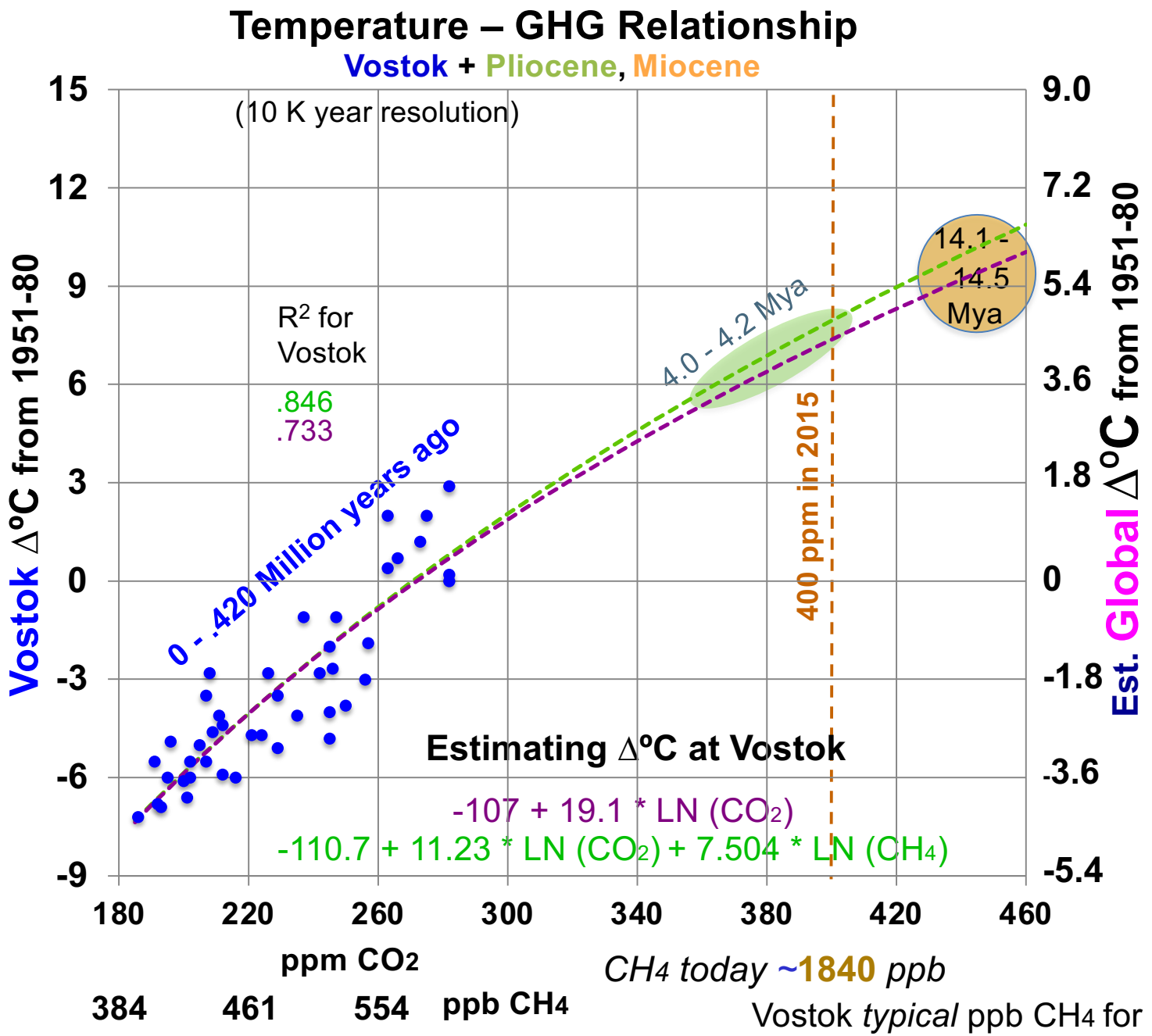
Lessons for Our Future from Ages Ago



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

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

With current CO_2 & CH_4 levels, the equations yield global surface warming of 8.3°C,

but only **4.9**°C **<u>if</u>** CH_4 is neglected.

Warming how fast?

40-50% in decades, the rest over centuries.

Take Carbon **Out** of the Air.

1 **Farming** can put 4.3 GT CO_2 / year in soils (0.7 in the US), for $20-100 / T.
Organic farms can add 1 T C / acre / yr to soil, with no-till & compost cover.
Rebuild soil organic matter: from 1-3% now, to 6-10% before farming.

2 Speed up **rock weathering** by grinding up basalt, olivine, peridotite.
Sow olivine dust across the tropics, for $5-63 / T of CO_2 removed.
Add small olivine gravel to farming soils, for fertilizer & CO_2 removal.

3 **Capture CO_2 from air** using amines in artificial leaves or ceramics, or using polyanthraquinone with battery charge-discharge: $20-70 / ton of CO_2.
Turn the CO_2 into rock in concrete or basalt, or just store it underground.

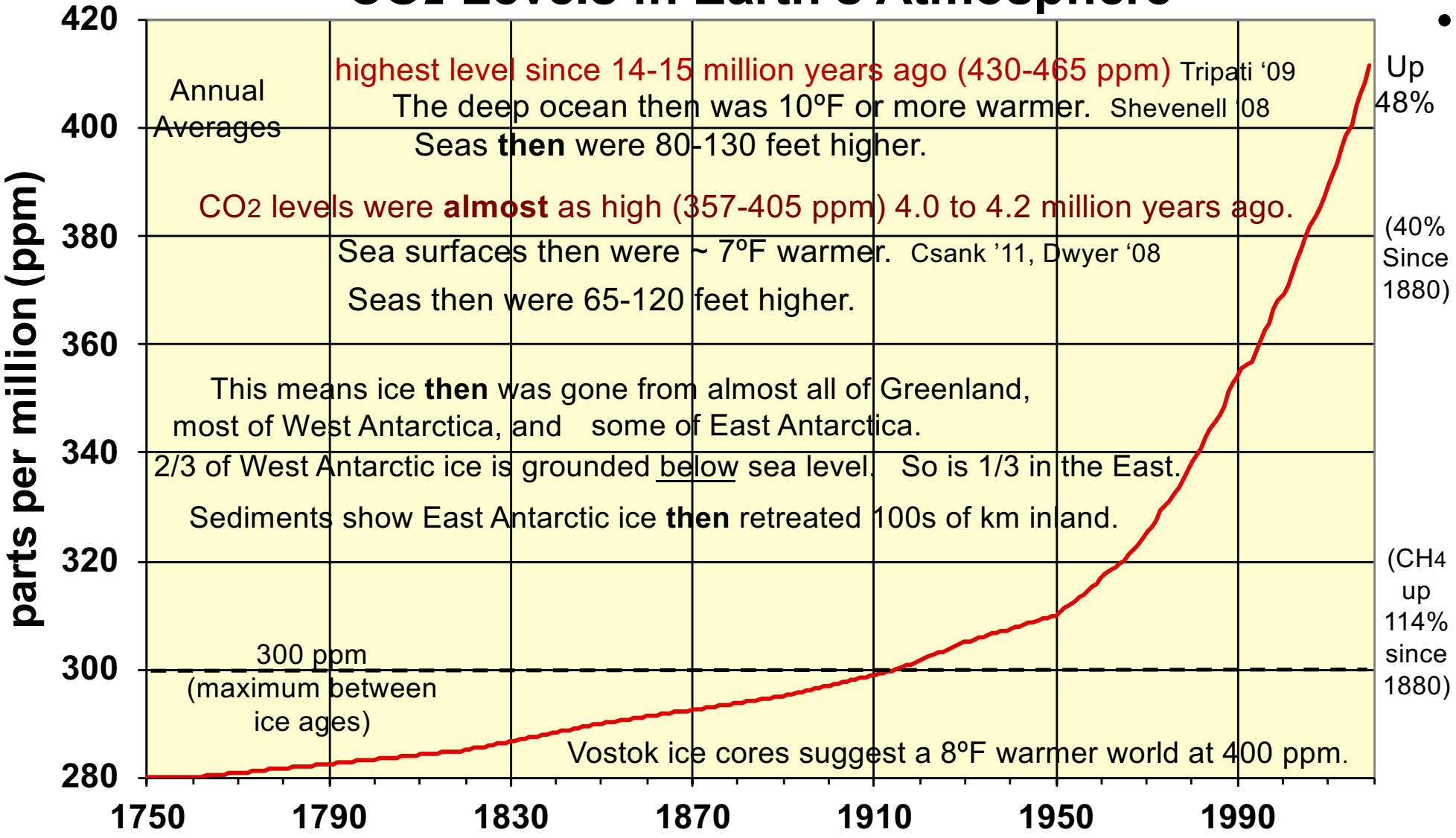
4 Farm the **oceans**. Grow algae in pans miles on a side, many inches deep.
Harvest the algae, turn them into biochar. Sink the biochar (2+ g / cc).
Or use open ocean, mangroves, kelp. Add fertilizer - Fe, also N, P, K, etc.

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

6 Rebuild **rangelands** with perennial grasses. 1 T carbon / acre / year?
Add soil carbon **5 x** faster with **short** rotation cattle grazing, like buffalo.
Deep roots, dung beetles move carbon into soil, so 75-90% of rain soaks in.

7 **Plant** more trees. Less soil moisture, forest fires soar. Few trees grow back.

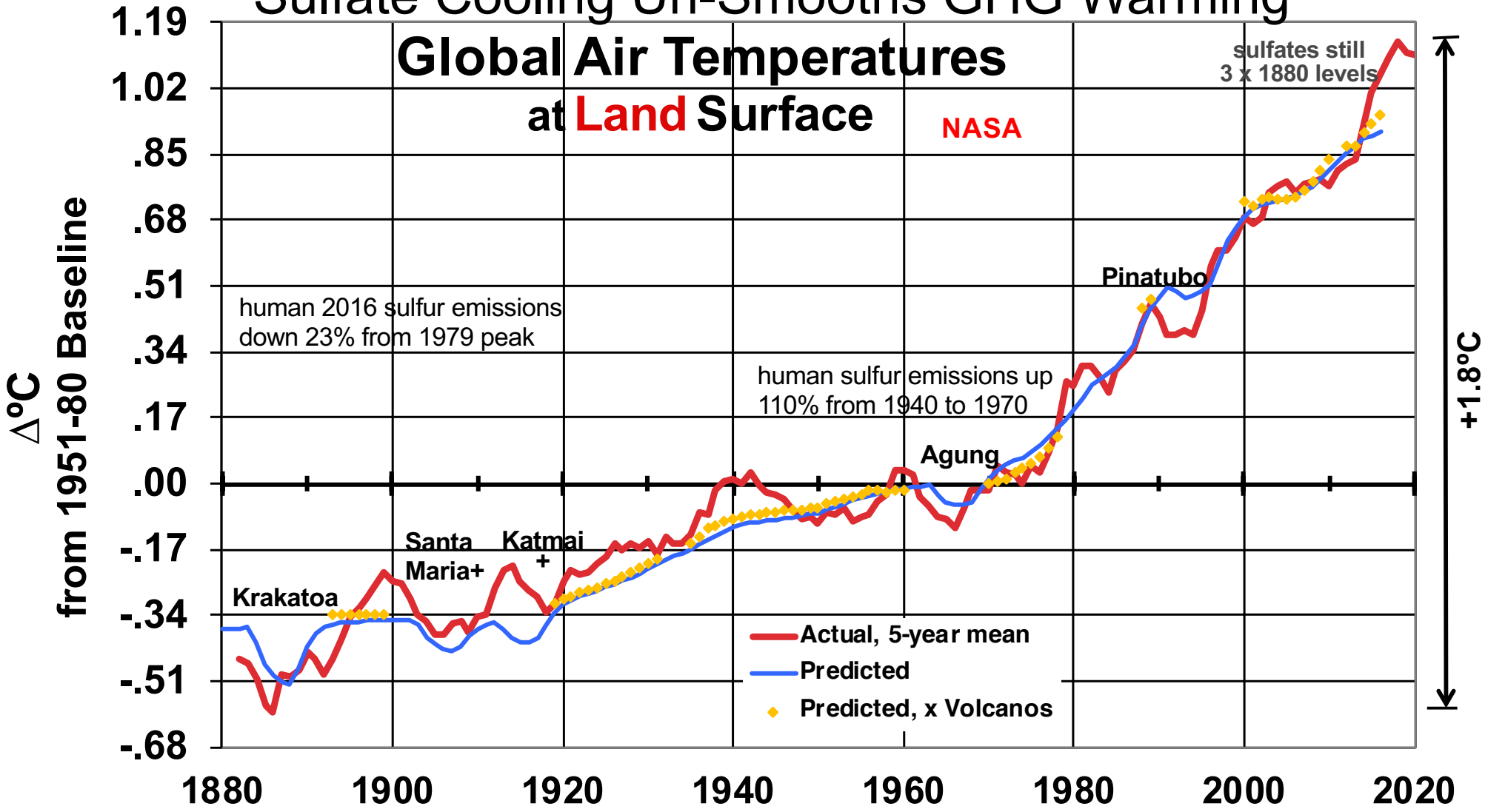
CO_2 Levels in Earth's Atmosphere



8ºF warmer world makes dry Kansas summers hotter than Las Vegas ones now.
We face BIG lag effects.

Current CO_2 levels are **already** too high for us.

Sulfate Cooling Un-Smooths GHG Warming



Predicted Δ˚C = -20.51 + 2.223 * LN (CO_2 ppm) + 1.133 * LN (CH_4 ppb) - .00319 * SO_4 ppb

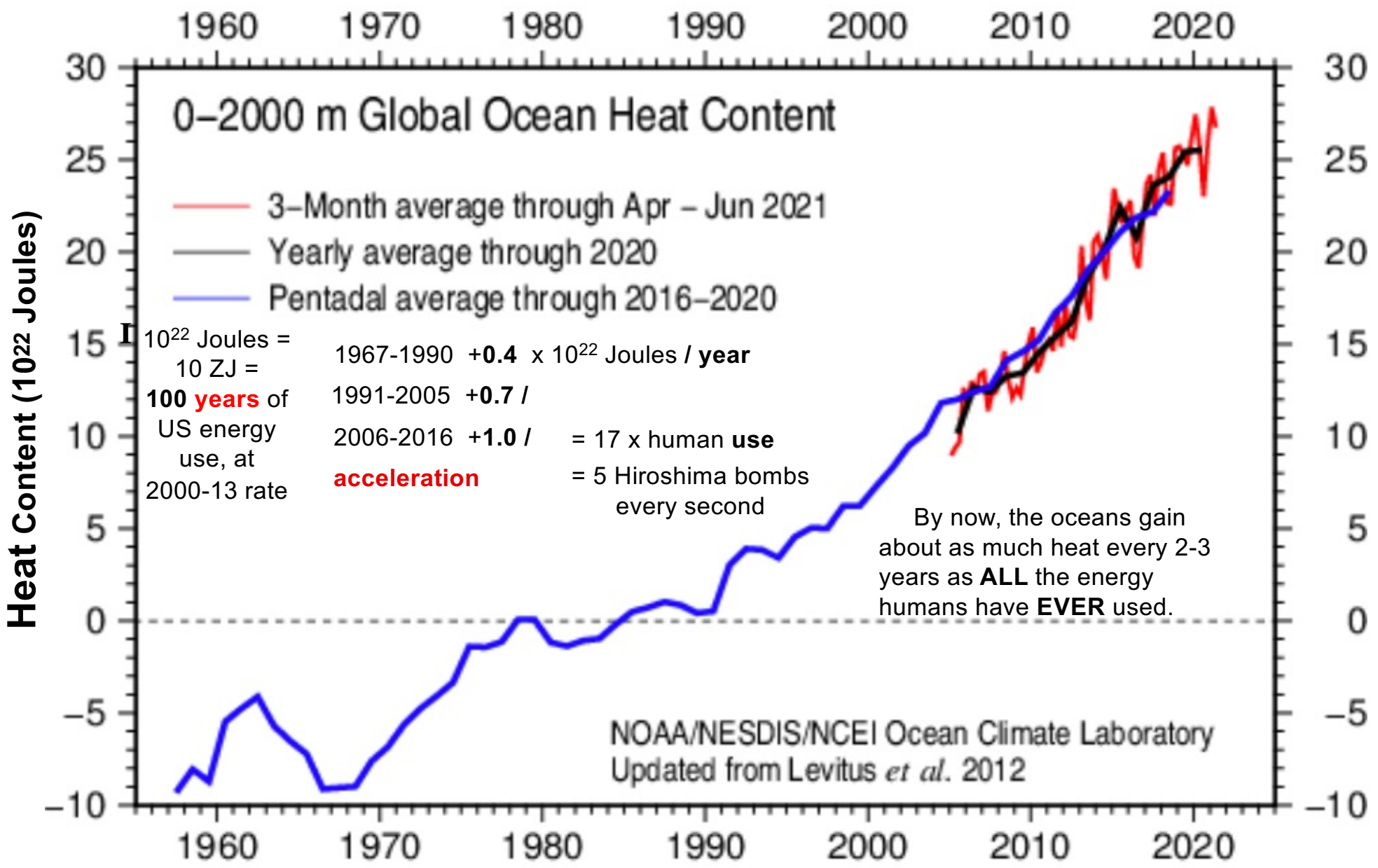
adjusted R^2 = 97.8%. CO_2, CH_4 & SO_4 (also 5-year averages (SO_4 lag 1 year)) are all highly significant (|t| = 9.7 to 11.6).

SO_4 data includes industrial, occasional large volcanic, and other natural emissions.

Averages: 80 (100 now) 8 (episodic) 30

Predicted Δ˚C, w/o Volcanos = -20.48 + 2.089 * LN (CO_2 ppm) + 1.252 * LN (CH_4 ppb) - .00393 * SO_4 ppb

adjusted R^2 = 98.3%. CO_2, CH_4 & SO_4 (also 5-year averages) are all highly significant (|t-ratios| = 6.4 to 8.7).

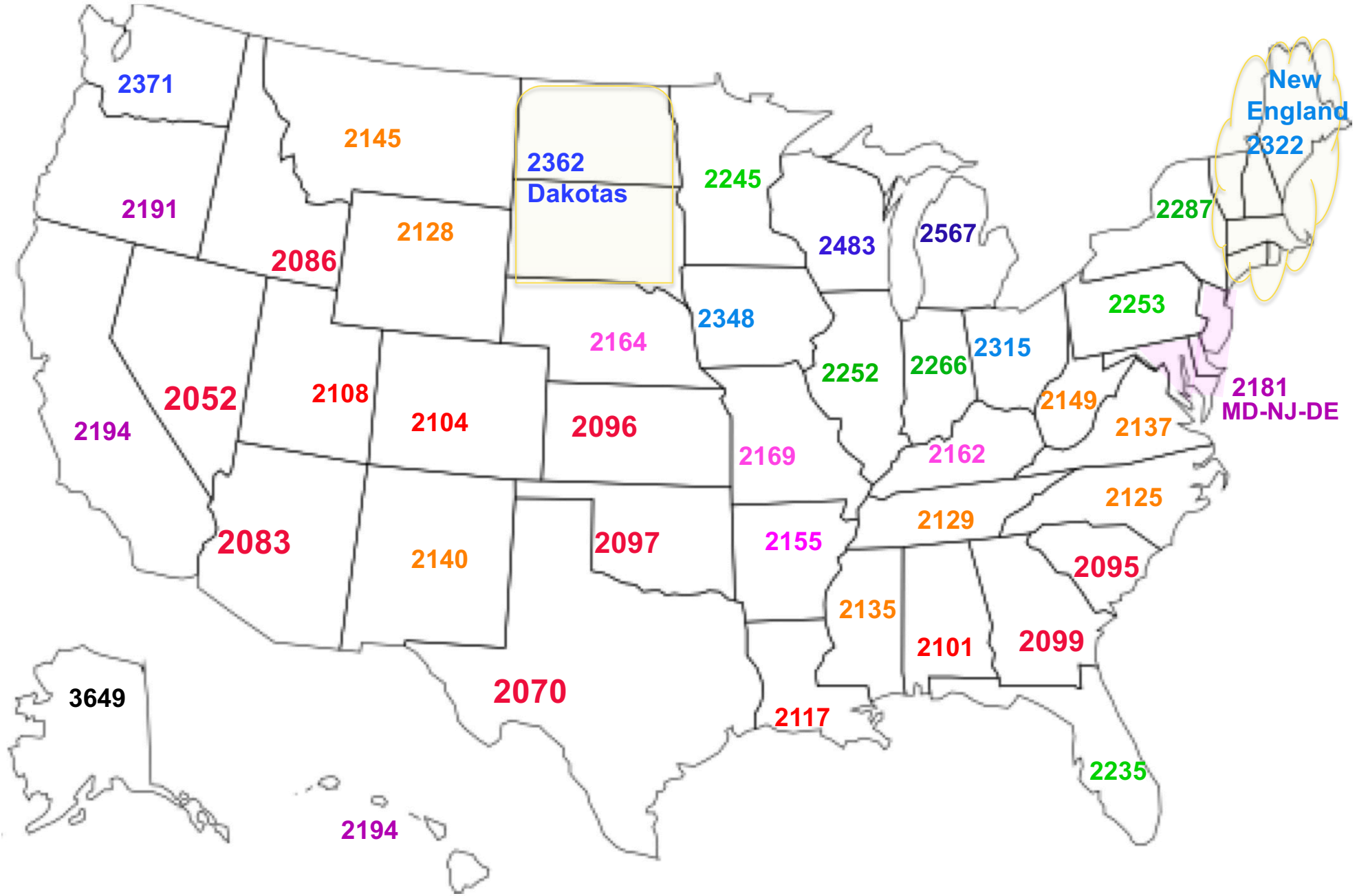

0–2000 m Global Ocean Heat Content
3–Month average through Apr – Jun 2021
Yearly average through 2020
Pentadal average through 2016–2020
Heat Content (10^{22} Joules)
1960
1970
1980
1990
2000
2010
2020
30
25
20
15
10
5
0
−5
−10
10^{22} Joules = 10 ZJ = **100 years** of US energy use, at 2000-13 rate
1967-1990 +**0.4** x 10^{22} Joules / **year**
1991-2005 +**0.7** /
2006-2016 +**1.0** /
acceleration
= 17 x human **use**
= 5 Hiroshima bombs every second
By now, the oceans gain about as much heat every 2-3 years as **ALL** the energy humans have **EVER** used.
NOAA/NESDIS/NCEI Ocean Climate Laboratory
Updated from Levitus *et al.* 2012

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 **100.1**ºF.

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

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



"Once a century" droughts are now happening once a decade.

US #3 now When I was young, the leading wheat producers were the US Great Plains, Russia's steppes, Canada, Australia, and Argentina's Pampas.

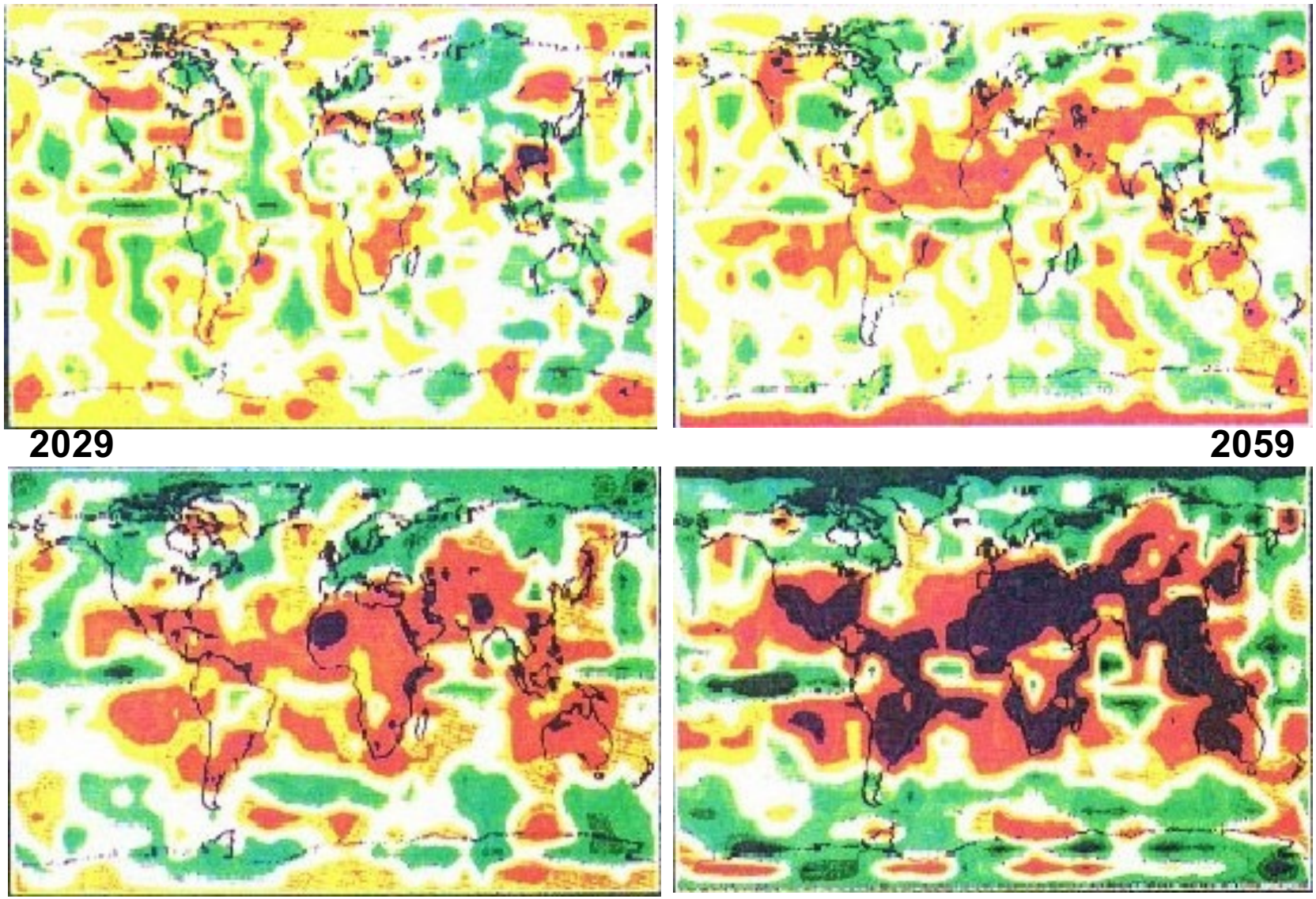
China now #1 in wheat.

Notable Recent Droughts

When	Where	How Bad
2003	France, W Europe	record heat , 20-70K die. hotter in 2012
2003-10	Australia	worst in 900 years. Record heat in 2013.
2005	Amazon Basin	once a century. Worse in 2010 & esp. 2013-16.
1998-2012	Syria, Iraq, Jordan+	10% worse than any other in 900 years
2007	Atlanta, US SE	once a century
2007	Europe: Balkans	record heat, Greek fires, hundreds die.
'07-9, '13-15	California	record low rains. Drought worst in 900+ years.
2008-9	Argentina	worst in half a century
2008-11	north China	~worst in 2 centuries. Severe in Yunnan '09-13.
2009	India #2 in wheat	Monsoon rain down 10-20% in N & C-E (1901-2012).
2010	Russia 15K die.	record heat, forest fires. Wheat prices up 75%.
2011	Texas, Oklahoma	record heat & drought
2012	US: SW, MW, SE	most widespread in 78 years; record heat

By 2059, “Once a Century” Drought Can Cover 45% of Earth.

Supply-Demand Drought Index



Business as Usual . Emissions

in **2059**
2 x CO_2
+4.2˚C
+14% rain

Climate Model:
NASA
Goddard
Institute for
Space Studies
(GISS)

DRY — WET

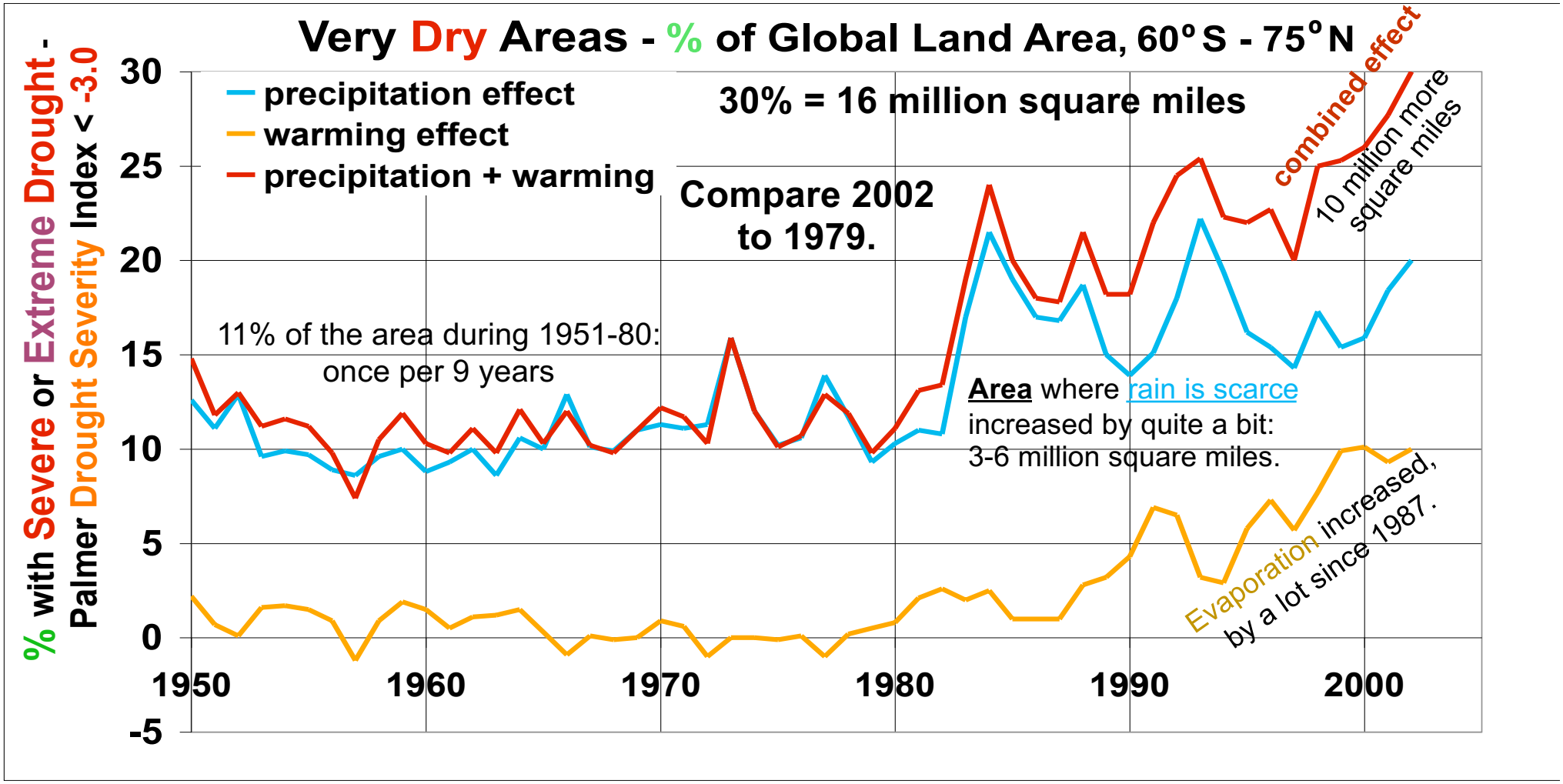
0 1 5 16 36 36 16 5 1 0

% Occurrence in Control Run

Fig. 1 in David Rind, R. Goldberg, James Hansen, Cynthia Rosenzweig, R. Ruedy, “Potential Evapotranspiration and the Likelihood of Future Droughts,” *Journal of Geophysical Research*, Vol. 95, No. D7, 6/20/**1990**, 9983-10004.

Droughts Are Spreading Already.

Switch from what could happen to what **has** happened already.



from Fig. 9 in Aiguo Dai, Kevin E. Trenberth, Taotao Qian [NCAR], "A Global Dataset of Palmer Drought Severity Index for 1870-2002: Relationship with Soil Moisture and Effects of Surface Warming." *Journal of Hydrometeorology*, December 2004, 1117-1130

Compare 30% **actual** severe drought area in 2002 (11% of the time during 1951-80) to 27% **projected** for 2000-2004 in previous slide. Droughts spread, as projected or faster.

Earth's area in severe drought has **tripled** since 1979. Evaporation at work

Over 23 years, the area with severe drought **grew** by the size of North America.

Crop Yields Fall.

Rind *et al.*, 1990

United States: 2059 Projections - doubled CO_2 - Business as Usual

– Great Lakes, Southeast, southern Great Plains

- Corn, Wheat, Soybeans - 3 of the big 4 crops (rice is the 4th)

2 Climate Models (Scenarios)

- NASA GISS Results (based on 4.2˚C warmer, 14% more rain)

  Goddard Institute for Space Studies

  –Yields fall **30**%, averaged across regions & crops.

- NOAA GFDL Results (based on ~ 4.5˚C warmer, 5% less rain)

  Geophysical Fluid Dynamics Lab

  –Yields fall **50**%, averaged across regions & crops.

CO_2 fertilization **not** included

Temperature effects of doubled CO_2 will growing to 4.2 or 4.5ºC after 2060, but continue to grow afterward, past 8ºC by 2400, as positive feedbacks continue to amplify direct effects.

CO_2 fertilization (2 x CO_2) boosts yields 4-34% in experiments, where water and other nutrients are well supplied, and weeds and pests are controlled. That won't happen as well in many fields. Other factors (esp. nitrogen) soon limit growth, so CO_2 fertilization will falter.

Besides, with higher CO_2, plants make more carbs but less protein.

1.2ºC warming is here. 3ºC more is in the pipeline. **Emissions** continue.

2ºC warming is unavoidable, absent **MASSIVE** CO_2 removal.

Holding warming to 2ºC, not 4º, **prevents** these losses:

3/4 of Gross World Product

$42 Trillion ~ 3/4 of GWP

1/5 of the World's Food

2/3 of the Amazon Rainforest

1/8 of the world's **oxygen** supply

Gulf Stream +

West Antarctic Icecap - Norfolk area, much of Florida & Louisiana, central CA, Long Island, Cape Cod

1/2 of all Species

4ºC warming **threatens civilization itself**. **5ºC** is **worse.**

Details to follow: first 2ºC, next 3ºC, then 4ºC, finally 5ºC.

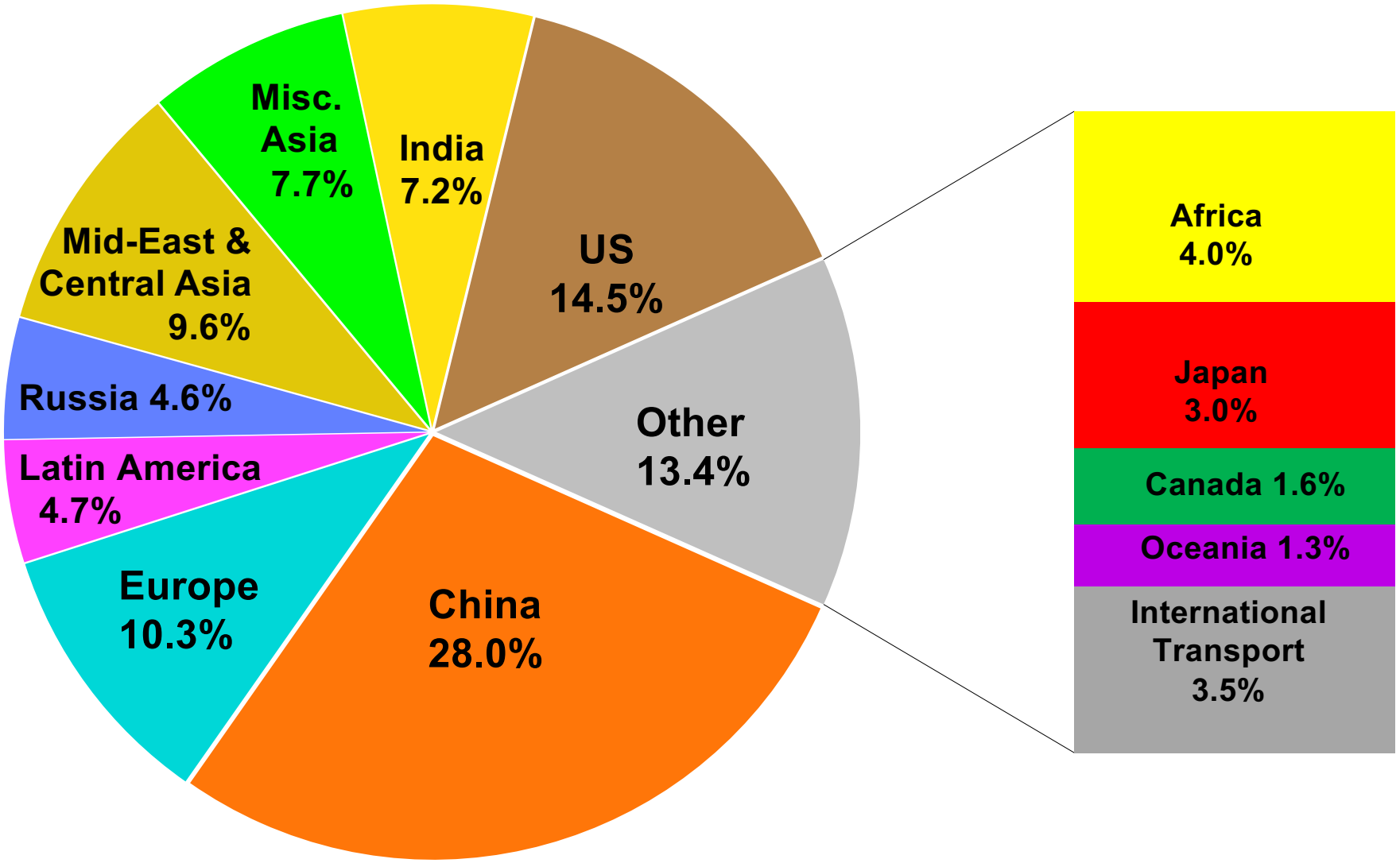
* Misc. = Korea, Indonesia, Thailand, Taiwan, Malaysia, Vietnam, Bangladesh, etc.

World CO_2 Emissions

from Fossil Fuels

36.4 Billion Tons in 2019

Carbon Tracker



In 2019, US fossil fuel CO_2 came 46% from oil, 33% from natural gas, 21% from coal.
37% came from transportation, 32% from electricity, 20% from industry.

Earth will warm 3-4 x more, even if we stop emitting now.

Blame phasing out coal's sulfur emissions (about .7ºF),

vanishing polar sea ice (~1.1ºF),

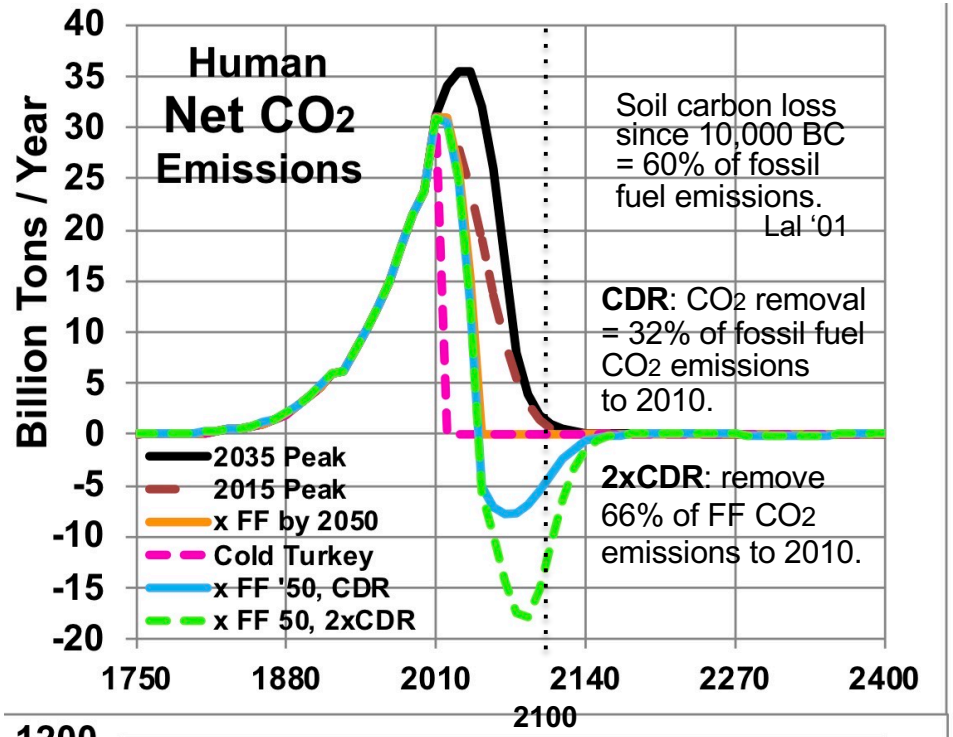
receding northern snow cover (~1.3ºF),

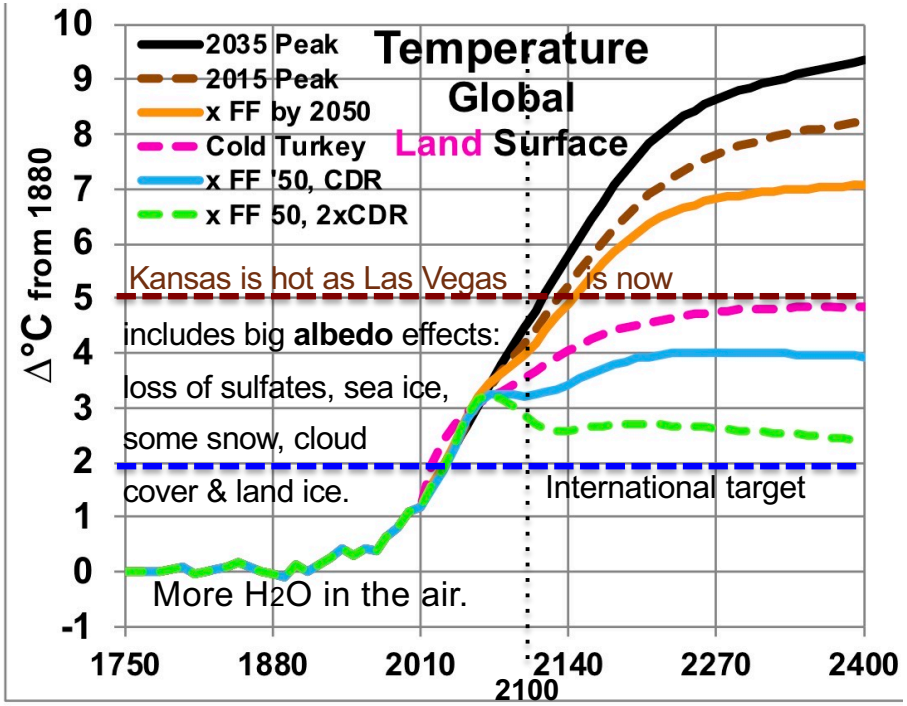
receding Greenland & Antarctic ice (~.5ºF),

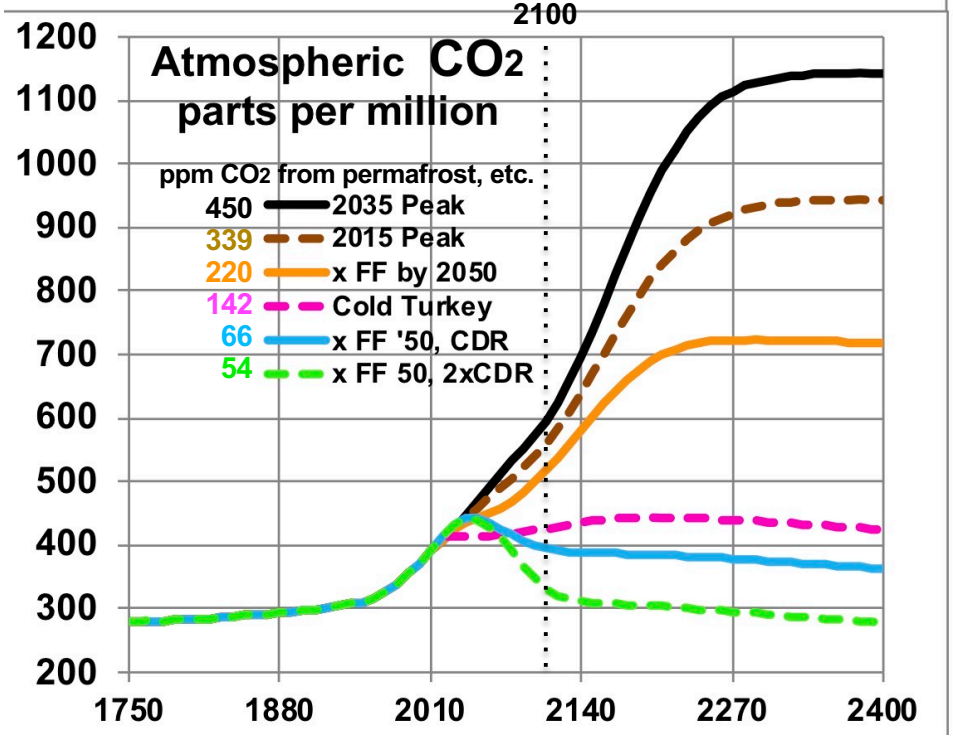
warming oceans enough so energy out = in (~.3ºF),

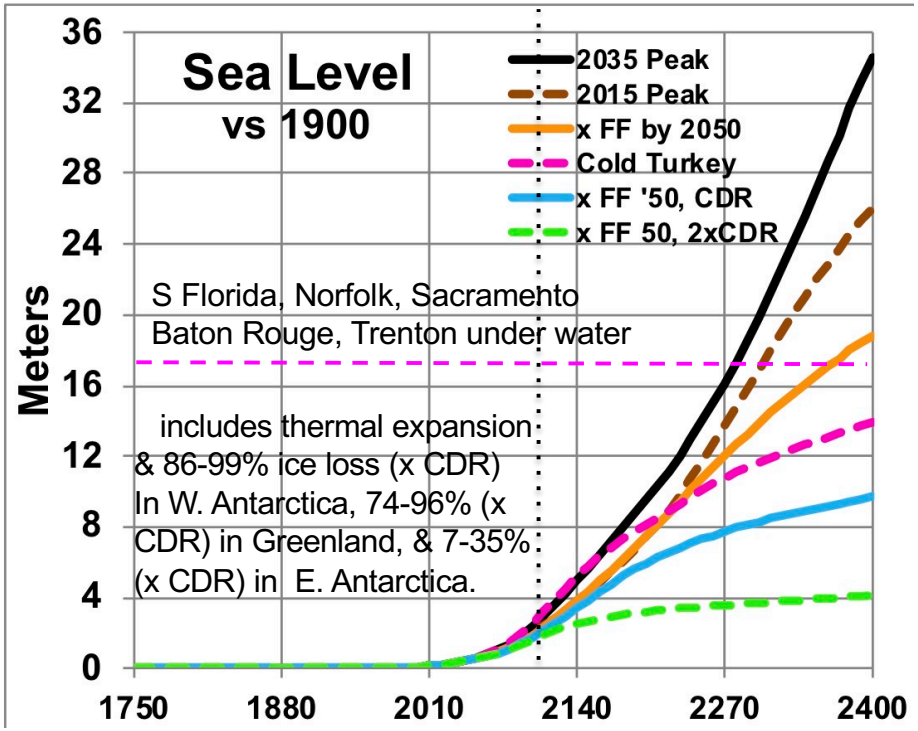
more H_2O vapor & less cloud cover (1.68 multiplier).

If carbon emissions don't peak till 2035, add 2.9º from more CO_2, 1.6 from snow, 1.8 from permafrost, 1.4 from H_2O vapor & .8 from the other factors.


Human
Net CO2
Emissions
Billion Tons / Year
Soil carbon loss since 10,000 BC = 60% of fossil fuel emissions.
Lal '01
CDR: CO2 removal = 32% of fossil fuel CO2 emissions to 2010.
2xCDR: remove 66% of FF CO2 emissions to 2010.
2035 Peak
2015 Peak
x FF by 2050
Cold Turkey
x FF '50, CDR
x FF 50, 2xCDR
2100


Temperature
Global
Land Surface
Δ°C from 1880
2035 Peak
2015 Peak
x FF by 2050
Cold Turkey
x FF '50, CDR
x FF 50, 2xCDR
Kansas is hot as Las Vegas is now
includes big albedo effects:
loss of sulfates, sea ice,
some snow, cloud
cover & land ice.
International target
More H2O in the air.
2100


Atmospheric CO2
parts per million
ppm CO2 from permafrost, etc.
450
339
220
142
66
54
2035 Peak
2015 Peak
x FF by 2050
Cold Turkey
x FF '50, CDR
x FF 50, 2xCDR
2100


Sea Level
vs 1900
Meters
2035 Peak
2015 Peak
x FF by 2050
Cold Turkey
x FF '50, CDR
x FF 50, 2xCDR
S Florida, Norfolk, Sacramento
Baton Rouge, Trenton under water
includes thermal expansion & 86-99% ice loss (x CDR) In W. Antarctica, 74-96% (x CDR) in Greenland, & 7-35% (x CDR) in E. Antarctica.
2100