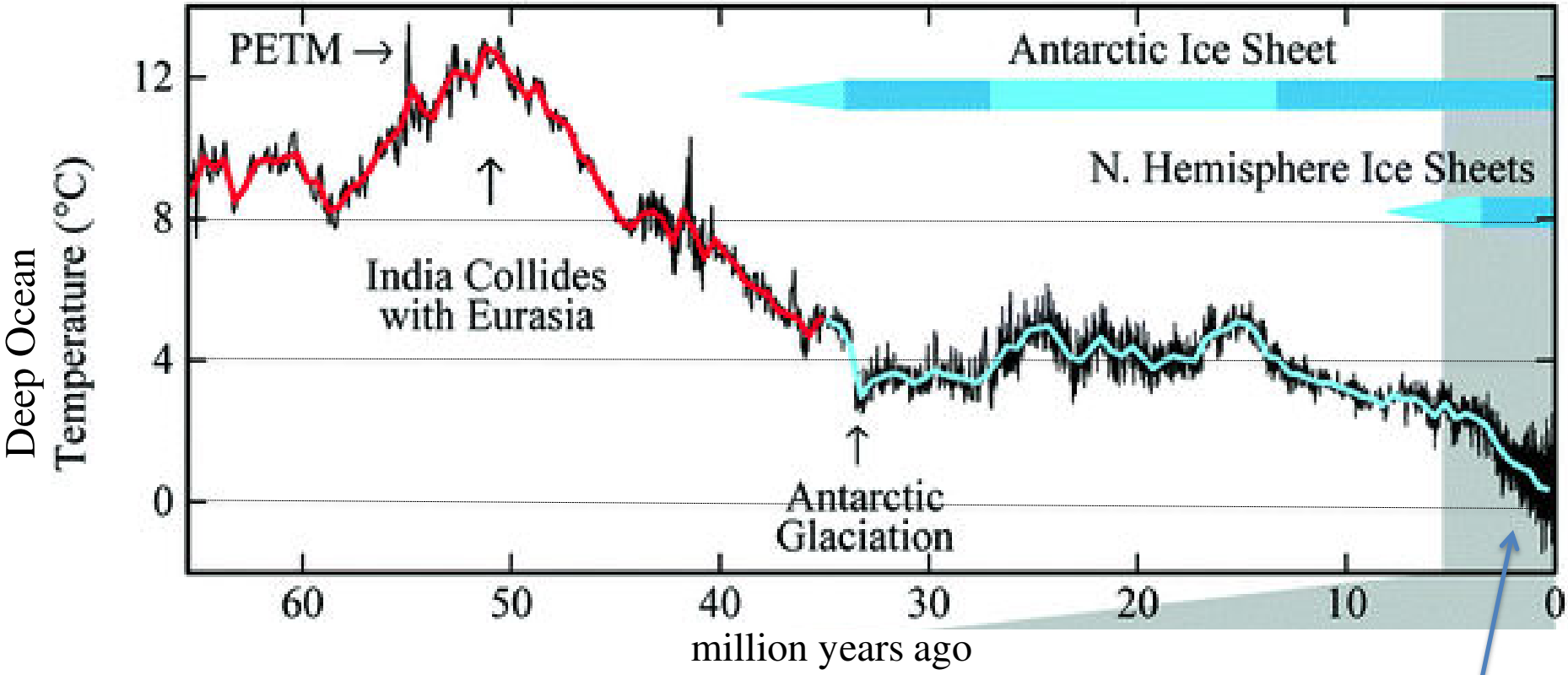
4.5 to 7.8ºC
Global Surface Warming
from Today's
CO_2 and CH_4 Levels

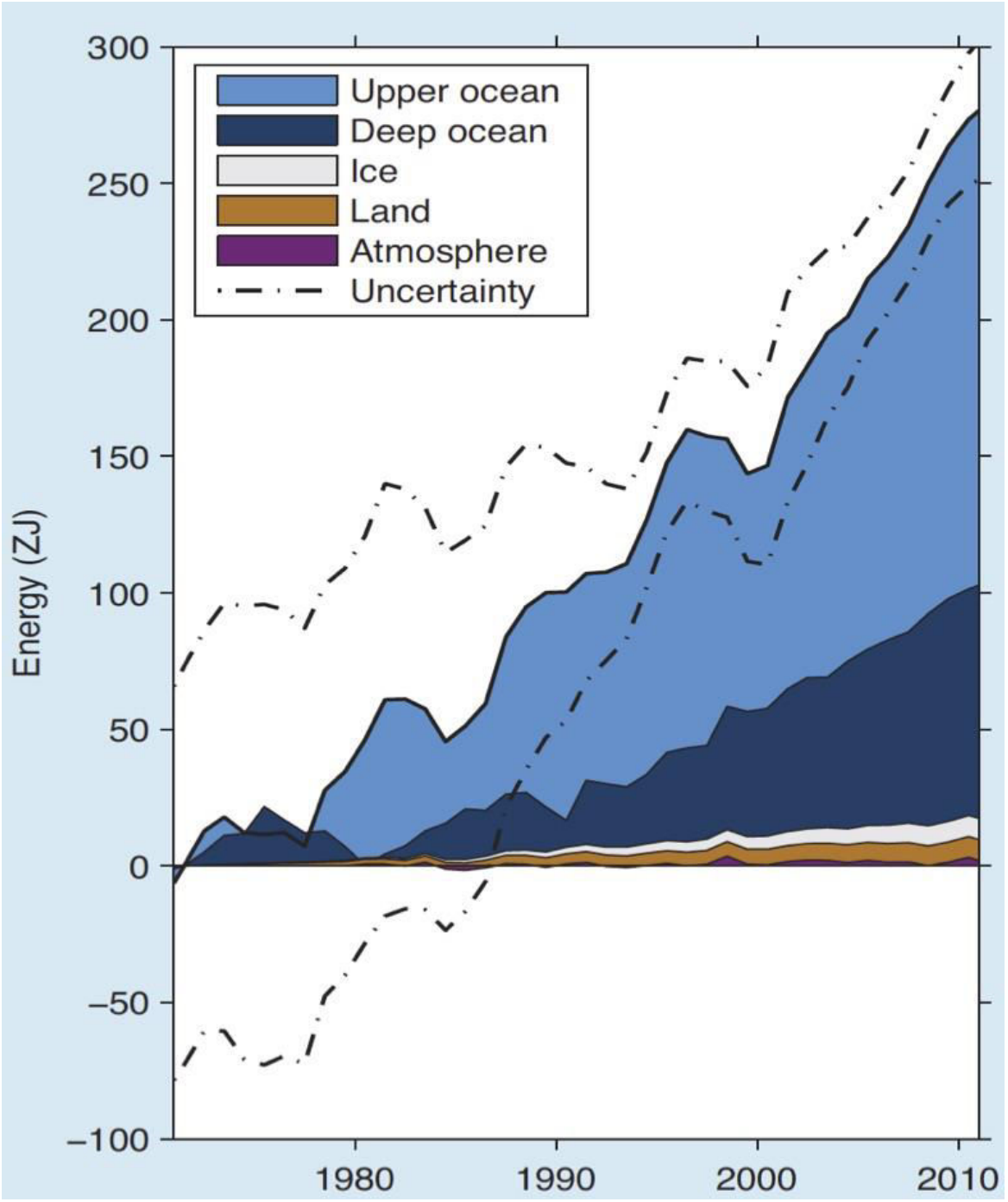
Gene R. H. Fry

We can learn lessons from the distant past.



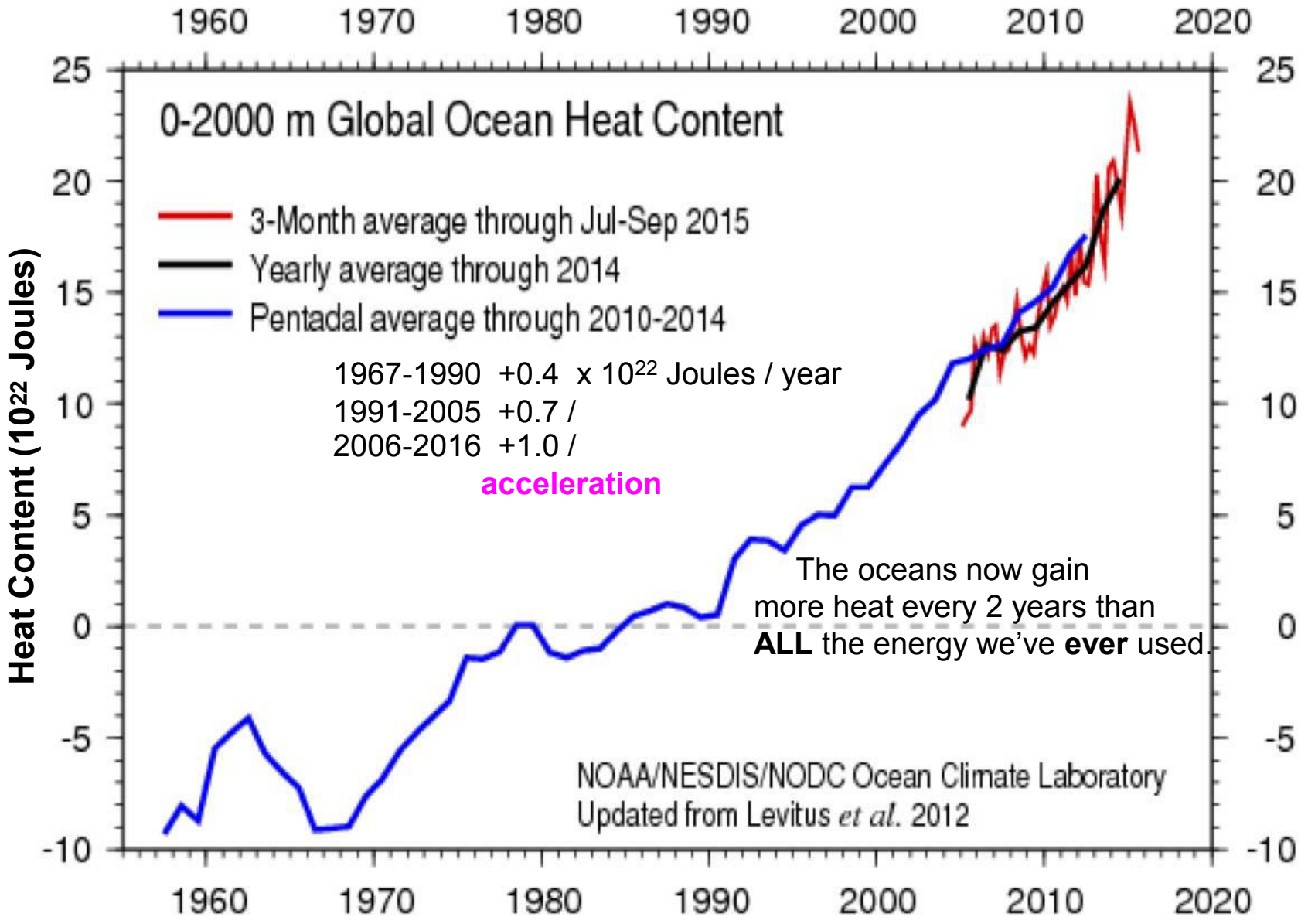
Earth's surface can grow far warmer than now.

With more ice, temperature swings are wider, since albedo changes - from icy to less icy - are larger.

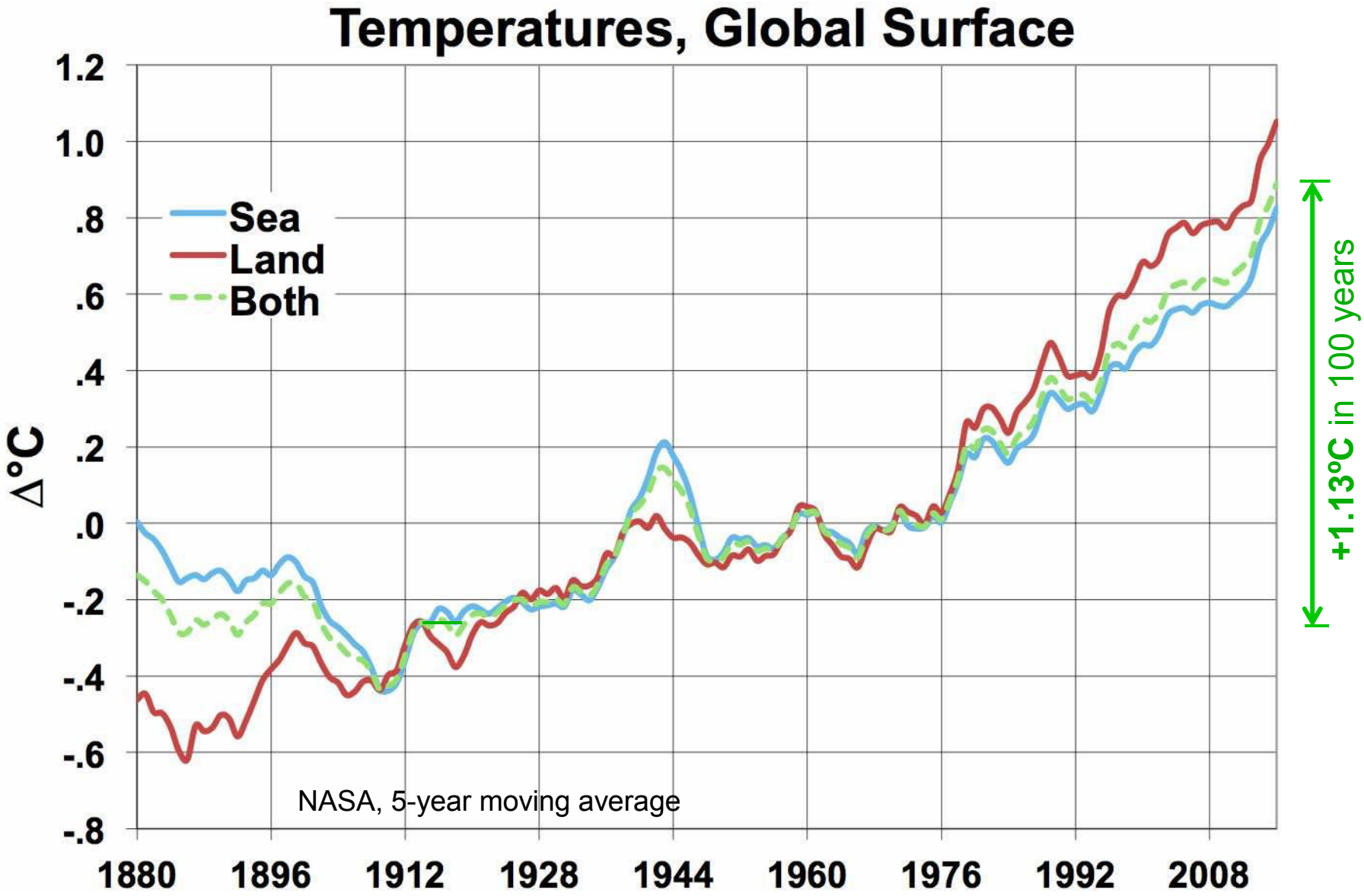


Only a tiny fraction of warming goes into the atmosphere.

Ocean Heat Content



10^{22} Joules = 100 years of US energy use



The 1996-2016 rate of change was
2.4ºC / 100 years for Land,
2.1 for Sea,
2.2 for Both.

At that rate, “Both”
will pass 2ºC above 1880 levels in 2068.

“Land” in 2056.

Earth Is Heating Up.

- Earth now absorbs 0.25% more energy than it emits:

a 300 (±75) million MW heat gain (Hansen '11)

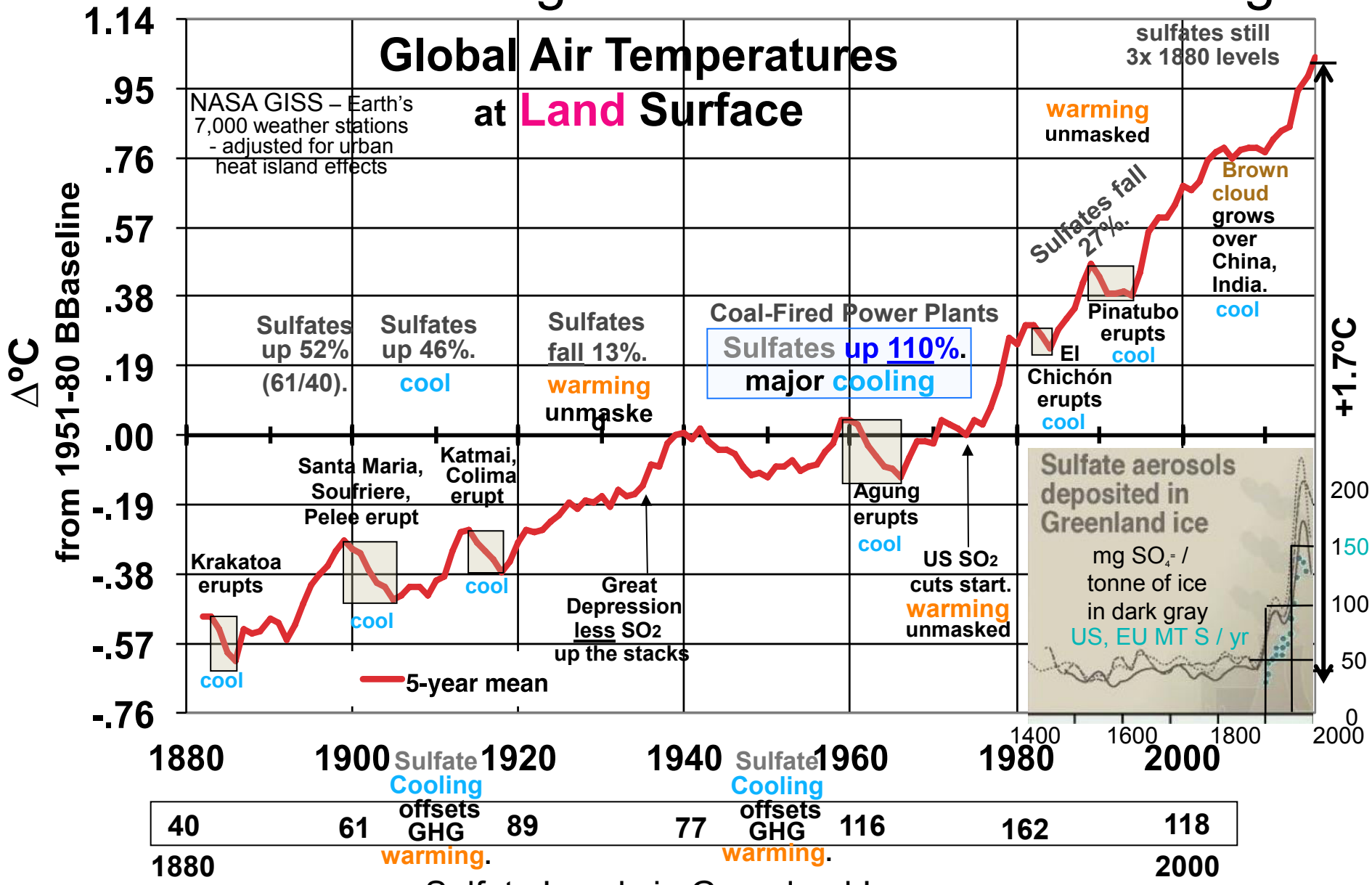
= 50 x global electric supply.

This absorption has been accelerating, from near zero in 1960.

Earth's surface must warm another 0.6ºC
so it emits enough heat to balance absorption.

The oceans have gained ~ 10 x more heat in 40 years
than all the energy humans have EVER used.

Sulfate Cooling Un-Smooths GHG Warming

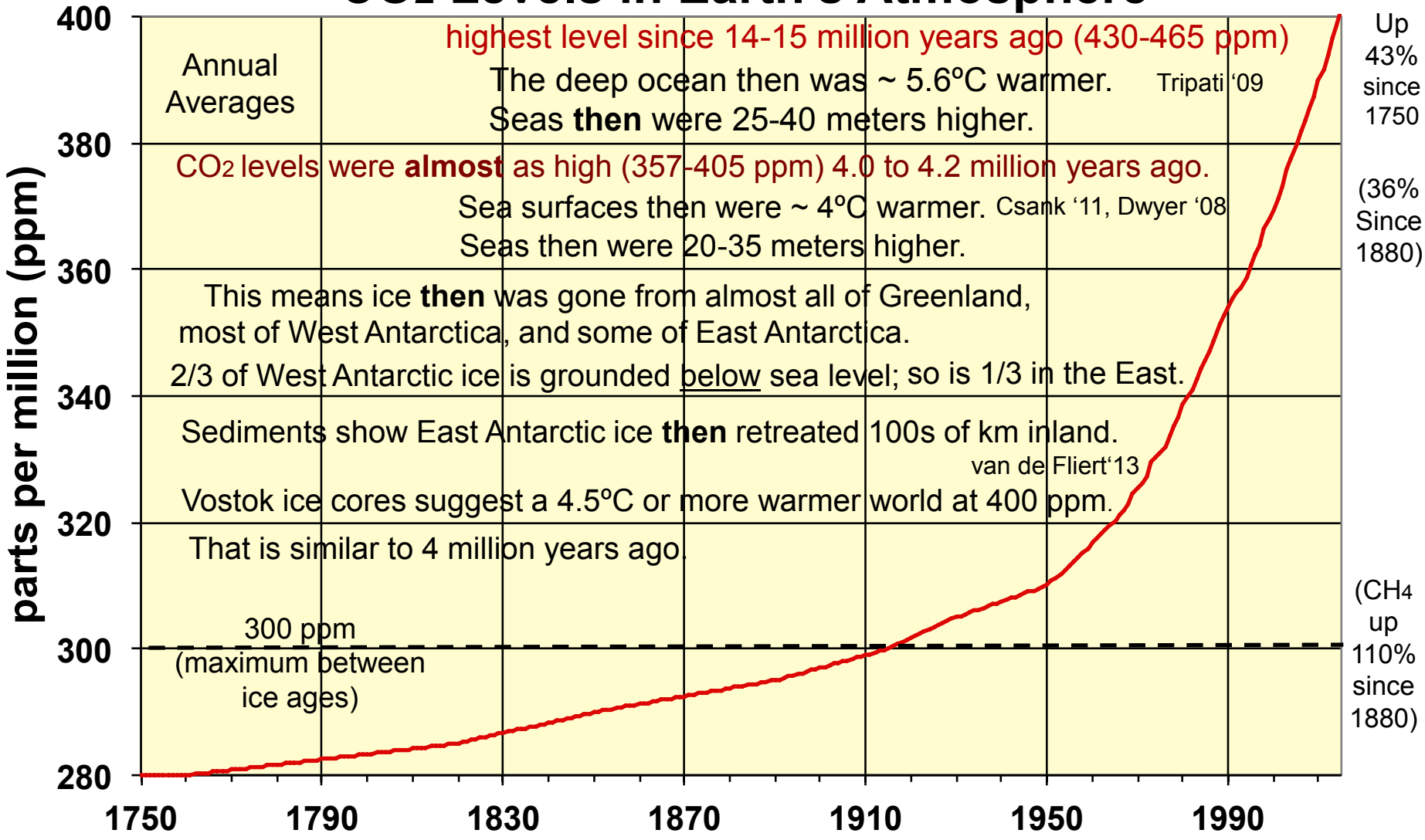


Sulfate Levels in Greenland Ice

milligrams of Sulfate per Ton of Ice

(Intergovernmental Panel on Climate Change, 2002)

CO_2 Levels in Earth's Atmosphere

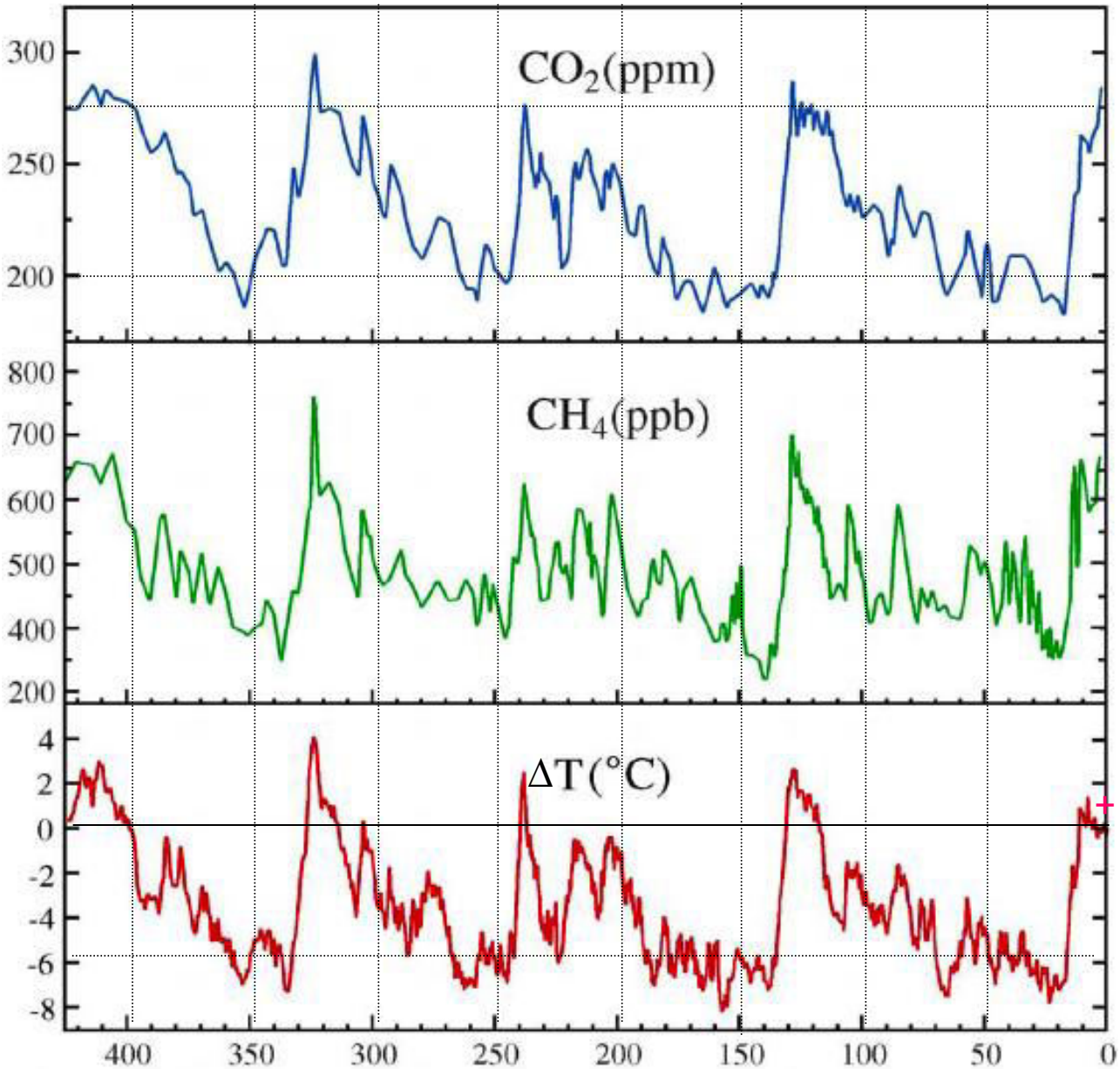


What happened before will happen again with 400+ ppm.

CO_2 levels now will warm Earth's surface 4+ºC, not just the 1.2ºC seen to date.

Vostok Ice Core Data

+ 2015 CH_4 level ~ 1836 ppb
+ 2015 CO_2 level ~ 400 ppm



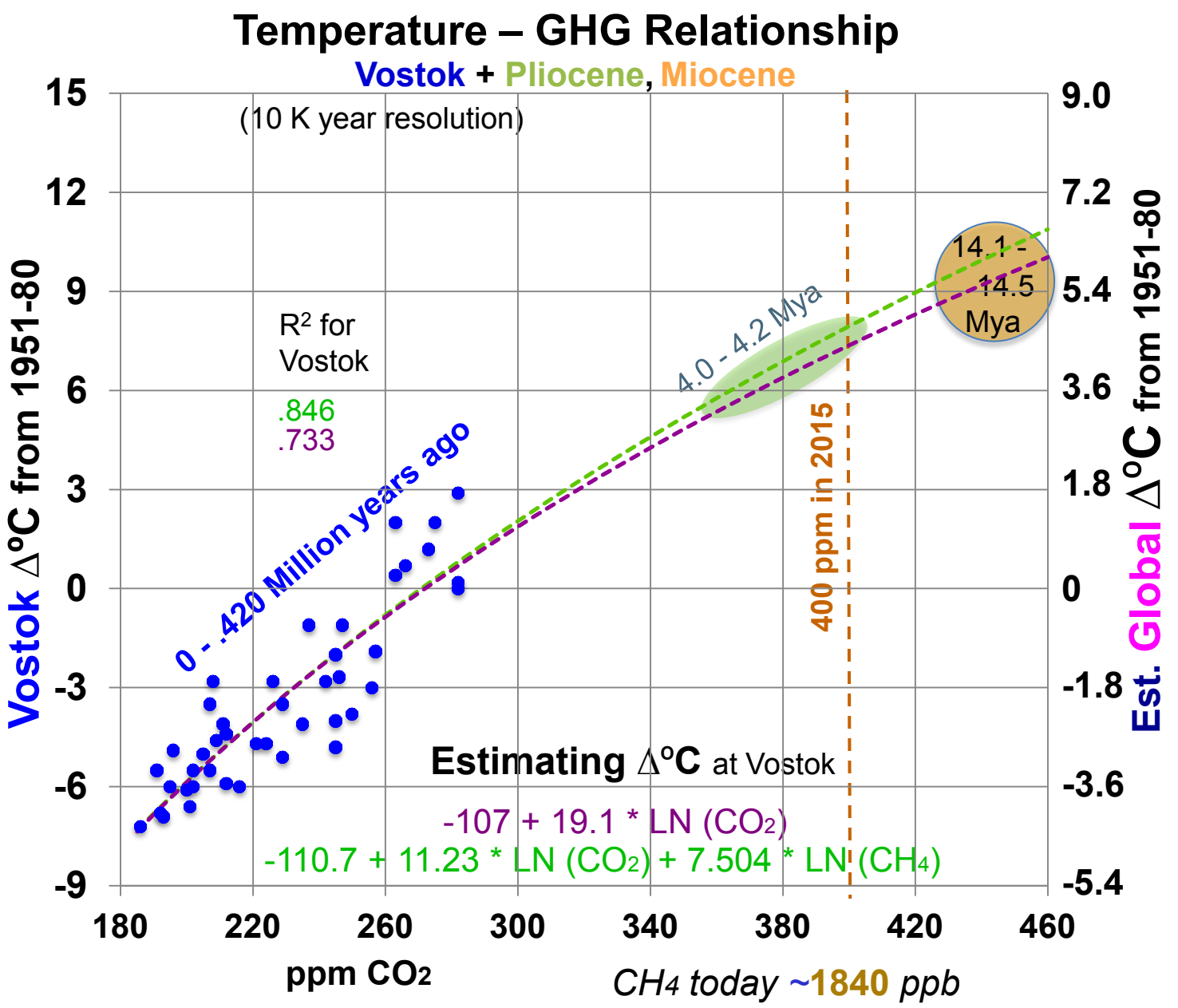
+ 2015

ppm = parts per million

ppb = parts per billion

Vimeux, Cuffey & Jouzel, *Earth and Planetary Science Letters* 203: 829-843 (2002)

Lessons for Our Future from Ages Ago



For the ratio of the global average Δ°C to Vostok Δ°C,

I use 0.6, the ratio of polar change to global, over the last 2 million years,
from Snyder (2016).

With current CO_2 & CH_4 levels, the equations yield global surface warming of 7.8°C,

but only **4.5**°C **if** CH_4 is neglected.

Warming
how fast?

20-40% in decades, the rest over centuries.

Vostok *typical* ppb CH_4 for ppm CO_2: 2.13 x

Global Surface Δ°C = 0.6 *
(-110.7 + 11.23 * LN (CO_2) + 7.504 * LN (CH_4))

+2ºC globally requires (*e.g.*)

323 ppm CO_2 and

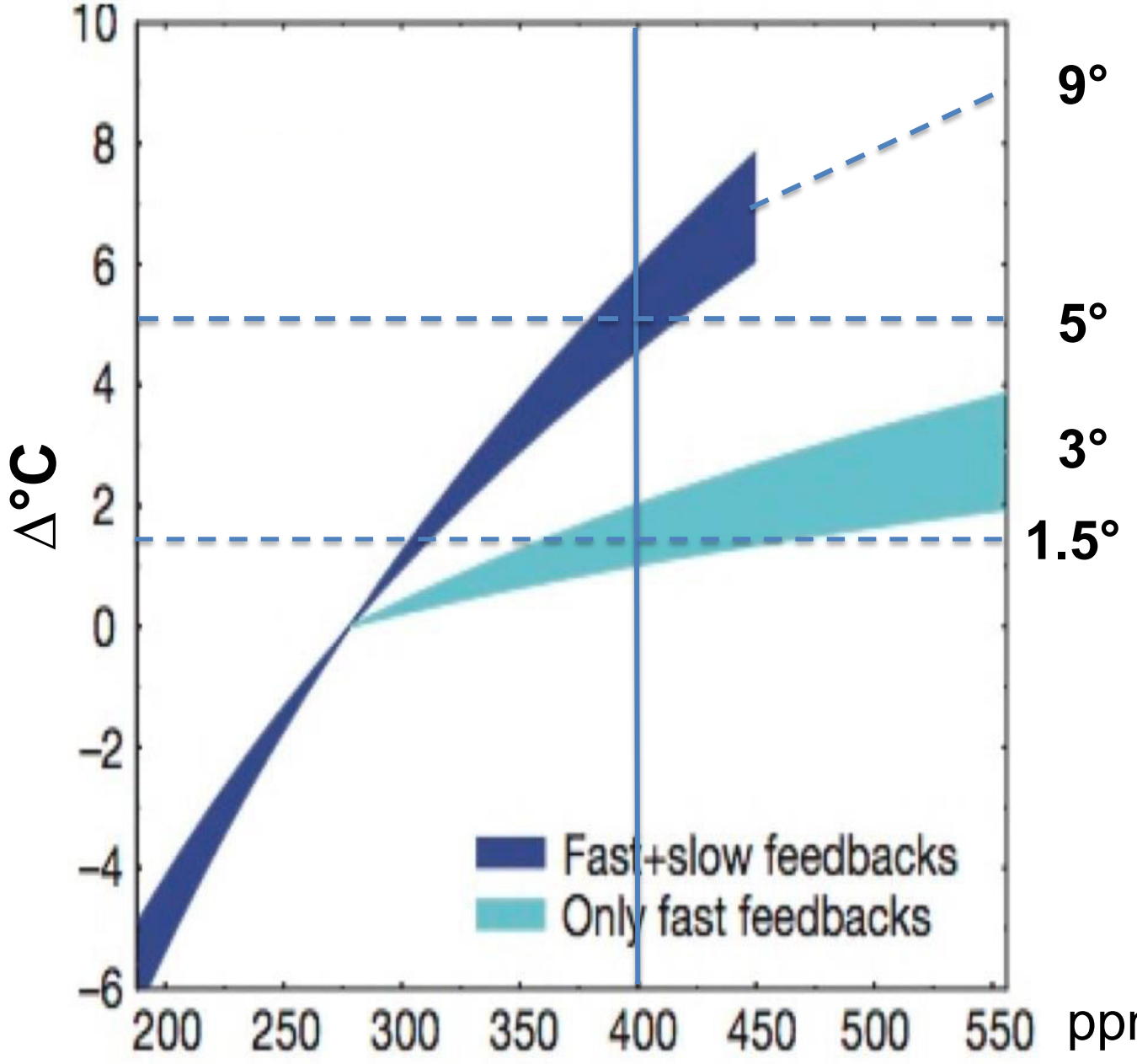
700 ppb CH_4.

This means removing 65% of the CO_2
that humans have emitted

and all of the CH_4.

Humanity's remaining carbon budget
for burning fossil fuels is
NEGATIVE 250 GT of carbon.

Climate Sensitivity



from the last 20 million years, by van der Wal, 2011

also Snyder, 2016 data from last 2 million years, based on CO_2

Warming to 2100 and beyond
will be dominated by
albedo changes
and
permafrost emissions.

How do albedo effects produce
that much warming?

Earth will warm 3 x more, even if we stop emitting now.

Blame phasing out coal's sulfur emissions (about 0.5ºC),

vanishing Arctic sea ice (~0.3ºC),

receding northern snow cover (~0.3ºC),

receding Greenland & Antarctic ice (~0.3ºC),

warming oceans enough so energy out = in (~0.6ºC),

more H_2O vapor & less cloud cover (1-1.5ºC), and

carbon emissions from permafrost, etc. (~0.6ºC).

More carbon emissions can add up to 2.2ºC **each**
from H_2O vapor, clouds & permafrost.

When? (How fast?)

Sulfur and sea ice loss (Mar-Nov) will be complete before 2100.

Snow cover and cloud cover losses will continue.

Permafrost + emissions ramp up in an S-curve thru 2300.

Polar land ice loss and warming deep oceans span centuries.

Sulfate Cooling

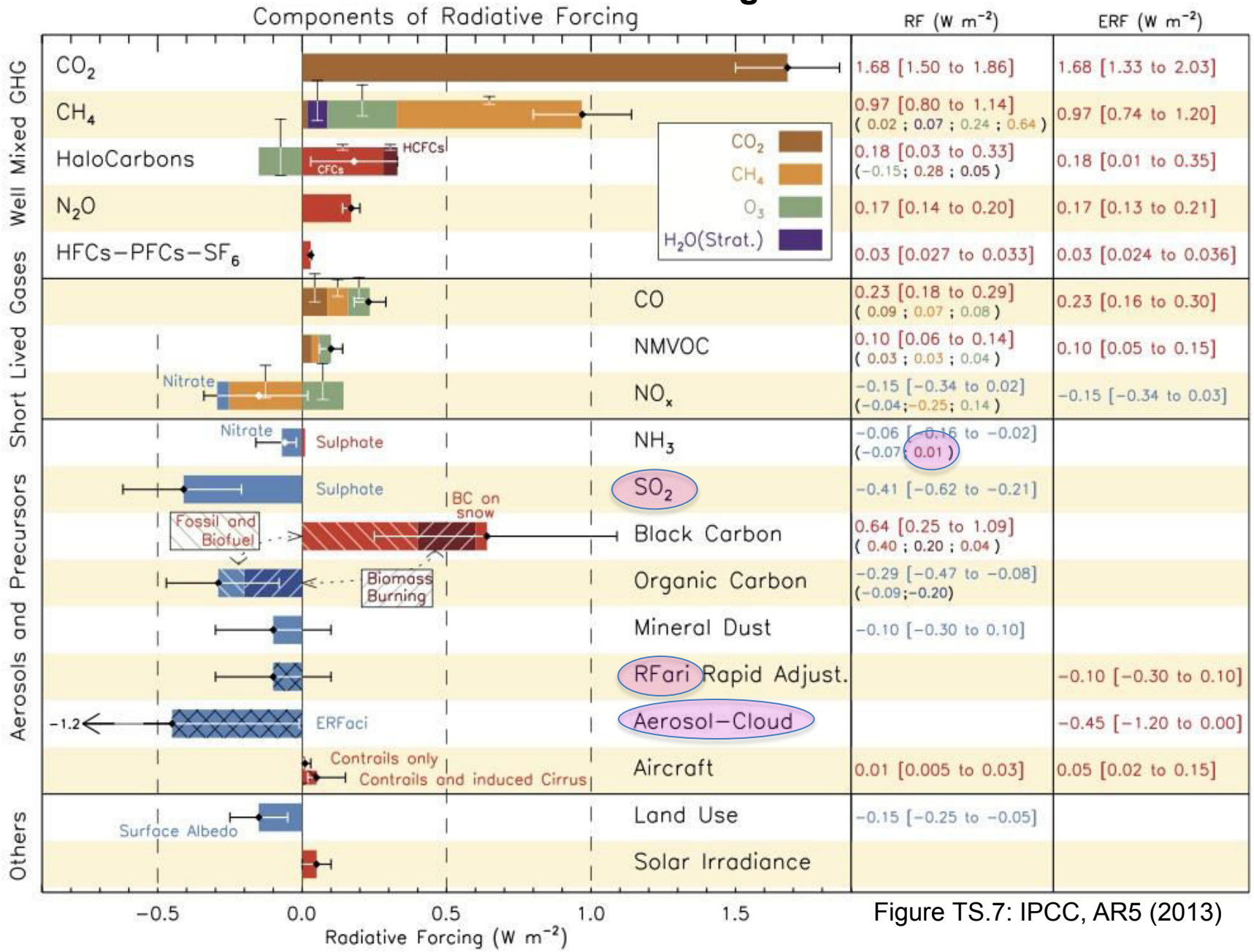
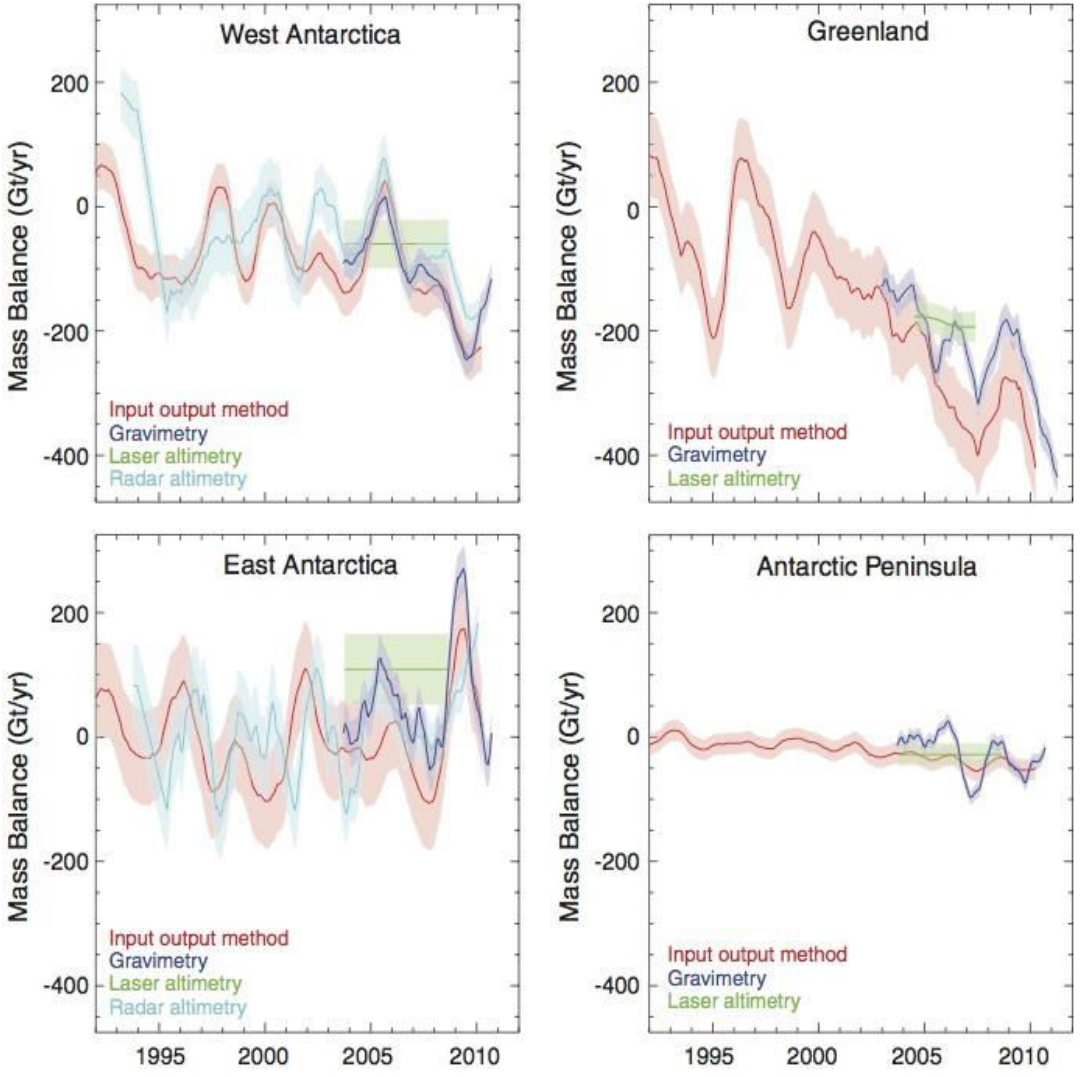
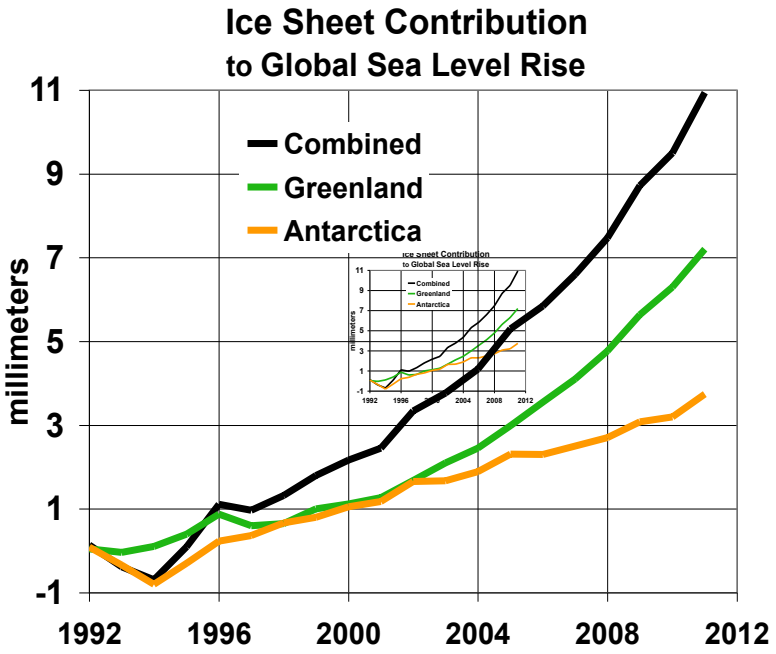


Figure TS.7: IPCC, AR5 (2013)

Sulfates offset (0.41 + 0.10 + 0.45 - .01 = 0.95) / (sum of above = 2.30 + 0.95) = 29% of GHG warming.

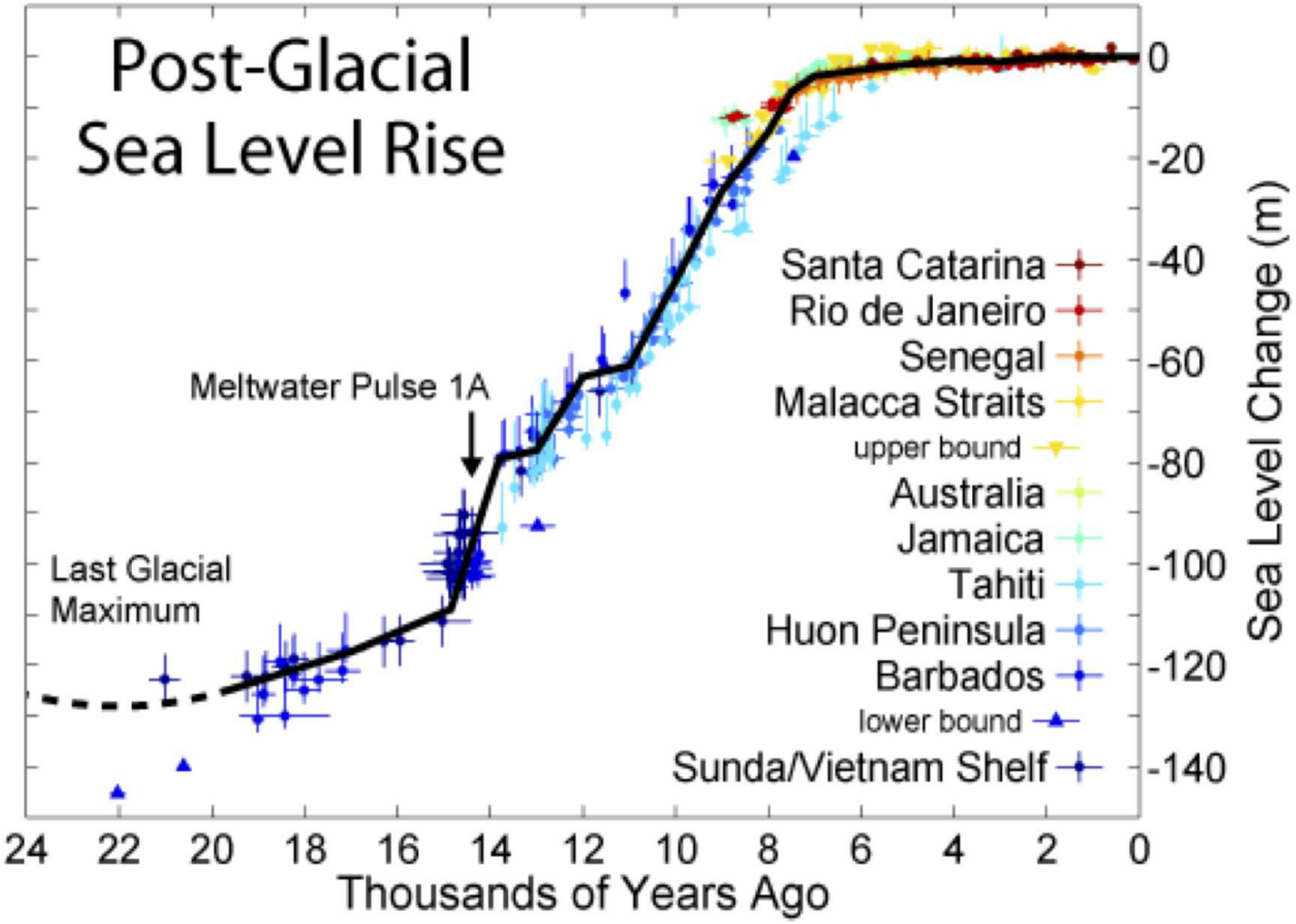




Polar Ice Mass Change (GigaTons / year)					
	1992 -2011	1992-2000	1993-2003	2000-2011	2005-2010
Antarctic Peninsula	-20	-8	-12	-29	-36
West Antarctica	-65	-38	-49	-85	-102
East Antarctica	14	-2	-9	26	58
Antarctic Total	-71	-48	-71	-87	-81
Greenland	-149	-51	-83	-211	-263
Total	**-213**	**-100**	**-152**	**-298**	**-344**
	Error Bar Widths (± GigaTons / yr)				
	1992-2011	1992-2000	1993-2003	2000-2011	2005-2010
Antarctic Peninsula	14	17	17	12	10
West Antarctica	26	32	31	22	18
East Antarctica	43	54	50	36	31
Antarctic Total	53	65	61	43	37
Greenland	49	65	63	37	30
Total	72	92	88	58	48
Human Carbon Emissions from Burning Fossil Fuels = 10 GT / year. US fresh water use ~ 450 GT / Year.					

Andrew Shepherd et al.,
"A Reconciled Estimate of Ice-Sheet Mass Balance",
Science 38(6111):1183-1189. Nov. 30, 2012

Sea Levels over Last 24,000 Years

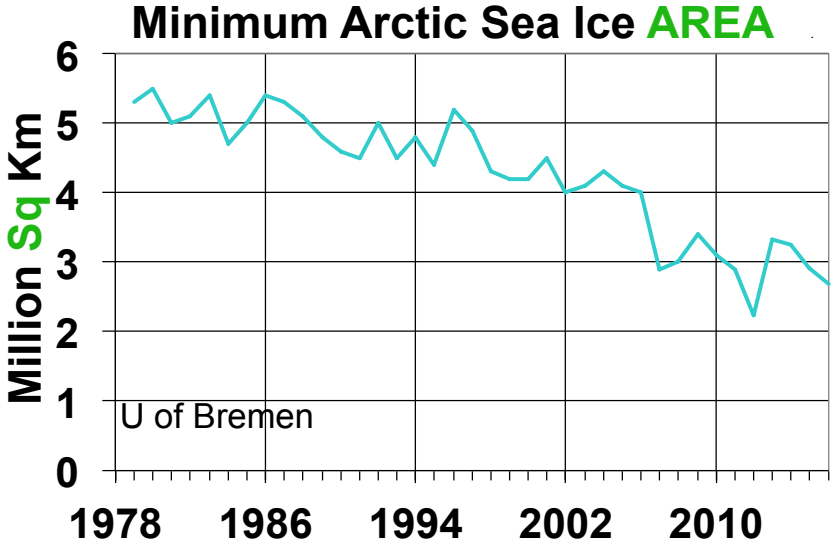


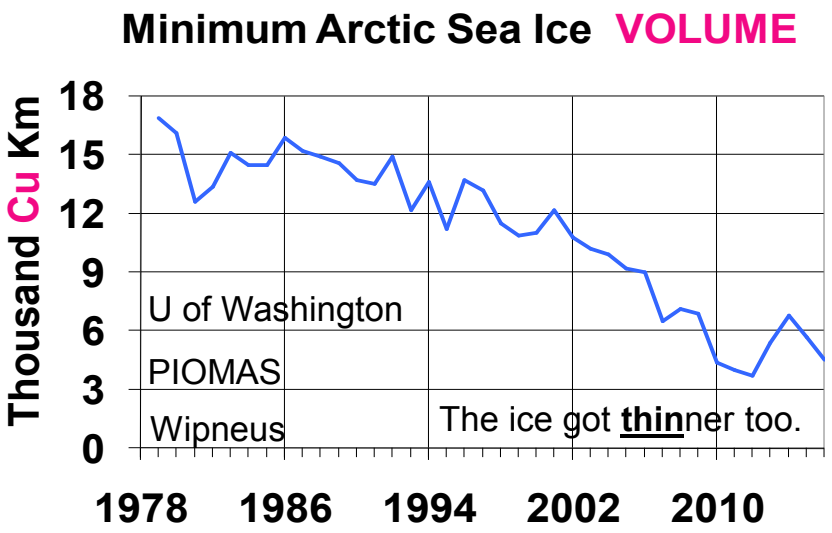
3 meters per century during Meltwater Pulse 1A (1 millennium)

1.5 meters per century from 15 to 8 millennia ago

Warming is 40-50 times as fast as then, but only 1/3 as much ice is left.

Arctic Ocean ice is shrinking fast.



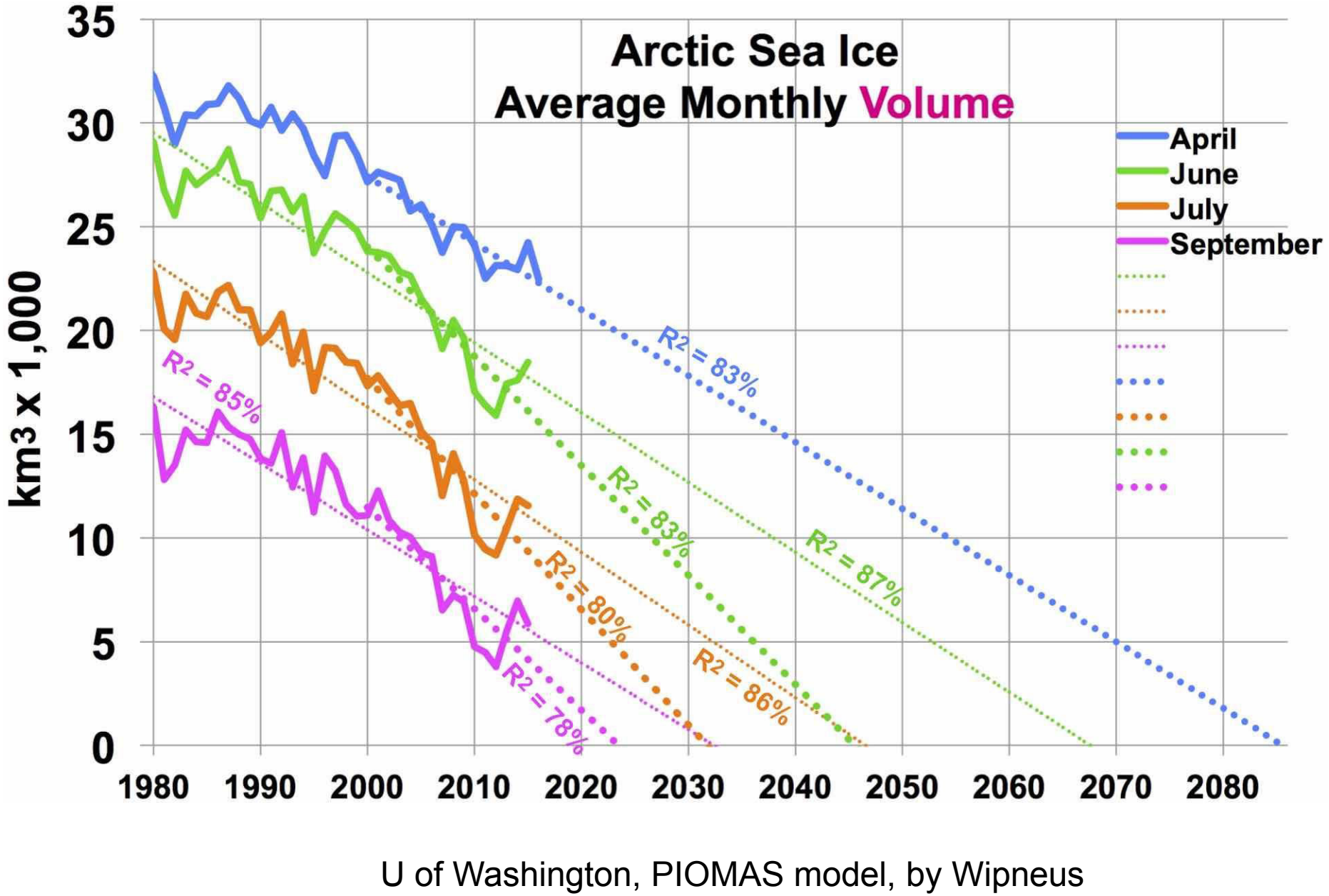


Minimum ice area fell 49% in 37 years, while volume fell 73% , 50% in the last 10.
The ice could melt away by fall in 4-9 years & be gone all summer in 9-30.
The dark water absorbs far more heat than ice: so far, like 20 extra years of CO_2.

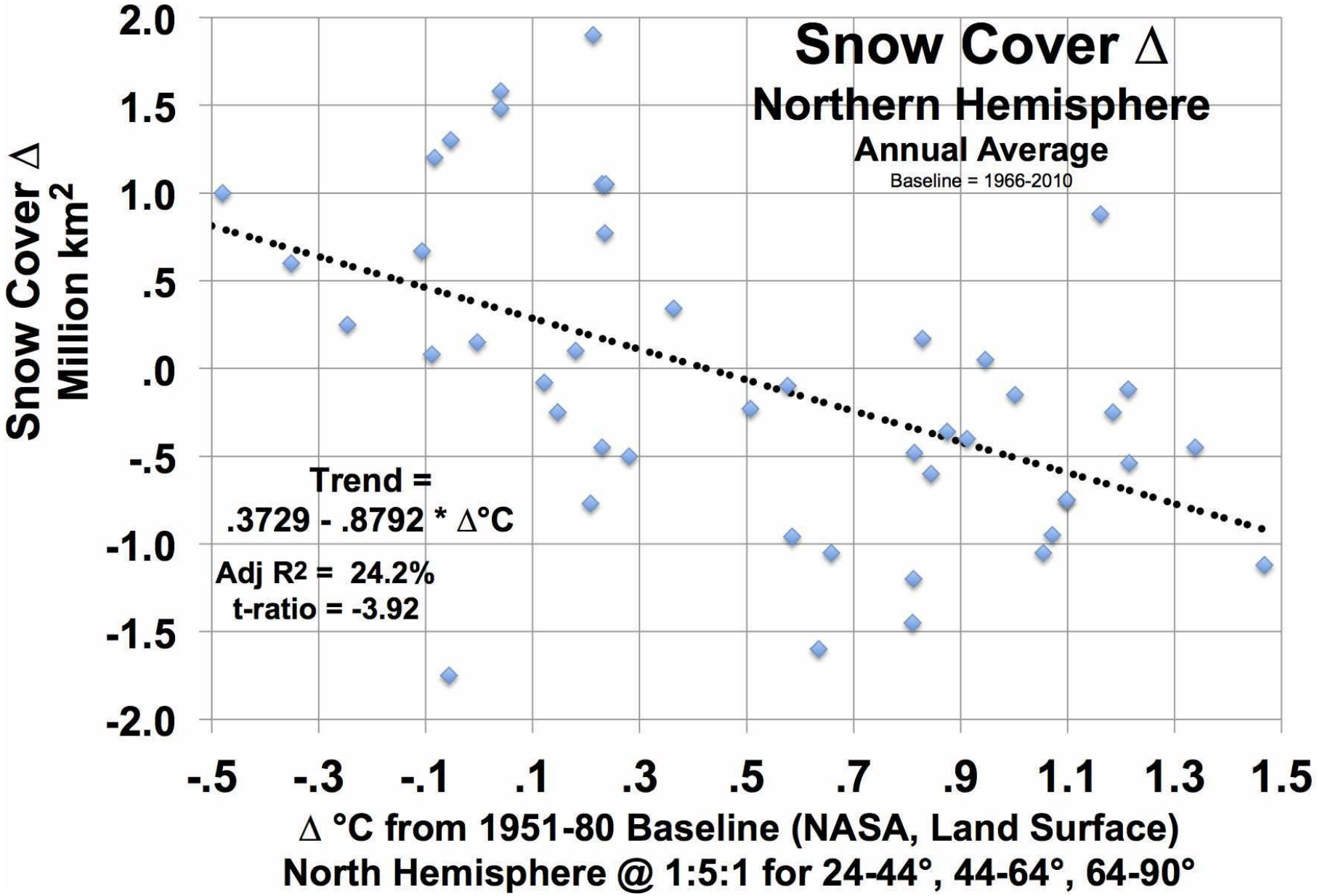
Greenland's net ice-melt rate rose 7 x in the past 17 years.
So, the ice cap's life expectancy fell from 60,000 years to 8,000.

Antarctica's yearly net ice-melt was ~ 1/3 of Greenland's.
Its melt rate doubled over 2007-11. It has 9 x the ice. It will last longer.

Seas may rise .3 to 2 meters by 2100 & 30 meters over centuries.



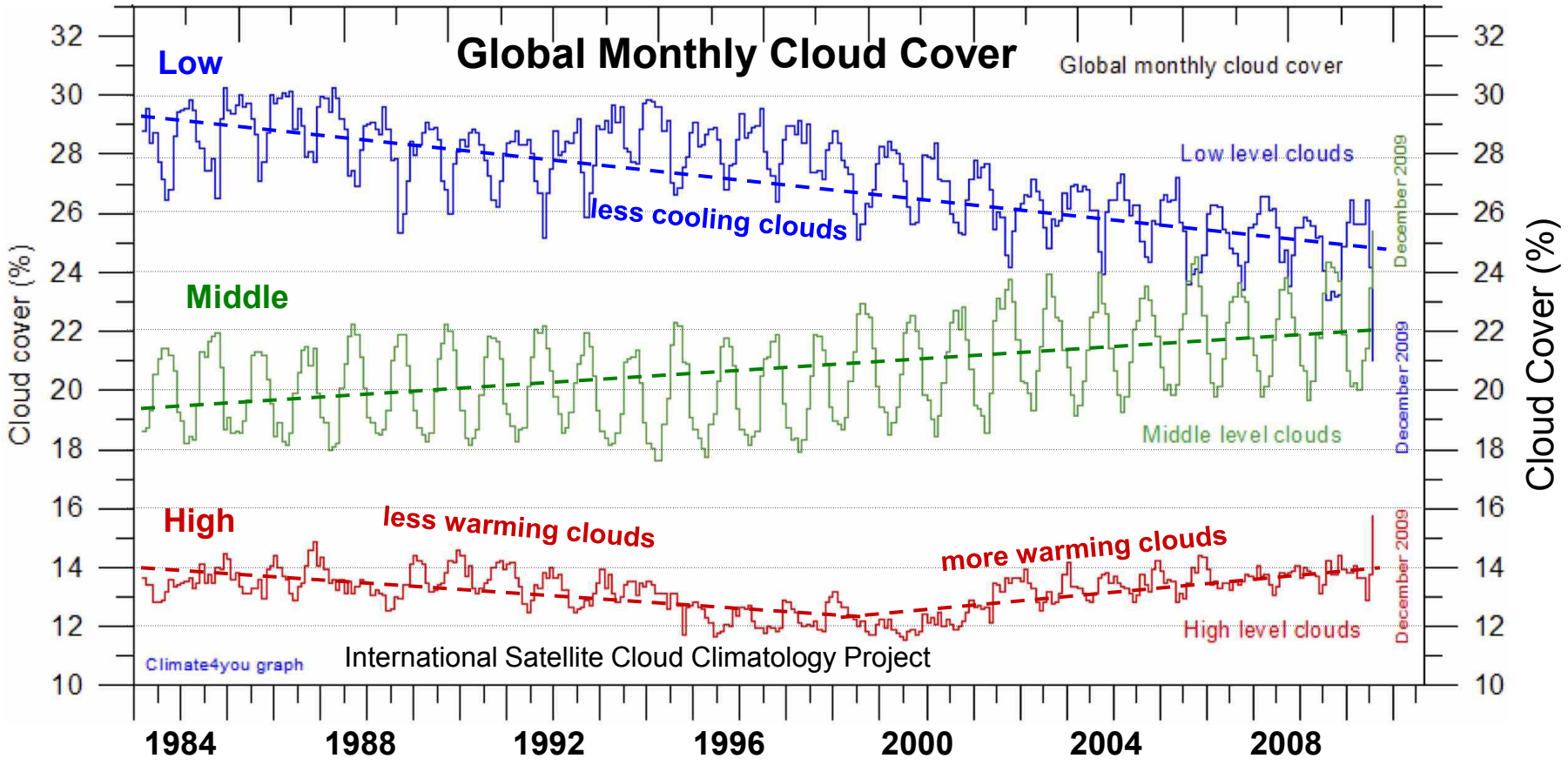
U of Washington, PIOMAS model, by Wipneus



Snow Observations, 1965-2012

***S**tate of the Climate in 2012*, American Meteorological Organization

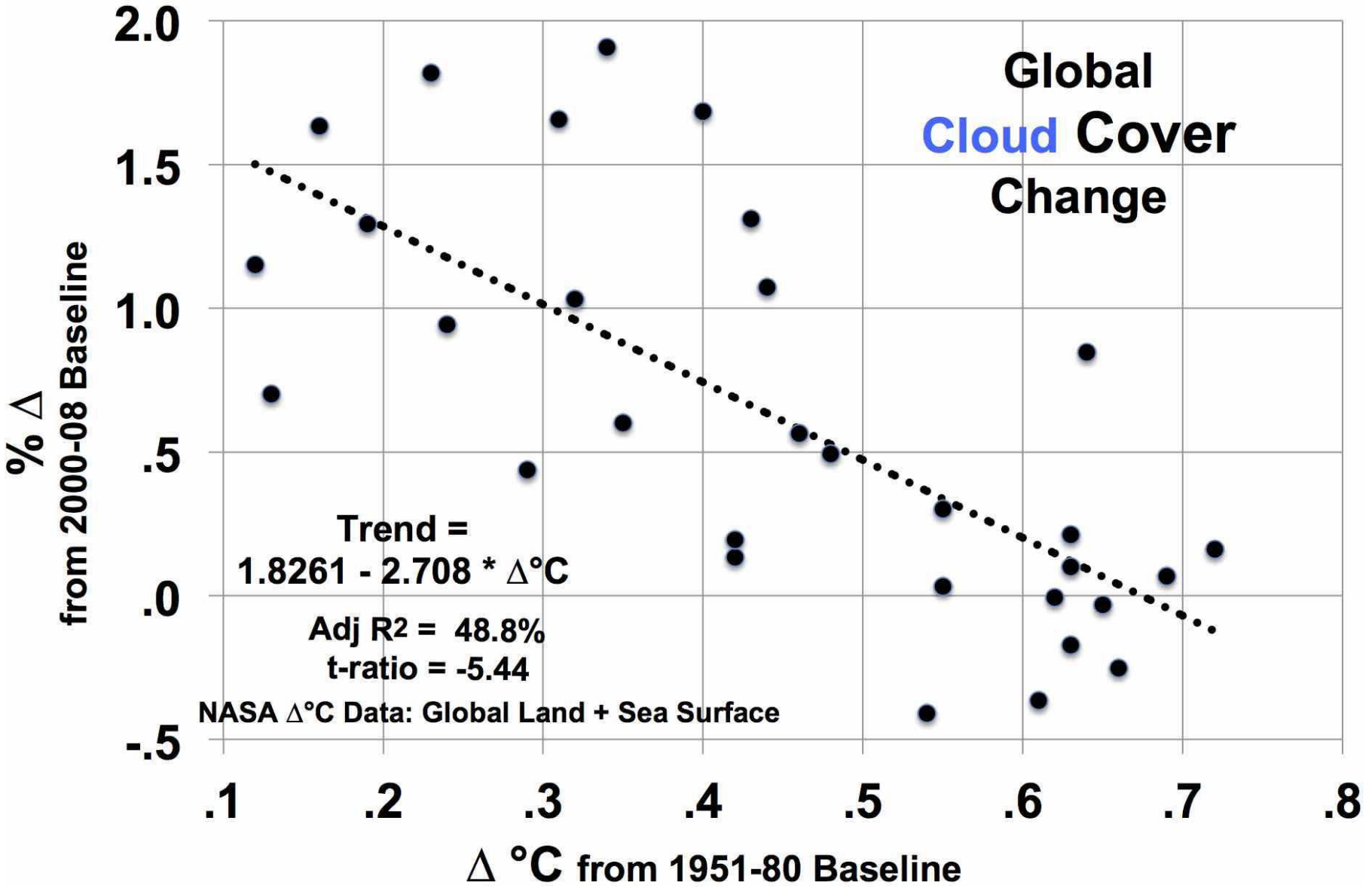
Clouds by Altitude



dashed lines by Gene Fry

net warming effect. Magnitude?

Clouds reflect ~17.5% of incoming sunlight (~ 59 W/m^2) = 10 W/m^2.



Annual Average Cloud Observations, 1982-2012
State of the Climate in 2012, American Meteorological Organization

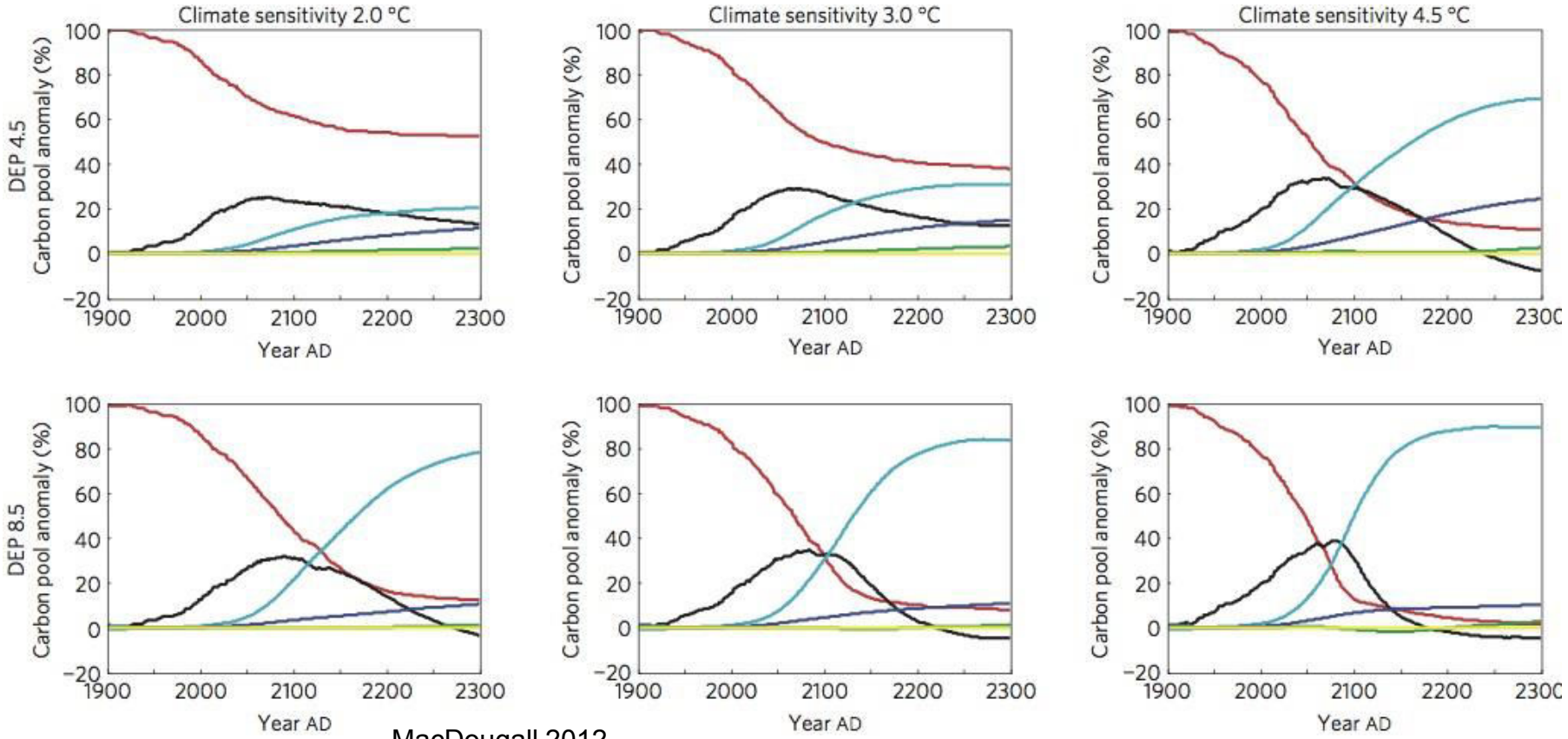
mean of 5 data sets,
including ISCCP

Water Vapor's GHG Effect

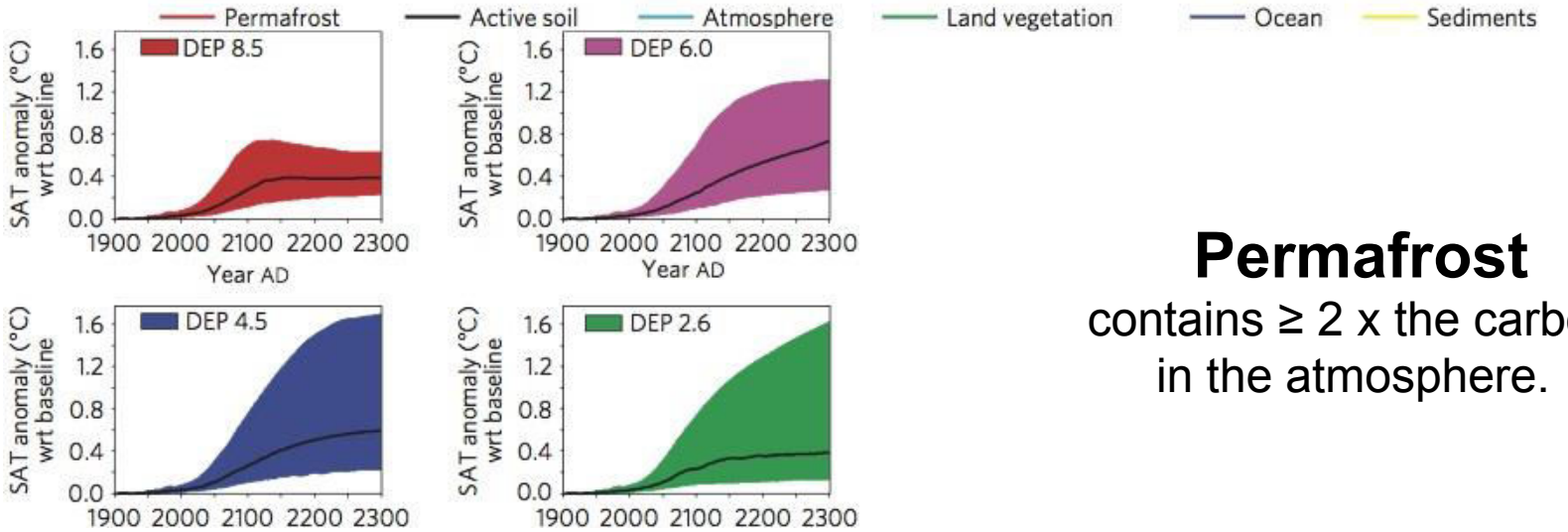
1°C warmer air contains 7% more H_2O vapor, on average.

That increases radiative forcing by 1.45 W/m^2.

That is 86% as much as from CO_2 emitted since 1750.



MacDougall 2012



Permafrost

contains ≥ 2 x the carbon in the atmosphere.

Scenarios on the next slide spread ocean warming over 1,000 years. They use the previous 10 slides for permafrost emissions, sea level, water vapor & albedo effects of reduced sulfates, snow, ice, and clouds.

For clouds, 60% of the amount from AMO 2013 is used.
Cloud changes are complex and explain part of warming to date.

The effect of Arctic sea ice loss from Hudson (2011) is used: globally, 0.7 W / sq meter for total loss, during the daylight season, of which 0.1 had already occurred.

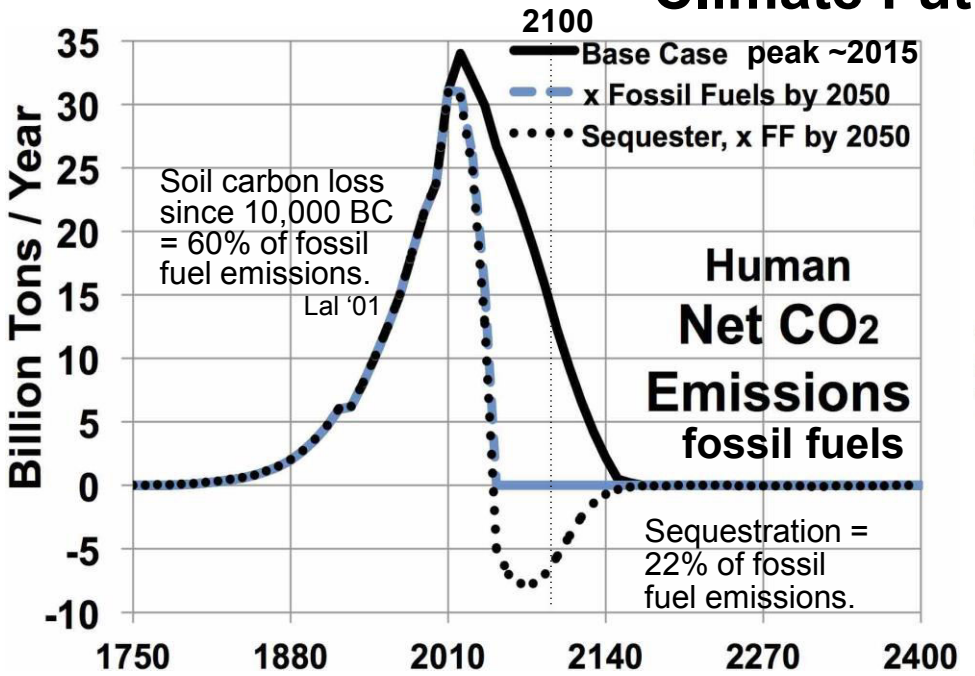
Permafrost carbon emission trajectories in the scenarios are based on work by MacDougall *et al*. (2012).

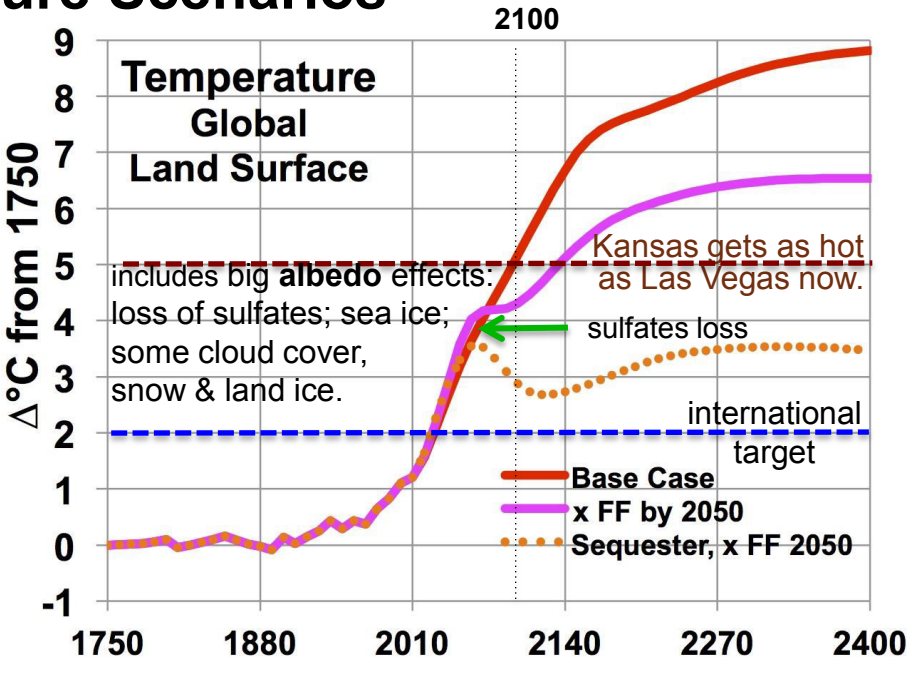
But permafrost has twice the carbon he modeled.
Albedo changes will warm permafrost faster than he modeled.

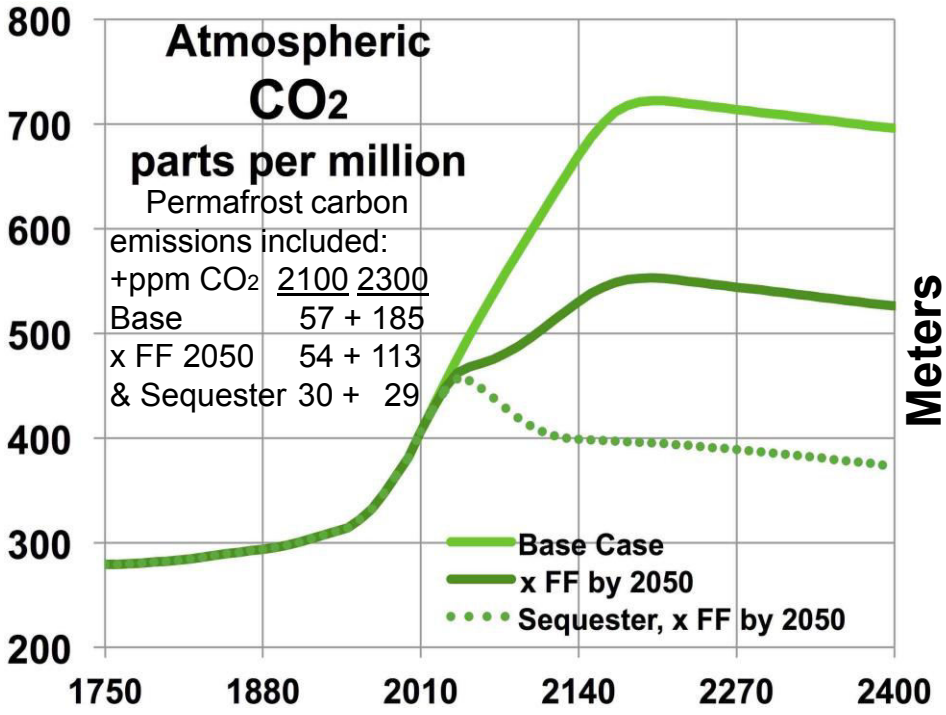
So, in the case of fossil fuel phase-out by 2050, and especially the base case (peak ~ 2015, but zero only after 2100), permafrost emissions exceed those shown by MacDougall.

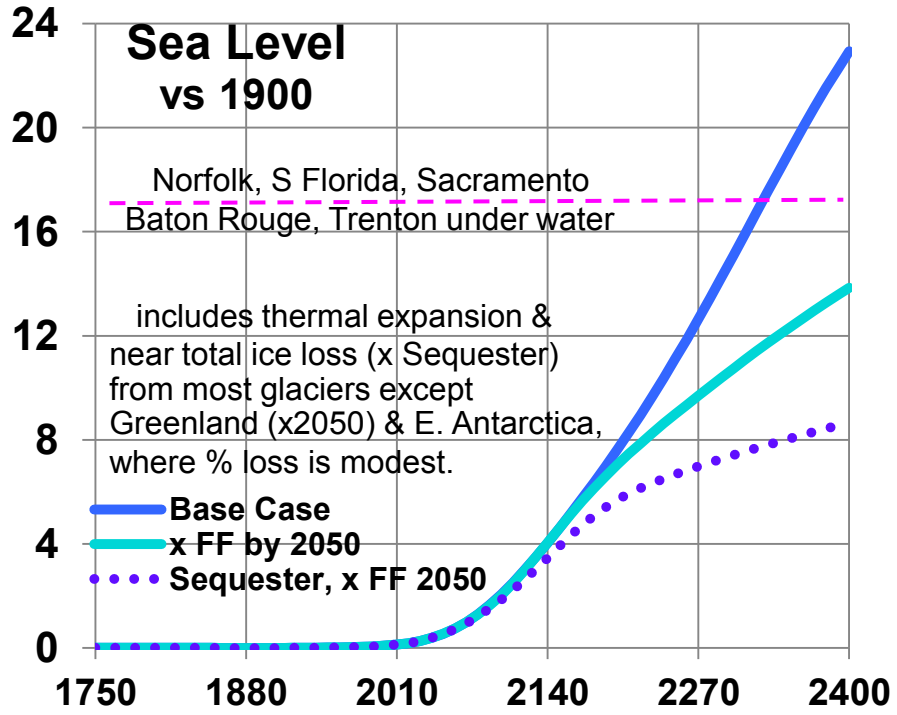
In the carbon sequester case, they are lower.

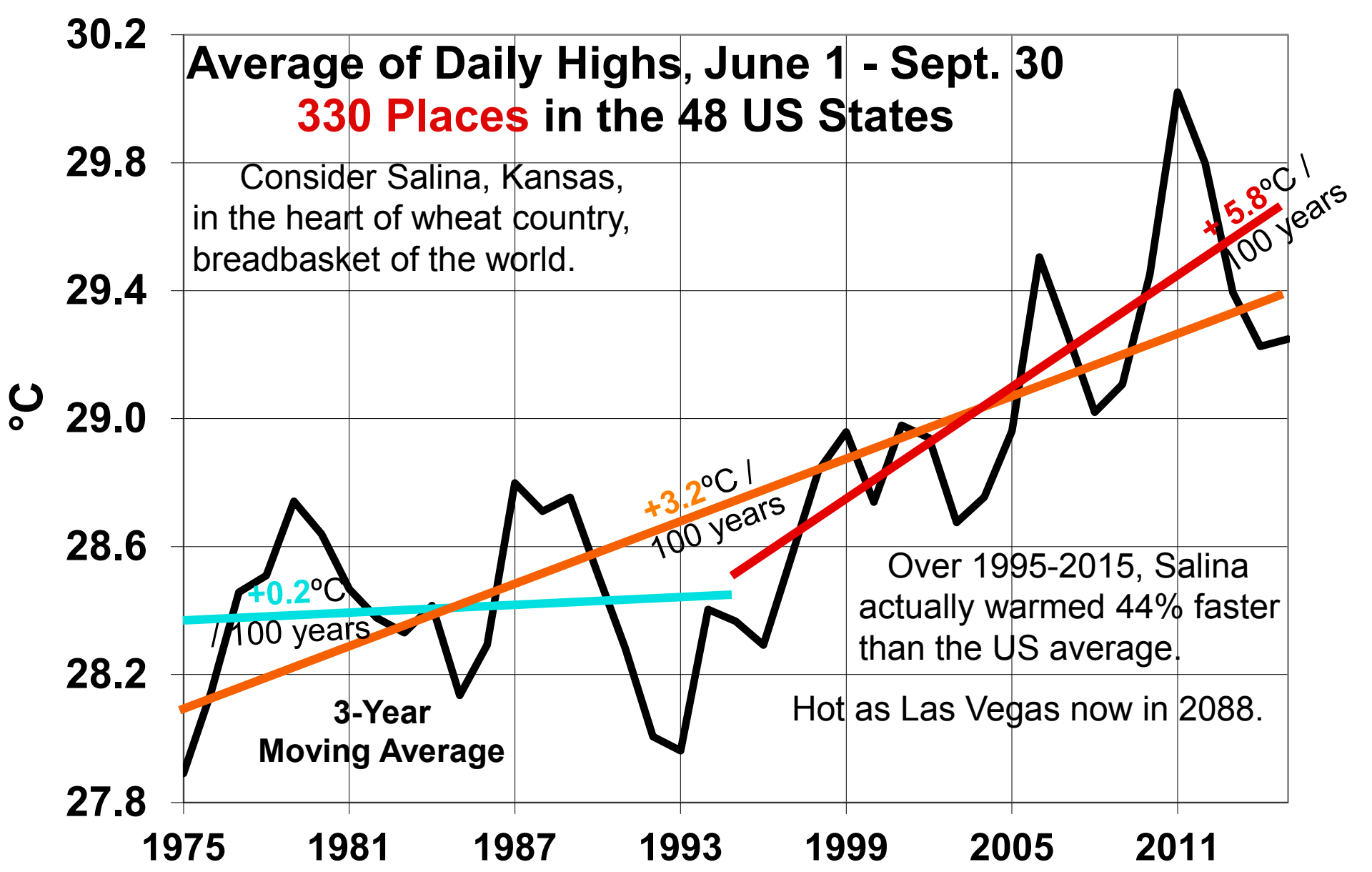
Climate Future Scenarios











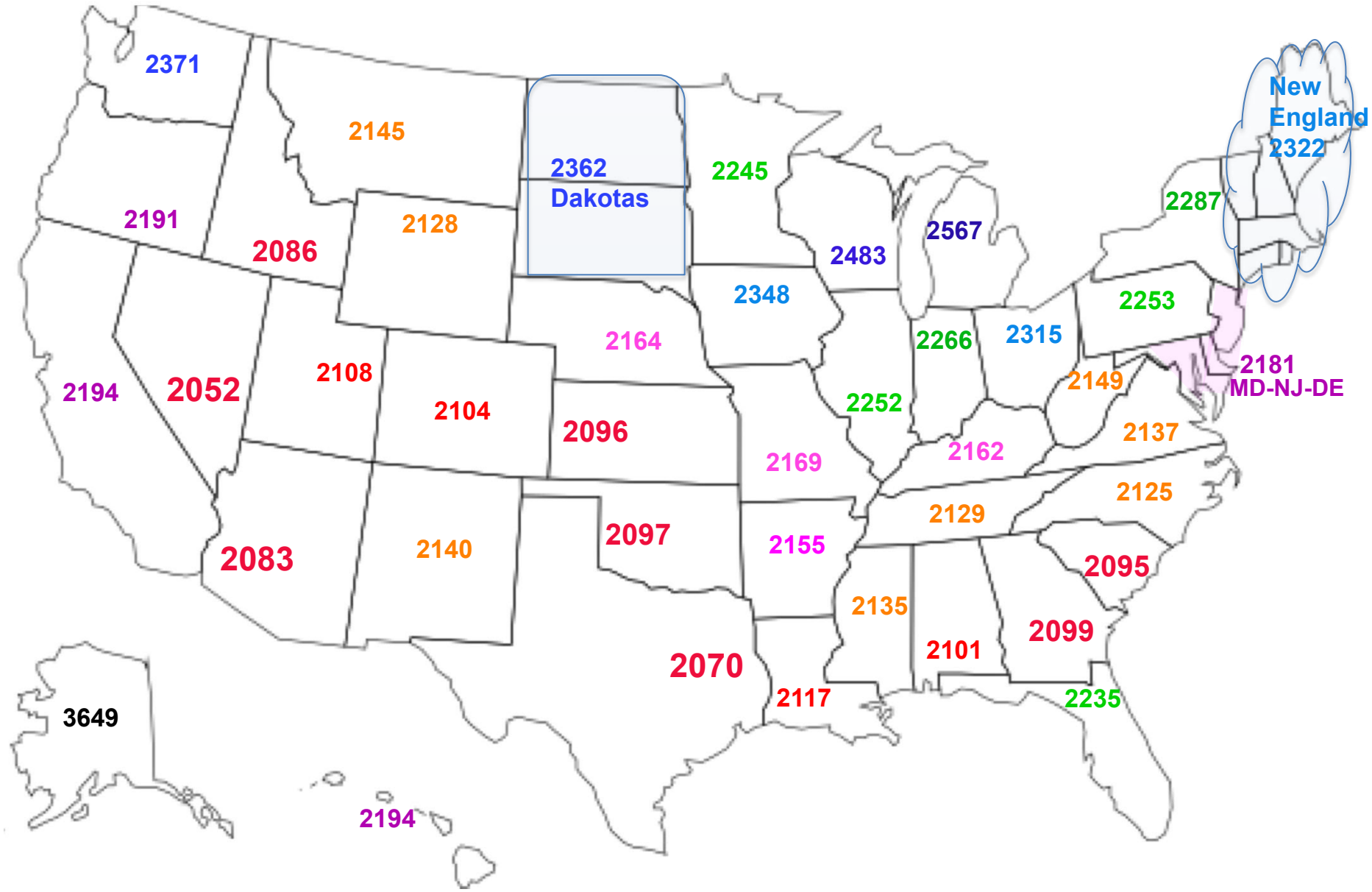
At +3.2ºC / 100 years, by 2100 summer in Salina would be hotter than Dallas now.
At 5.8ºC / 100 years, in 2120 it would be as hot as Las Vegas now.
We should PREVENT this.

When Do State Summers Become as Hot as Las Vegas Now?

The average of daily highs in Las Vegas, June 1 thru September 30, 1995-2015, was **37.8**ºC.

Dates shown **assume LOCAL** daily high **trends** for **those 21 years CONTINUE**.

Trends use 21 years x 122 days, for 348 places.



Solutions

Stop putting carbon in the air.

Remove carbon from the air,
as fast as we put it in now.

Take Carbon **Out** of the Air.

1 Rebuild **rangelands** with <u>perennial</u> grasses. (Just 5-25% of rain soaks in now.)

<u>Add soil carbon</u> 10 x faster with **short** rotation cattle grazing, like buffalo.

Deep roots, dung beetles move carbon into soil. Absorb 2.5 T carbon / ha / yr.

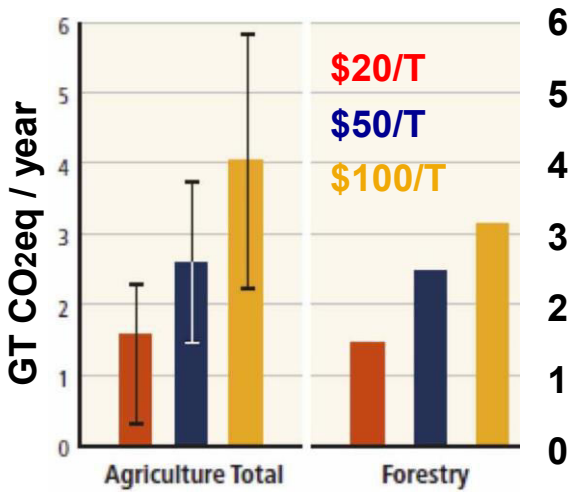
Cut CO_2 80 ppm. Fungi network holds water, so 75-90% of rain soaks in.

2 **Farming**, done right, can add 1.5 - 4.3 GT C / yr to soil.

Organic farms can add 2.5 T C / ha / yr: no-till, compost cover, no chemicals.

Rebuild soil organic matter (carbon): from 1-3% now, to 6-10% before farming.

Increase humus with fungi network & glomalin, holding water many months.



good for 2-3 decades

from Paustian *et al*. 2016. *Nature* 532:49.

3 Bury **biochar** shallow in soils:
more soil carbon - stays eons, holds water.

Take **More** Carbon Out of the Air.

4 **Rocks** have weathered for eons, taking 1 GT CO_2 / year from the air.

Speed up the process.

Move CO_2 into crushed basalt, olivine, peridotite.

Blow air thru millions of silos full of gravel, or artificial trees.

Scatter GT / year of olivine dust across the tropics,

for $5-63 per ton of CO_2.

5 Add iron filings to select **ocean** areas. Algae bloom, suck CO_2 from the air.

Dead algae may not sink. Tiny critters eat them. Soon carbon returns to air.

Additional fertilizers (K, P, N, etc.) may be needed. Other problems will arise.

6 Plant more **trees**. It's a good idea, but

trees need water. Evaporation leaves <u>less</u> in soils.

Droughts hurt. Forest fires skyrocket.

Policy

Tax carbon across fossil fuels, worldwide, in proportion to carbon content. Impose the tax upstream.

It should start low, but then rise substantially and briskly, on a pre-set trajectory.

End subsidies for production and use of fossil fuels.

Give carbon tax credits for carbon removal from ambient air, at the same rate carbon emissions are taxed.

US$40 / tonne of carbon ($10 / ton CO_2), rising 10% / year.

Return net proceeds as equal tax credits to individuals.

We humans must go
carbon negative
by 2050.