

I prefer “Global Warming” rather than “Climate Change”, because “Climate Change” does not specify the direction of the change.

# Global Warming

[tinyurl.com/GlobalWarmingRoper](http://tinyurl.com/GlobalWarmingRoper)

L. David Roper  
[roperld@vt.edu](mailto:roperld@vt.edu)

Discovery of Global Warming: <http://www.aip.org/history/climate/>

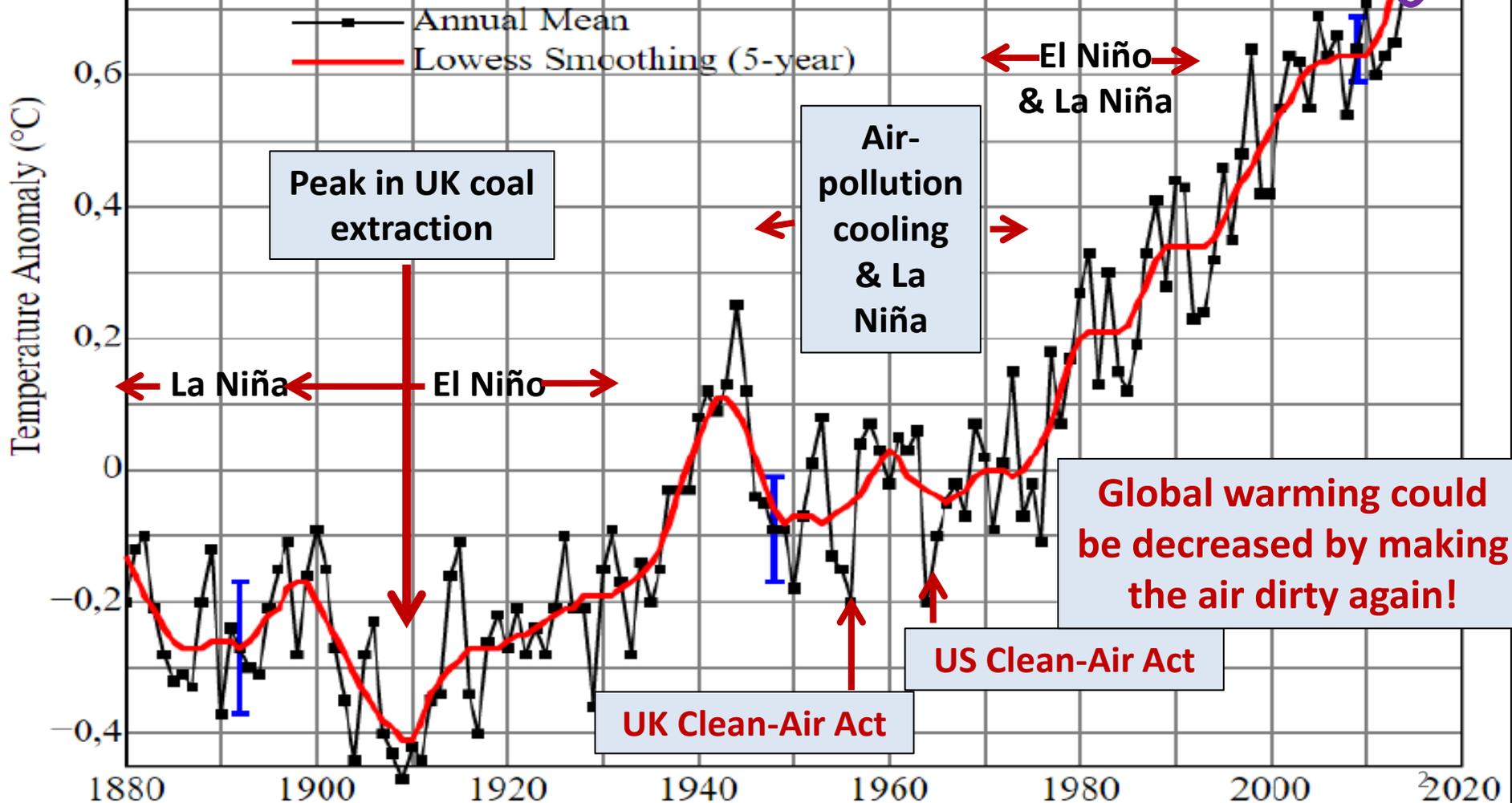
# El Niño increases global warming & La Niña decreases global warming.

NASA Global Land-Ocean Temperature Index 1951-1980 base

1.8°F

**2016 was the hottest year on record!**

**As was 2015, 2014, 2010 and 2005!**

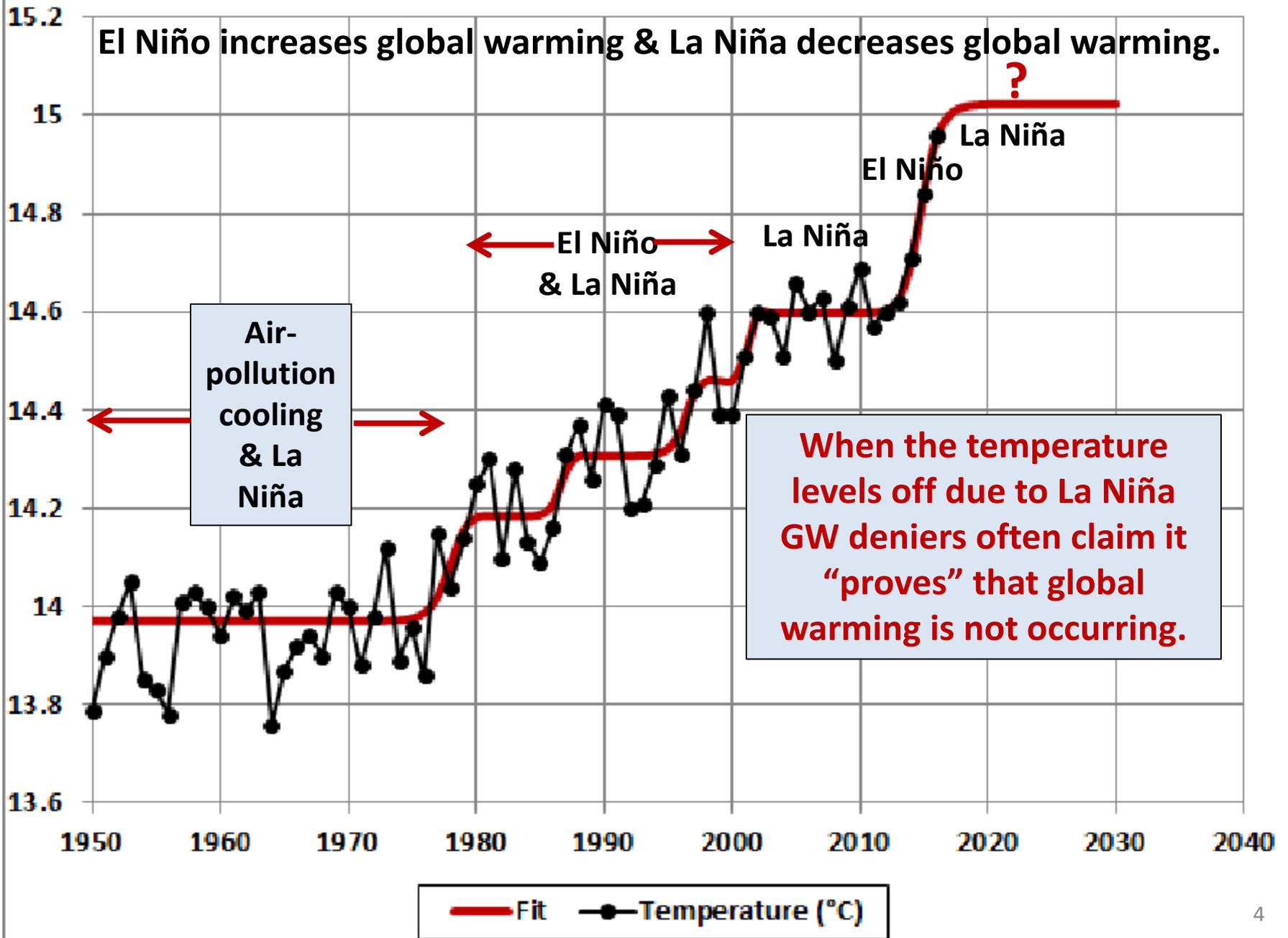


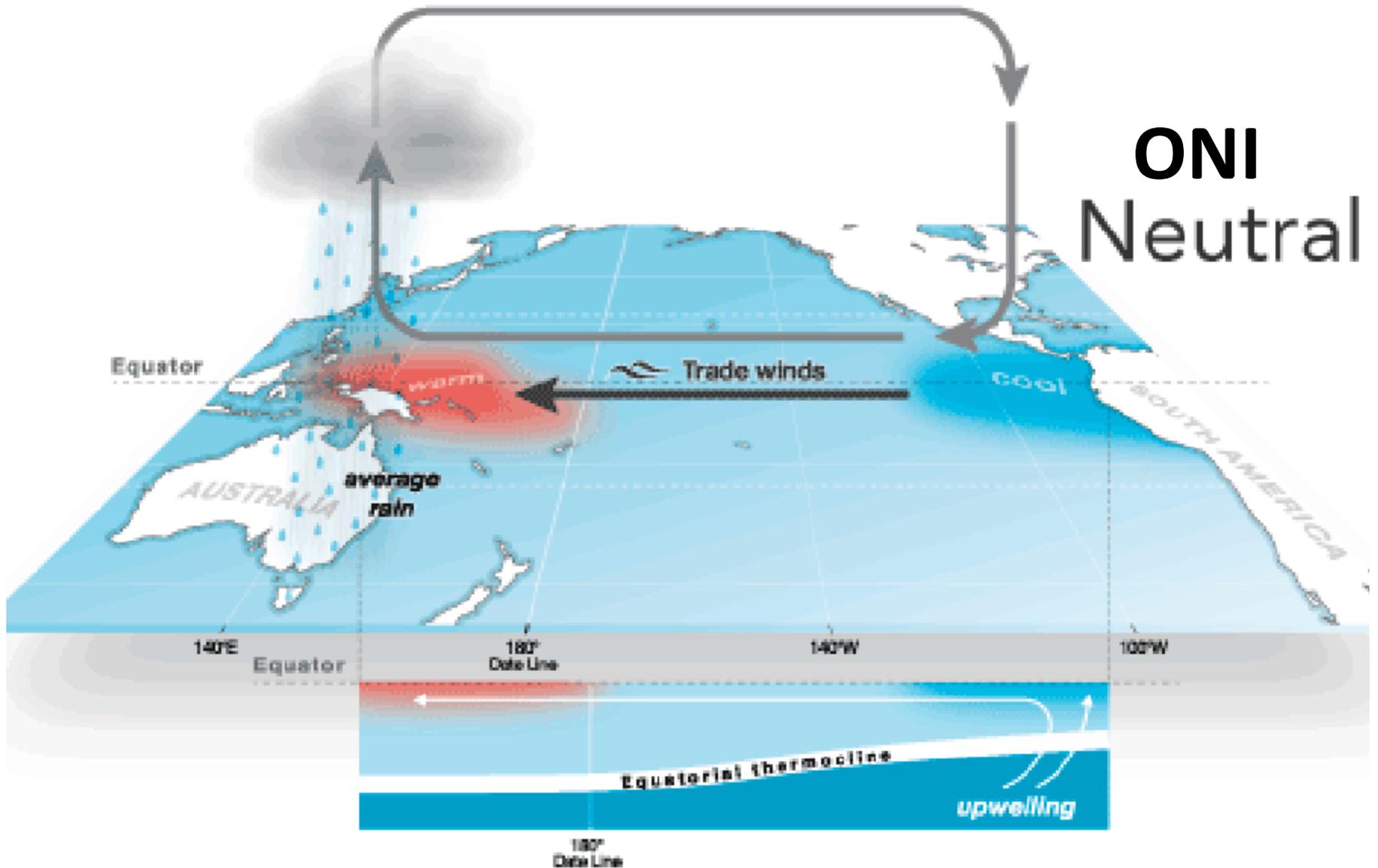
# Pacific-Ocean **El Niño**/**La Niña**

## Oceanic Niño Index (**ONI**)

- **La Niña** is **cooling** of Pacific-Ocean surface.
- **El Niño** is **heating** of Pacific-Ocean surface.
- Each lasts several months and occurs 3-10 years.
- **La Niña** involves upwelling of cold deep water.
- **El Niño** reduces the upwelling of cold deep water.
- **La Niña reduces** global warming.
- **El Niño increases** global warming ~4 times less than La Niña reduces it.

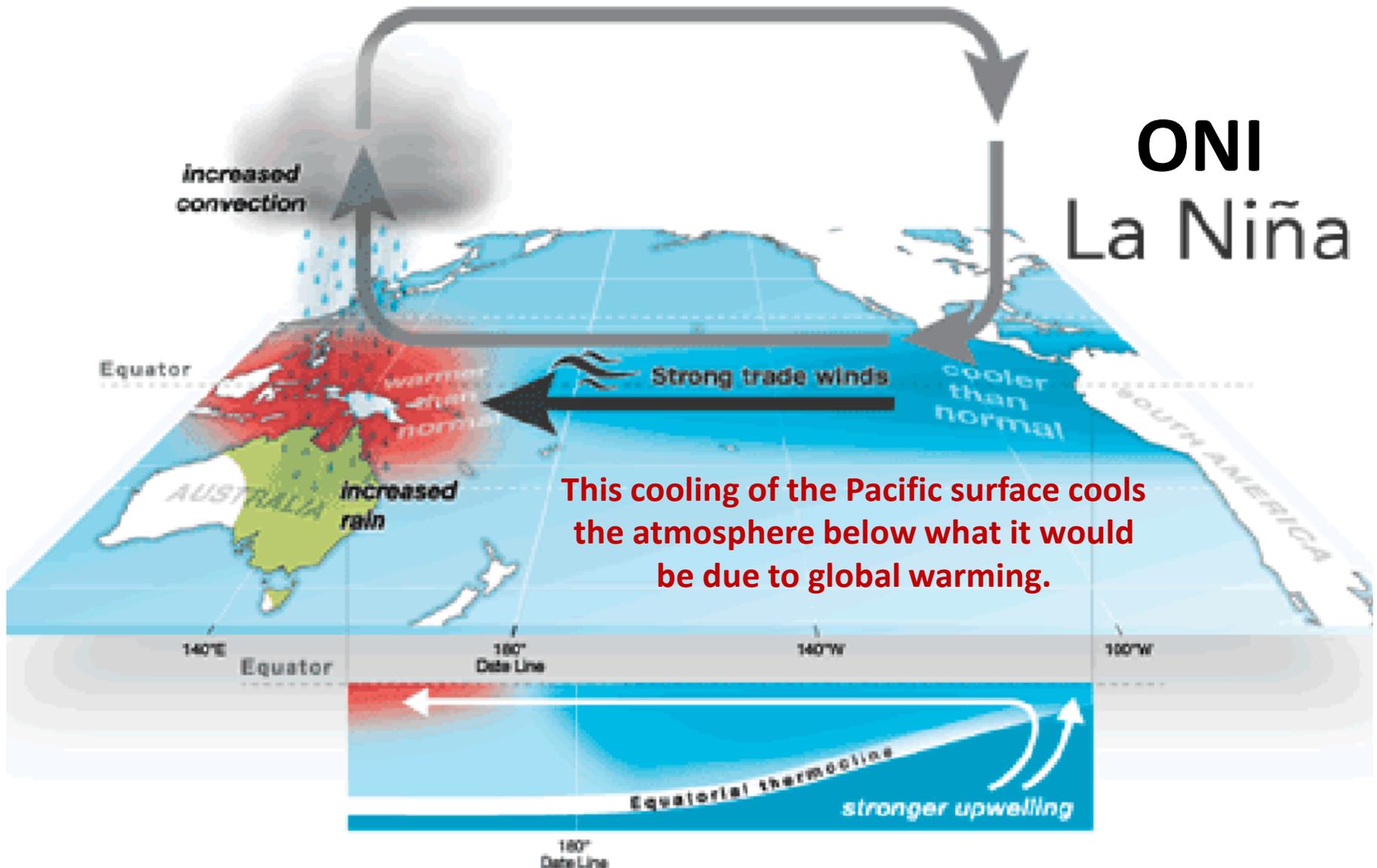
# Global Temperature Average (°C)





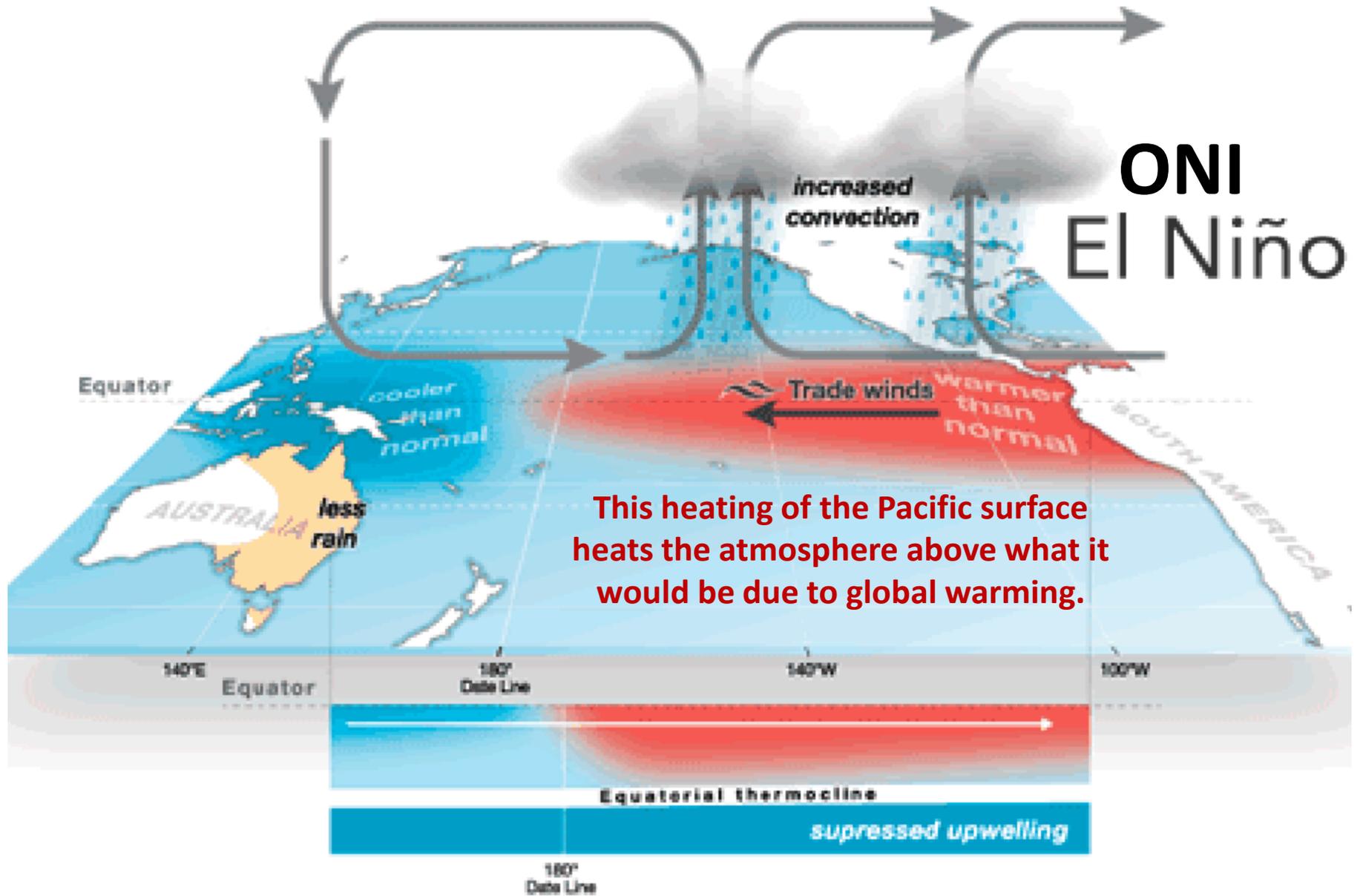
Neutral ONI involves some upwelling of cold deep water.

# ONI La Niña



This cooling of the Pacific surface cools the atmosphere below what it would be due to global warming.

La Niña ONI involves strong upwelling of cold deep water.



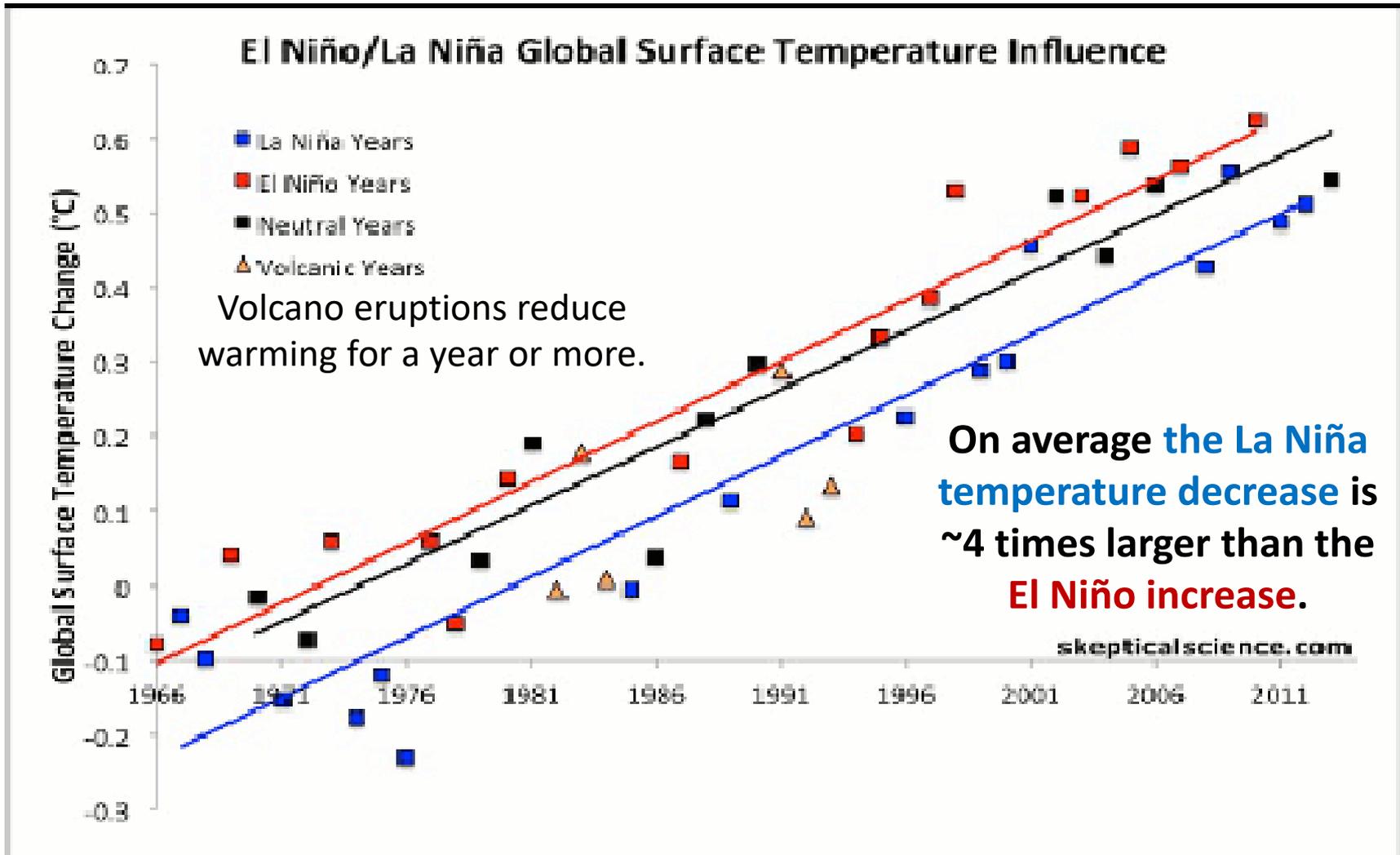
# ONI El Niño

This heating of the Pacific surface heats the atmosphere above what it would be due to global warming.

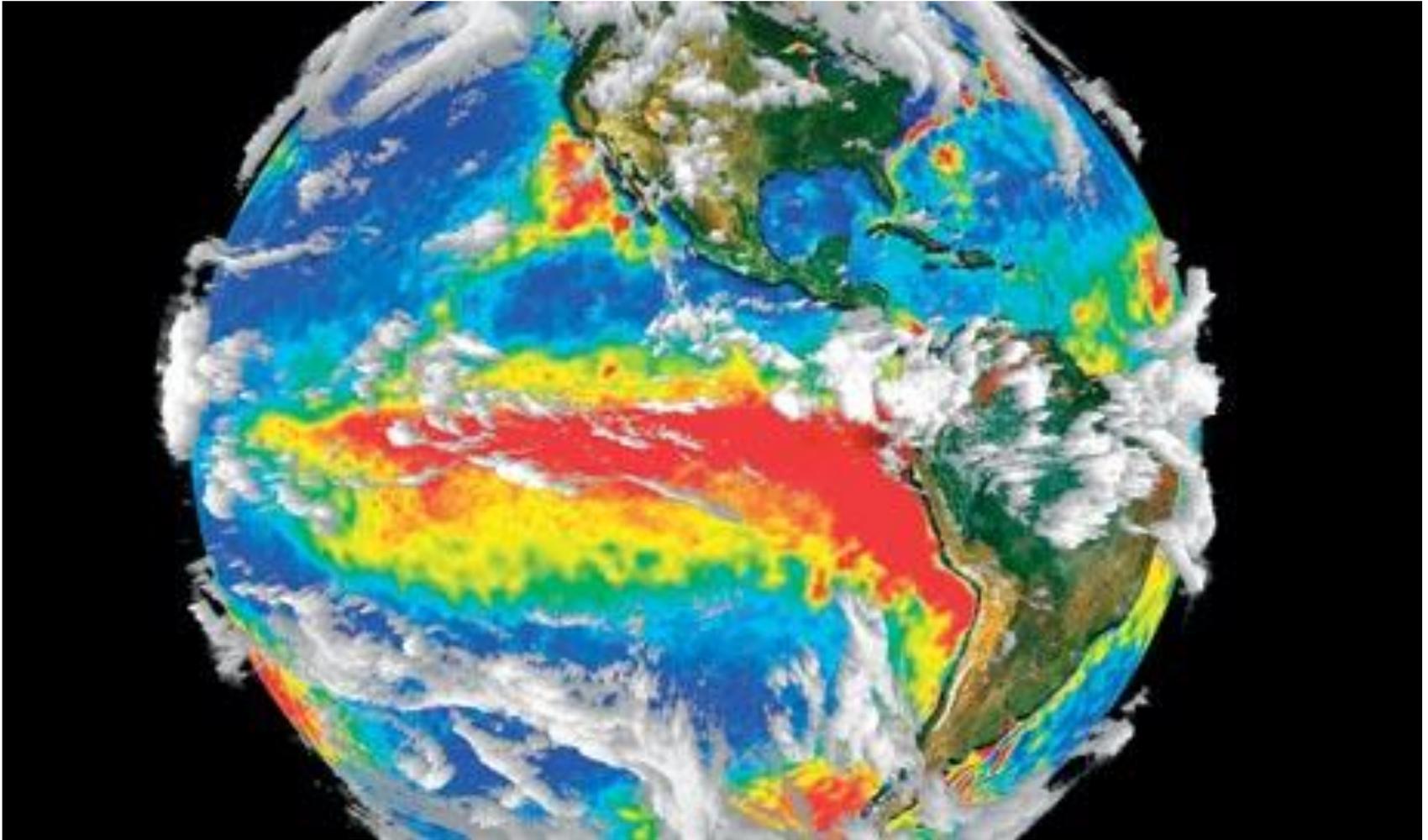
El Niño ONI involves suppressed upwelling of cold deep water.



# El Niño/La Niña Effects on Earth Temperature



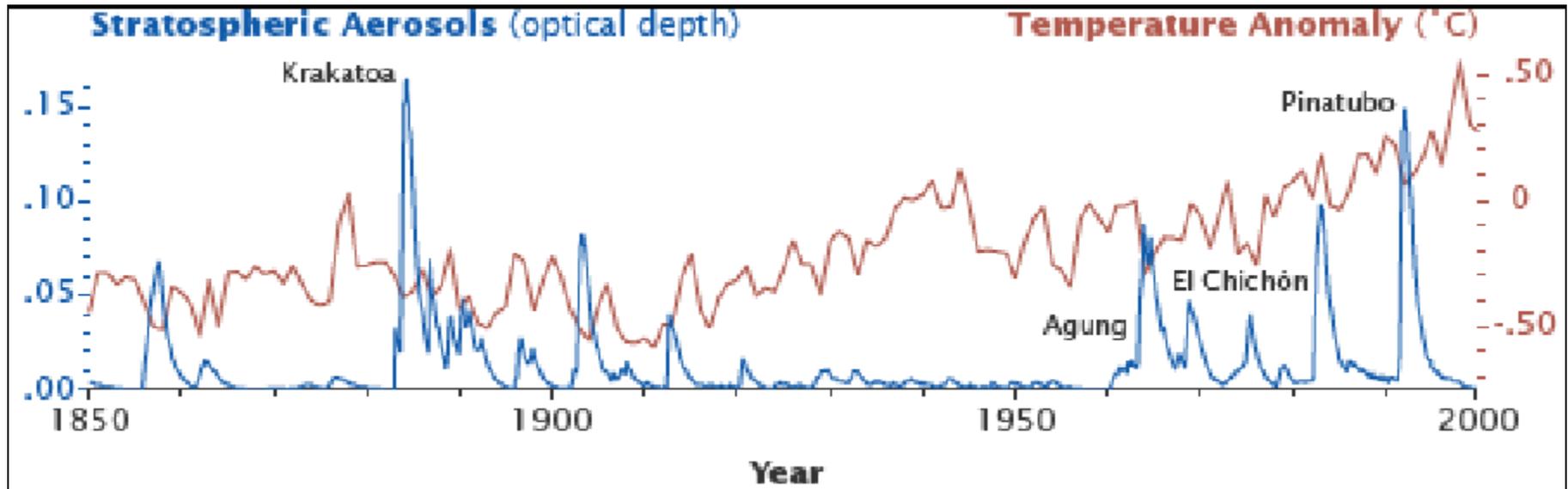
# Typical El Niño Event



**El Niño** causes greater **surface temperature**, especially in eastern Pacific.  
**La Niña** causes greater **deep ocean temperature**; the heat sinks into the deep western Pacific.

# Volcano Eruption Atmospheric Cooling

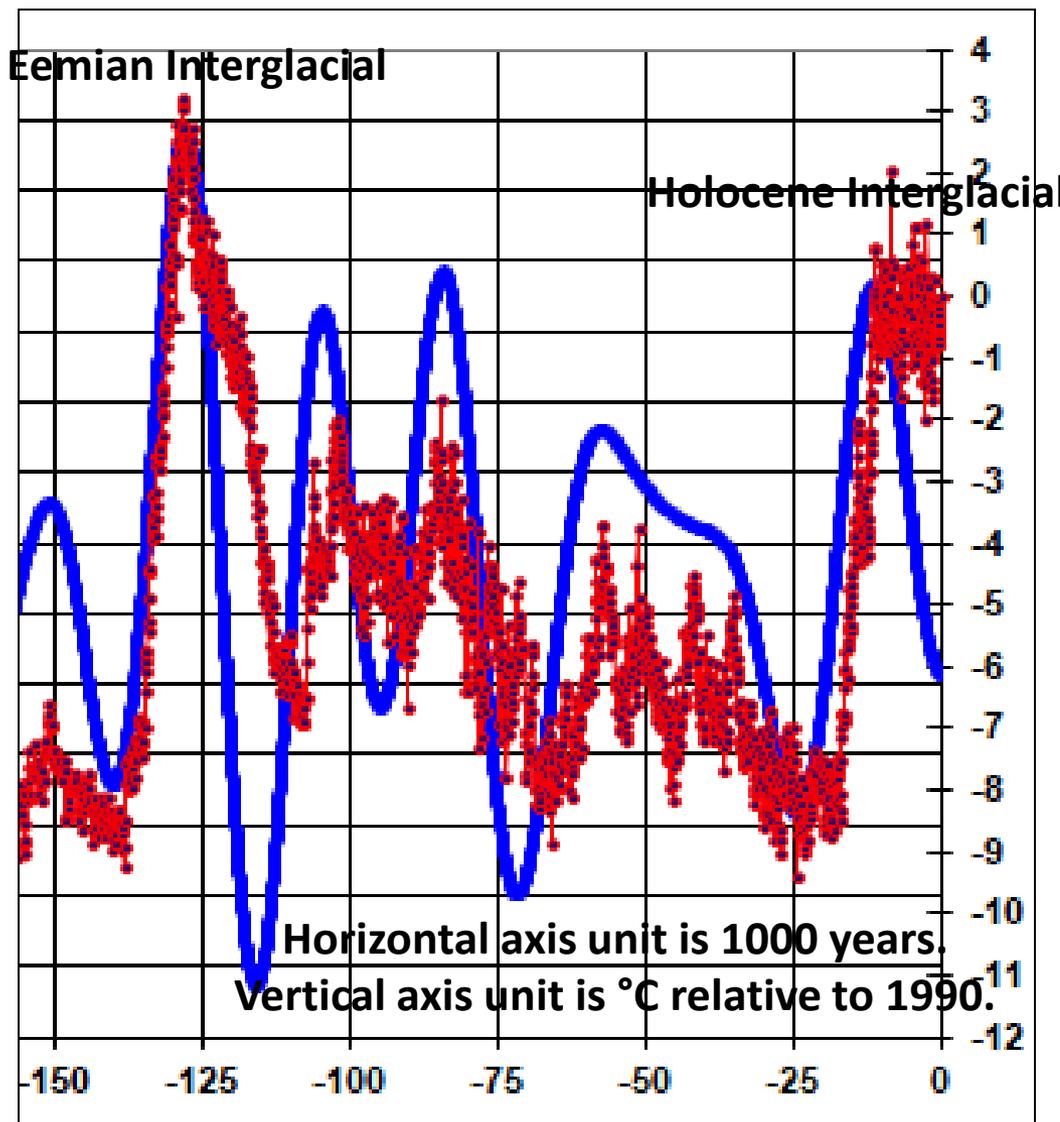
Emitted sulfate aerosols reflect sunlight for several years.



Also:

- Nitrate and light-colored particulate aerosols cool the atmosphere.
- Firestorms from nuclear explosions can cool the troposphere (lower atmosphere).

# Comparison to Last Major Ice Age



**Eemian sea level 20-30-ft higher than today**

**Temperature rise/year**

**Eemian: 0.00094 °C/year**

**Holocene: 0.00058 °C/year**

**Anthropocene: 0.015 °C/year  
(1970->2010)**

**~16 times Eemian!**

**~26 times Holocene!**

**Much faster since 2014!**

**Red points are Antarctica temperatures relative to 1990 from ice cores.**

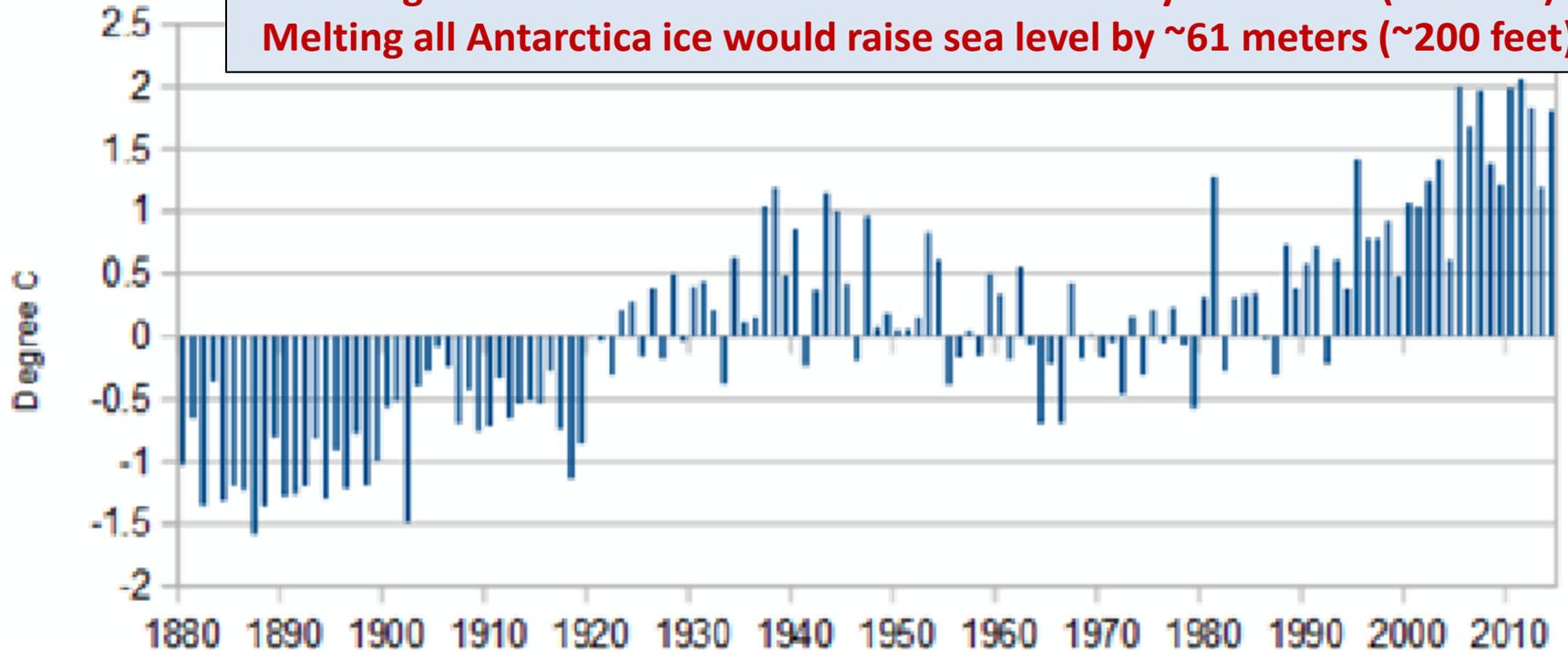
**Blue curve is North-Pole solar insolation, the driver of ice ages.**

## Arctic Temperature

GISS LOTI Annual Temperature Anomalies : 1880 to 2014

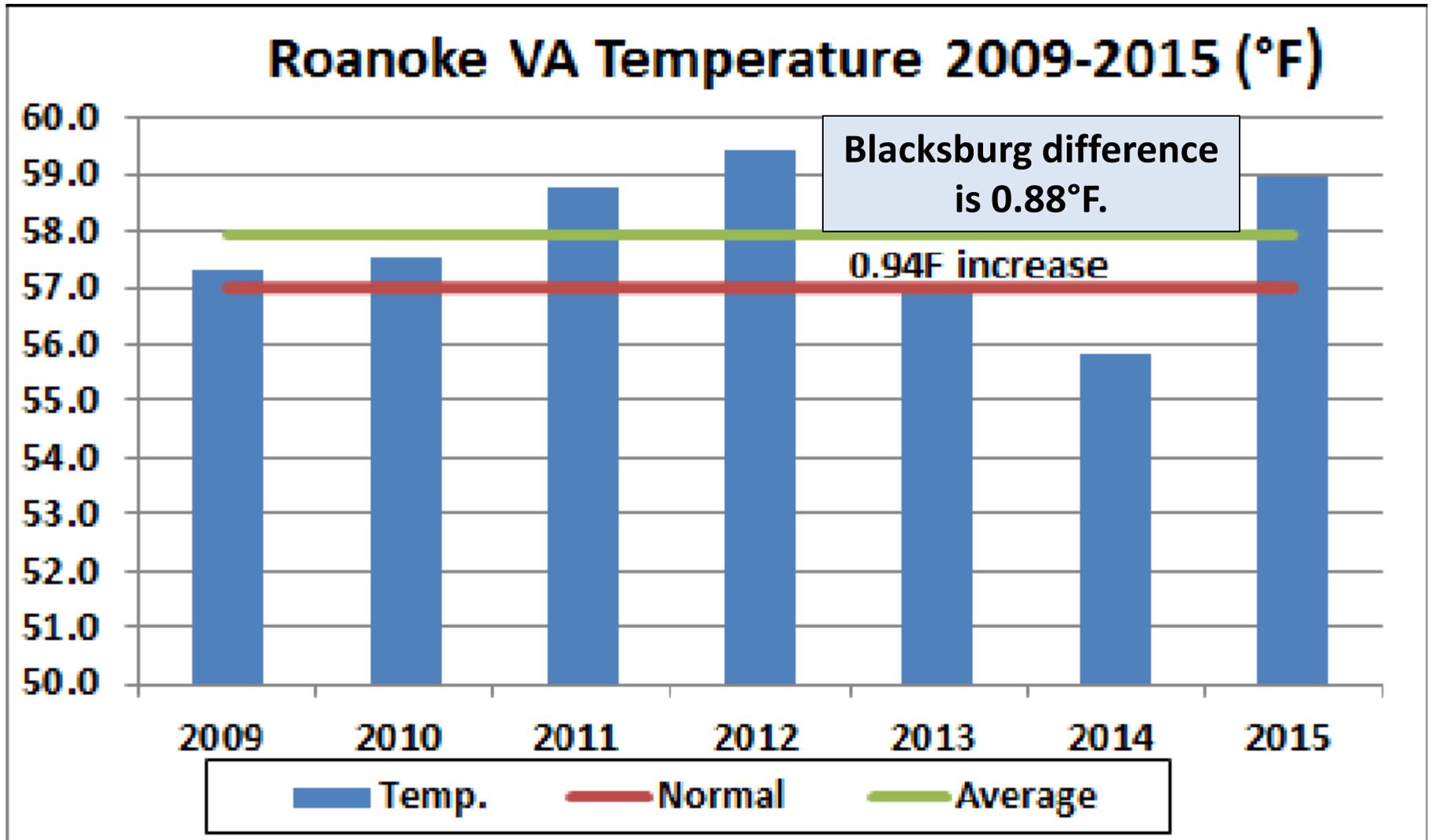
64N - 90N

Melting all Greenland ice would raise sea level by ~6 meters (~20 feet).  
Melting all Antarctica ice would raise sea level by ~61 meters (~200 feet).



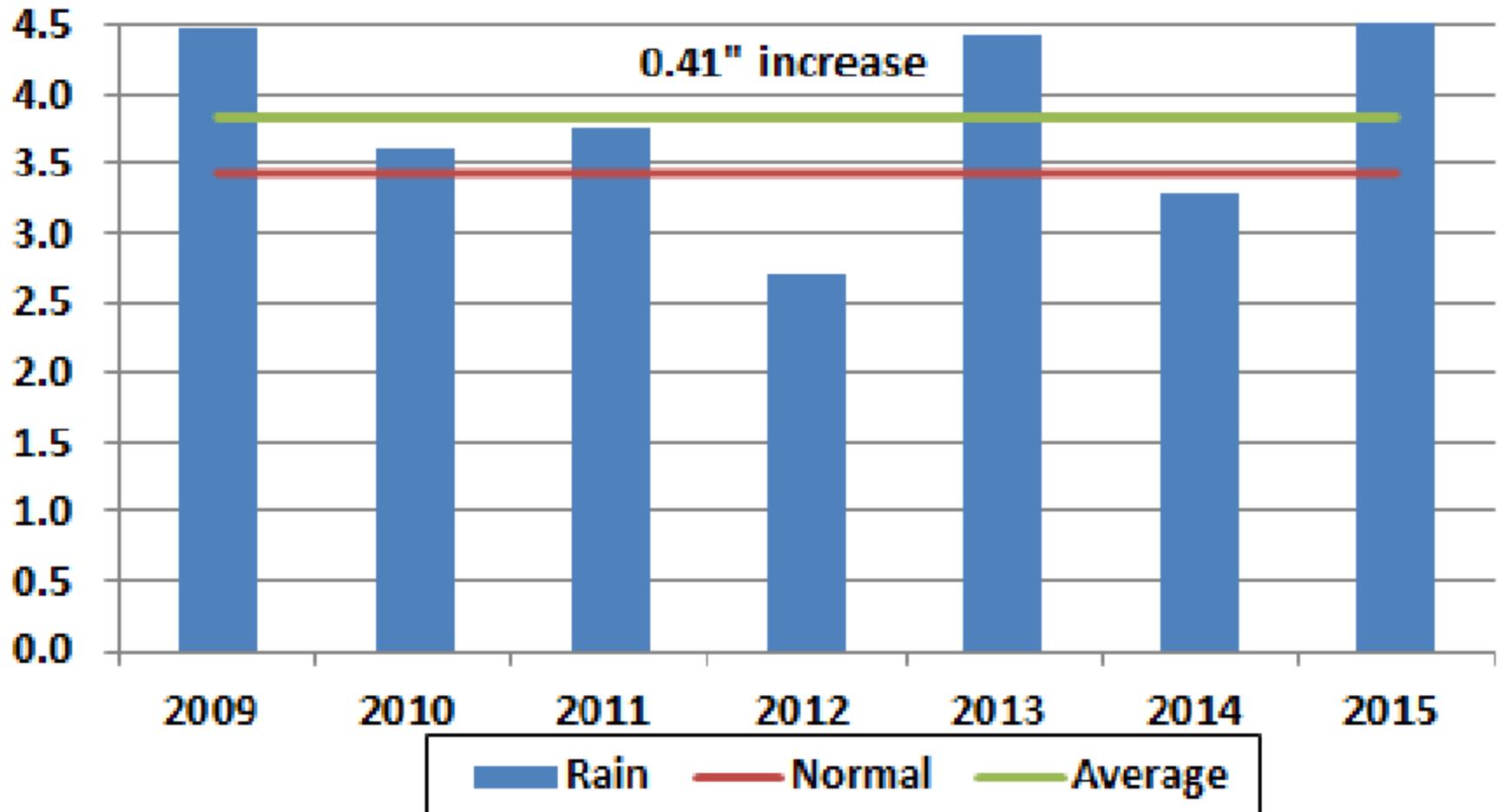
The Earth temperature rise is ~1.2°C (2.2°F) since 1880.  
The Arctic rise is ~3°C (5.4°F) since 1880, >2-times earth's!

# Trend is that Roanoke will be subtropical by 2030!



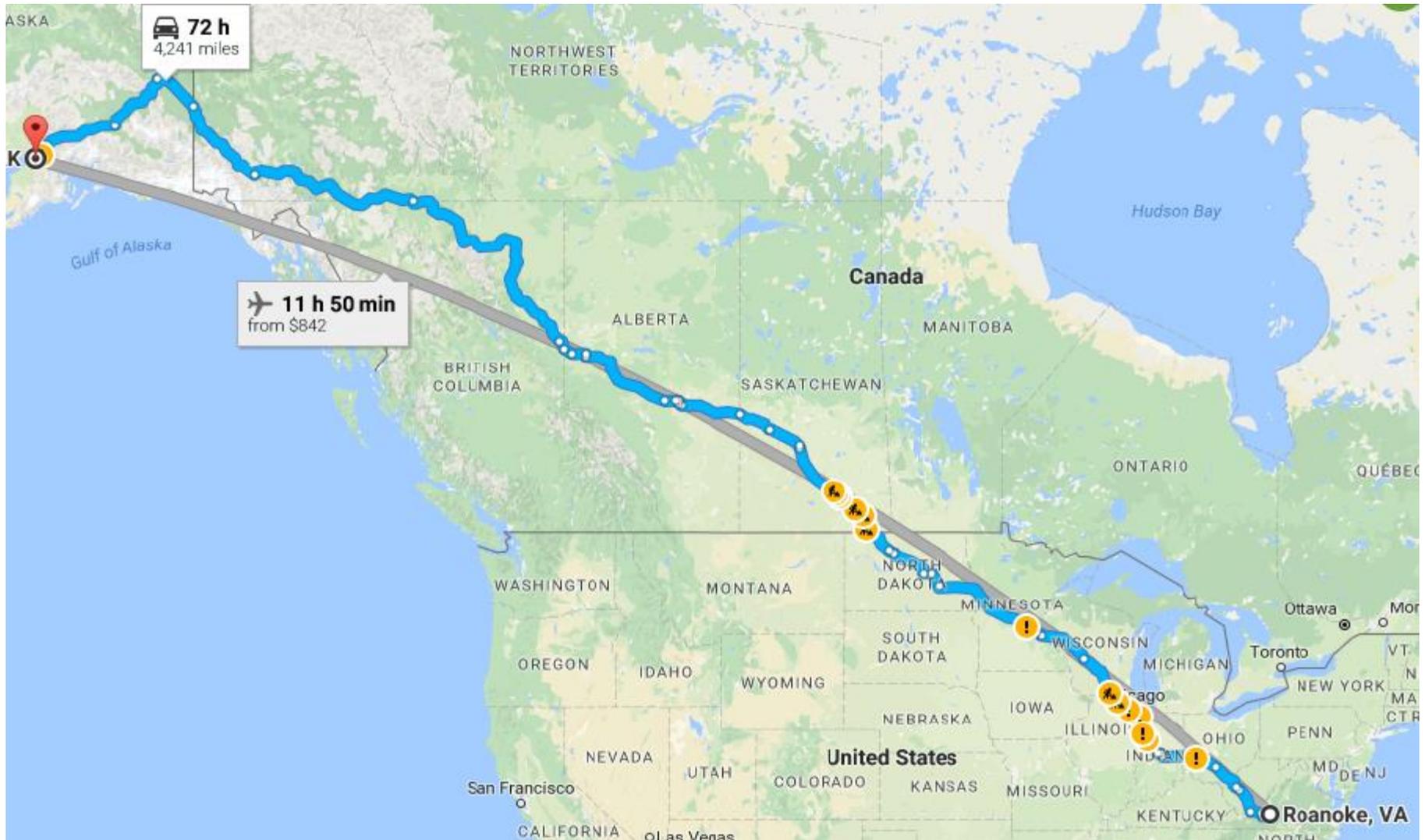
Average is larger than **normal** (1961-1990 average),  
as expected by Global Warming.

## Roanoke VA Rain 2009-2015 (inches)

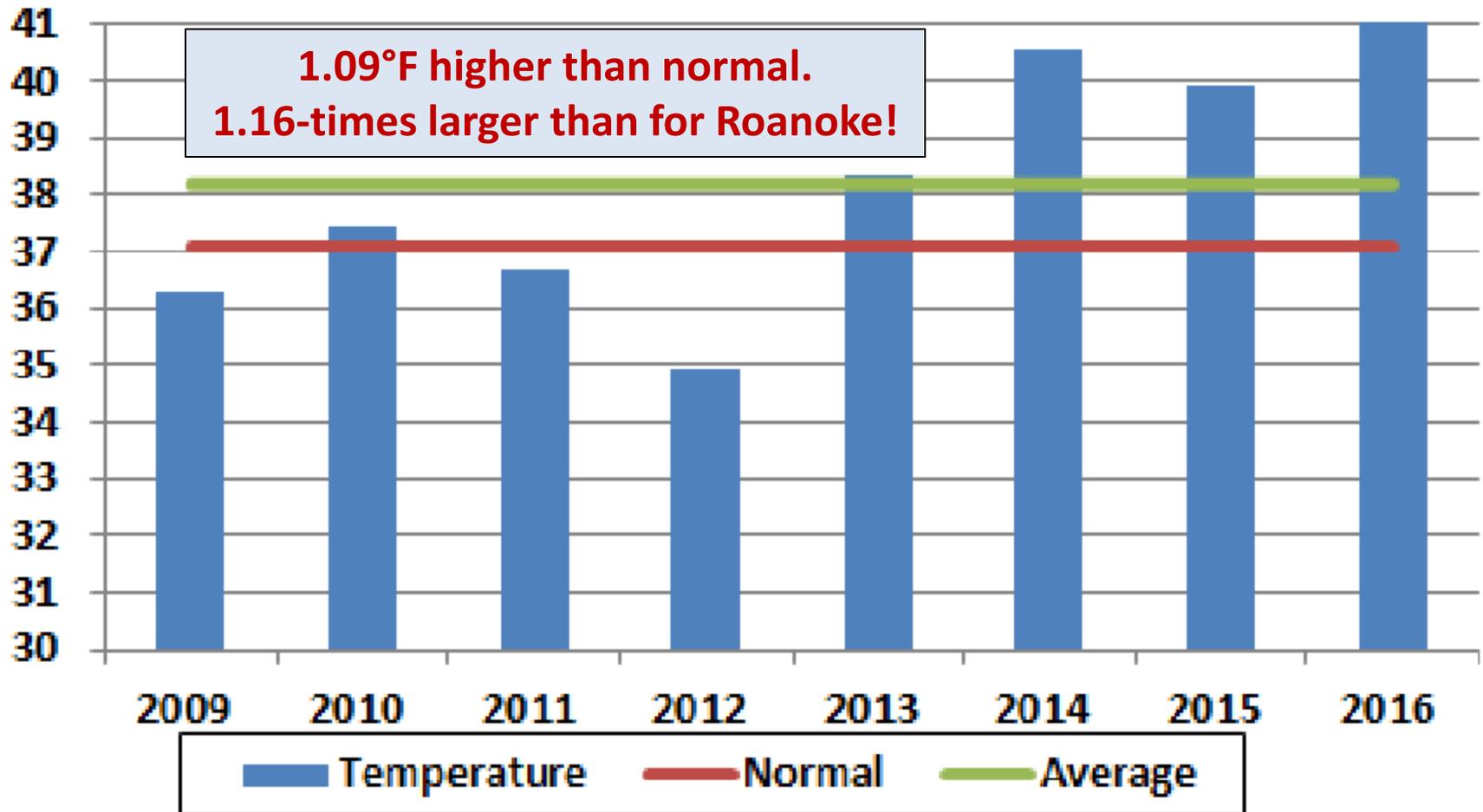


More rain than normal is consistent with Global Warming. <sup>15</sup>

# What about Anchorage, Alaska?

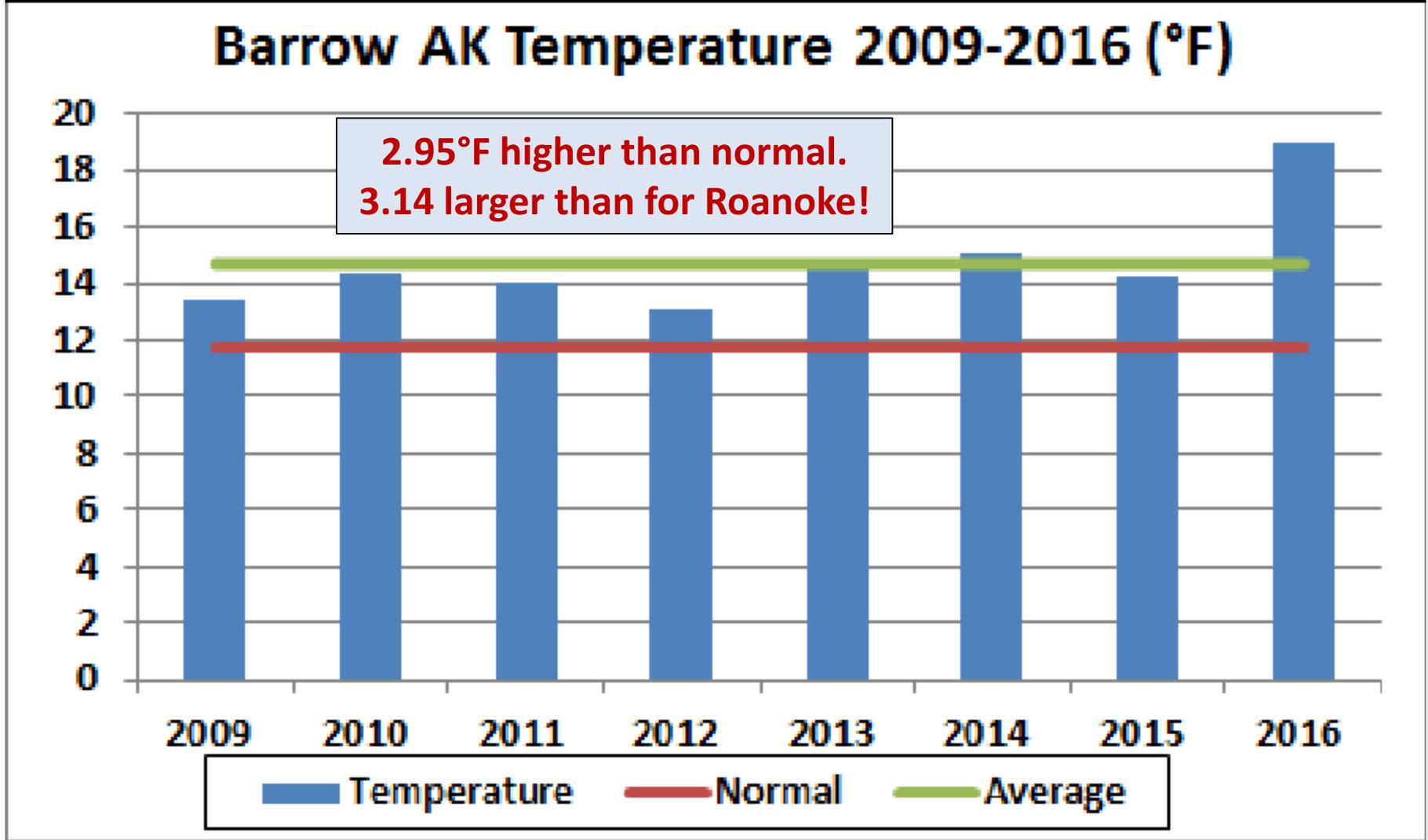


# Anchorage Temperature 2009-2016 (°F)



**Normal** = 1961-1990 average.

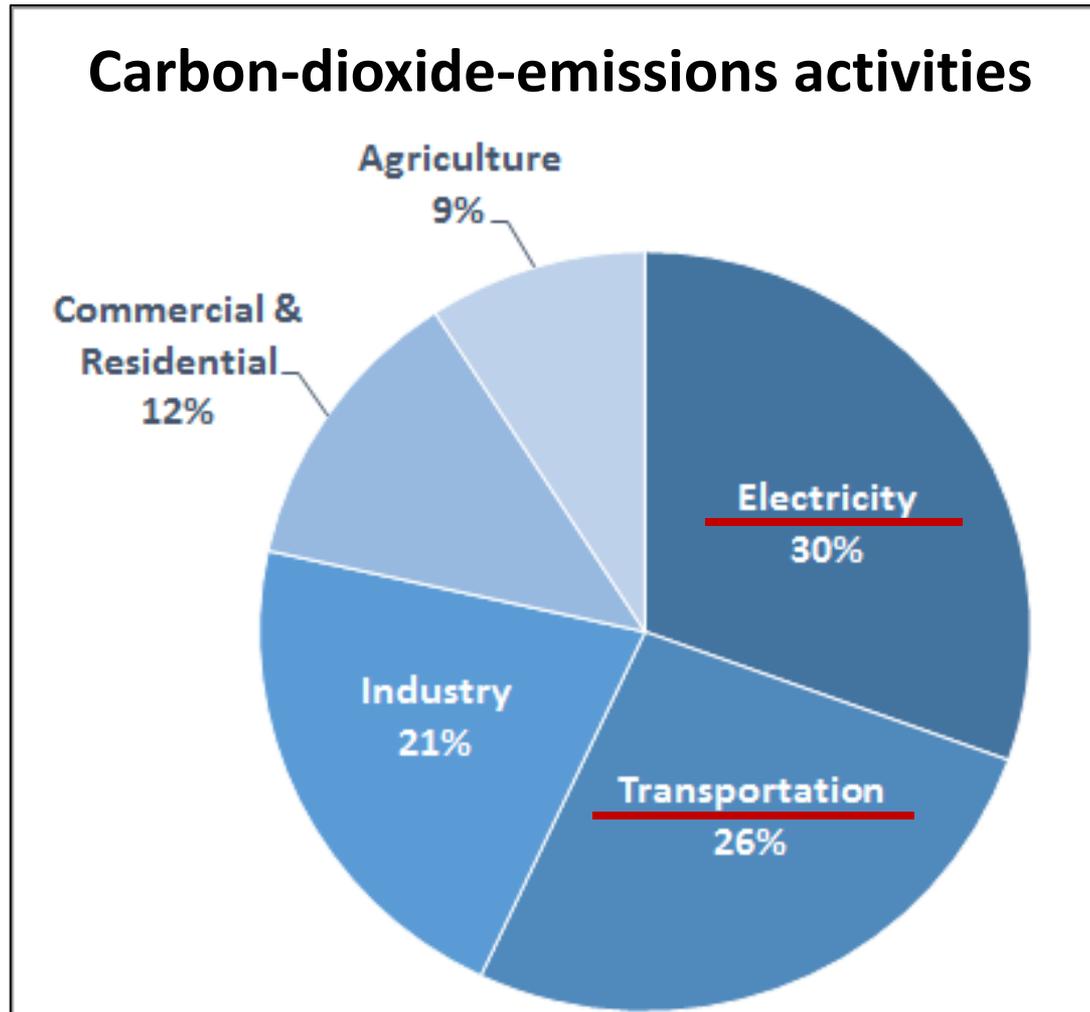
# What about Barrow, Alaska?



**Anchorage AK to Barrow AK is north 720 miles by air.  
There is no road!**

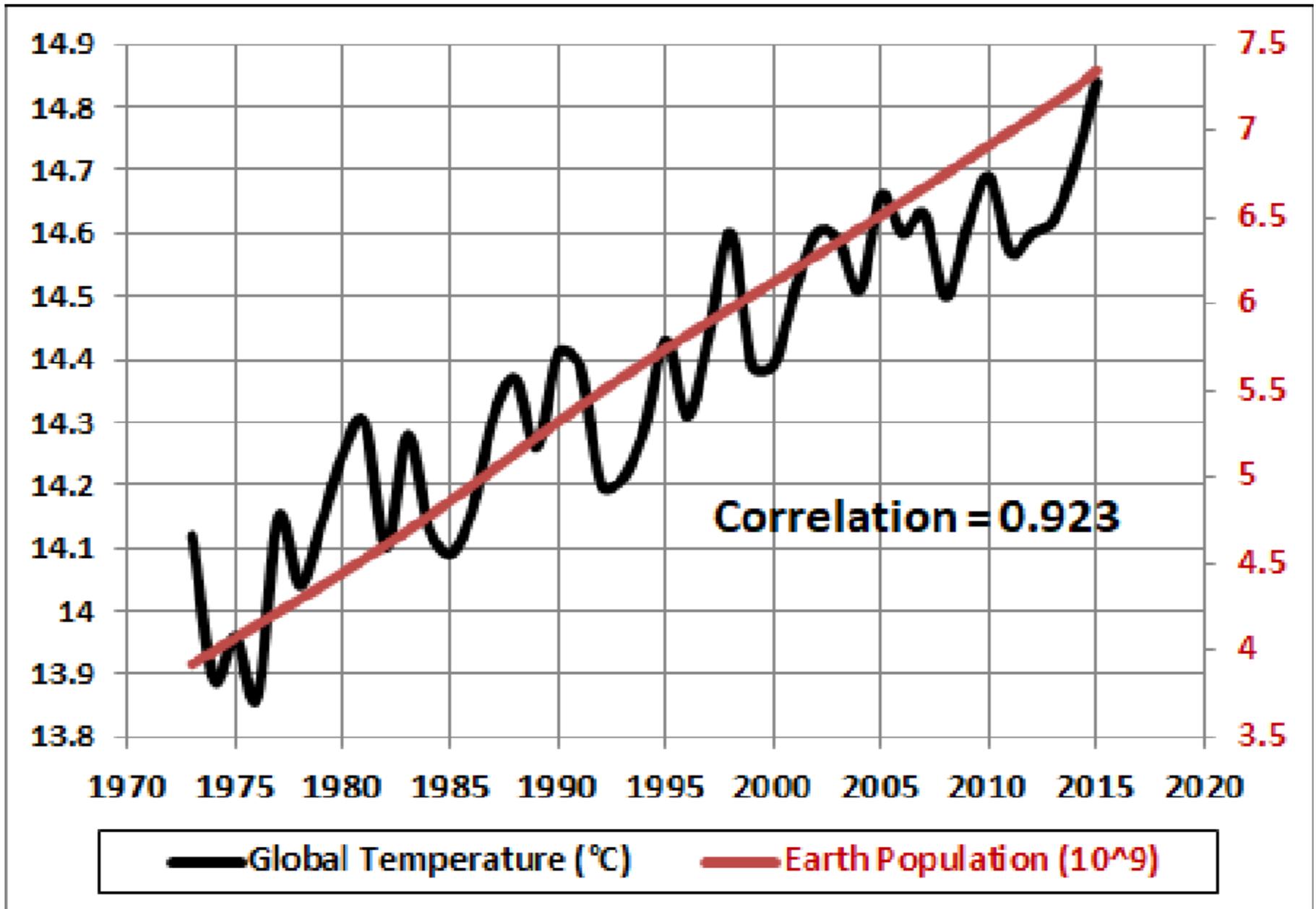
# Causes of Global Warming

## Too many people is basic cause!



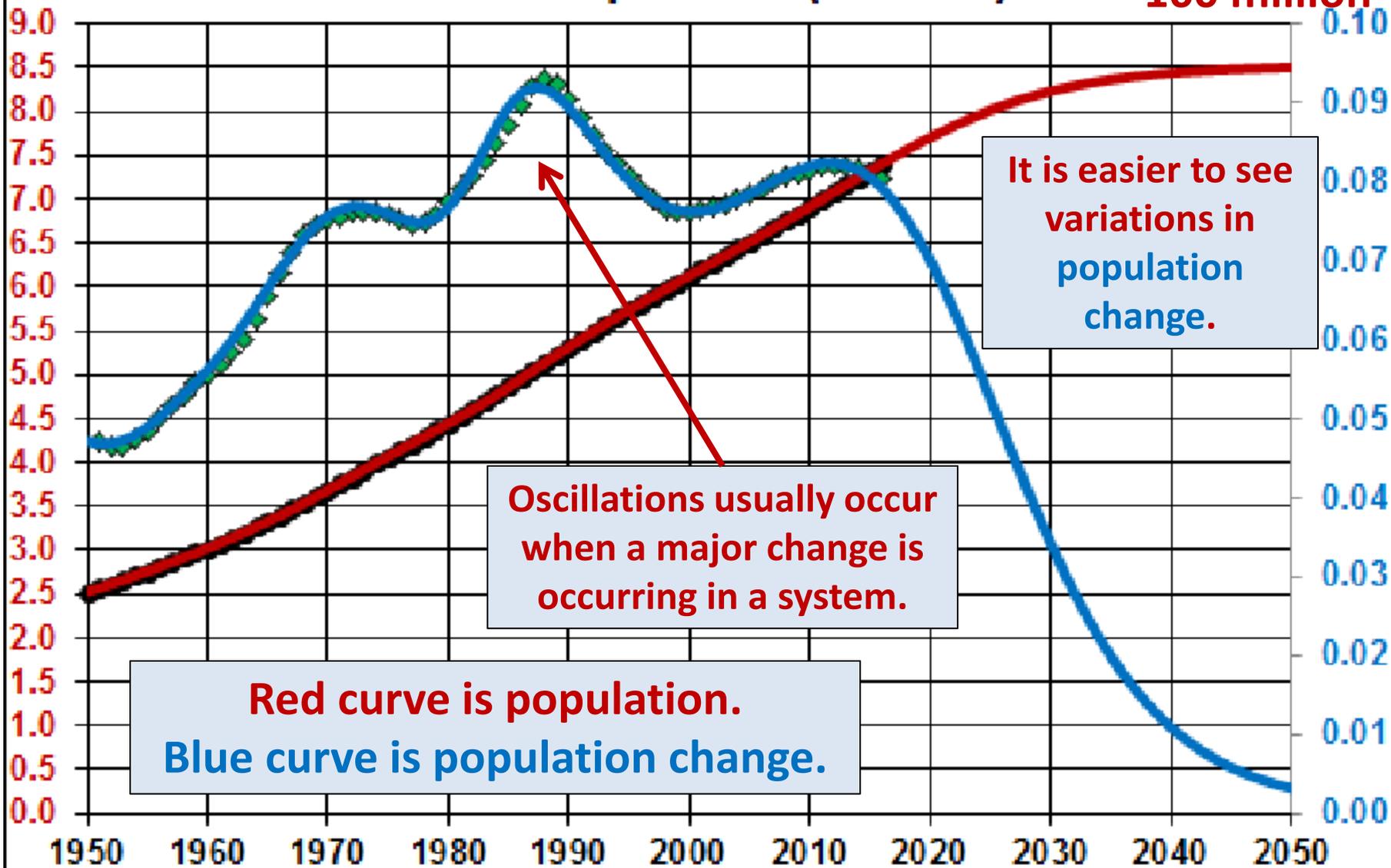
**We need renewable electrical energy & electric transport!**

# Too Many People Cause Global Warming



# World Population (billions)

100 million



Red curve is population.  
Blue curve is population change.

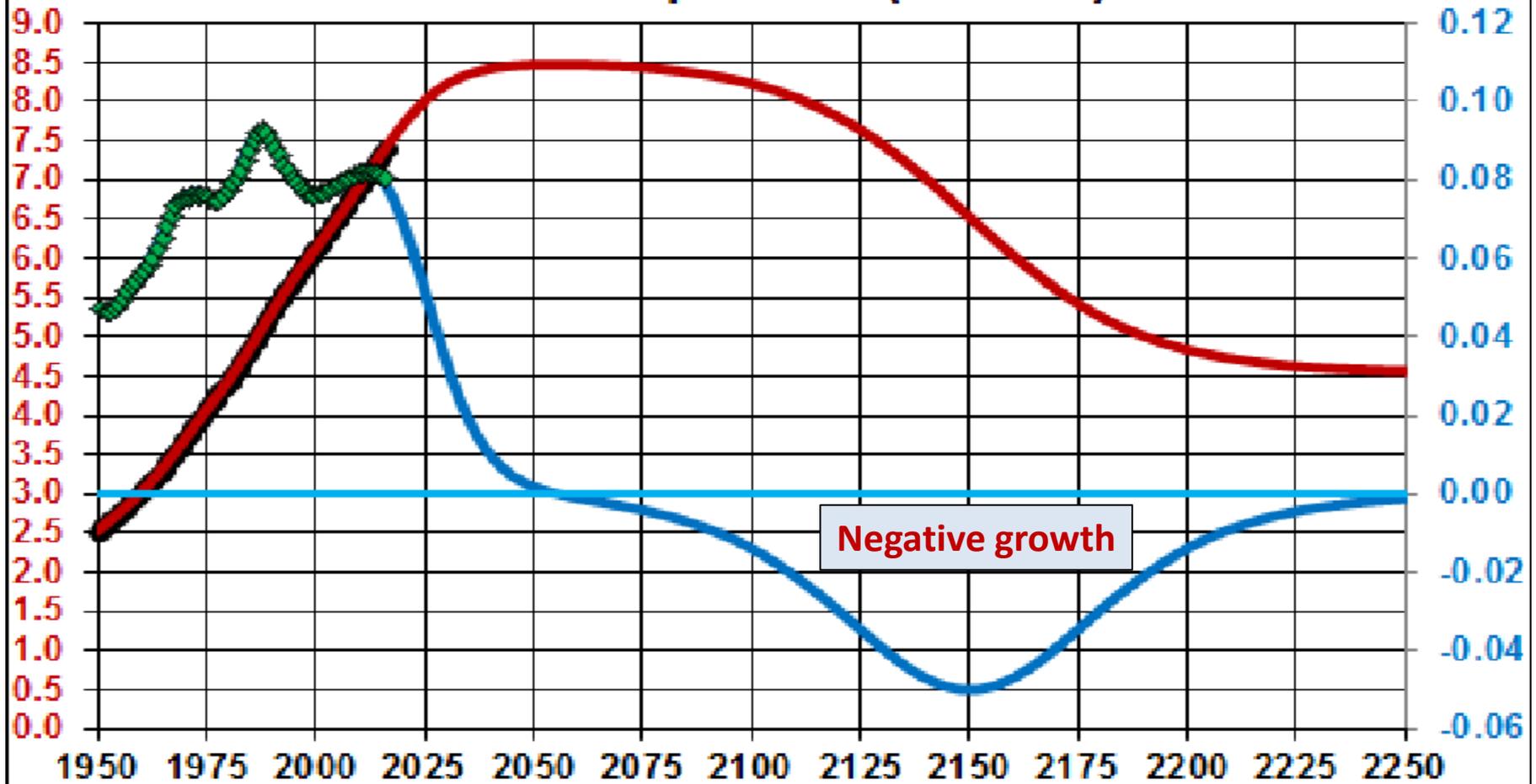
Oscillations usually occur  
when a major change is  
occurring in a system.

It is easier to see  
variations in  
population  
change.

● Population    ● Pop Change    — Fit Pop    — Fit Pop Change

**Much better would be for this to occur,  
if it occurred by human choice not by disaster!**

**World Population (billions)**



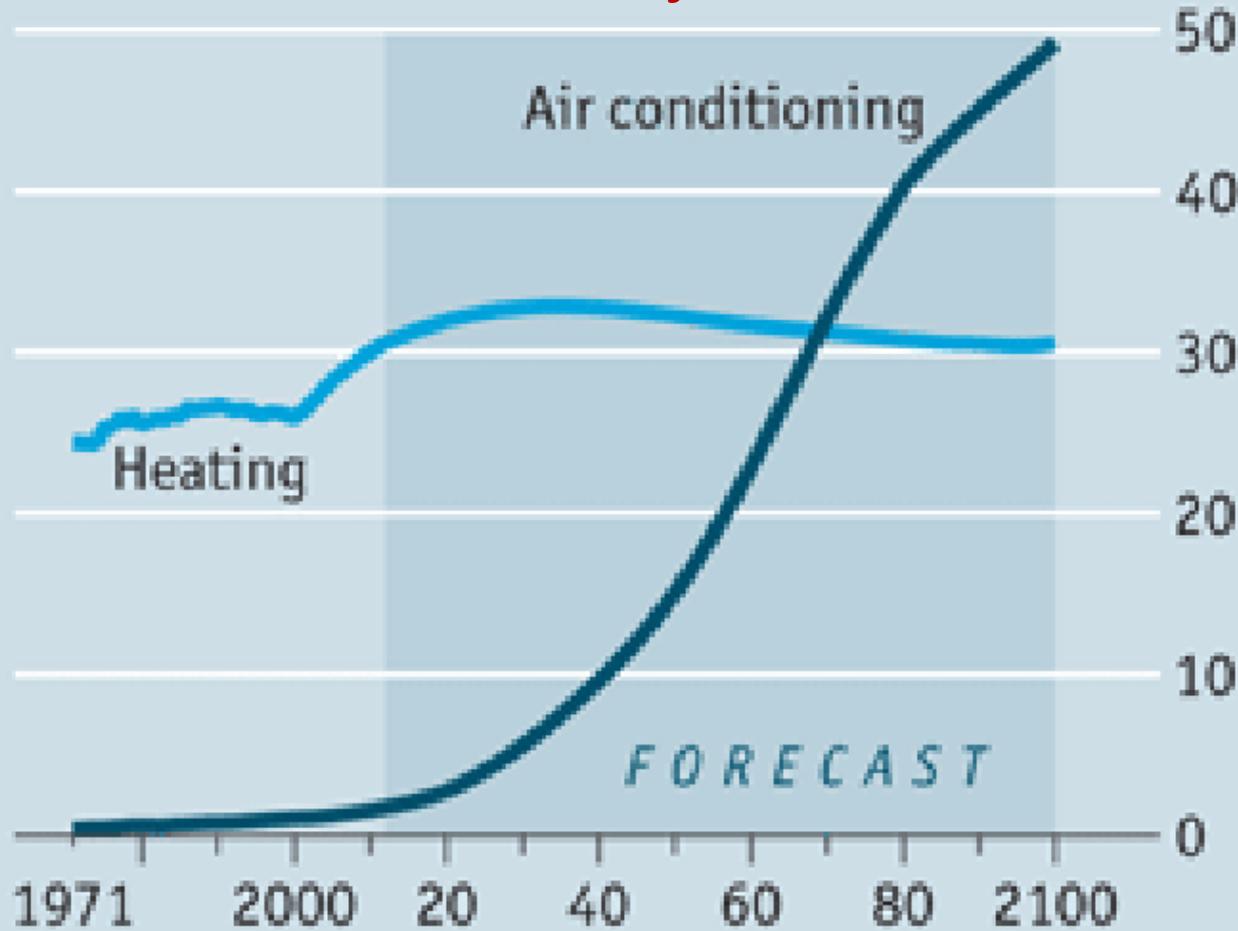
**Birth control should be free worldwide!**

● Population    — Fit Pop    — Fit Pop Change    ◆ Pop Change

# Perspiration perspectives

World energy demand, exajoules

1 exajoule =  $2.778 \times 10^{11}$  kWh



Source: PBL Netherlands Environmental Assessment Agency

Energy required to make people comfortable or viable.

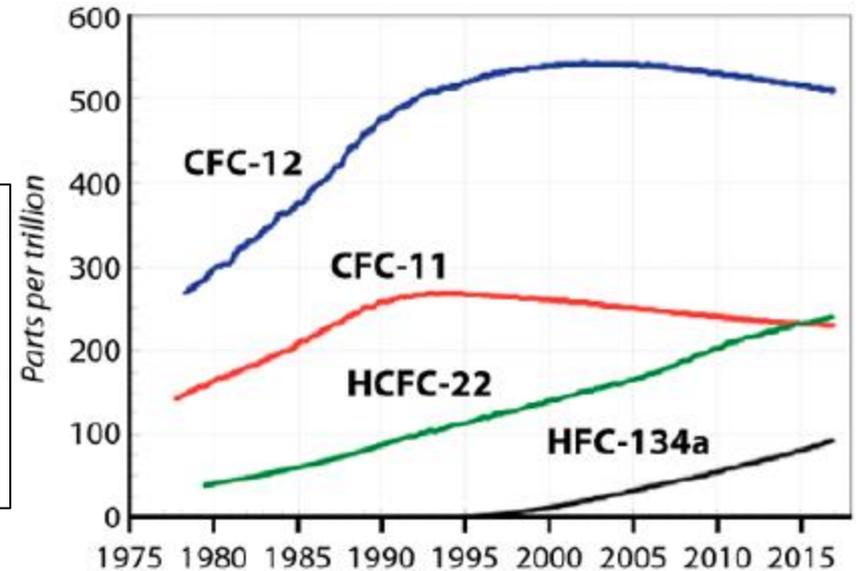
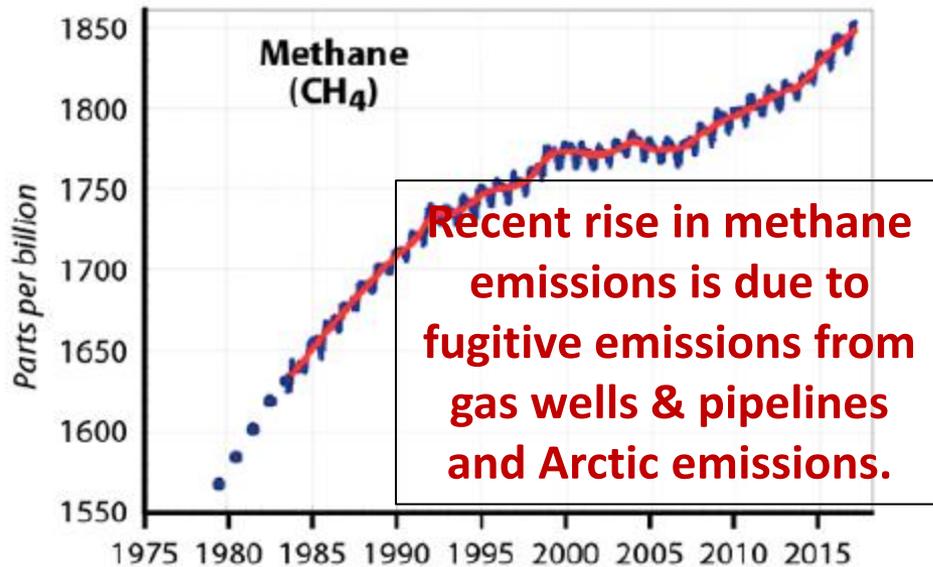
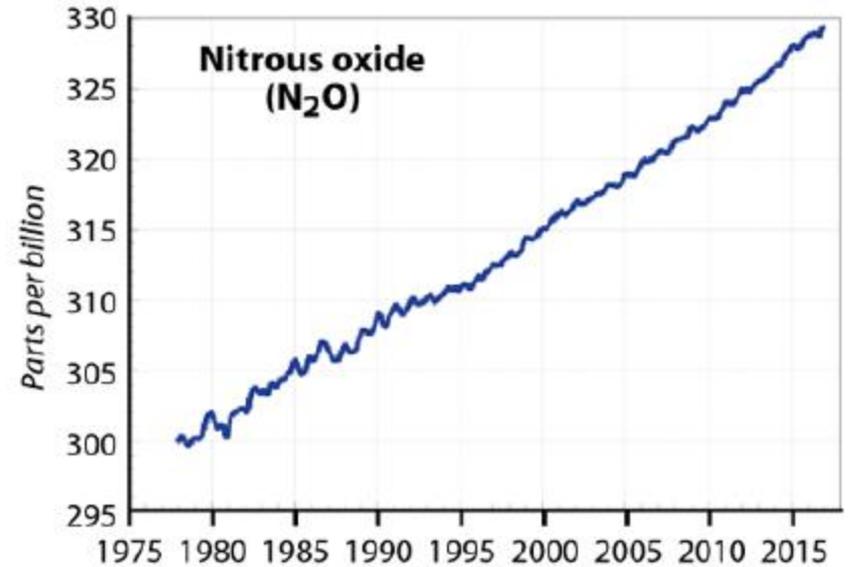
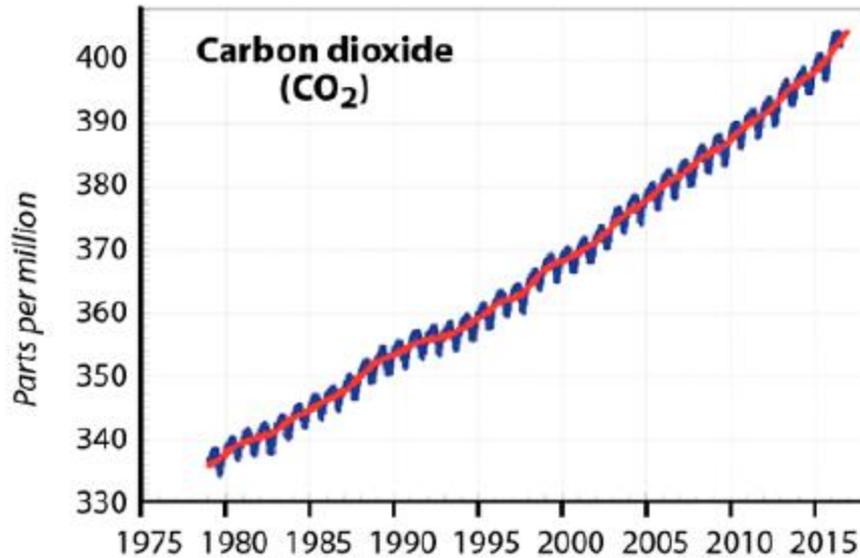
# Effect of Carbon in Atmosphere

- **Earth would be covered with ice (-18°C or -0.4°F)** if there were no carbon in the atmosphere (**currently >0.04%**). Instead it is **15°C or 59°F mostly because of carbon.**
- Venus is very hot (**462°C or 864°F**) because of **96% CO<sub>2</sub>** in a very dense atmosphere. Without carbon it would be **-53°C or -63°F** , because its clouds reflect 90% of solar energy.
- Extra carbon in the atmosphere (**currently >0.04%**) due to industrial revolution makes the Earth warmer.
- Burning fossil fuels puts carbon in the atmosphere.
- Burning coal puts about twice the carbon into the atmosphere as does burning natural gas.
  - **However methane leaks in gas drilling and pipelines make natural gas global-warming effect about the same as coal.**

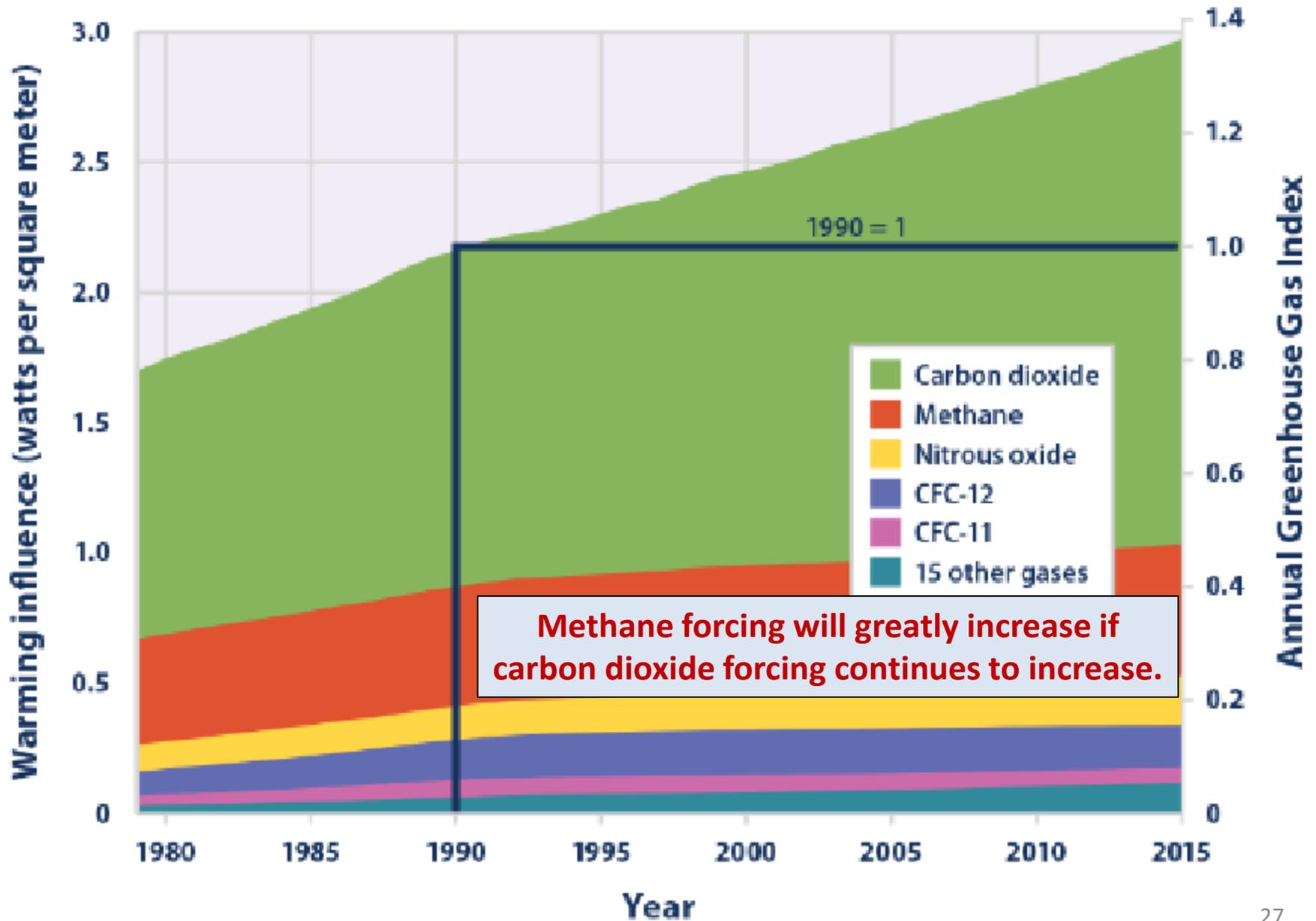
# Greenhouse Gases (GHG)

- **Carbon dioxide** (Global-Warming Potential = **GWP = 1**).  
Lifetime in atmosphere = ~1000 years.
- **Methane** (**GWP = ~85** in 20 years & **~32** in 100 years).  
Lifetime in atmosphere = 12 years.  
Reacts with oxygen to produce water & **carbon dioxide**.
- **Ozone** (**GWP = ~1000**).  
Lifetime in lower atmosphere = ~21 days.
- **Nitrous oxide** (**GWP = ~300** in 100 years).  
Lifetime in atmosphere = ~121 years.
- **Halocarbons** (many of them which have variable GWP and lifetimes in atmosphere)
- **Water vapor** is a major cause of GW (Lifetime in atmosphere = ~9 days) **Warming of atmosphere increases it and it ~doubles the effect of other GHGs.**

# Greenhouse Gases' Emissions that Cause Global Warming



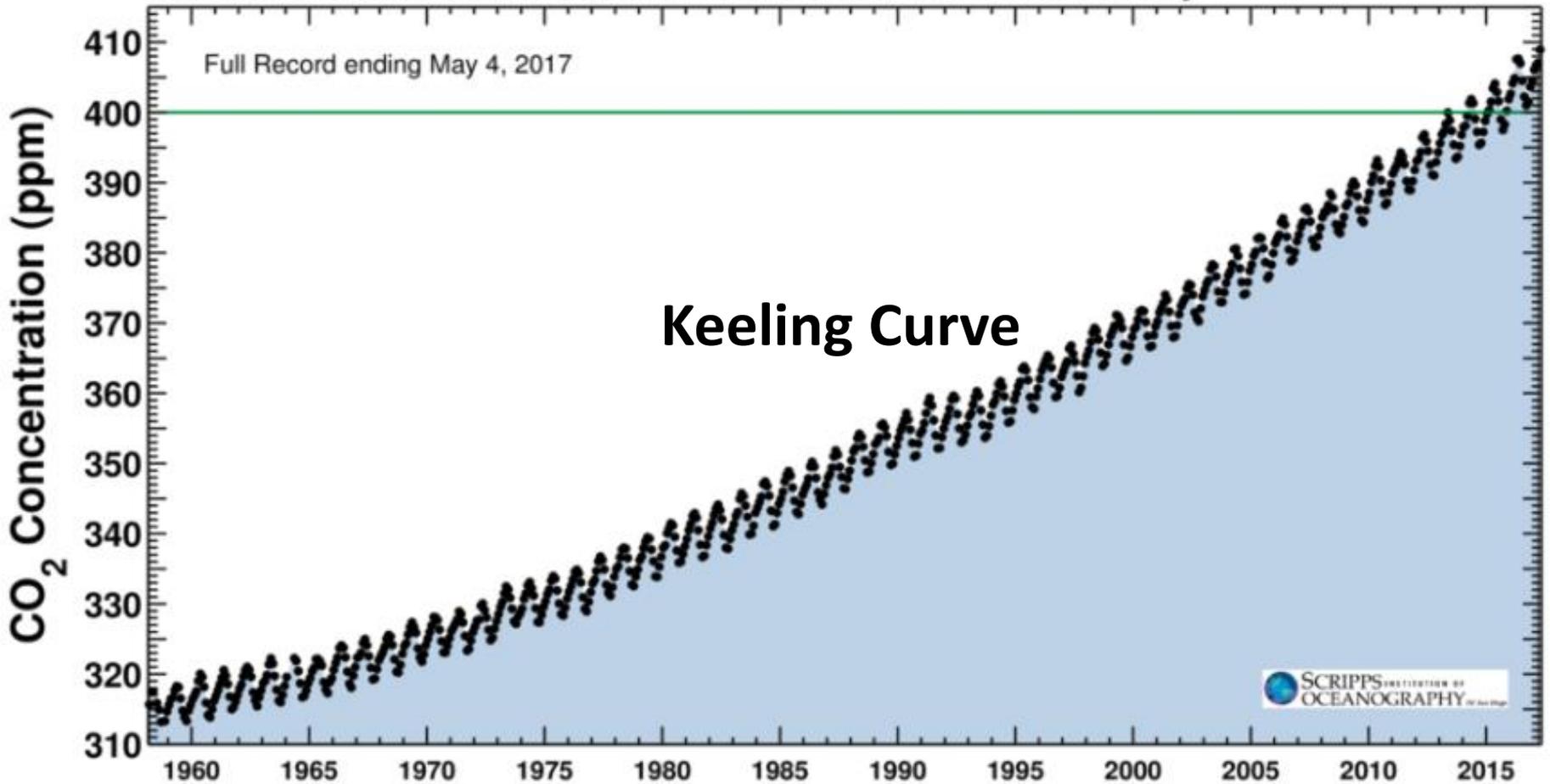
**Figure 1. Radiative Forcing Caused by Major Long-Lived Greenhouse Gases, 1979-2015**



Latest CO<sub>2</sub> reading  
May 04, 2017

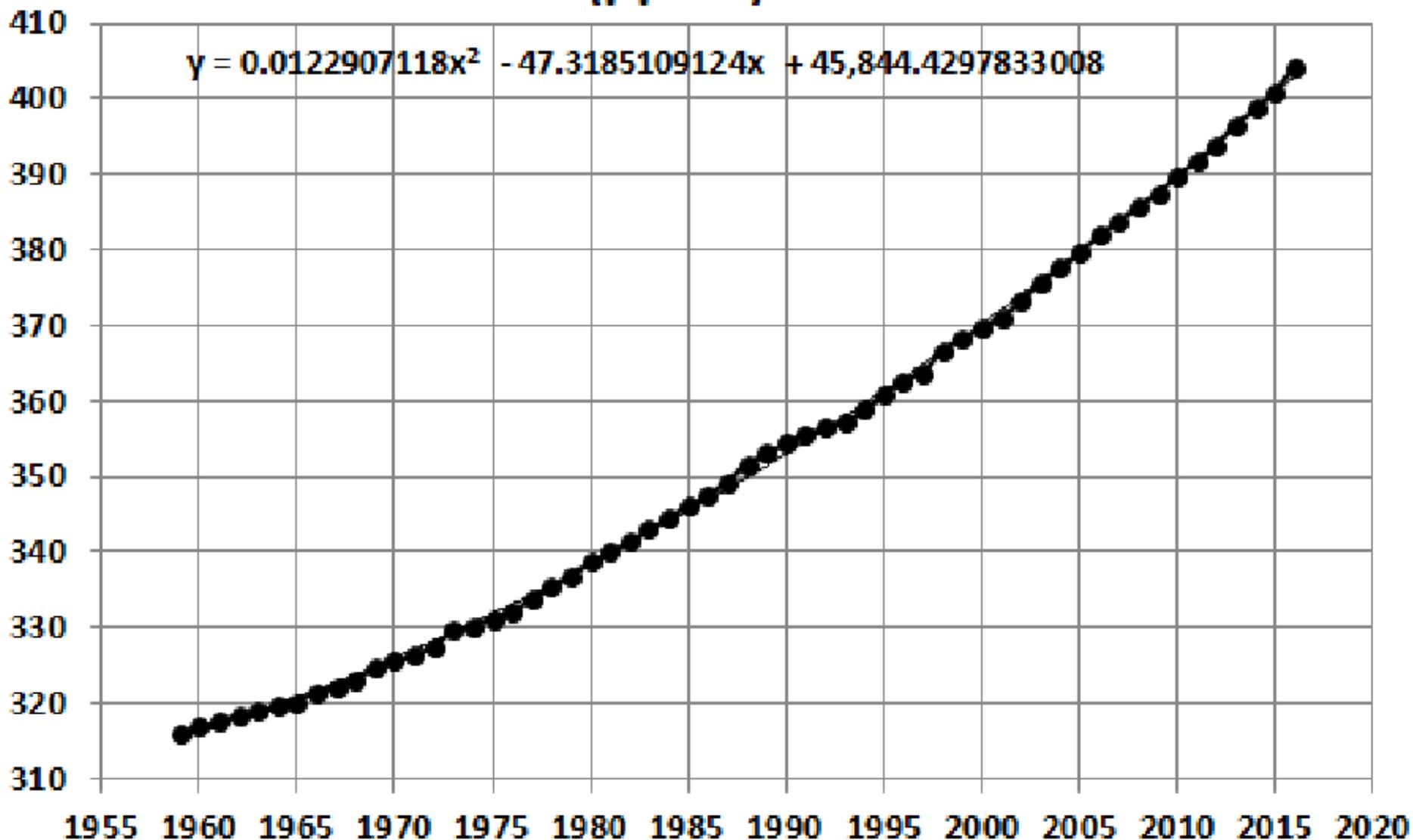
410.52 ppm

Carbon dioxide concentration at Mauna Loa Observatory



# CO2 (ppmv)

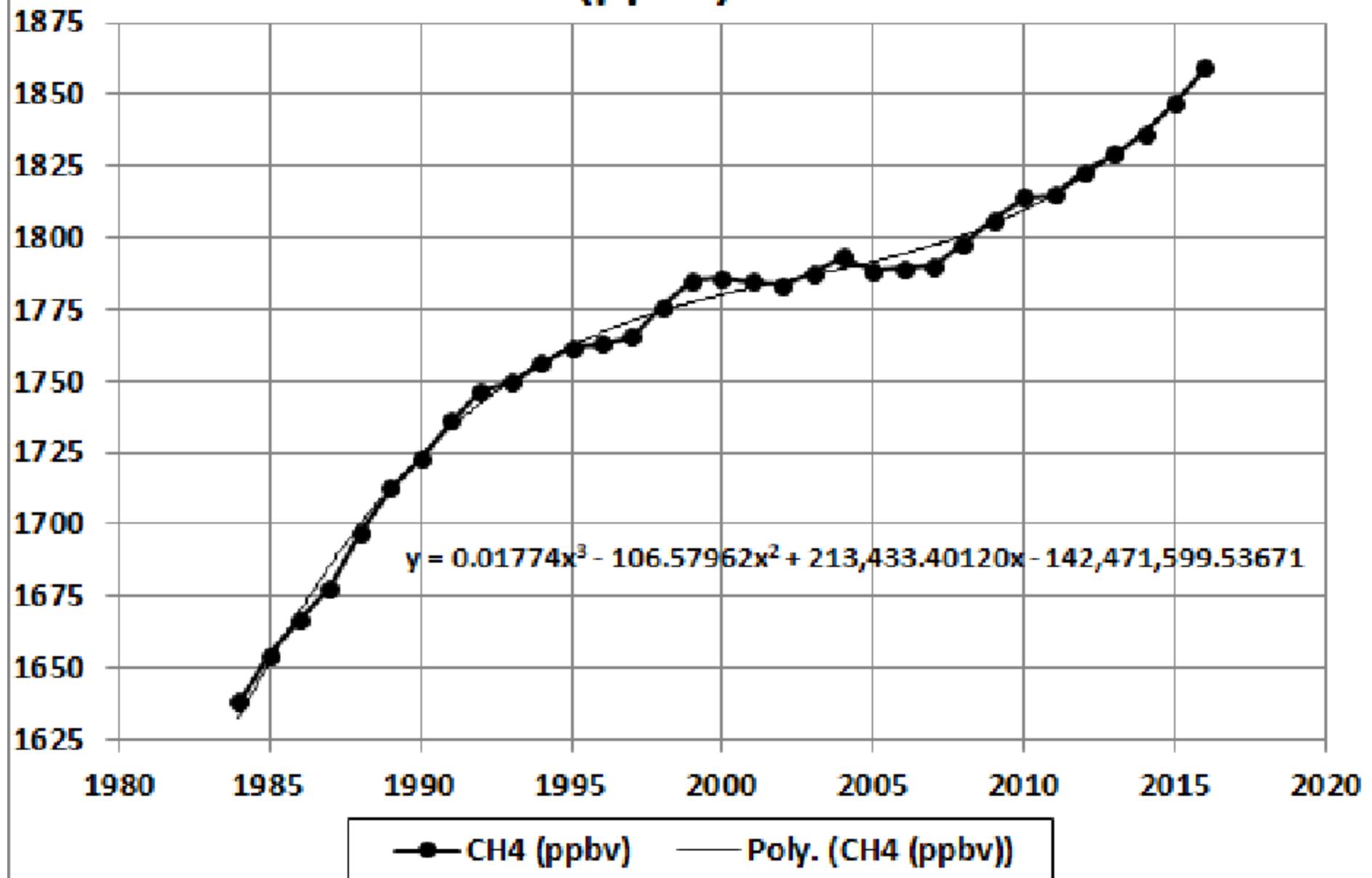
$$y = 0.0122907118x^2 - 47.3185109124x + 45,844.4297833008$$



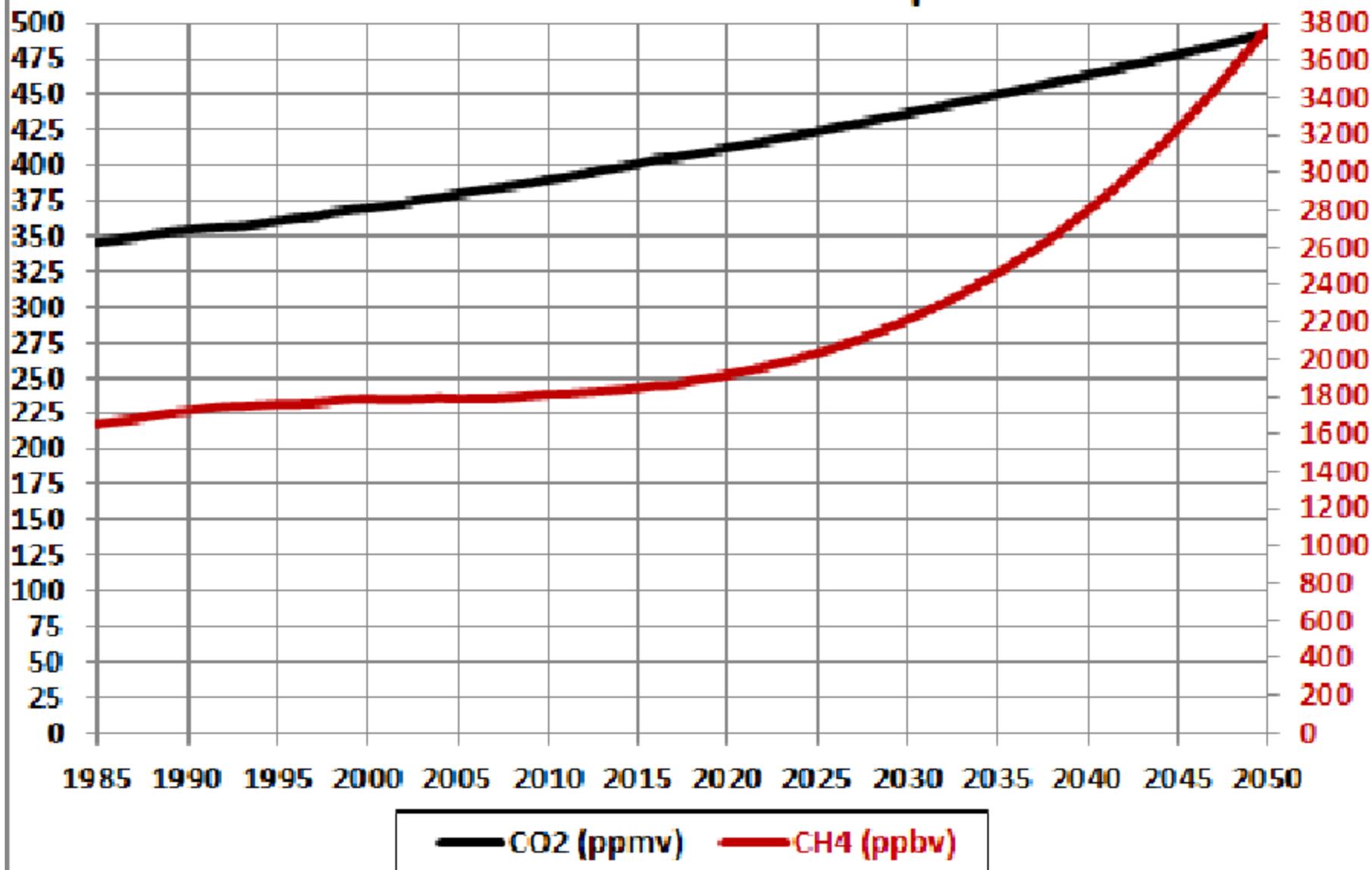
● CO2 (ppmv)

— Poly. (CO2 (ppmv))

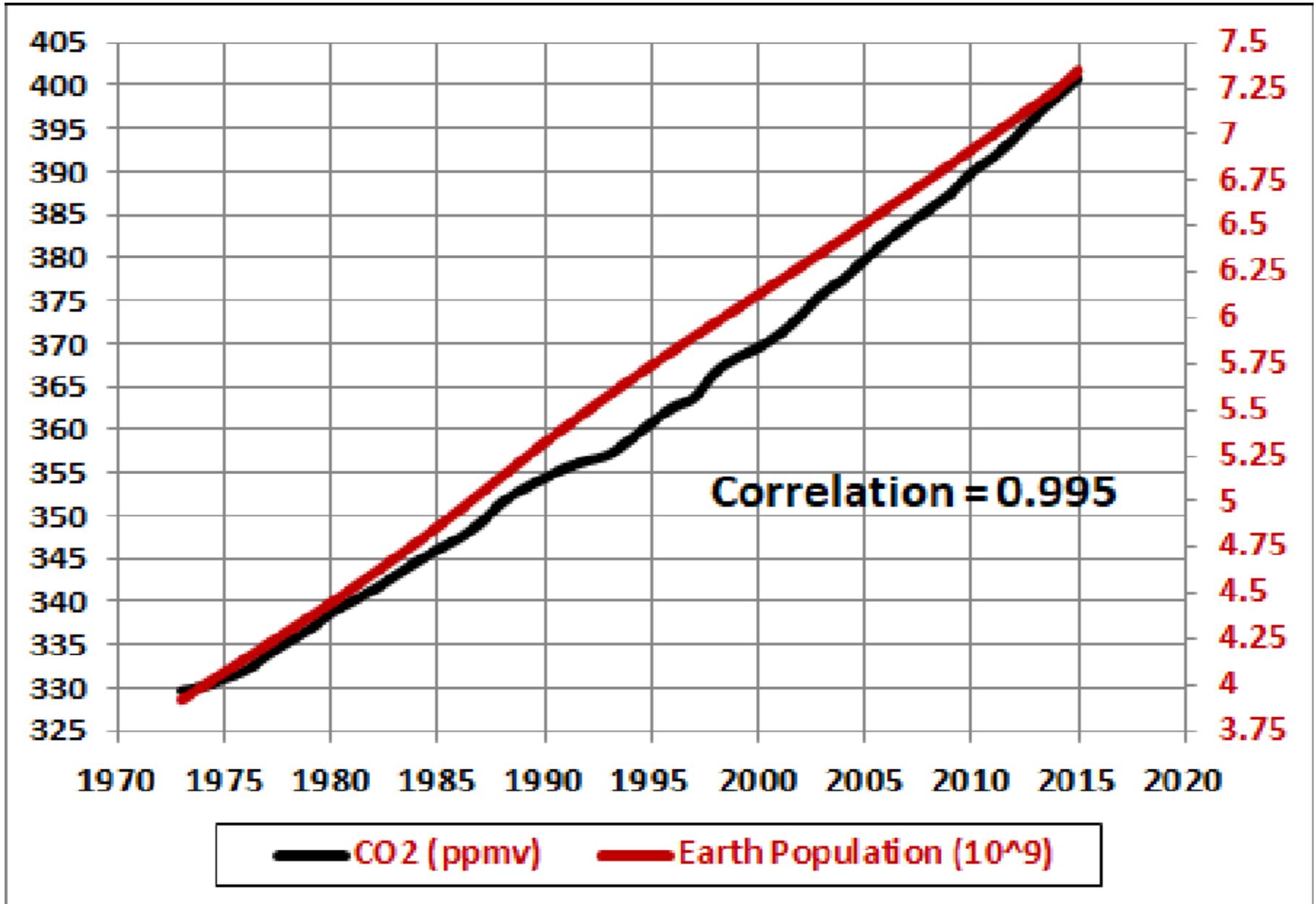
# CH4 (ppbv)



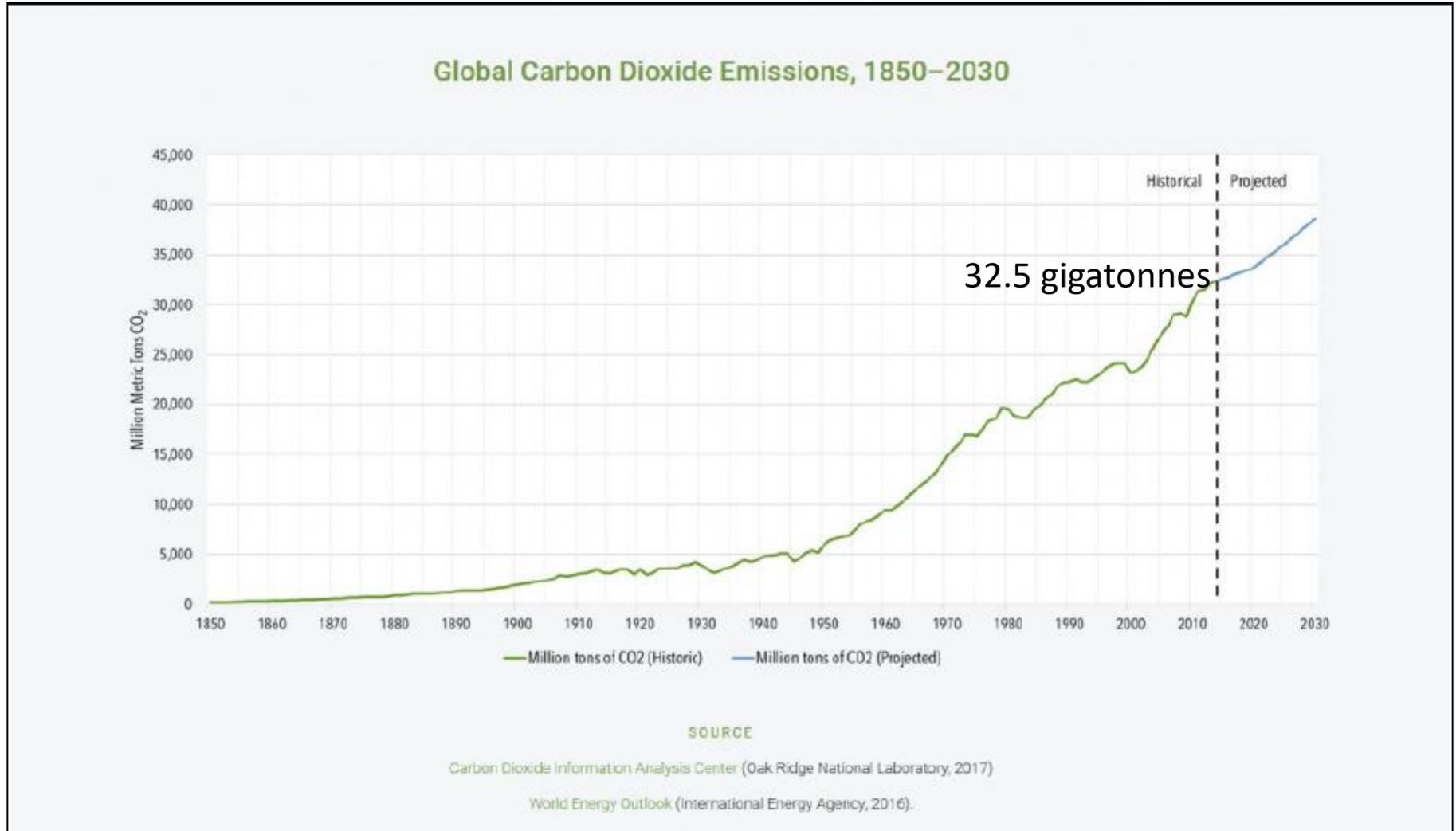
# CO2 & CH4 in Atmosphere



# Too Many People Cause Global Warming



# Global CO<sub>2</sub> Emissions 1850-2030 (10<sup>6</sup> tonnes)



# Global Temperature Calculation

$$\boxed{dT = S_C \ln(C_f / C_i) / \ln(2) + S_M \ln(M_f / M_i) / \ln(2)} \text{ where}$$

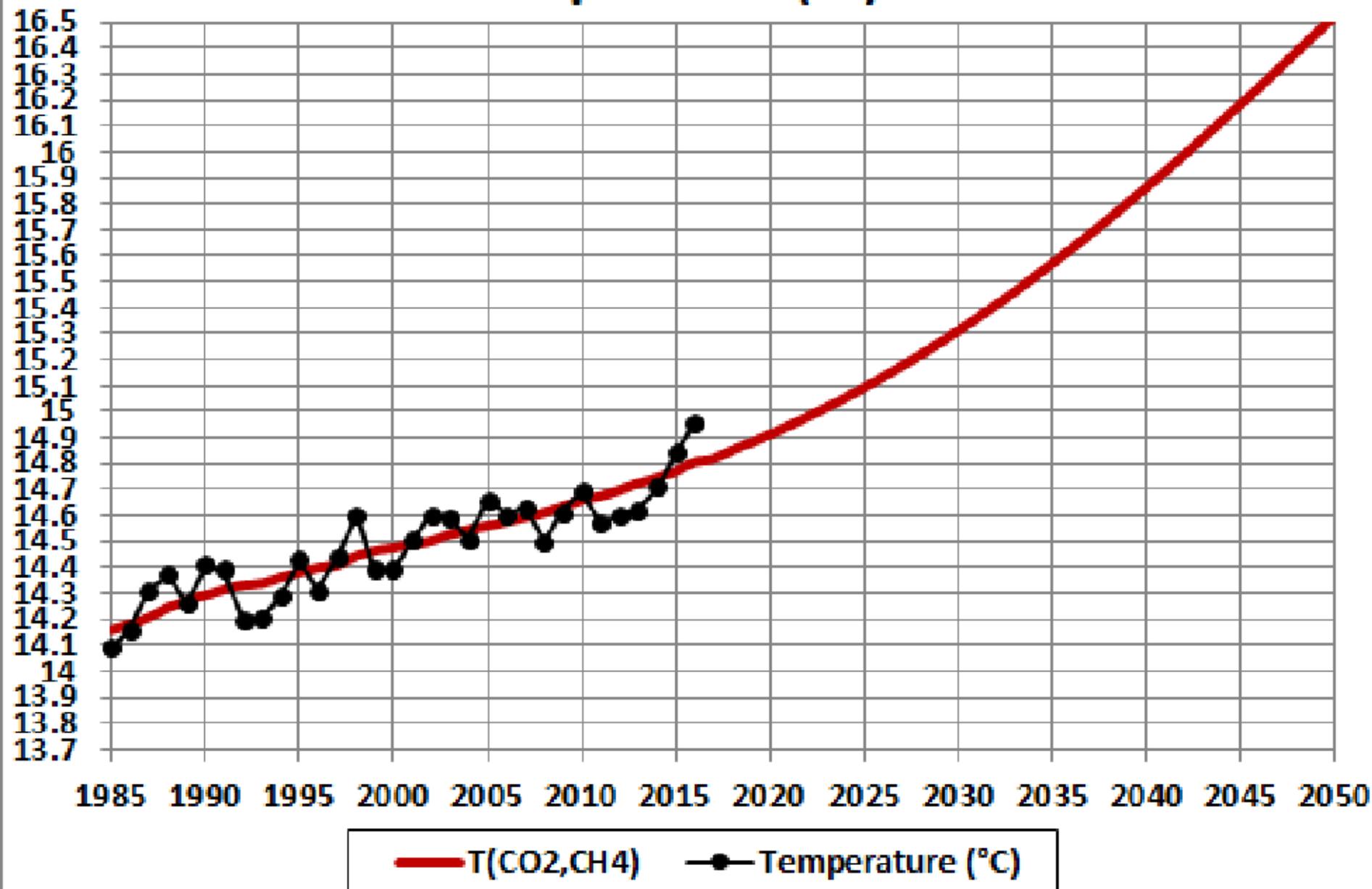
$S_C$  = climate sensitivity for carbon dioxide concentration (C) in the atmosphere and

$S_M$  = climate sensitivity for methane concentration (M) in the atmosphere.

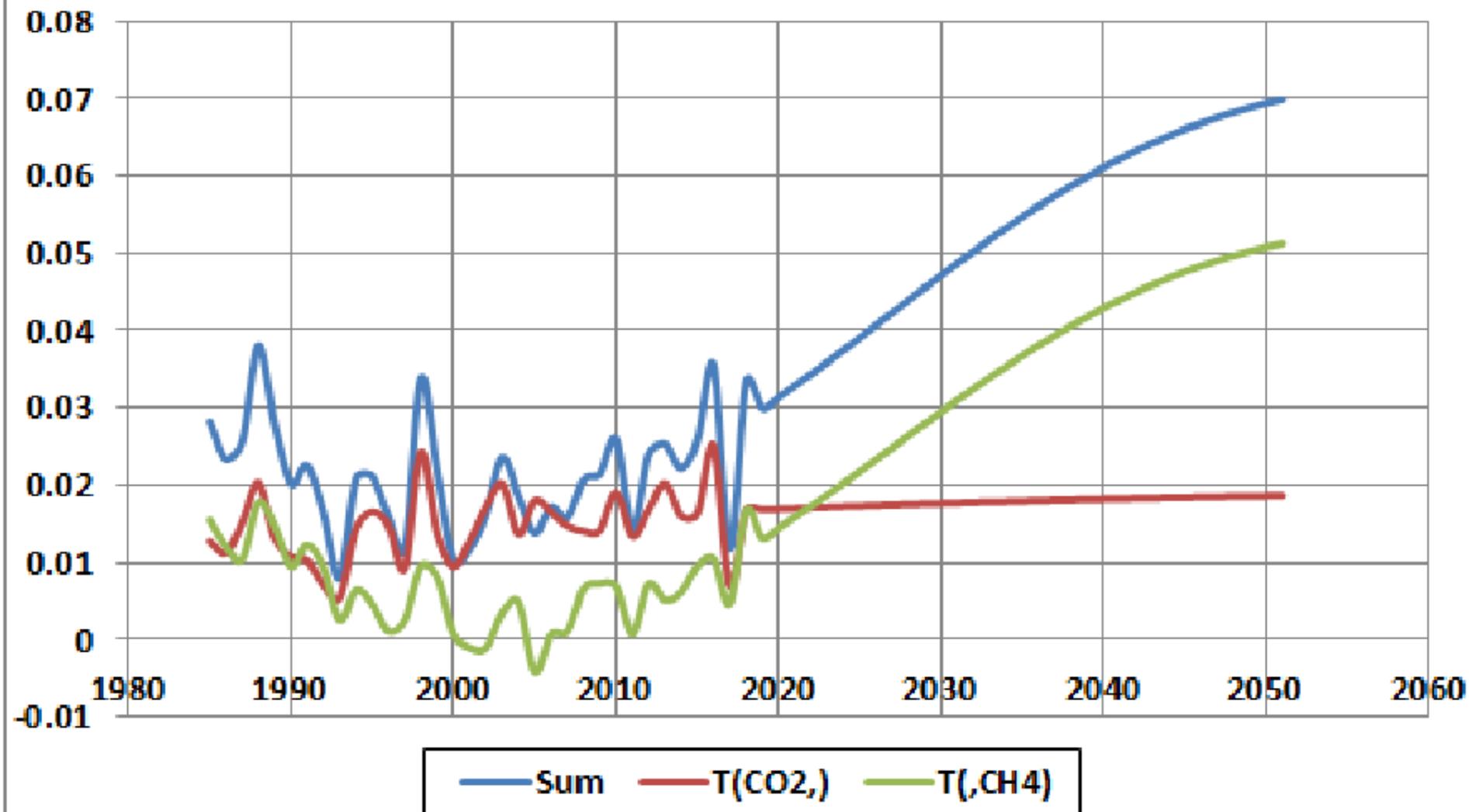
**Climate sensitivity** is the amount the global temperature changes when the concentration of a gas in the atmosphere doubles.

**More about this later.**

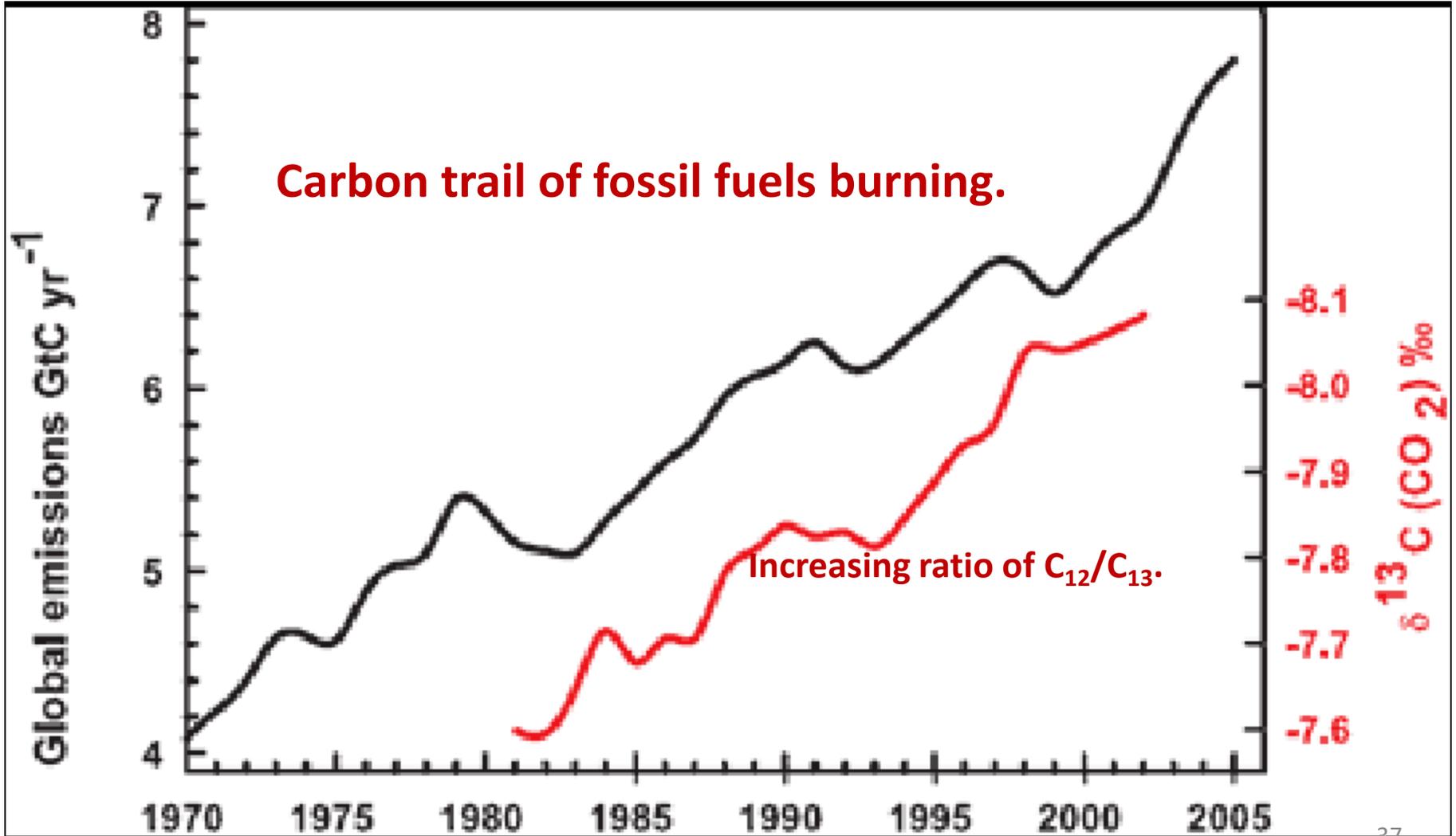
# Temperature (°C)



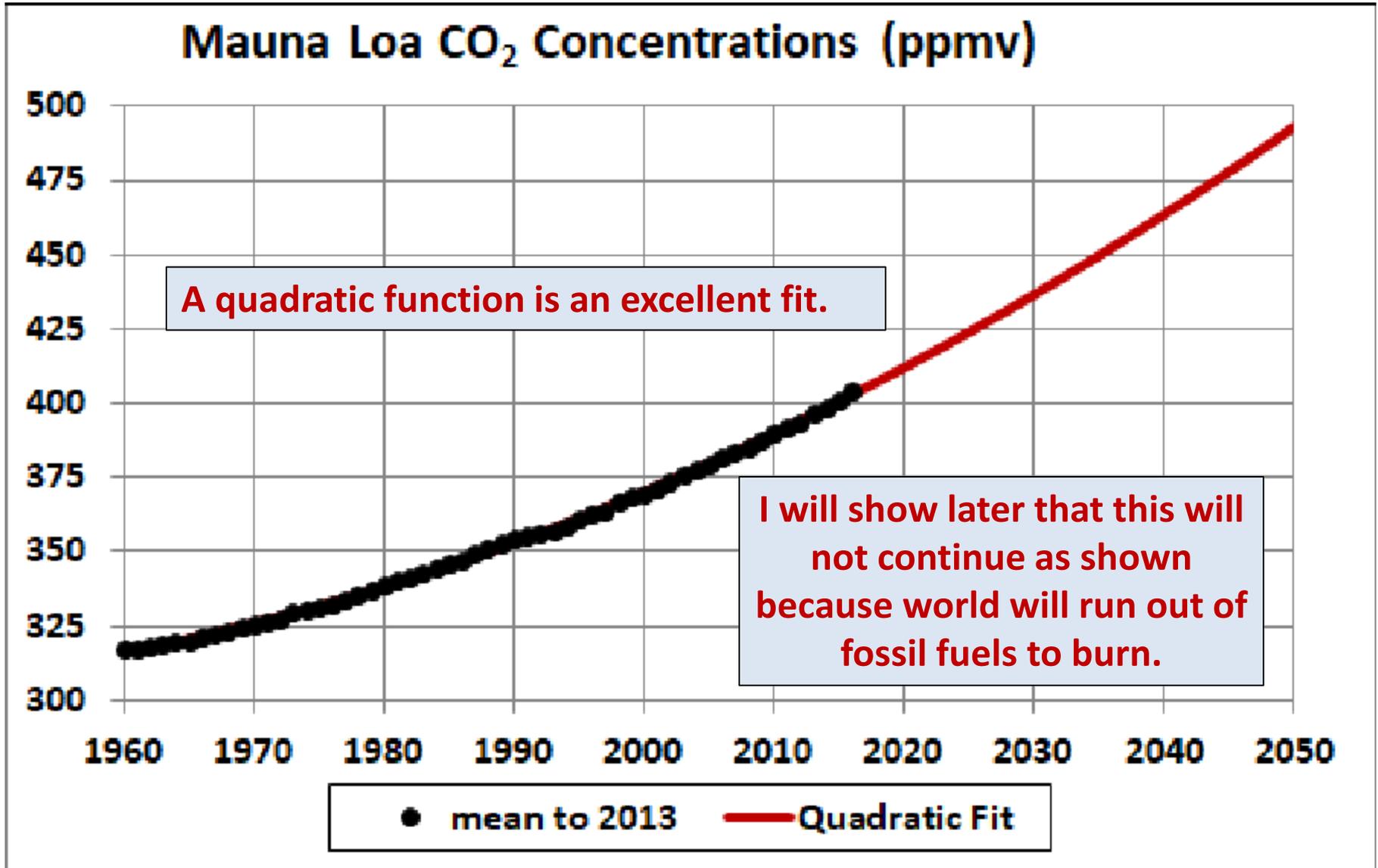
## Incremental Yearly Temperature Change Due to CO<sub>2</sub> & CH<sub>4</sub>



- Fossil fuels come from long-buried plants, which have mostly carbon 12.
- Before industrial revolution atmosphere had more carbon 13.
- Carbon 13 in atmosphere has been decreasing because of burning fossil fuels!



# CO<sub>2</sub> Concentration Projection



It's a complicated relationship, but the most important part of it is this: When there is a rise in CO<sub>2</sub>, the temperature rises more than it would otherwise.

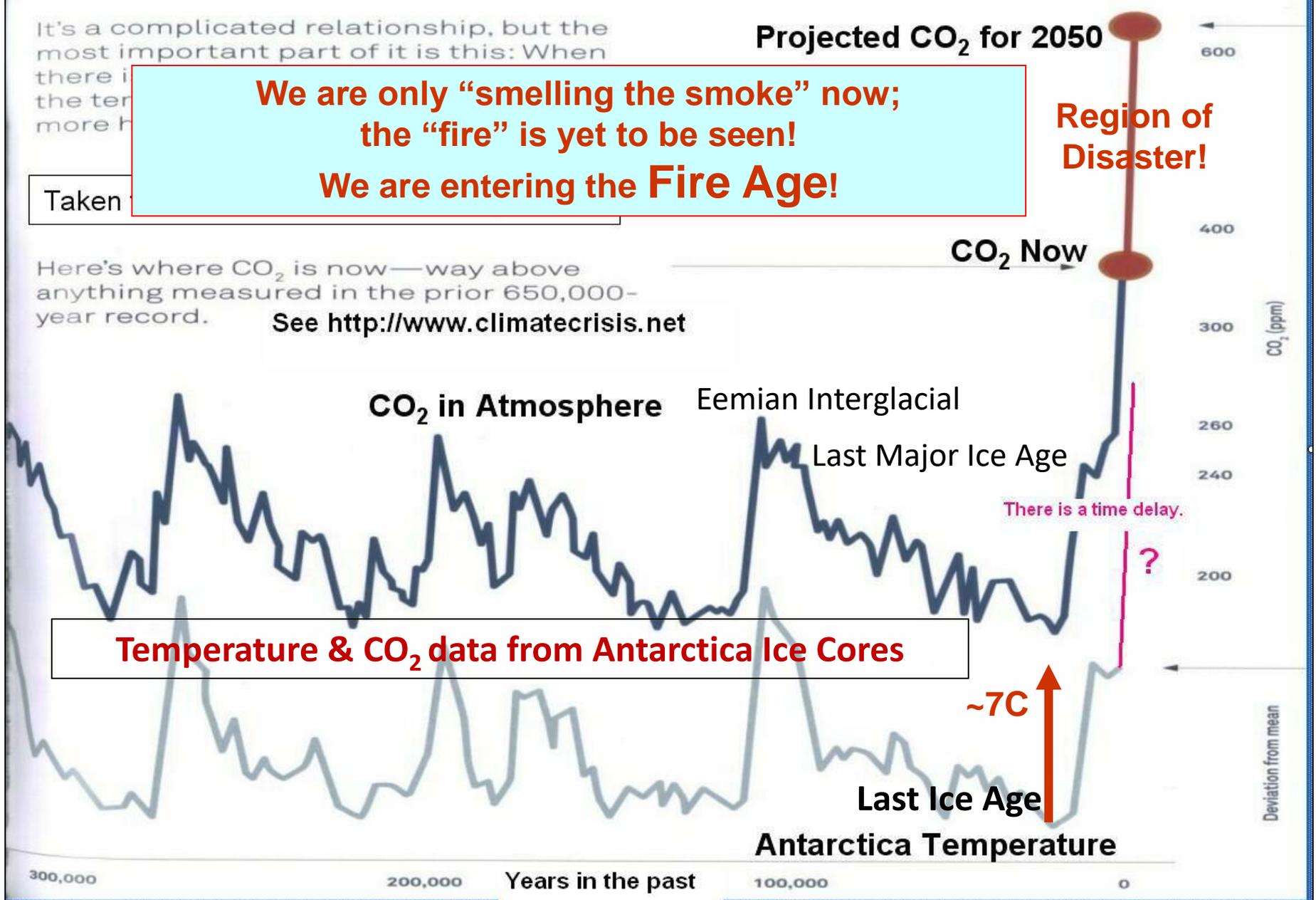
Projected CO<sub>2</sub> for 2050

**We are only "smelling the smoke" now;  
the "fire" is yet to be seen!  
We are entering the Fire Age!**

**Region of Disaster!**

Taken

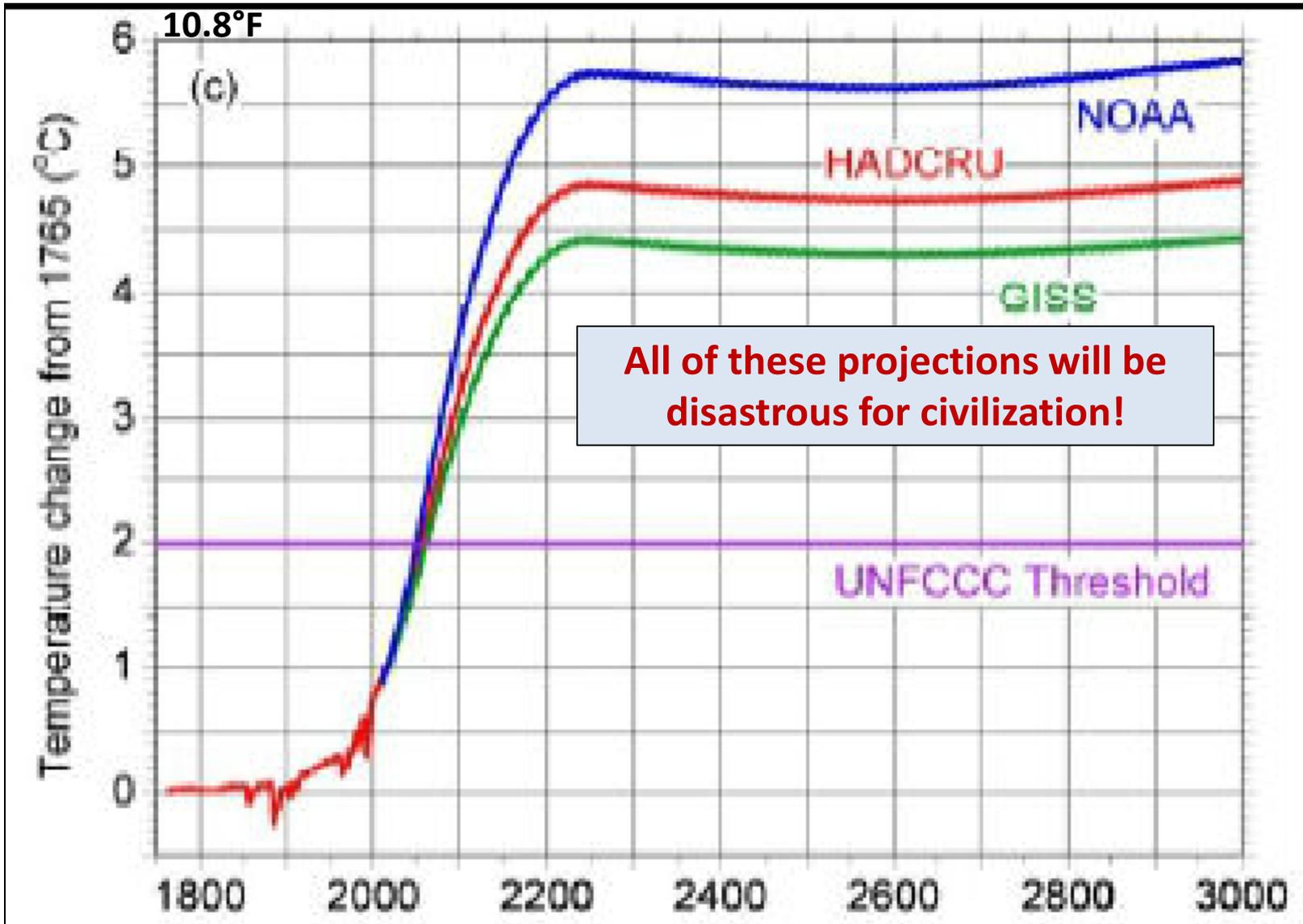
Here's where CO<sub>2</sub> is now—way above anything measured in the prior 650,000-year record. See <http://www.climatecrisis.net>



**Temperature & CO<sub>2</sub> data from Antarctica Ice Cores**

**Temperature & CO<sub>2</sub> are mutually reinforcing (positive feedback).**

# Global Temperature Rise since 1765 for three models.



From: Schlesinger et al. (2012) DOI: 10.4236/jep.2012.36055

# Global Warming is a Mathematical Problem

- **Climate Sensitivity Equation** (How much does temperature rise due to doubling CO<sub>2</sub> in atmosphere.)
- Amount of carbon-dioxide in atmosphere
- Residing time of carbon-dioxide in atmosphere
- Positive mutual feedback between carbon-dioxide in atmosphere & average earth temperature
- Positive mutual feedback between moisture in atmosphere & average earth temperature
- Positive mutual feedback between sea-ice melting & average Earth temperature
- **Positive mutual feedback between methane release from Arctic tundra and continental shelves & average earth temperature**
- Positive and negative feedbacks between clouds due to increased evaporation & average earth temperature
- Negative feedback between dust/aerosols in atmosphere due to droughts and winds & average earth temperature

Occasional large volcano eruptions can lower earth temperature for a few years.  
Collision of a large asteroid or comet with the earth can lower temperature.

# Climate Sensitivity Equation

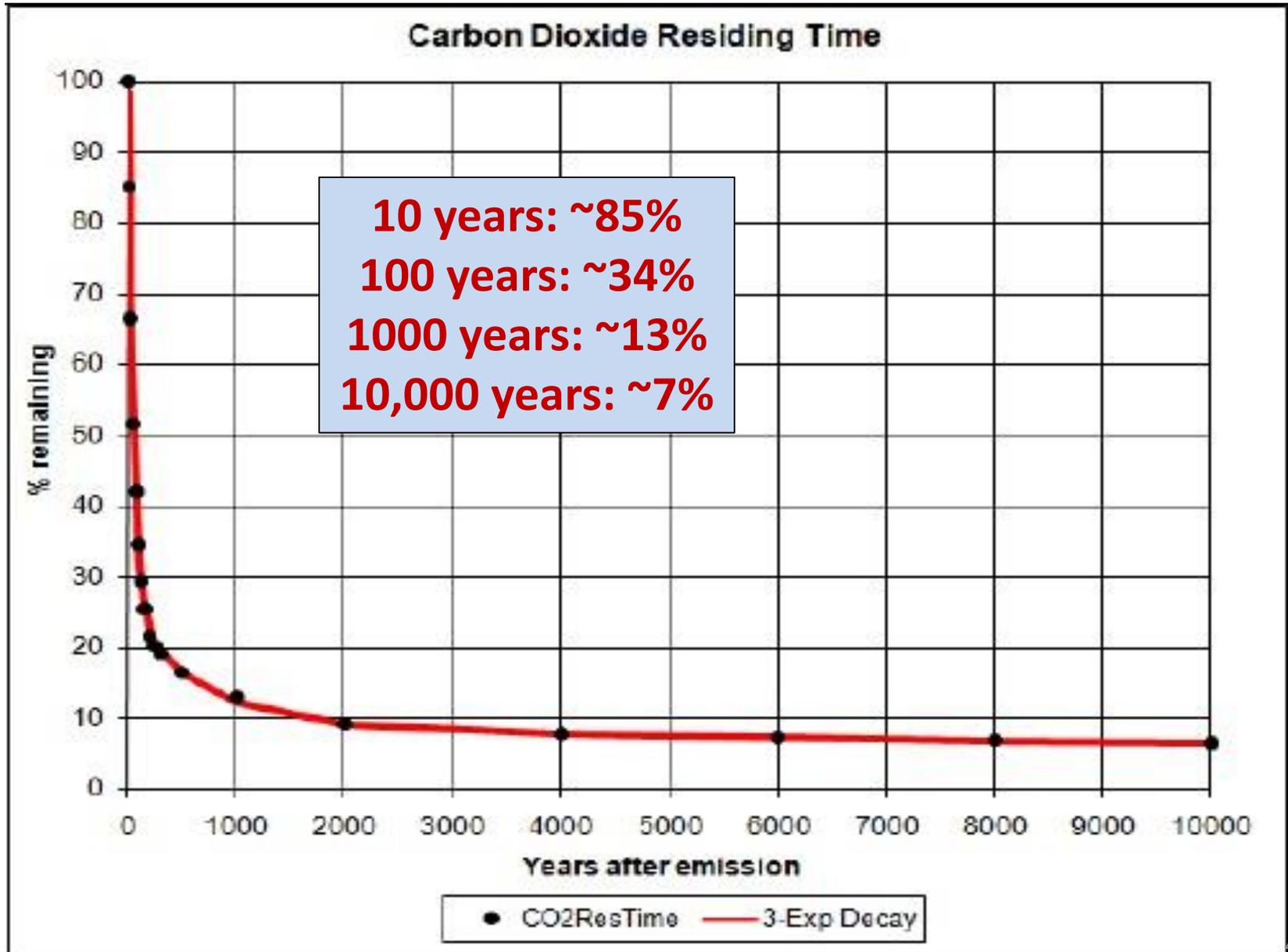
$$\boxed{dT = S \ln(C_f/C_i)/\ln(2)}$$
 where

- $dT$  = average Earth temperature change due to emitting  $\text{CO}_2$  into the atmosphere.
- $S$  = climate sensitivity = temperature when  $\text{CO}_2$  doubles
- $C_f$  = final  $\text{CO}_2$  concentration
- $C_i$  = initial  $\text{CO}_2$  concentration
- First stated by Svante Arrhenius in **1896!**
- $S = 3^\circ\text{C}$  (**5.4 °F**) for short-term positive feedbacks, determined by studying recent global warming. (**Recent study indicates  $S = 4^\circ\text{C}$ .**)
- $S = 6^\circ\text{C}$  (**10.8 °F**) for long-term positive feedbacks, determined by studying ice cores back  $\sim 500,000$  years.

# CO<sub>2</sub> concentration History & Future

- ~**285 ppmv** in year 1700.
- **410 ppmv** in year 2017: increase ratio ~1.43.
- $dT = \sim 1.5^{\circ}\text{C}$  ( $\sim 2.7^{\circ}\text{F}$ ) to  $\sim 2.9^{\circ}\text{C}$  ( $\sim 5.2^{\circ}\text{F}$ ) = eventual temperature beyond year 1700 **if CO<sub>2</sub> remained at 400 ppmv & no other GHGs & no triggered feedbacks.**
- **Add other GHGs:**  $dT = \sim 2.5^{\circ}\text{C}$  ( $\sim 4.5^{\circ}\text{F}$ ) to  $\sim 4^{\circ}\text{C}$  ( $\sim 7.2^{\circ}\text{F}$ ) since year 1700.
- **Future increases in GHGs** could cause  $dT = \sim 6^{\circ}\text{C}$  ( $\sim 10.8^{\circ}\text{F}$ ) since year 1700 due to triggered large feedbacks.
- **Time delay of ~1500 years**, so stopping emitting GHGs into atmosphere now will not stop Global Warming for a long time.

# CO<sub>2</sub> Stays in Atmosphere for a Long Time!



# Changes to Global Warming (GW) besides GHGs

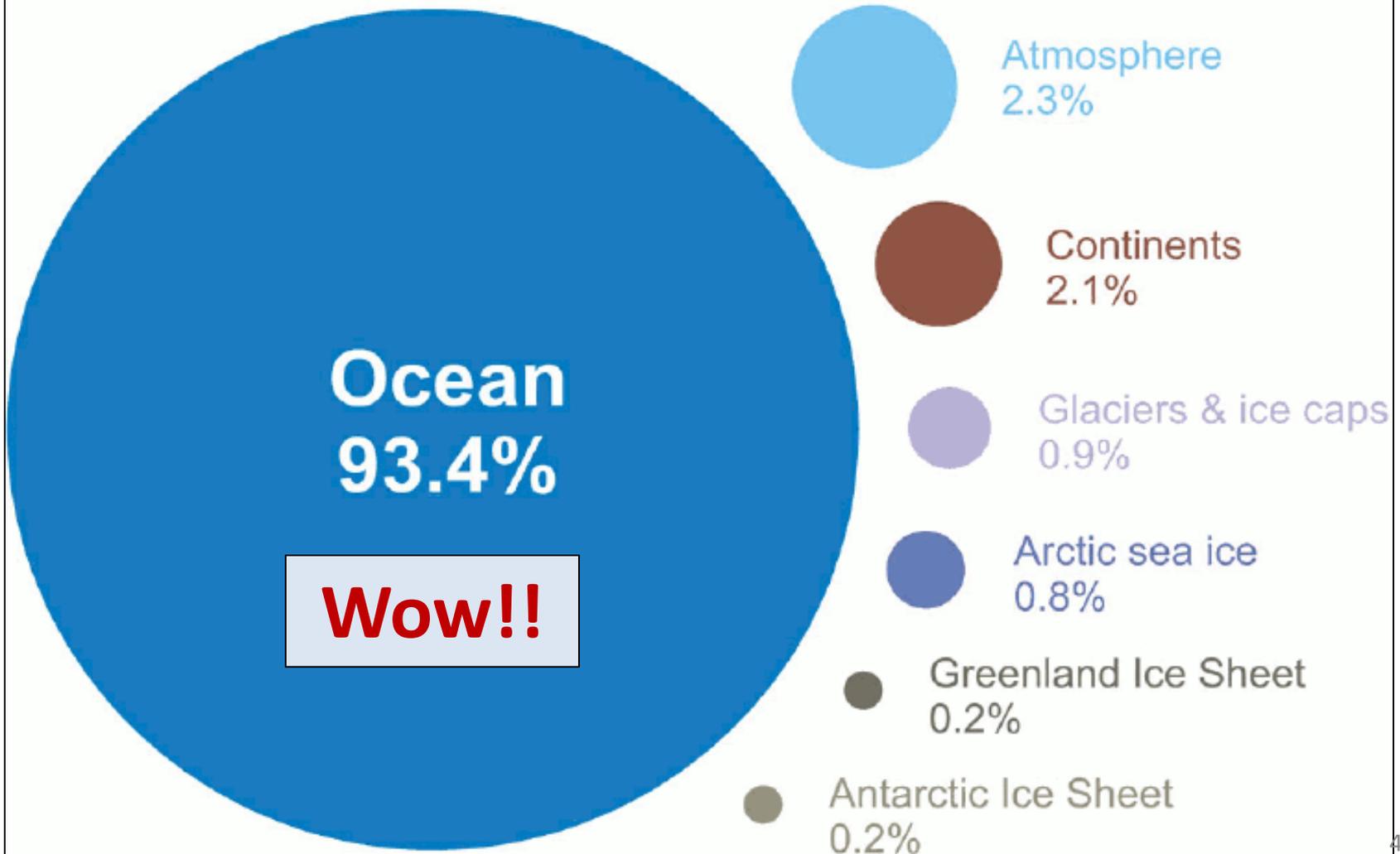
- **Deforestation** cancels the trees absorbing CO<sub>2</sub>.
- **Aerosols and particulates** in the atmosphere reduce GW. (Geoengineering is proposed to put aerosols into the atmosphere. They are detrimental to human health and reside only a few years in atmosphere.)
- **Geoengineering** proposals to reduce the sunlight striking the Earth (unintended side effects?) See ***Hack the Planet*** book.
- High temperature **melting Arctic sea** ice reveals dark water to absorb much more solar energy than does ice, causing increased GW.
- High temperature causes **release of methane from Arctic permafrost and continental shelves (triggered feedback)**.

# Climate Models

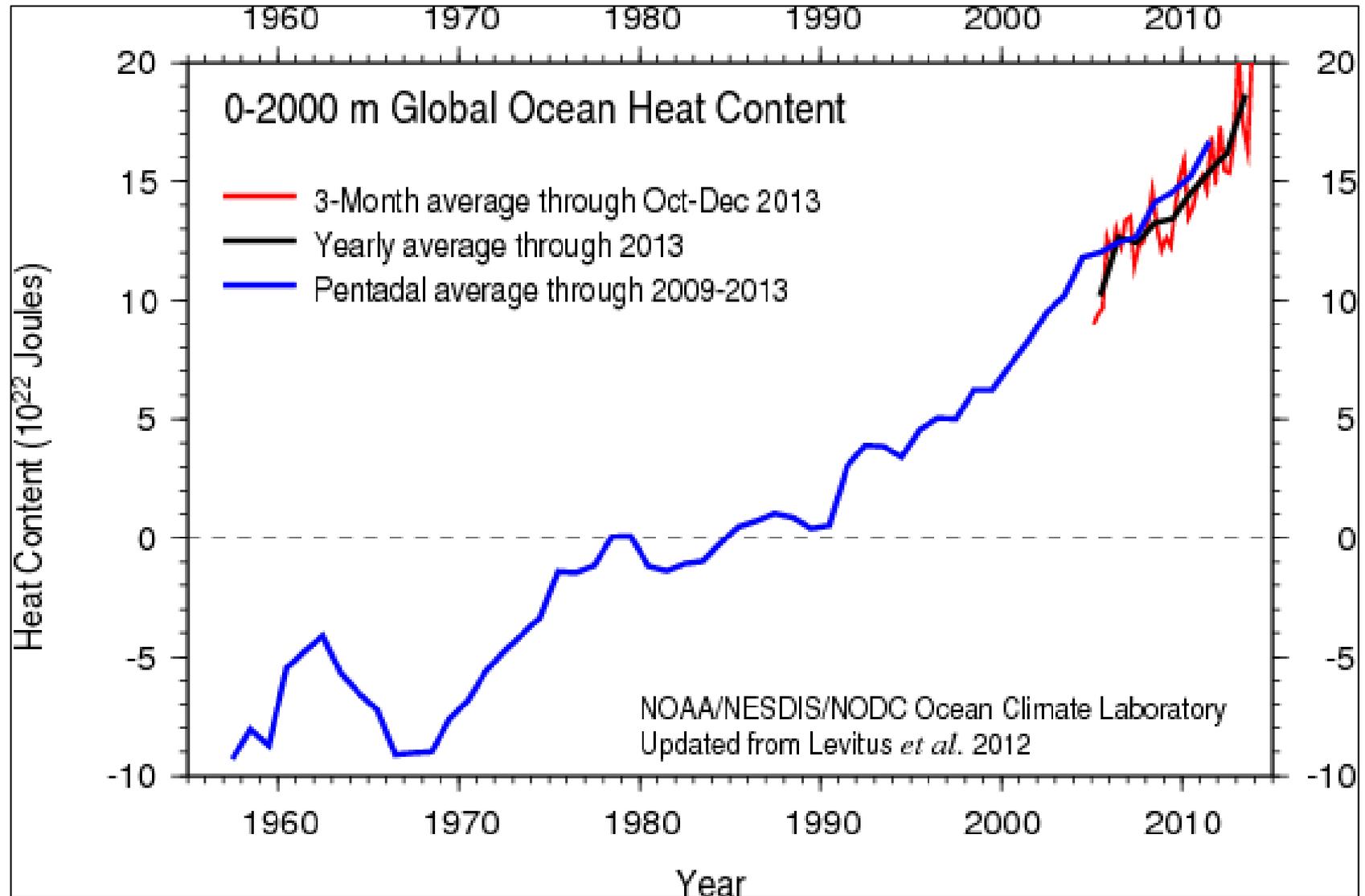
- Atmosphere of Earth divided into a large 3-dimensional grid to a particular height
- Surface of Earth divided into a large 2-dimensional grid
- Oceans of Earth divided into a large 3-dimensional grid to a particular depth
- Incoming solar energy at all wavelengths
- Outgoing energy from the Earth
- GHGs in atmosphere
- Intake of GHGs into the oceans
- Heat and mass transfer between the grid elements
- Instruments, including satellites, measuring climate variables
- Large supercomputers doing the climate calculations
- There are several major models that give similar results. An average of ~15 models' predictions is used.
- **Copious Earth data show larger current global warming effects than the models calculate. So, yes, the models are “wrong”, but in a bad direction!**

Ocean heat will transfer heat to atmosphere slowly over time after carbon emissions are stopped.

## Where Global Warming is Going



# Ocean Heat Content Increase

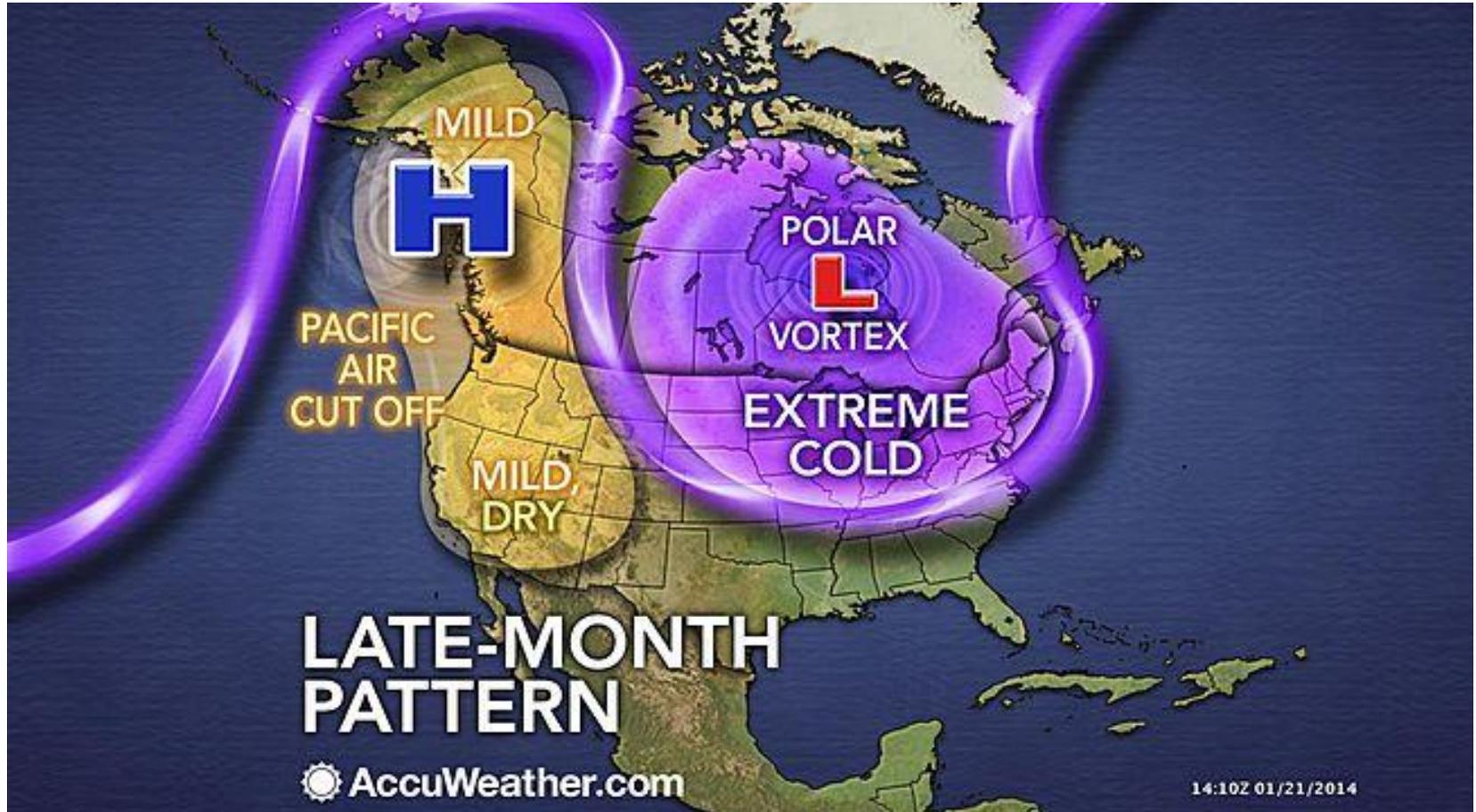


Oceans are heating faster than the atmosphere.

# Extreme Storms

- **Polar vortex**: fast counterclockwise winds around the Arctic
- Arctic warming more than temperate areas, such as US, reduces the temperature differential, which weakens the **Polar Vortex**.
- **Weakened Polar Vortex** causes undulations in the Jet Stream, **pulling warm air from western US into Arctic and cold air from the Arctic into eastern US**.
- Collision of Arctic cold air with south Pacific, south Atlantic and Gulf of Mexico warm moist air causes **extreme storms** with high precipitation in eastern United States, which deprives western United States of precipitation, causing extreme droughts and subsequent **forest fires**.
- U.S. storm damage cost was **2.5 times** more for 2011-2015 compared to 1980-2010.

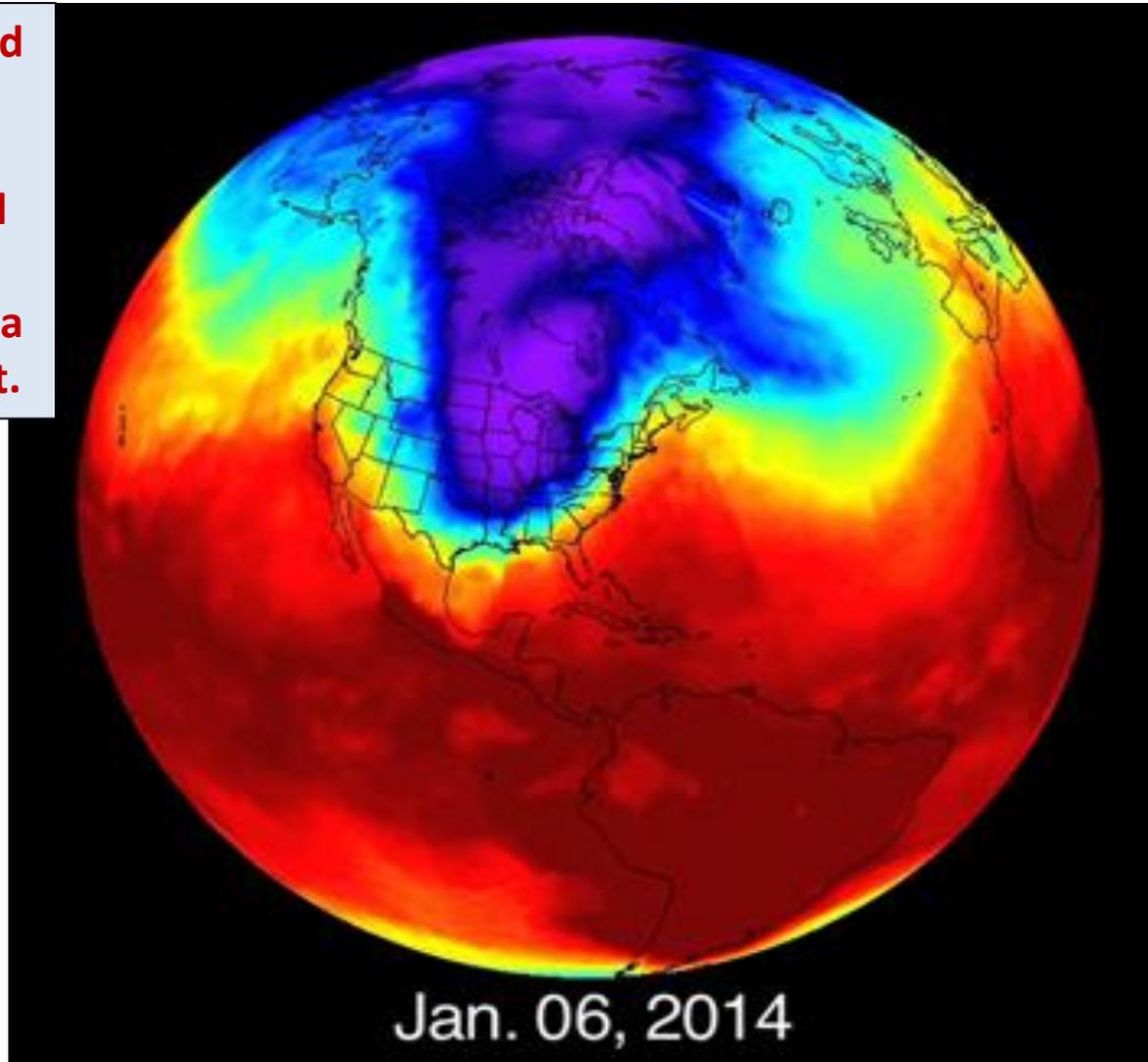
# Jet Stream late January 2014



Heating in the Arctic weakens the Polar Vortex that circulates counterclockwise around the polar region, causing it to deform and push warm air into the Arctic and cold air into eastern North America.

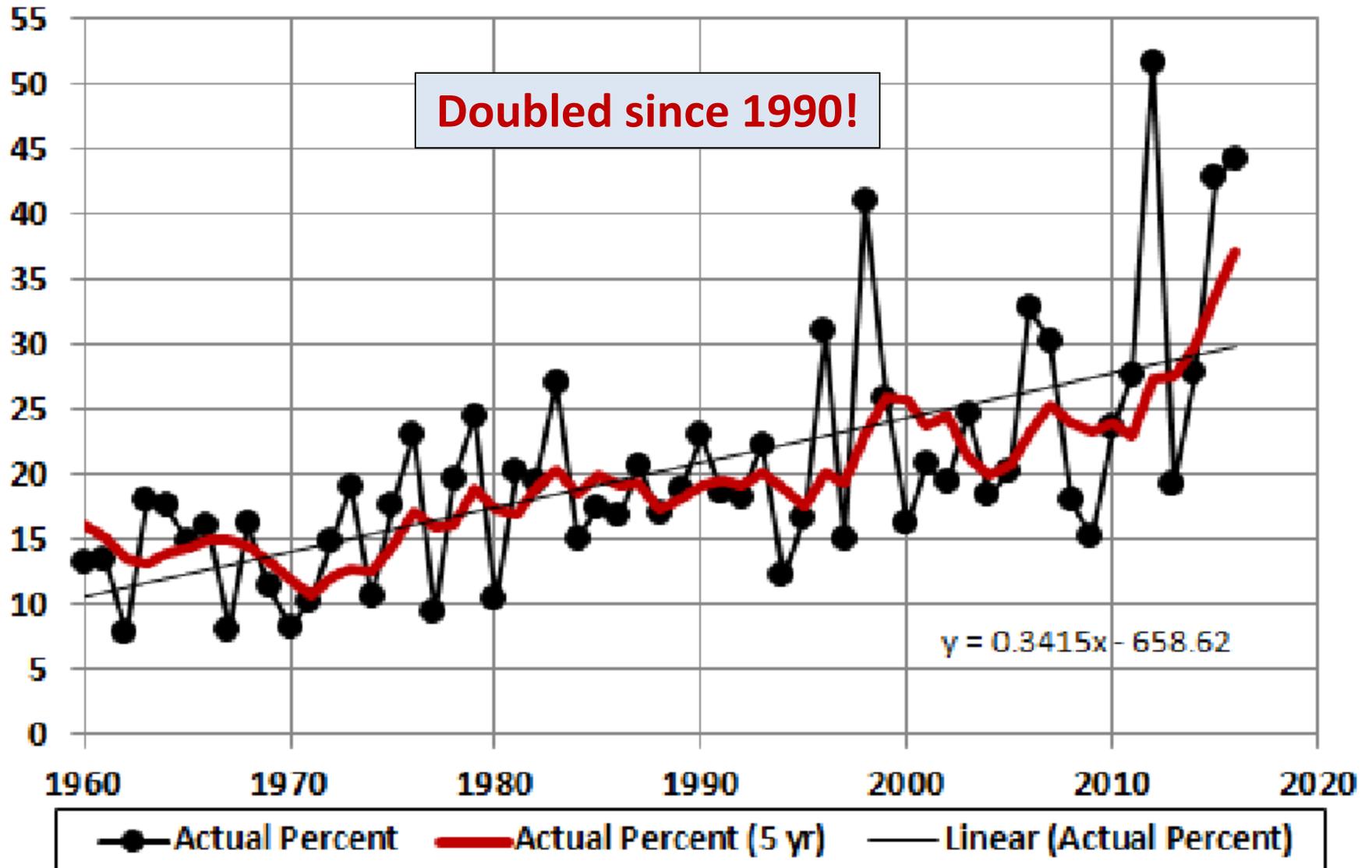
# Earth Temperatures 6 January 2014

**Severe winter cold spells in eastern U.S. do NOT invalidate Global Warming! In fact, many are a consequence of it.**



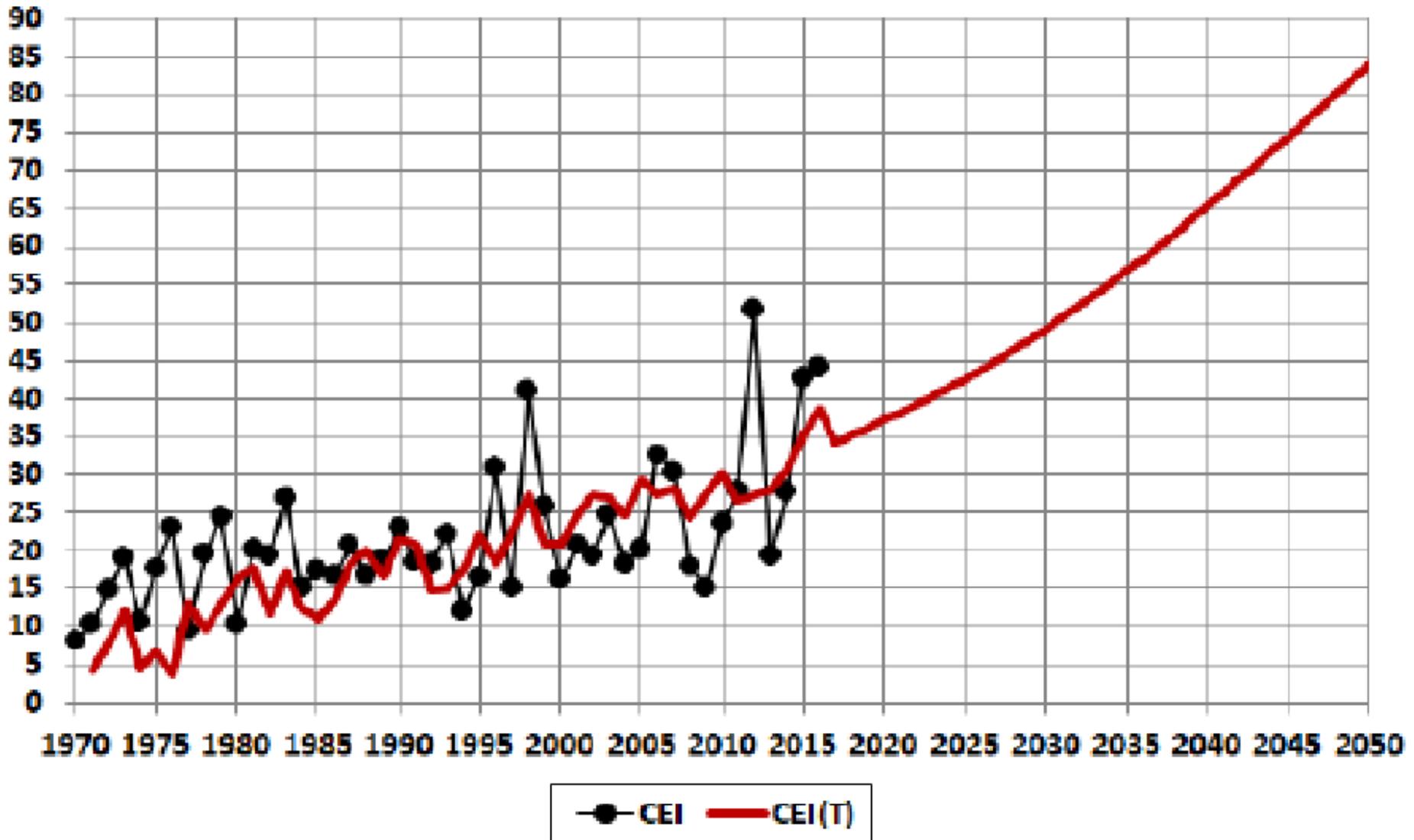
Western Hemisphere Northern View

# US Climate Extremes Index

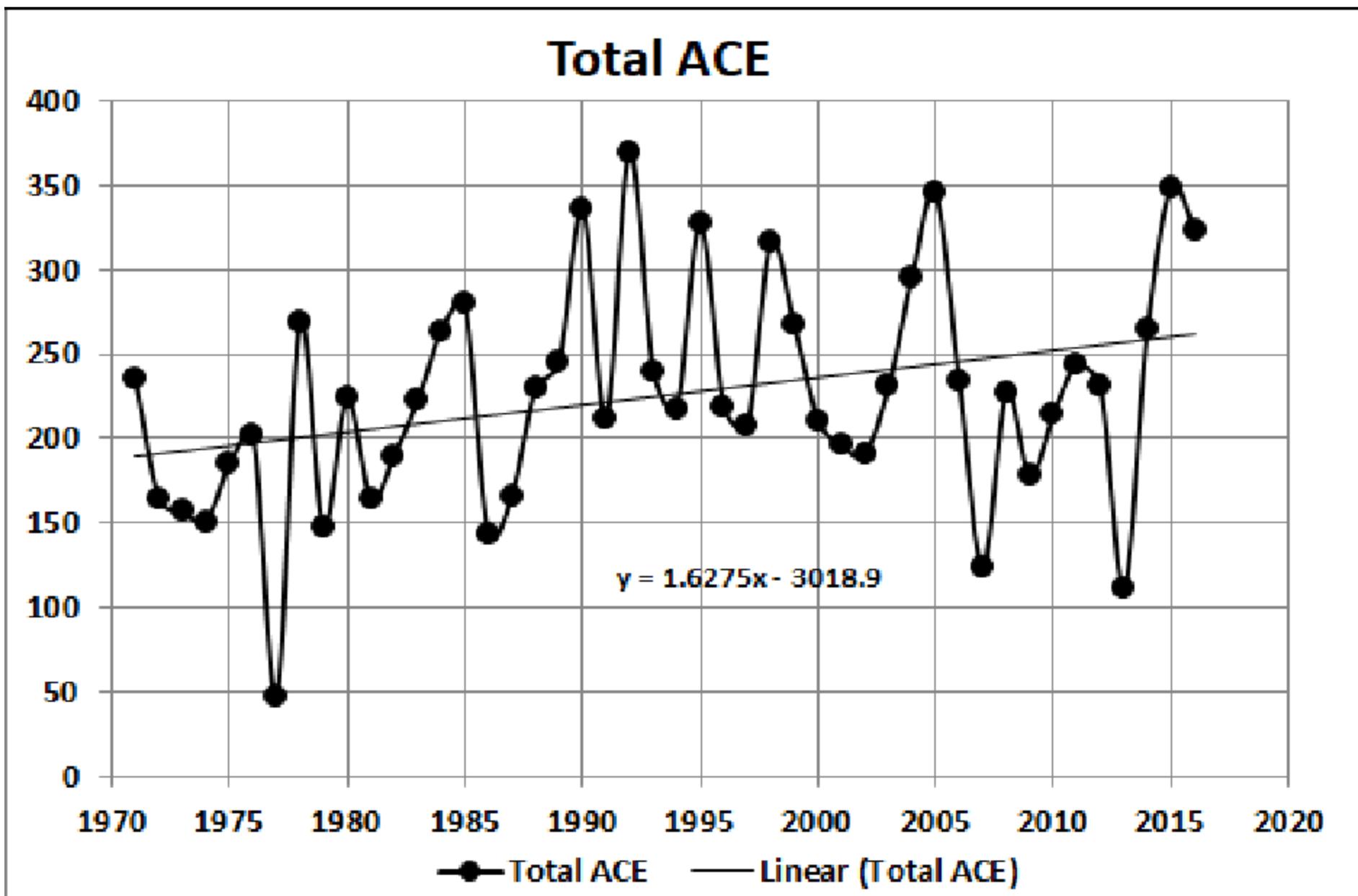


# U.S. Climate Extremes Index Projected

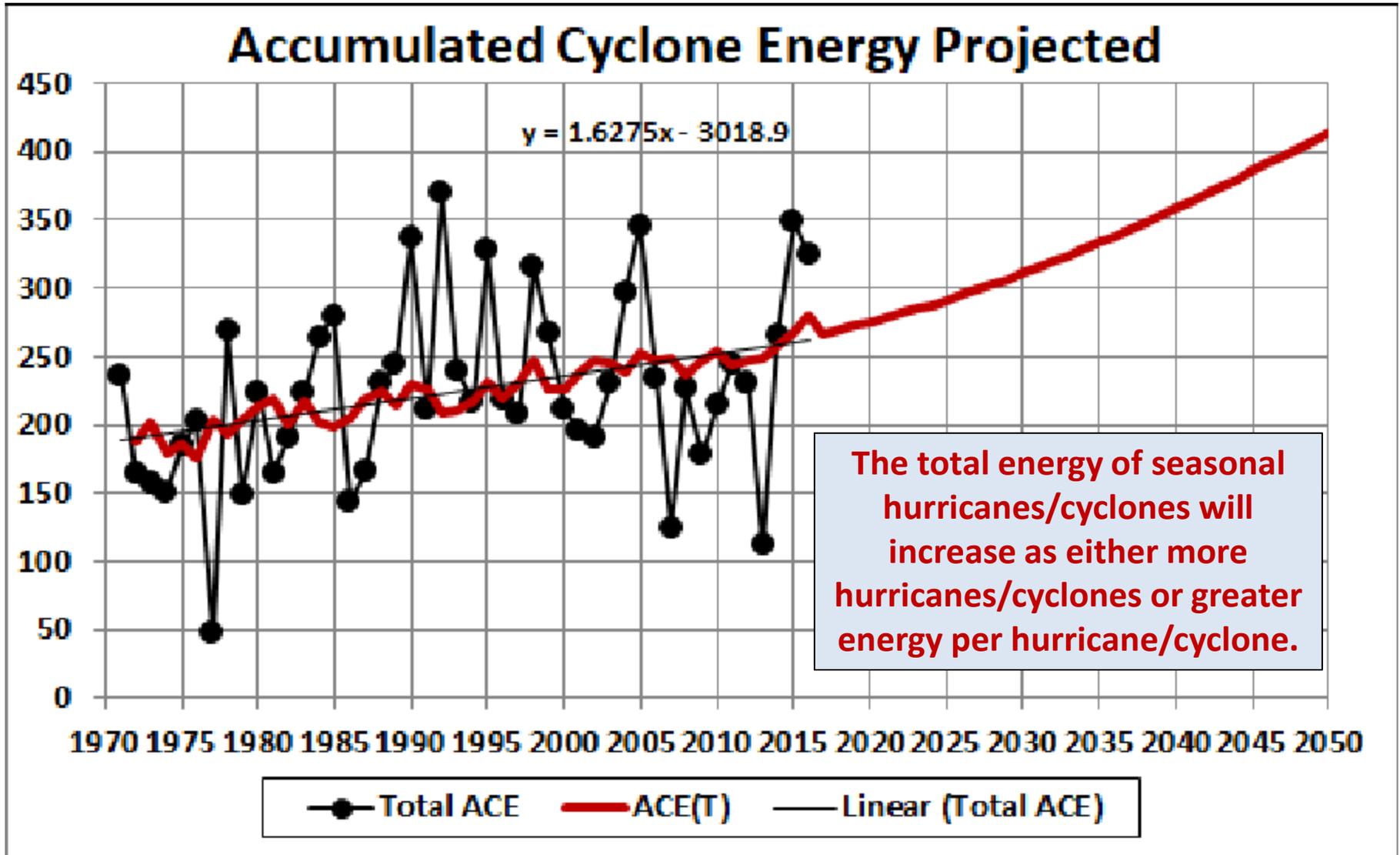
## US Climate Extremes Index



# Hurricanes/Cyclones Yearly Accumulated Energy

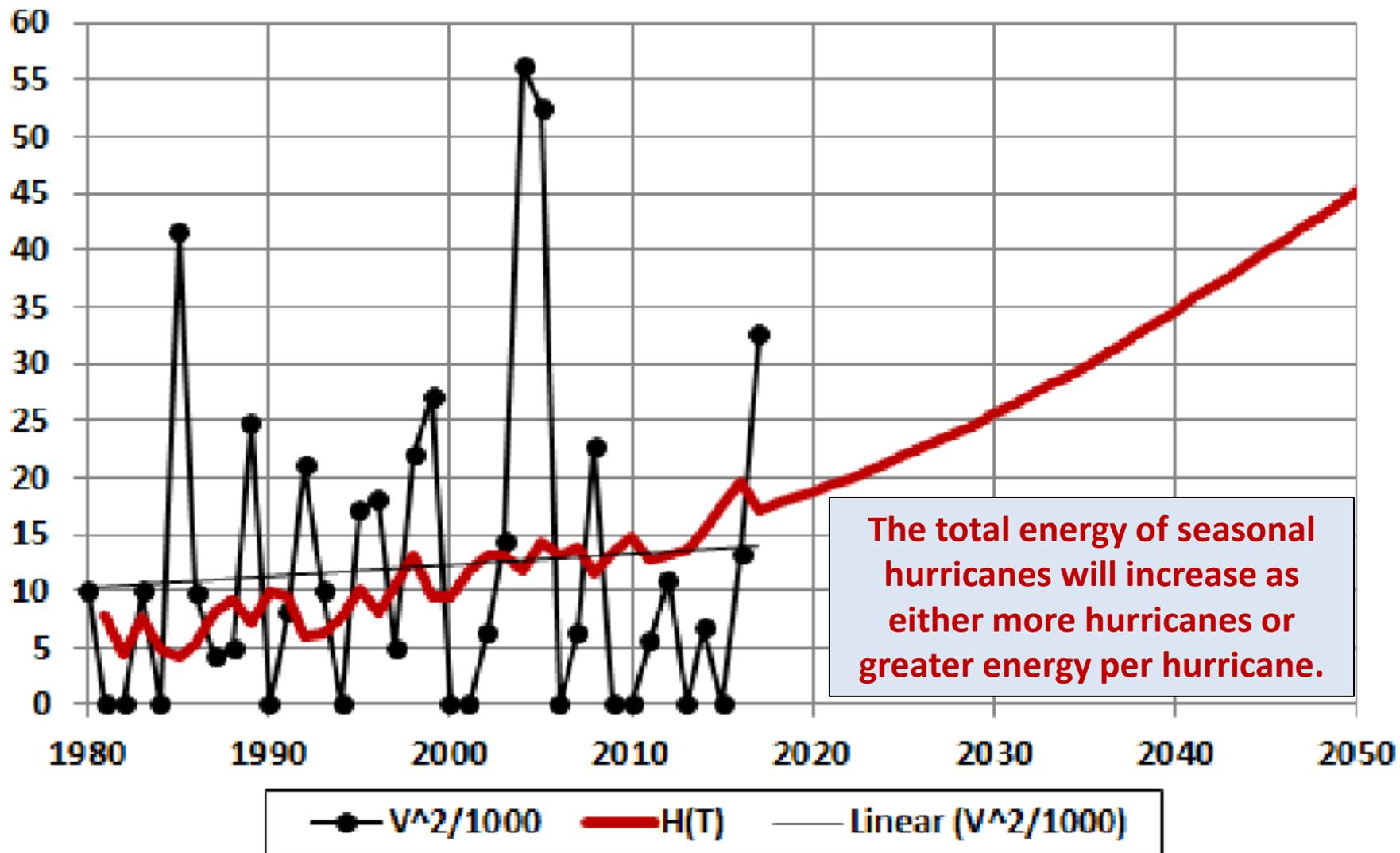


# Hurricanes/Cyclones Yearly Accumulated Energy

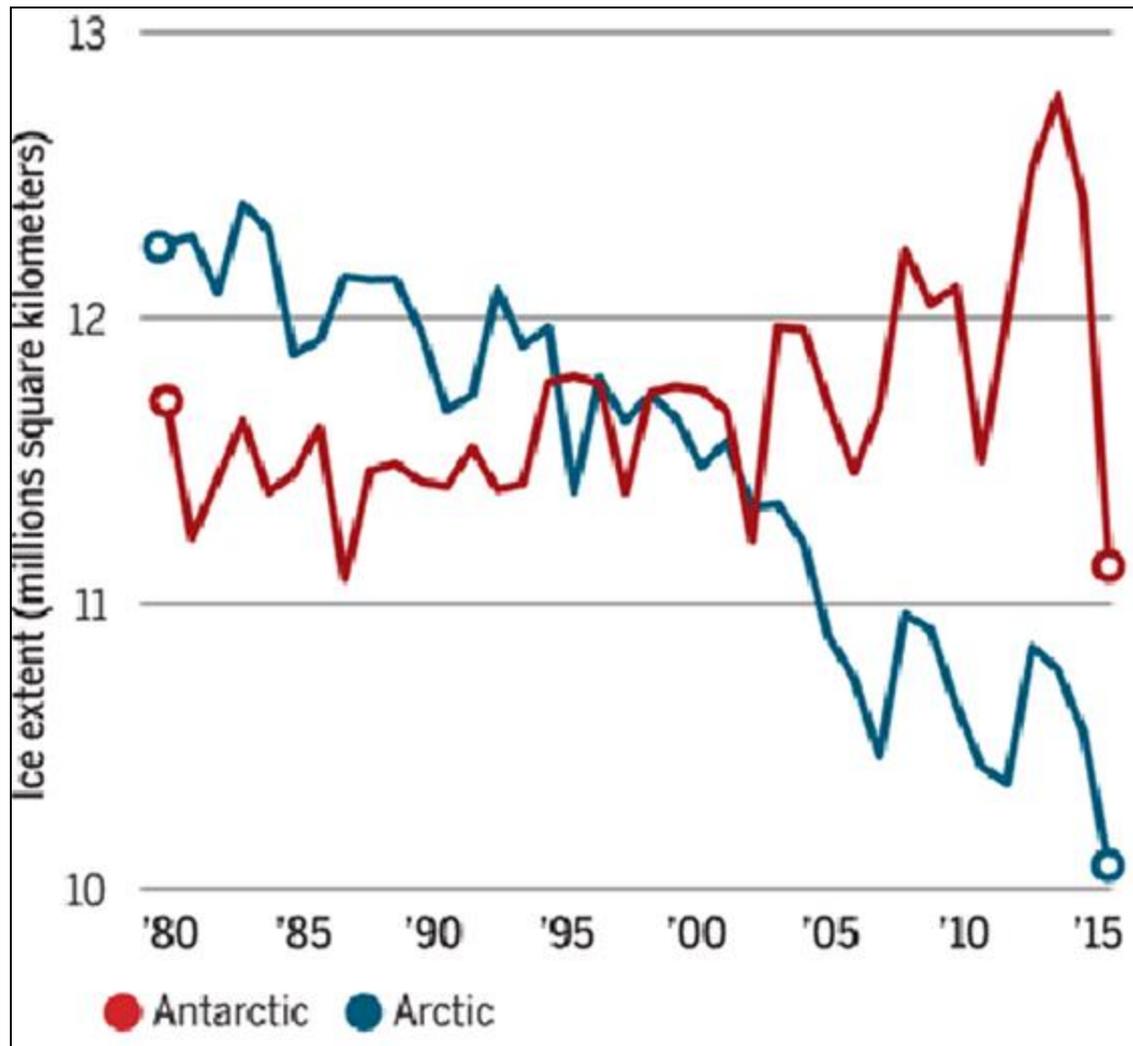


# U.S. Hurricanes Yearly Accumulated "Energy"

## $V^2/1000$ for U.S. Hurricanes



# Arctic and Antarctic Sea Ice



The large recent oscillations, especially in Antarctica, is a sign of rapid systemic changes.

Three large Antarctic ice shelves collapsed into the ocean by 2017.

"The Arctic will be reliably free of sea ice in the summer by the middle of the century."  
Melting sea ice does not raise sea level, but heating ocean water does.

# Exploiting the Arctic Sea



# Exploiting the Arctic Sea

- UN is assessing Russian, Danish and Canadian claims to own large portions of the Arctic seabed.
- China is investing in mines in Greenland.
- Petroleum companies are looking for Arctic seabed reserves of natural gas and oil.
- Large companies plan to expand fishing into the Arctic.
- Countries will probably want to dump wastes into the Arctic Sea.

# DECLINING ICE MASS IN GREENLAND

RATE OF CHANGE  
↓ 287.0  
Gigatonnes per year  
margin: ±21



**At this rate it will all melt before 2150.  
Melting all Greenland ice would raise sea level by ~6 meters (~20 feet).**

NOAA climate.gov, adapted from Arctic Report Card Update for 2016

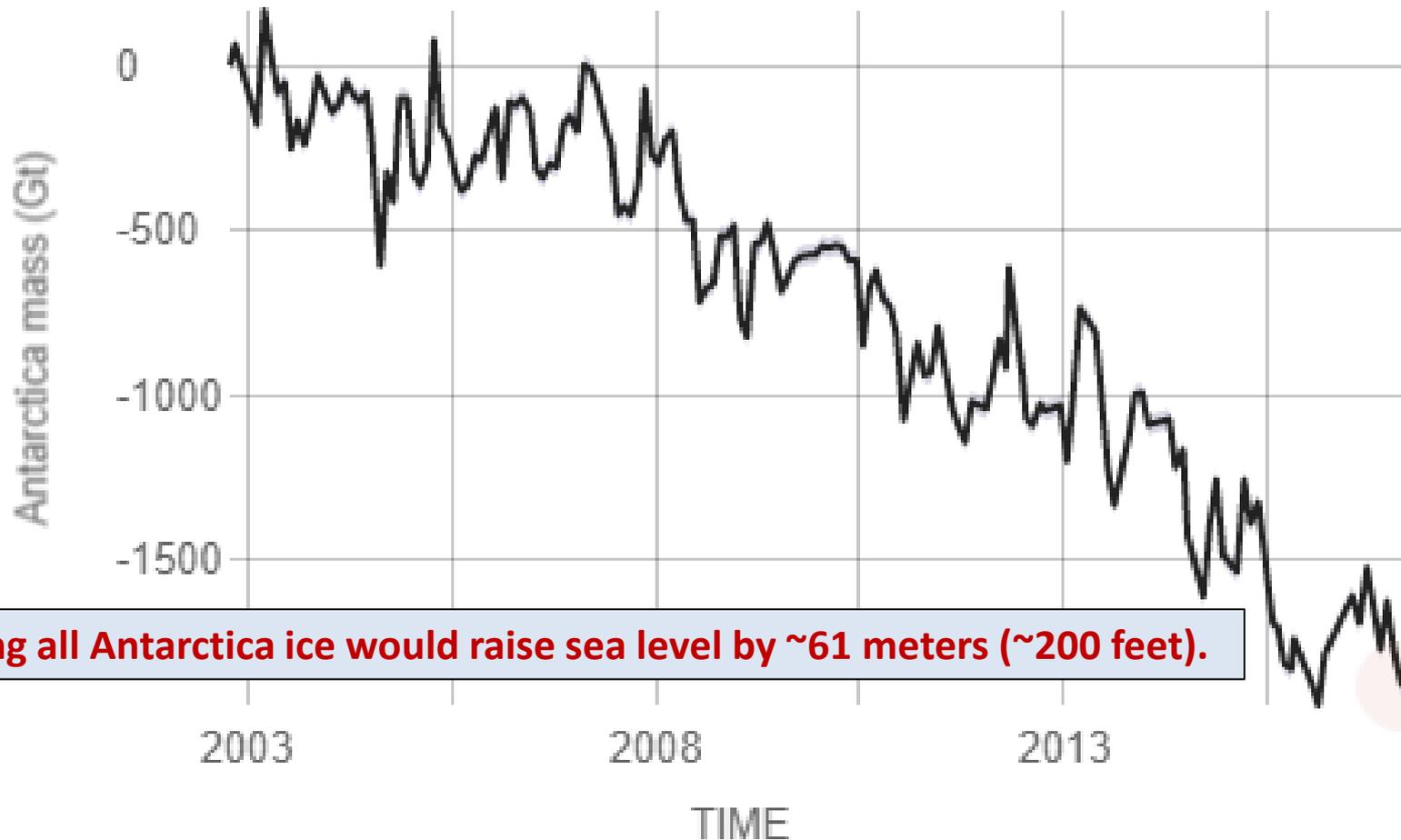
# ANTARCTICA MASS VARIATION SINCE 2002

RATE OF CHANGE

↓ 125.0

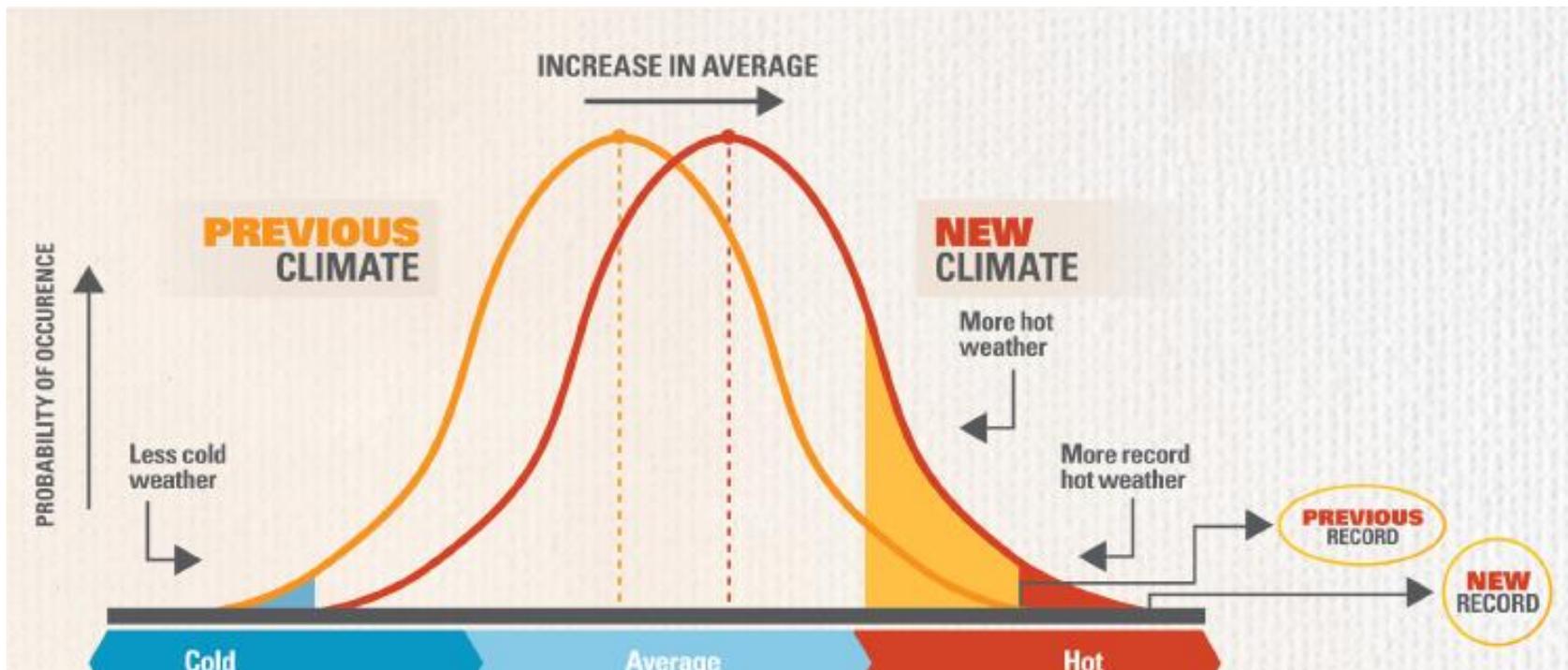
Data source: Ice mass measurement by NASA's GRACE satellites.  
Credit: NASA

Gigatonnes per year  
margin: ±39



**Melting all Antarctica ice would raise sea level by ~61 meters (~200 feet).**

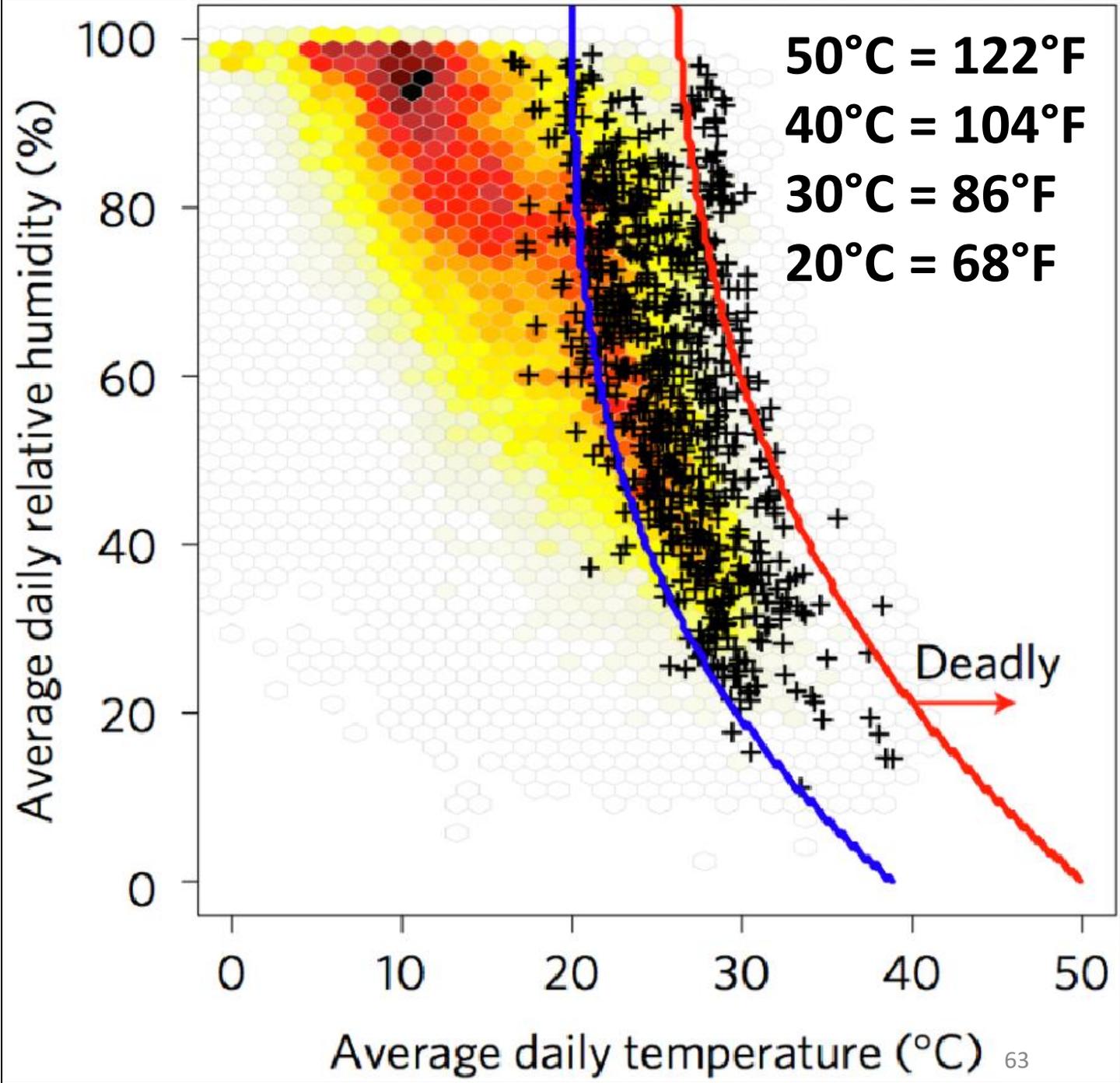
# Extreme Heat



**There will still be cold weather, but not as much as before.**

**Global Heat-related deaths by temperature and humidity:**

- **Black**=lethal
- **Red to Yellow**= non-lethal of equal duration
- **Blue line**= lethal threshold
- **Red line**= non-lethal cutoff

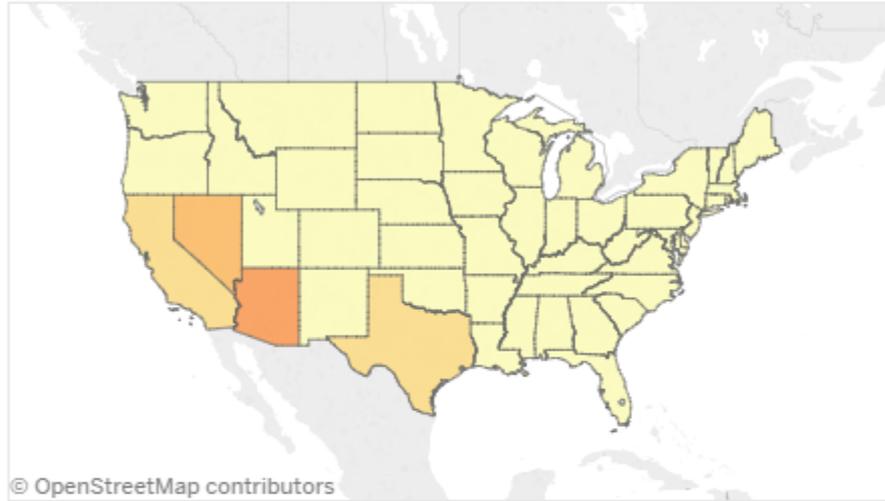


The number of days above 95 °F (35 °C) will rise dramatically in many parts of the United States if climate change continues unabated

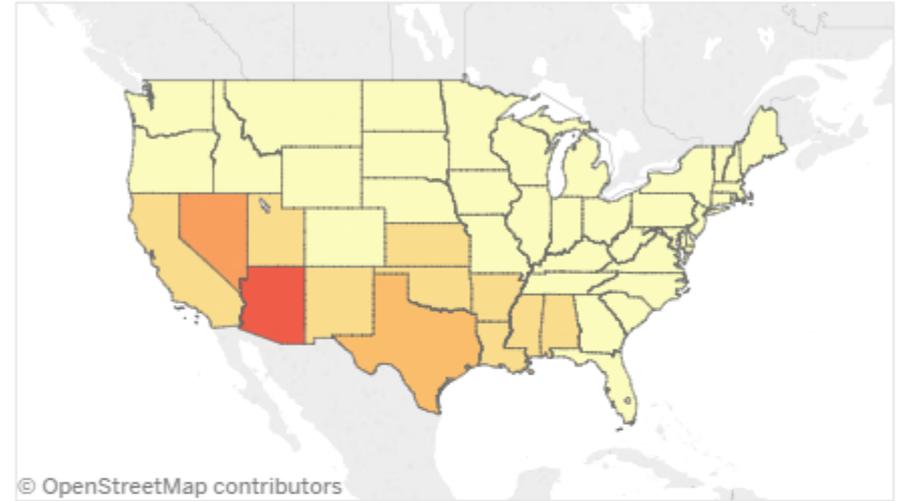
**AZ: 179; TX: 135; NV: 127**  
**FL: 108; CA: 72; VA: 60**  
**CO: 59; NY: 30; MI: 27**  
**MA: 26; WA: 22; ME: 15**

**Yellow->red colors 30 to 180 days/year**

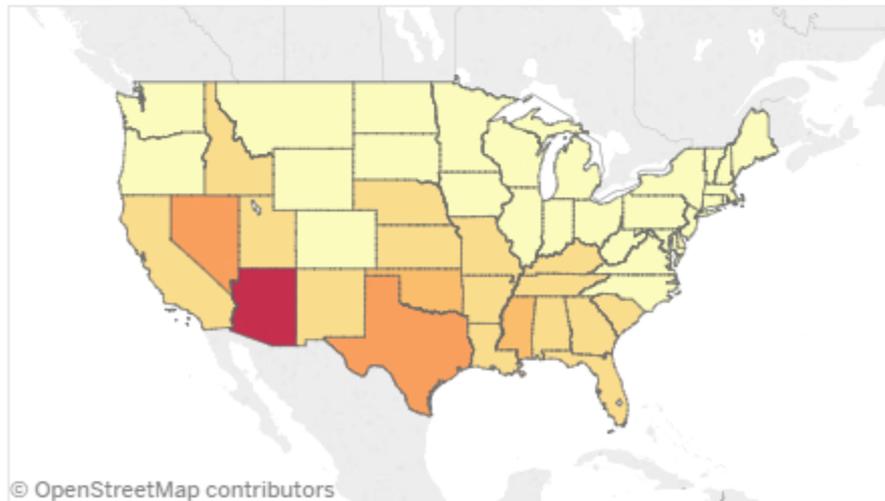
1981-2010



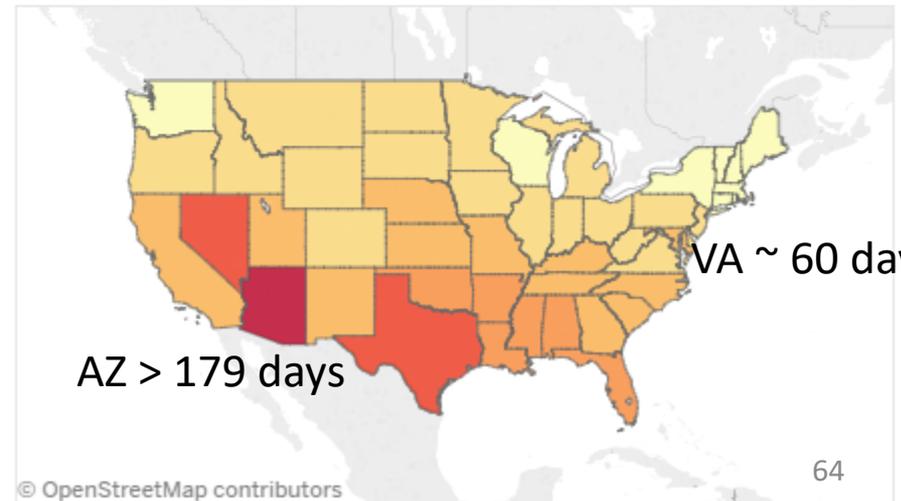
2020-2039



2040-2059



2080-2099 Most of U.S. > 60 days

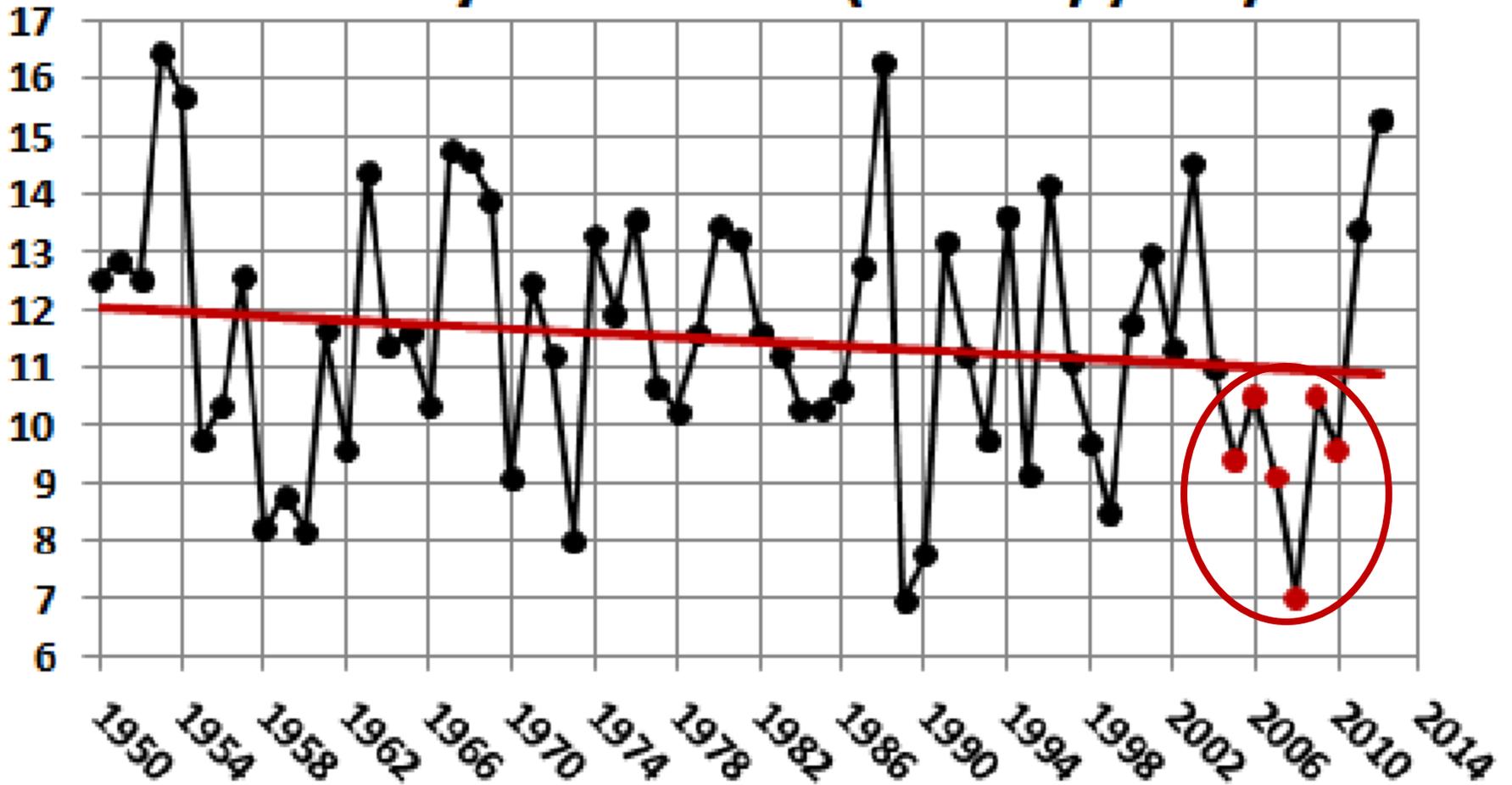


# Droughts and Floods

- **Higher temperatures evaporate more moisture into the atmosphere.**
- **Westerly winds (from the west) move the moisture from western U.S. to eastern U.S.**
- **The dry west gets dryer and the wet east gets wetter.**
- **Forest fires become more prevalent in the west because of lack of moisture.**
- **The rare large rains in the west cause floods because the trees and vegetation have burned to ashes.**
- **The increased rapid rainfall in the east causes more floods.**

2005-2010 Drought in Syria was a major factor in the rebellion.

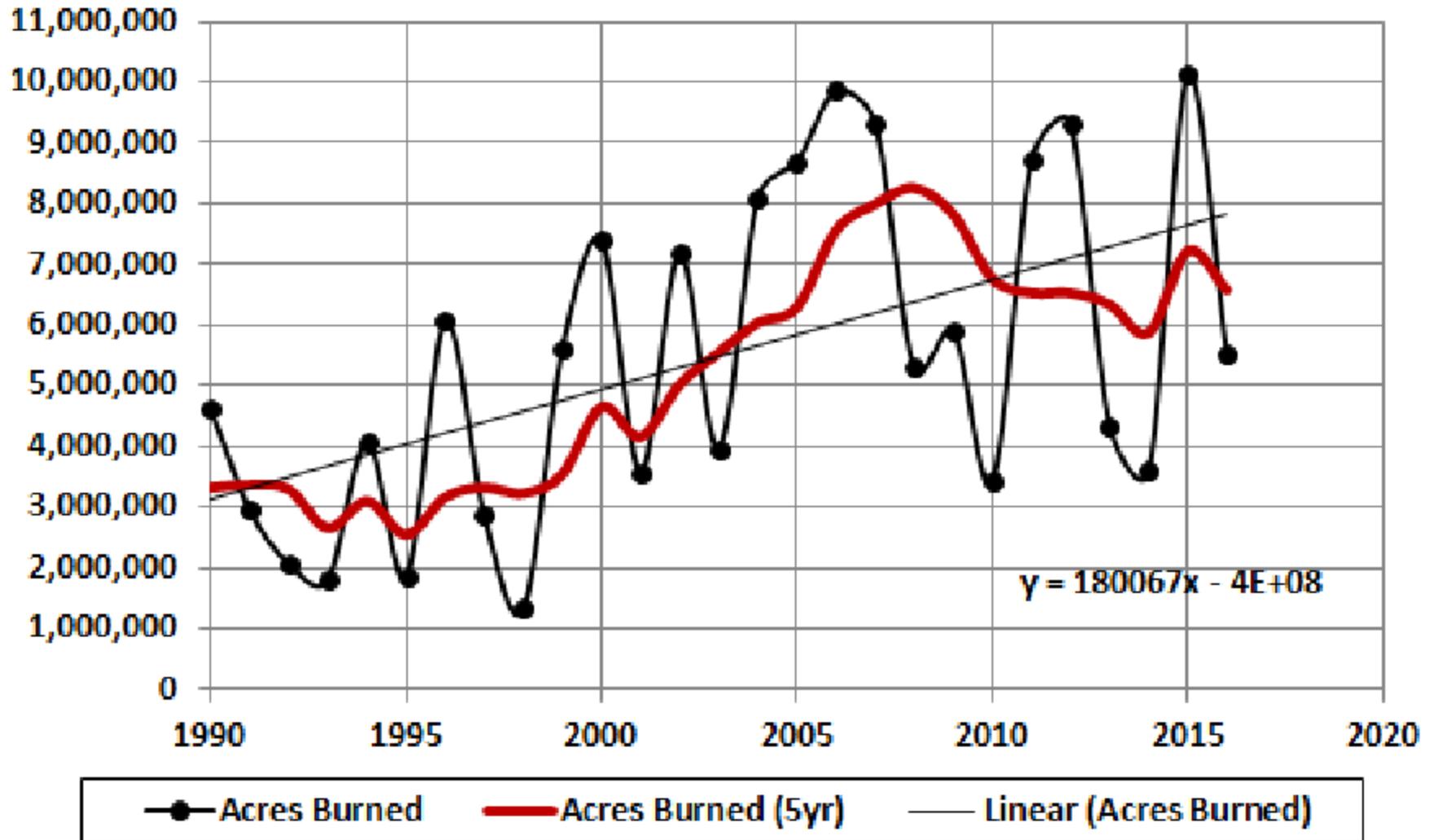
### Syria Rainfall (inches/year)



**This is one of the reasons the U.S. military is studying global warming.**

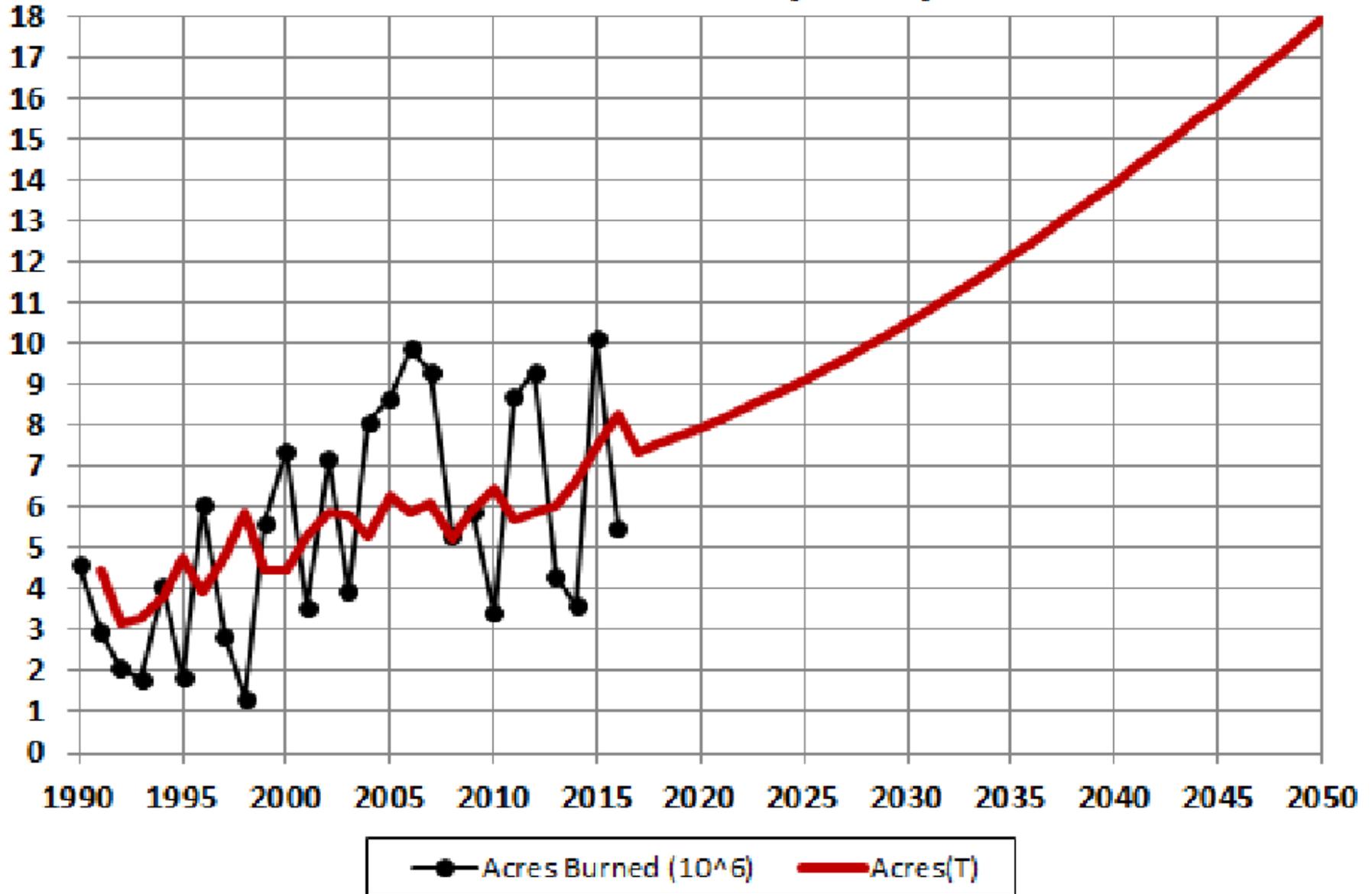
U.S. forest acres burned increased over a factor of 3 in 30 years!

## US Forest Acres Burned



# U.S. Forest Acres Burned Projected

## Acres Burned ( $10^6$ )

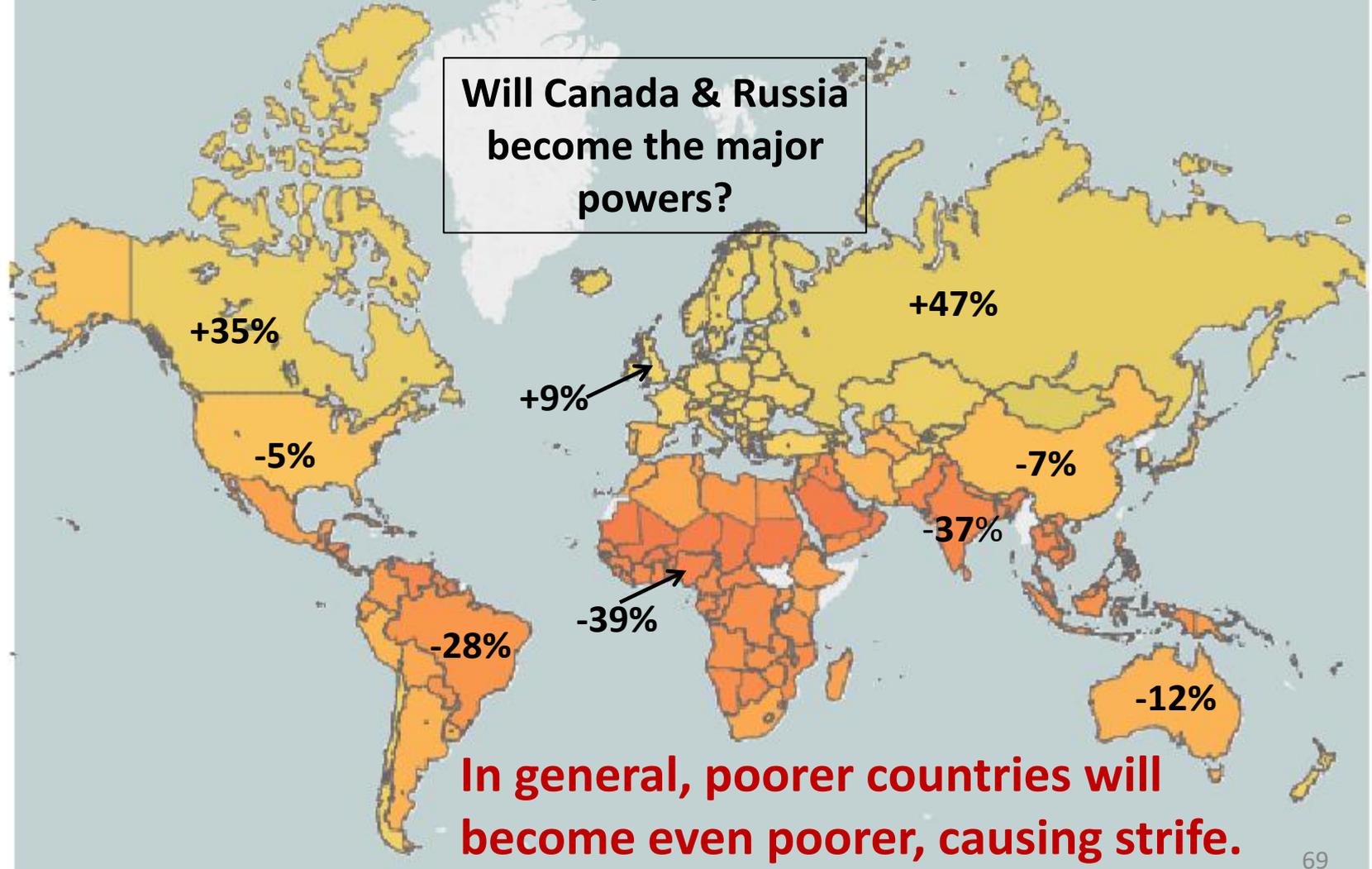


# Hotter Days Will Drive Global Inequality

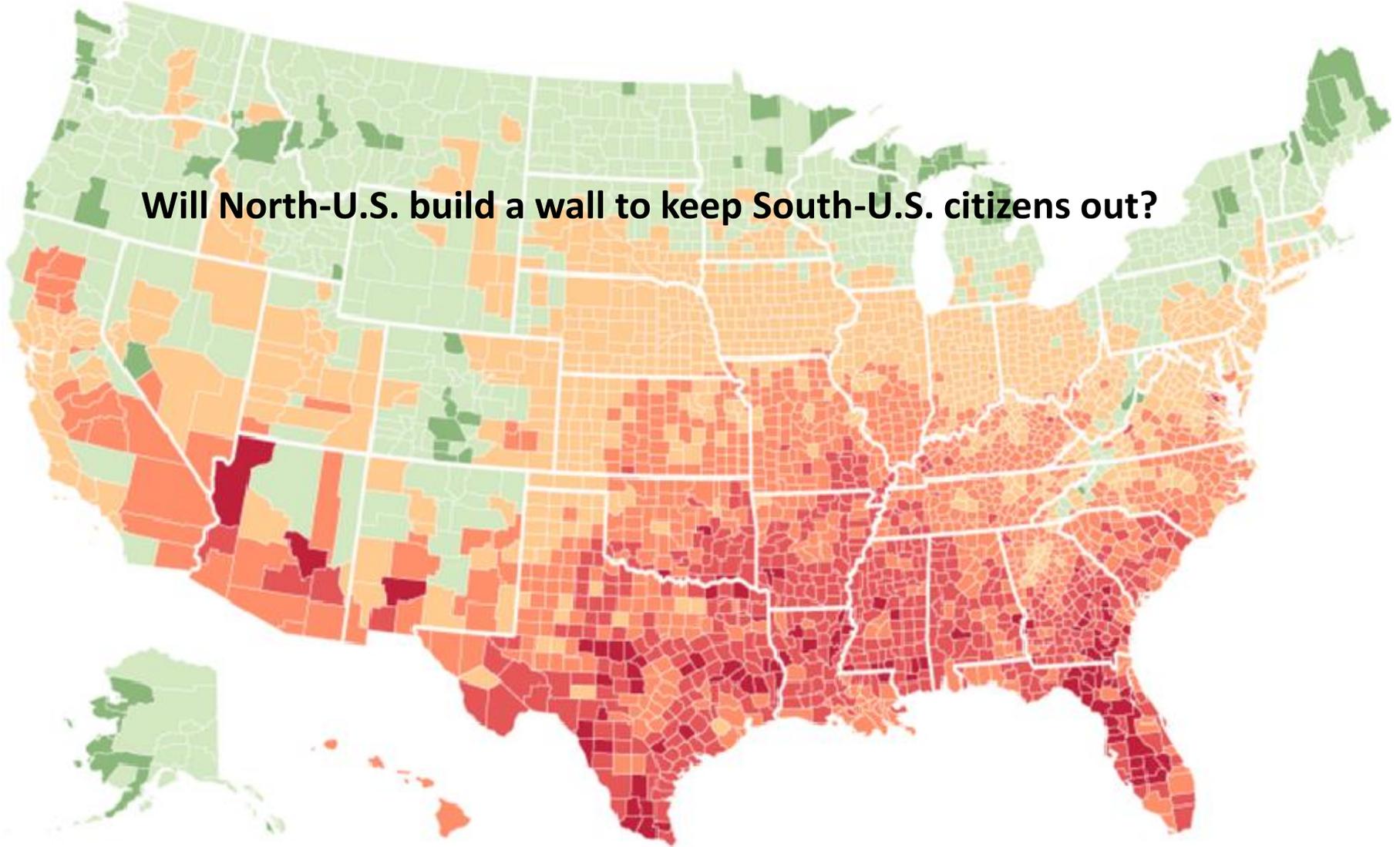
Percent Change GDP - 2050

Red->orange colors +50% to -50% GDP change

Will Canada build a wall to keep U.S. citizens out?



**Will North-U.S. build a wall to keep South-U.S. citizens out?**

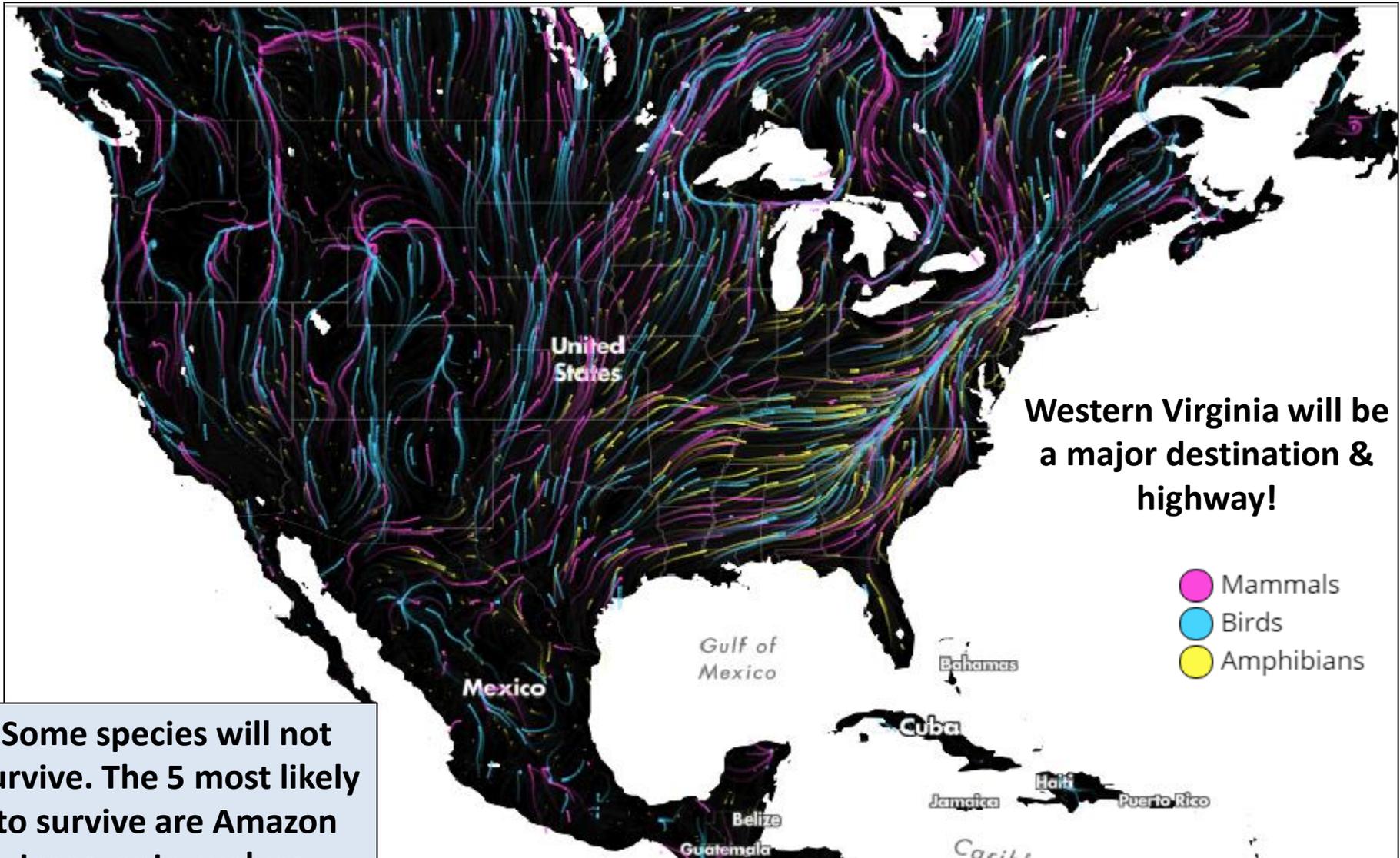


**Predicted damages, 2080 to 2099**

Percent of county G.D.P. per year



# Where animals will move to new homes because of global warming:

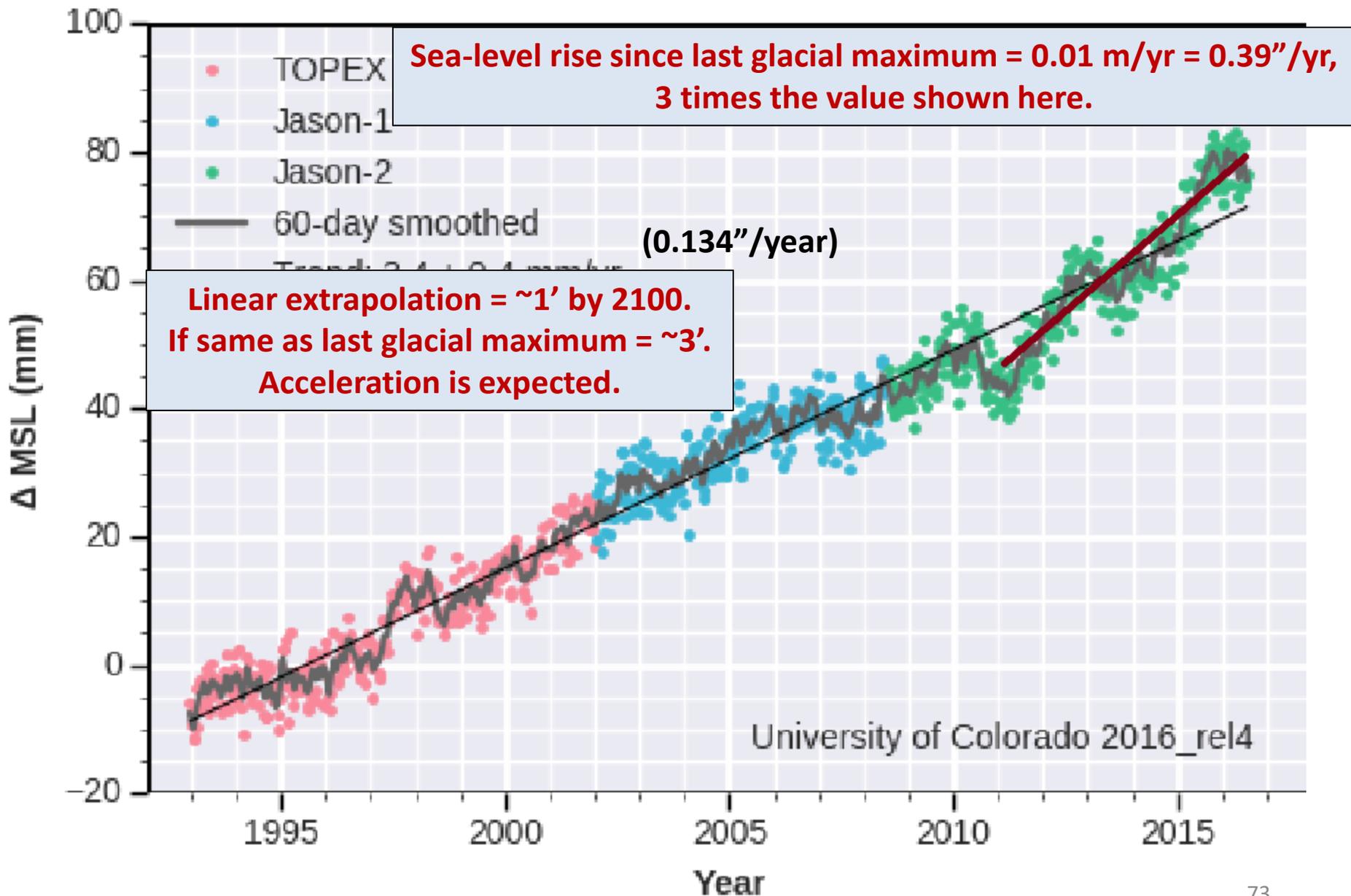


Some species will not survive. The 5 most likely to survive are Amazon trees, ants, wolves, coyotes & cockroaches.

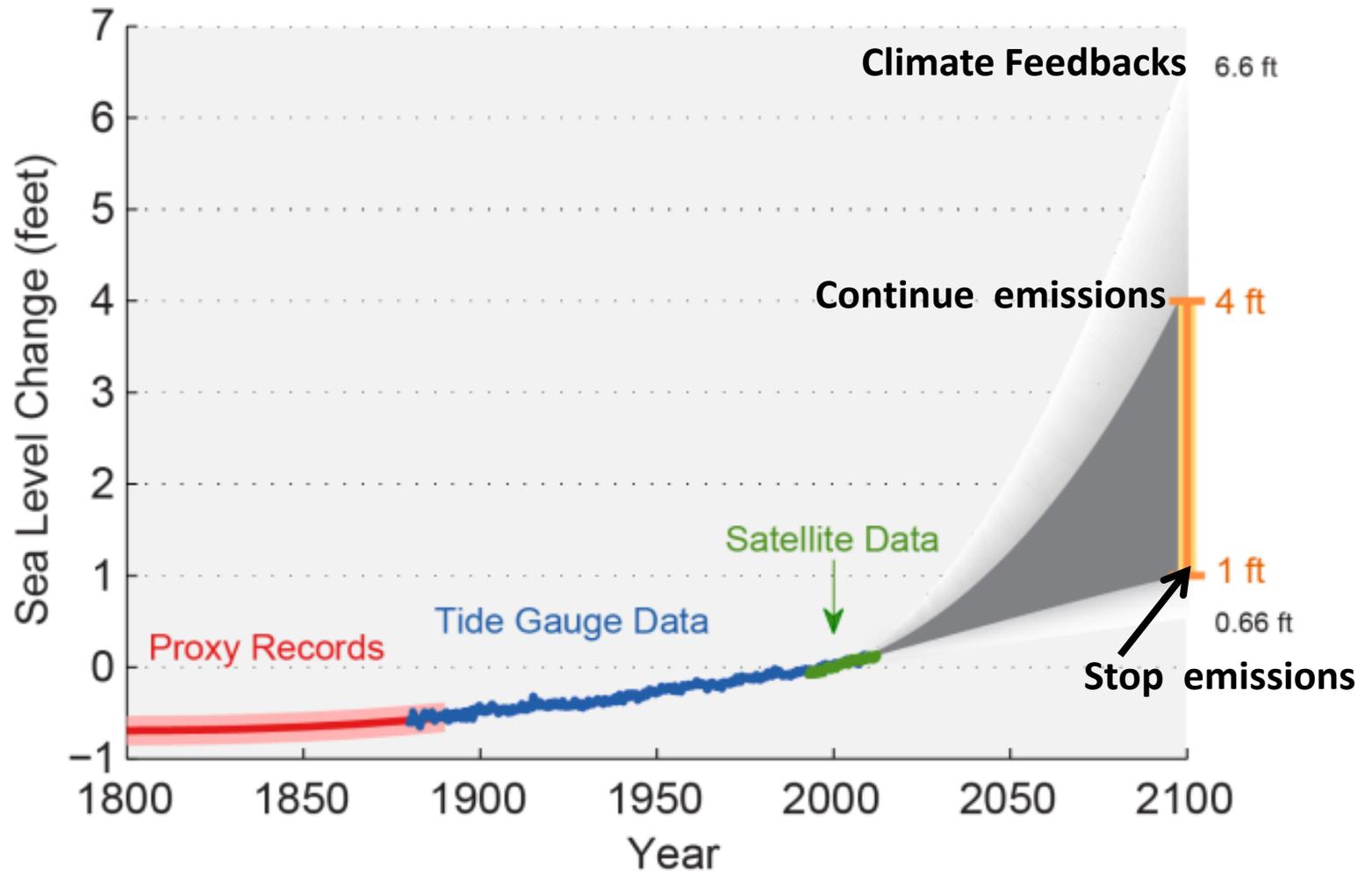
# Sea-Level Rise

- Melting Arctic sea ice indicates moderate sea-level rise because warm water occupies more volume than cold water (**thermal expansion**).
- **Melting ice on land**, such as Greenland and Antarctica, can cause great sea-level rise. If all the ice on Greenland melted, sea level would rise by **~7 meters (23 feet)**. If all the ice on Antarctica melted sea level would rise by **~60 meters (197 feet)**.
- Predictions for sea-level rise by year 2100 range from **0.5 meters (1.64 feet)** to **5 meters (16.4 feet)**.

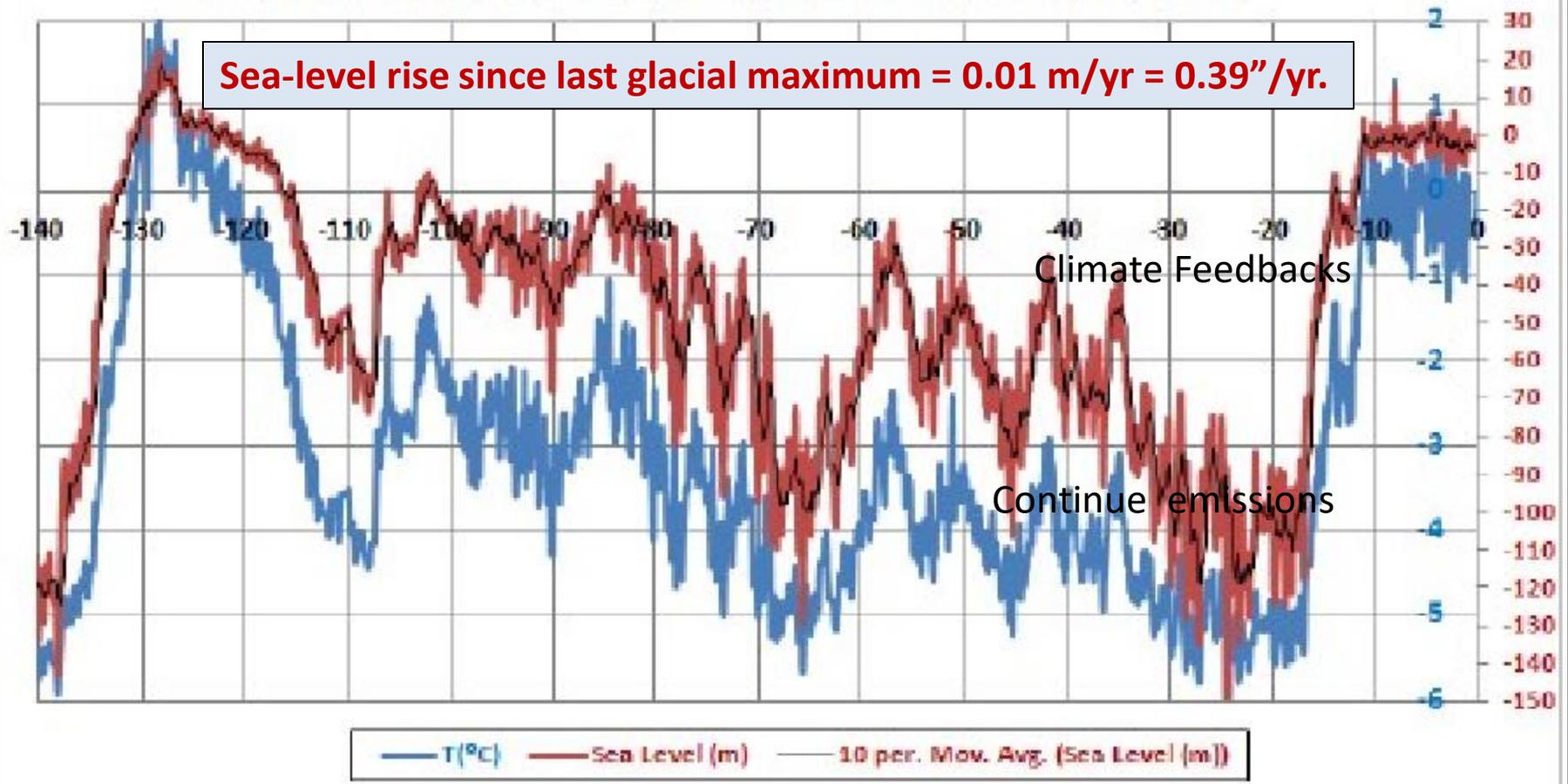
# Sea-Level Rise



# Past and Projected Changes in Global Sea Level



## Average Temperature & Sea Level Relative to 1990

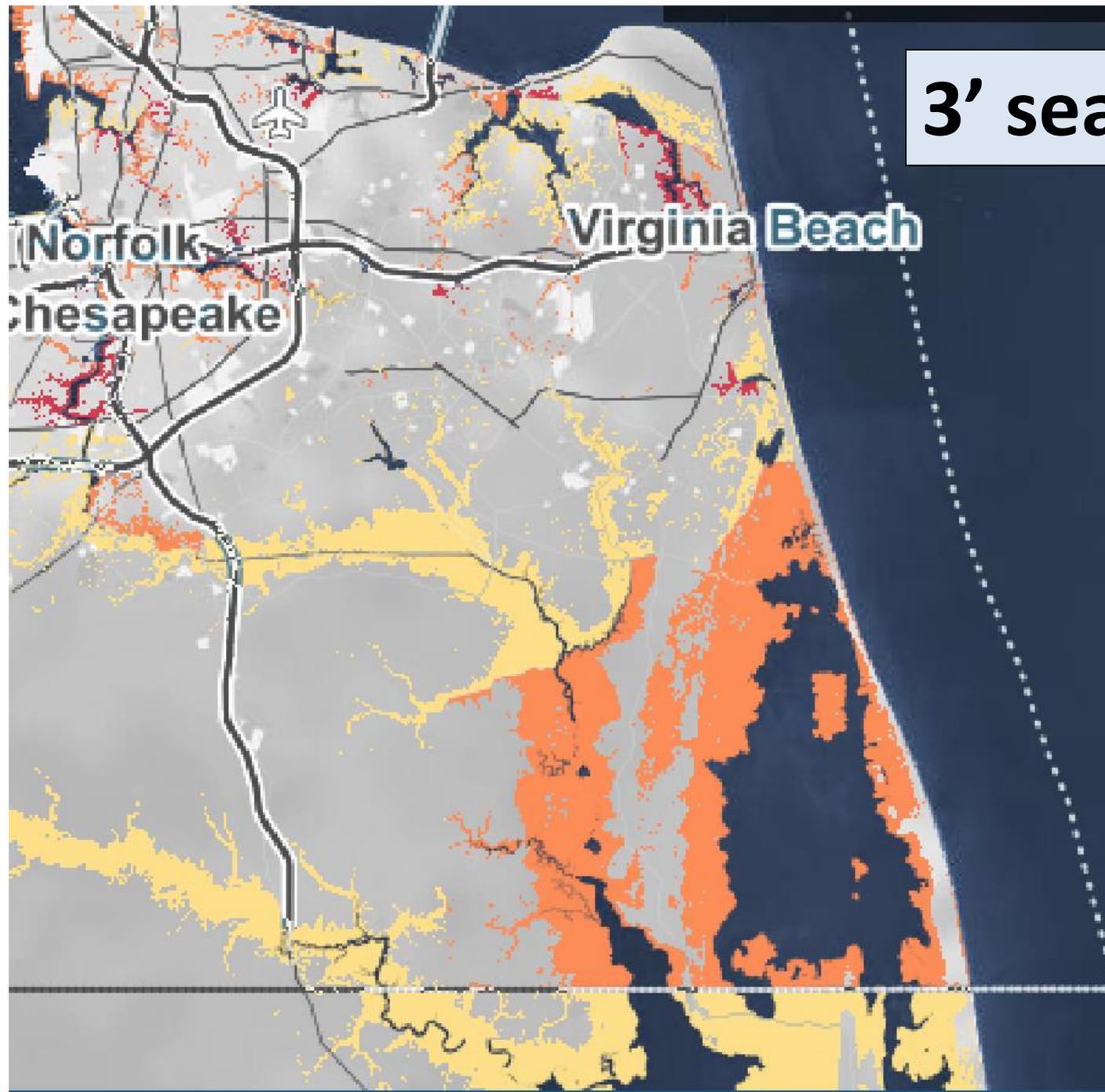


- This shows the **temperature** and **sea level** over the last **130,000** years.
- We are in the current **Holocene interglacial** at the extreme right.
- **20,000 years ago** was the **last glacial maximum** with **temperature ~-5.5°C (-9.9°F)** below 1990 and **sea level 130 meters (427 ft)** below 1990.
- **130,000 years ago** was the **Eemian interglacial** with **temperature ~+2°C (3.6°F)** above 1990 and **sea level 20 meters (66 ft)** above 1990.
- Many climate scientists say we are in a new era called the “**Anthropocene**”.

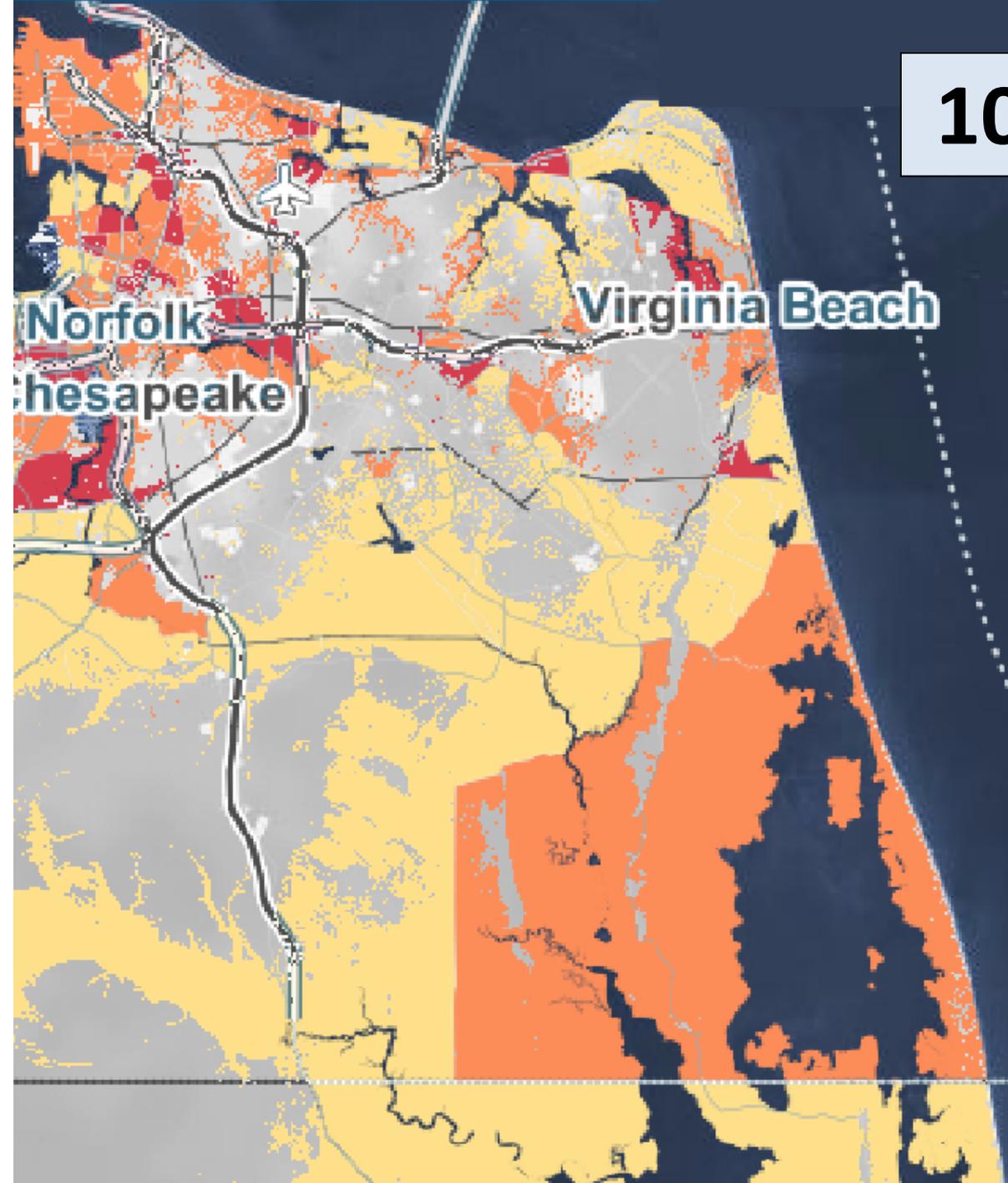
**3' sea-level rise**

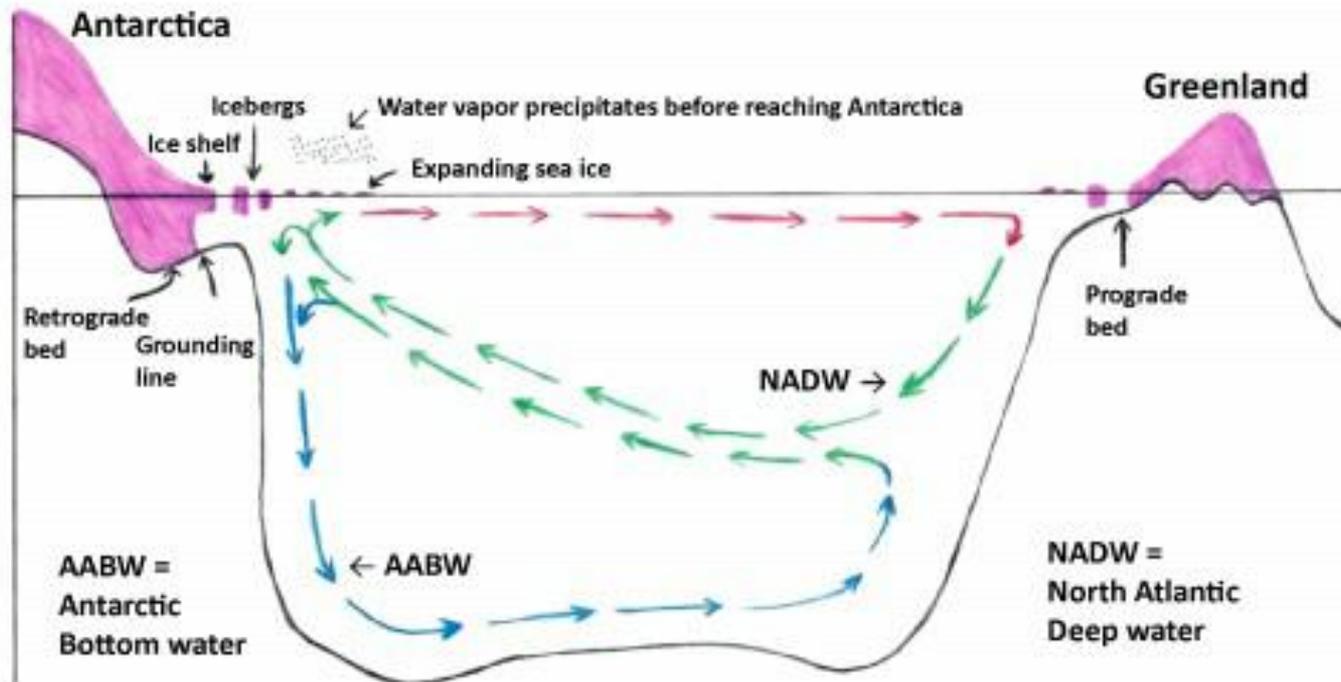
Norfolk  
Chesapeake

Virginia Beach

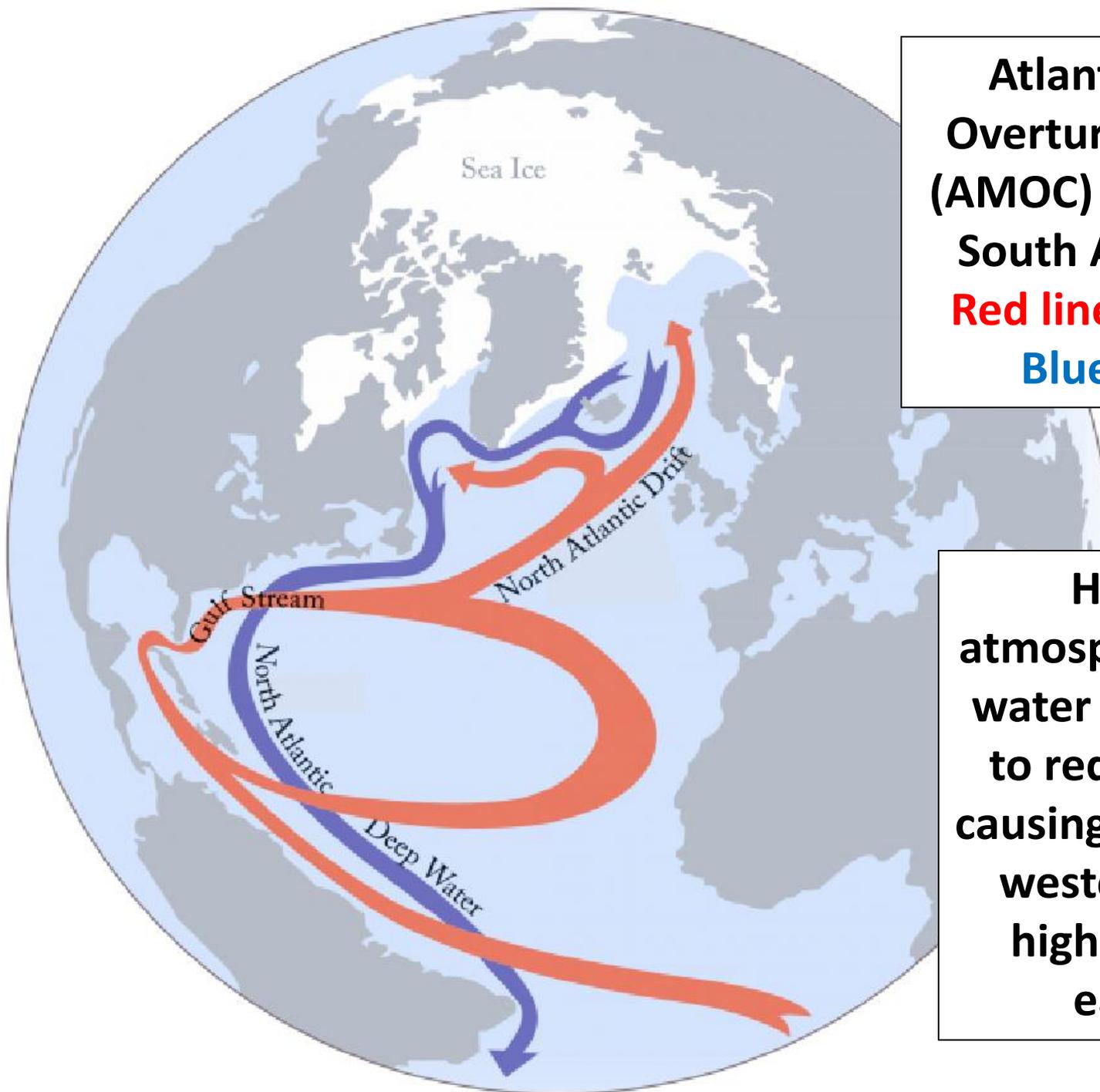


# 10' sea-level rise





**Figure 18.** Schematic of stratification and precipitation amplifying feedbacks. Stratification: increased freshwater flux reduces surface water density, thus reducing AABW formation, trapping NADW heat, and increasing ice shelf melt. Precipitation: increased freshwater flux cools ocean mixed layer, increases sea ice area, causing precipitation to fall before it reaches Antarctica, reducing ice sheet growth and increasing ocean surface freshening. Ice in West Antarctica and the Wilkes Basin, East Antarctica, is most vulnerable because of the instability of retrograde beds.



**Atlantic Meridional Overturning Circulation (AMOC) in the North and South Atlantic oceans.**

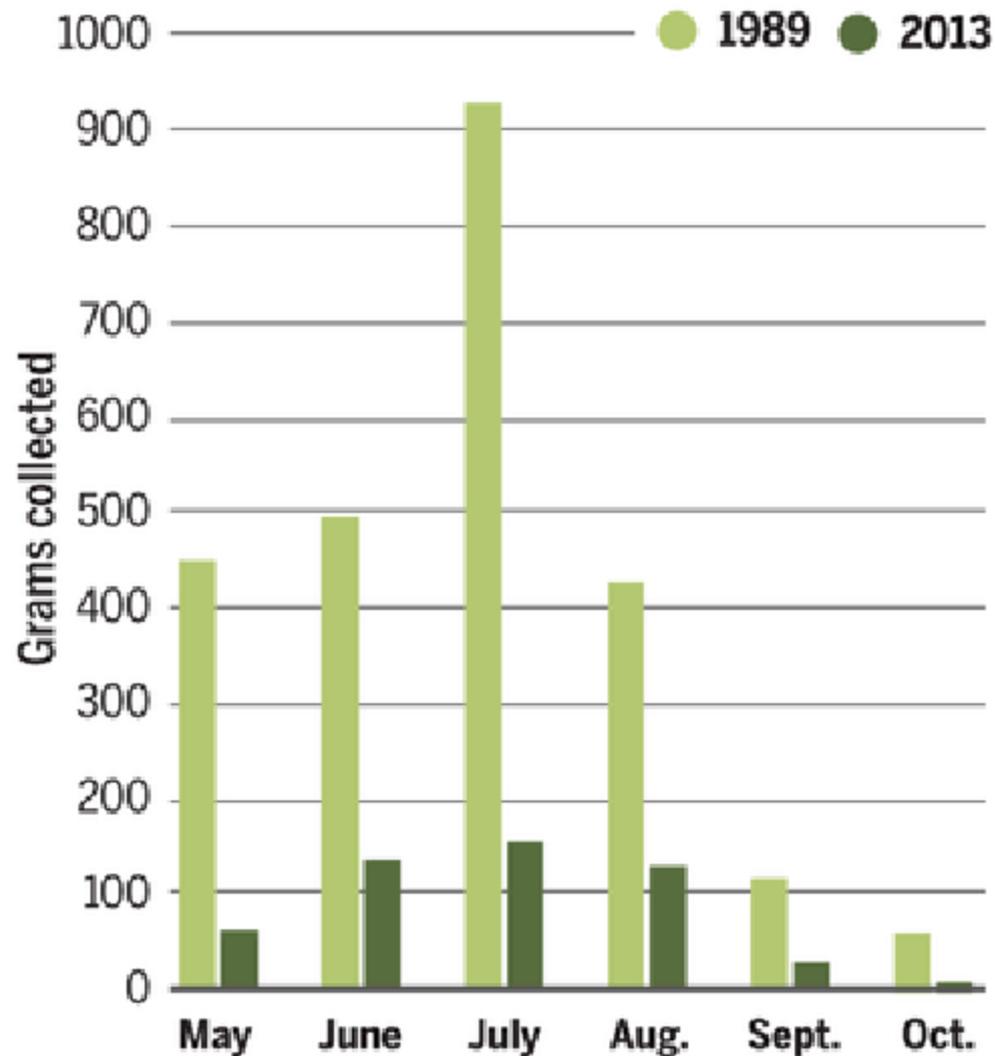
**Red lines: surface flow.**

**Blue: deep flow.**

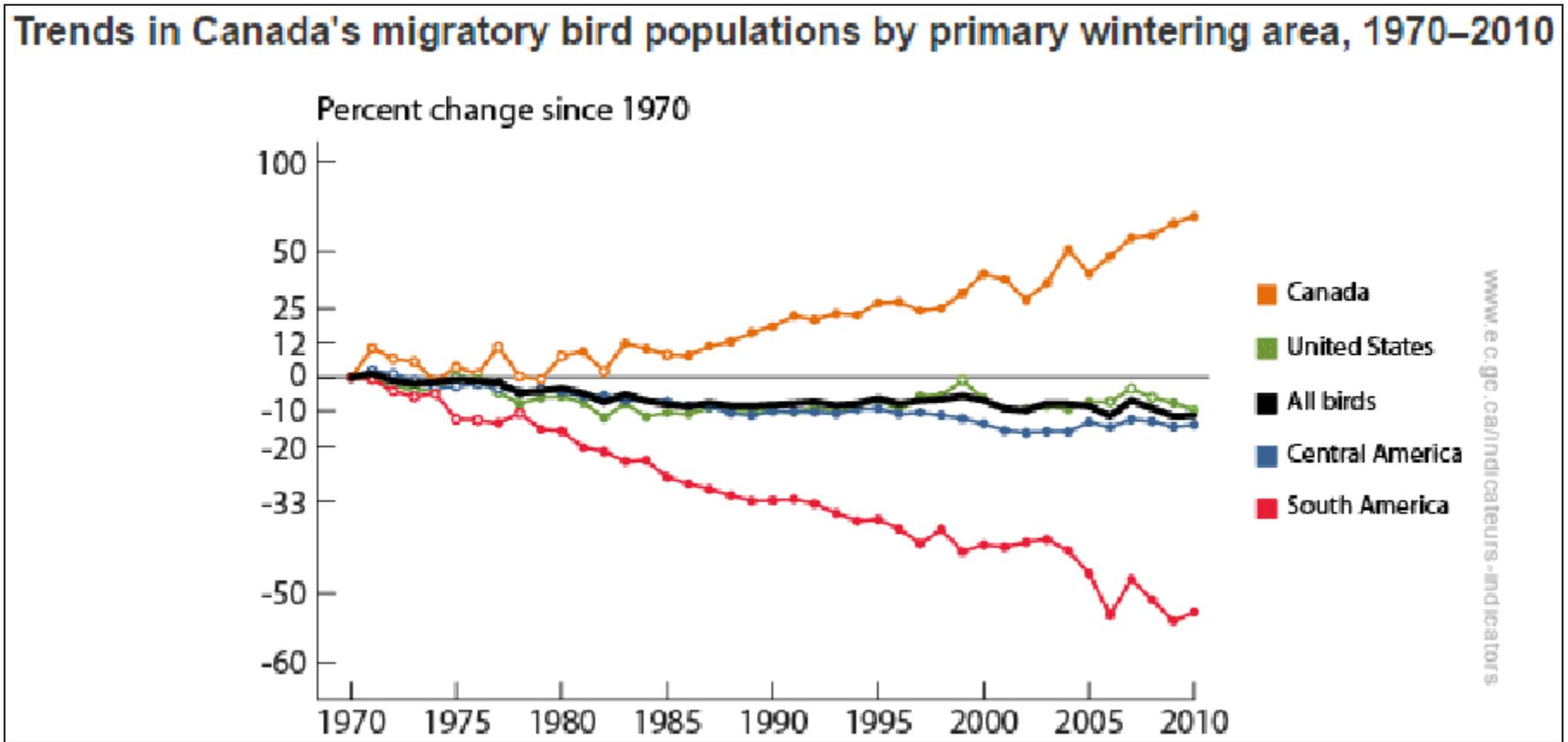
**Hot northern atmosphere causes cold water from melting ice to reduce the AMOC, causing severe storms in western Europe and higher sea levels in eastern USA.**

# Weighty disappearances

The mass of insects collected by monitoring traps in the Orbroicher Bruch nature reserve in northwest Germany dropped by 78% in 24 years.



Migratory birds that spend summers in Canada are wintering farther north.



**By 2010, bird species spending the entire year in Canada increased in population on average by 68% since 1970.**

# Global Warming and Insurance

- Rise in sea level will increase risk of storm surges.
- Extreme storms will have more high winds and tornados.
- Extreme storms will cause more floods.
- Insurance companies plan to increase rates to keep their profits up as disasters increase.
- Insurance companies are promoting storm-resistant buildings and clean and efficient uses of energy.
- Global warming could bankrupt the insurance industry.

# Global Warming Effects on Oceans

- 20%-40% of CO<sub>2</sub> emitted into the atmosphere is dissolved in the oceans.
- This lowers the pH of the oceans making them more acidic. ~30% decrease since Industrial Revolution began.
- CO<sub>2</sub> in oceans prevents production of calcium carbonate to form shells for shelled sea life. Sea water must be saturated with carbonate ions for shells to form and remain intact.
- CO<sub>2</sub> threatens the food chains in the oceans because shelled sea life occurs at many links in the chains.
- Coral bleaching destroys species that live on them.
- Fish migrate toward the poles disrupting fisheries.

# Triggering **Rapid** Climate Change

- Drastic rapid climate events have occurred in the past.
- **Climatology is not yet able to predict which and when drastic rapid events will be triggered.**
- Rapid melting of ice on Greenland and Antarctica can cause rapid sea-level rise.
- One possible trigger event that may be underway is rapid massive release of the powerful **GHG methane** in the Arctic and on the continental shelves, which greatly accelerates global warming.

## Position Statements Acknowledging Human-Induced Climate Change (mid-2015)

American Academy of Pediatrics  
American Association for the Advancement of Science (AAAS)  
American Chemical Society  
American College of Preventive Medicine  
American Geophysical Union  
American Institute of Biological Sciences  
American Institute of Physics  
American Medical Association  
American Meteorological Society  
American Physical Society  
American Public Health Association  
American Quaternary Association  
American Society for Microbiology  
Australian Coral Reef Society  
Australian Medical Association  
Australian Meteorological and Oceanographic Society  
Canadian Foundation for Climate and Atmospheric Sciences  
Canadian Meteorological and Oceanographic Society  
Ecological Society of America  
European Academy of Sciences and Arts  
European Federation of Geologists  
European Geosciences Union  
European Physical Society  
European Science Foundation  
Federation of Australian Scientific and Technological Societies  
Geological Society of America  
Geological Society of Australia  
Geological Society of London  
Institute of Biology (UK)  
Institute of Professional Engineers New Zealand

Institution of Engineers Australia  
InterAcademy Council  
International Association for Great Lakes Research  
International Council of Academies of Engineering and Technological Sciences  
International Union for Quaternary Research  
International Union of Geodesy and Geophysics

**National Academies of:** Australia, Belgium, Brazil, Cameroon Royal Society of Canada, the Caribbean, China, Institut de France, Ghana, Leopoldina of Germany, of Indonesia, Ireland, Accademia nazionale delle scienze of Italy, India, Japan, Kenya, Madagascar, Malaysia, Mexico, Nigeria, Poland, Royal Society of New Zealand, Russian Academy of Sciences, Senegal, South Africa, Sudan, Royal Swedish Academy of Sciences, Tanzania, Turkey, Uganda, The Royal Society of the United Kingdom, the United States, Zambia, and Zimbabwe.

**National Association of Geoscience Teachers**

**Network of African Science Academies** (The science academies of Cameroon, Ghana, Kenya, Madagascar, Nigeria, Senegal, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe, as well as the African Academy of Sciences)

**Royal Meteorological Society (UK)**  
**World Federation of Public Health Associations**  
**World Meteorological Organization**

# Mitigating Global Warming

- The only sure way to mitigate global warming is for humans to **quit burning fossil fuels**, especially coal and unconventional fossil fuels such as tar-sands oil.
- Currently, although extraction of crude oil and natural gas for the world is expected to peak within the next decade, **coal extraction for the world is expected to peak at year ~2050! That would be disastrous!**
- We need to greatly accelerate replacing energy from fossil fuels with **renewable energy**, such as wind, solar and biodiesel made from algae and transform our means of transportation to **electric trains, electric cars and biodiesel trucks and airplanes.**

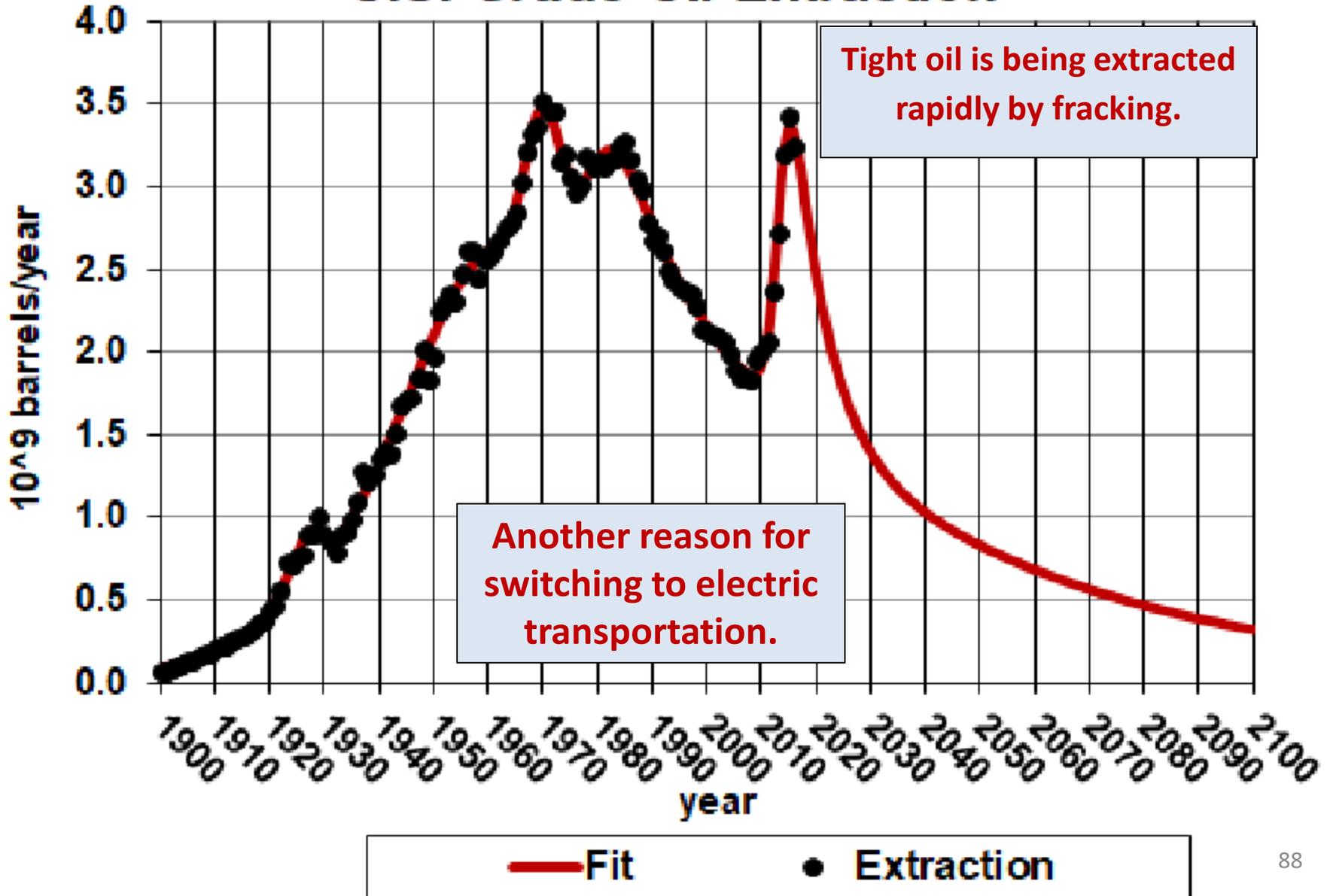
# Global Warming Due to Burning Fossil Fuels

Fuel	CO <sub>2</sub> emitted (g/10 <sup>3</sup> J)
Natural gas	~50
Gasoline	~67
Coal	~90

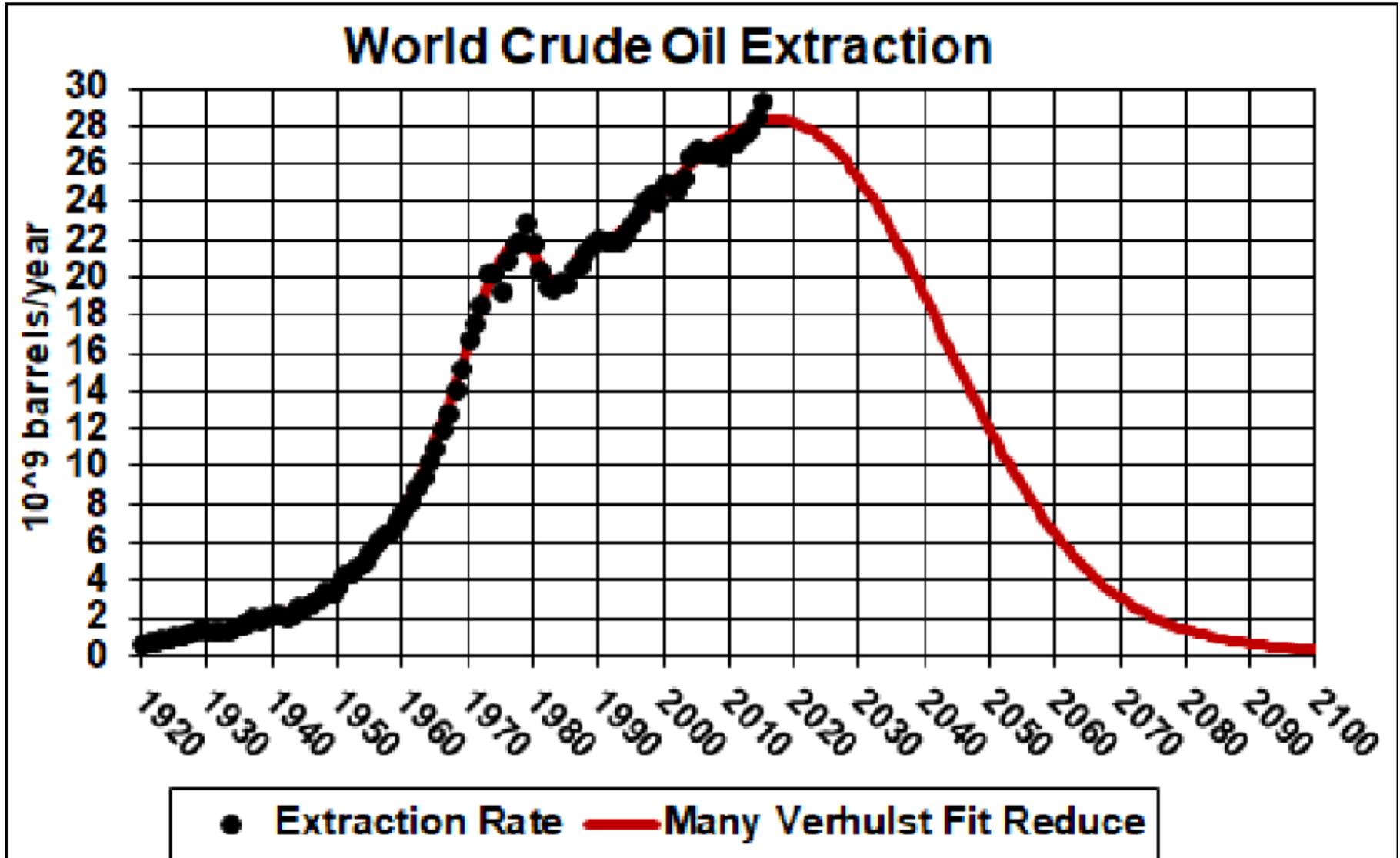
However, methane emissions from drilling and pipelines make using natural gas for energy as bad as coal for causing global warming!

# US Crude-Oil Boom & Coming Bust

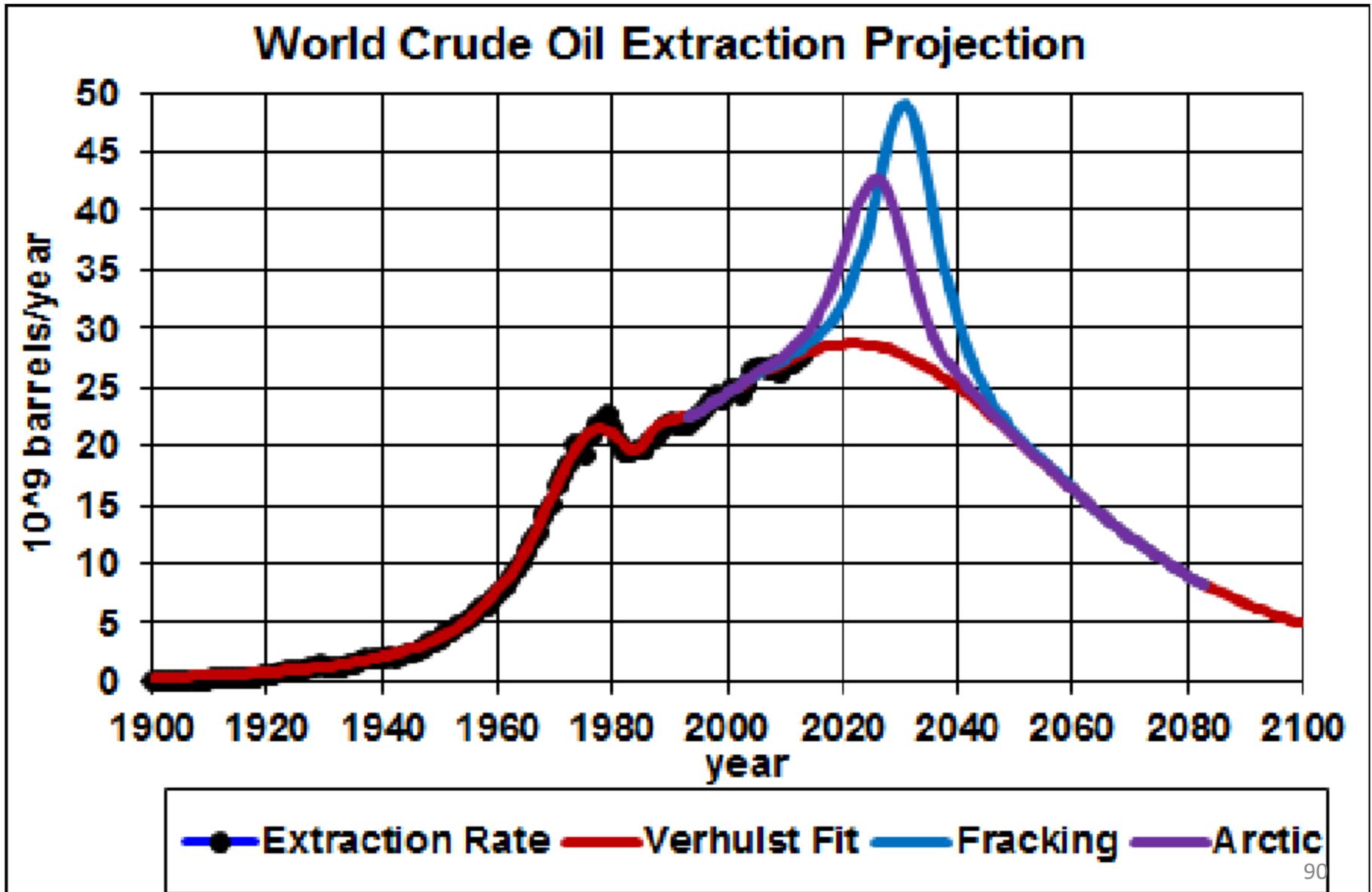
## U.S. Crude Oil Extraction



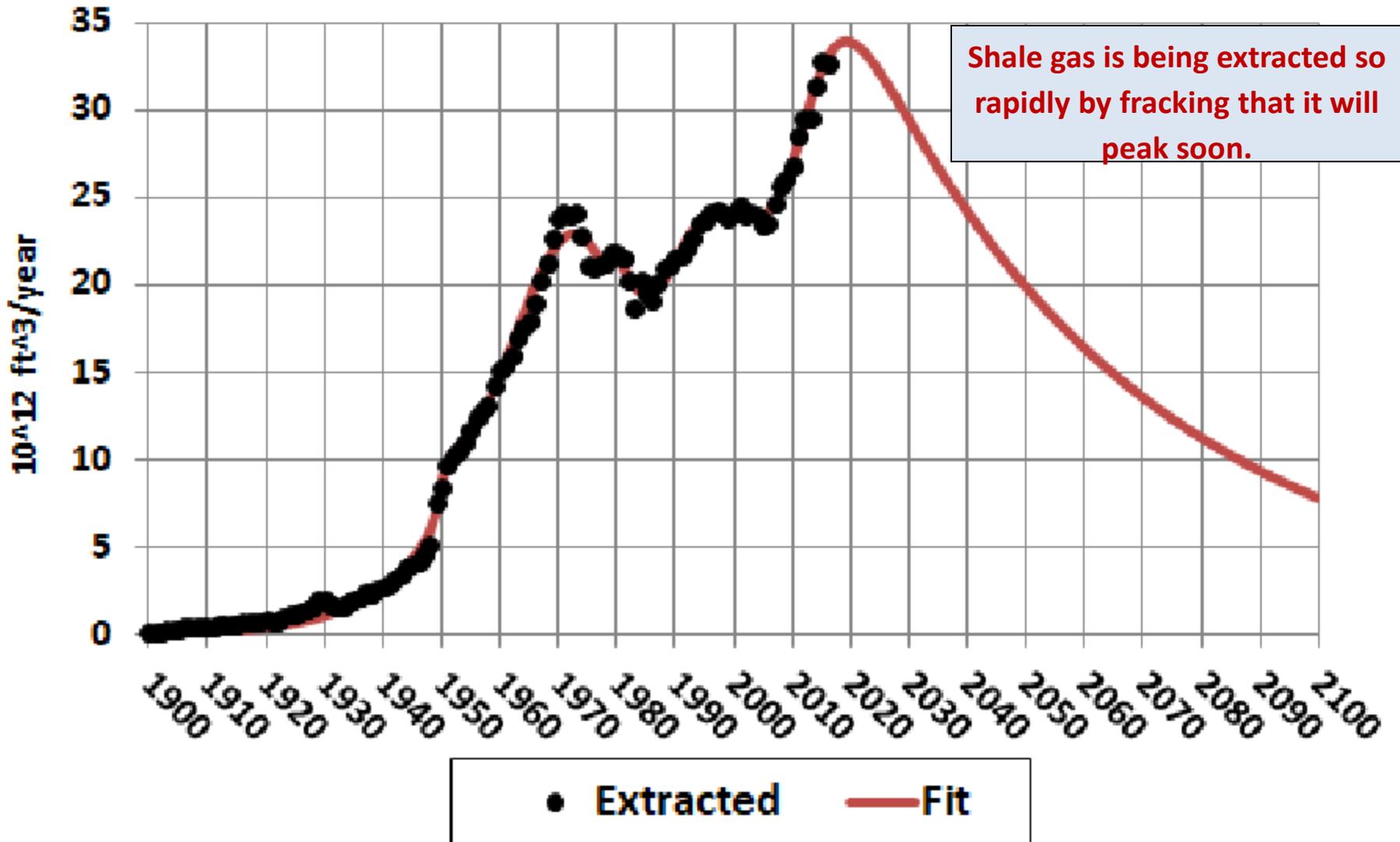
# World Extraction of Conventional Crude Oil



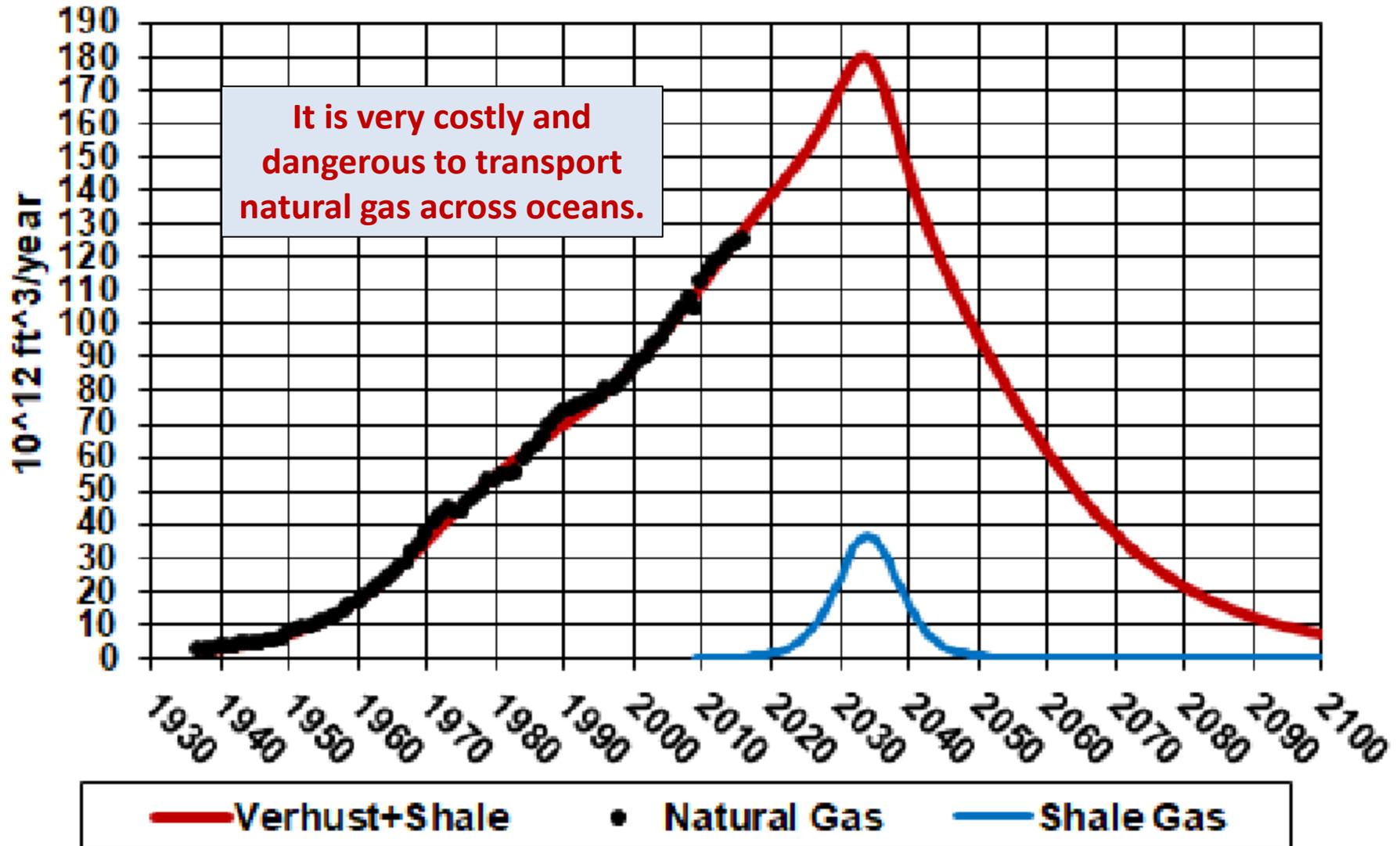
# What if the world extracts crude oil by fracking and/or extracts it in the Arctic after the ice melts?



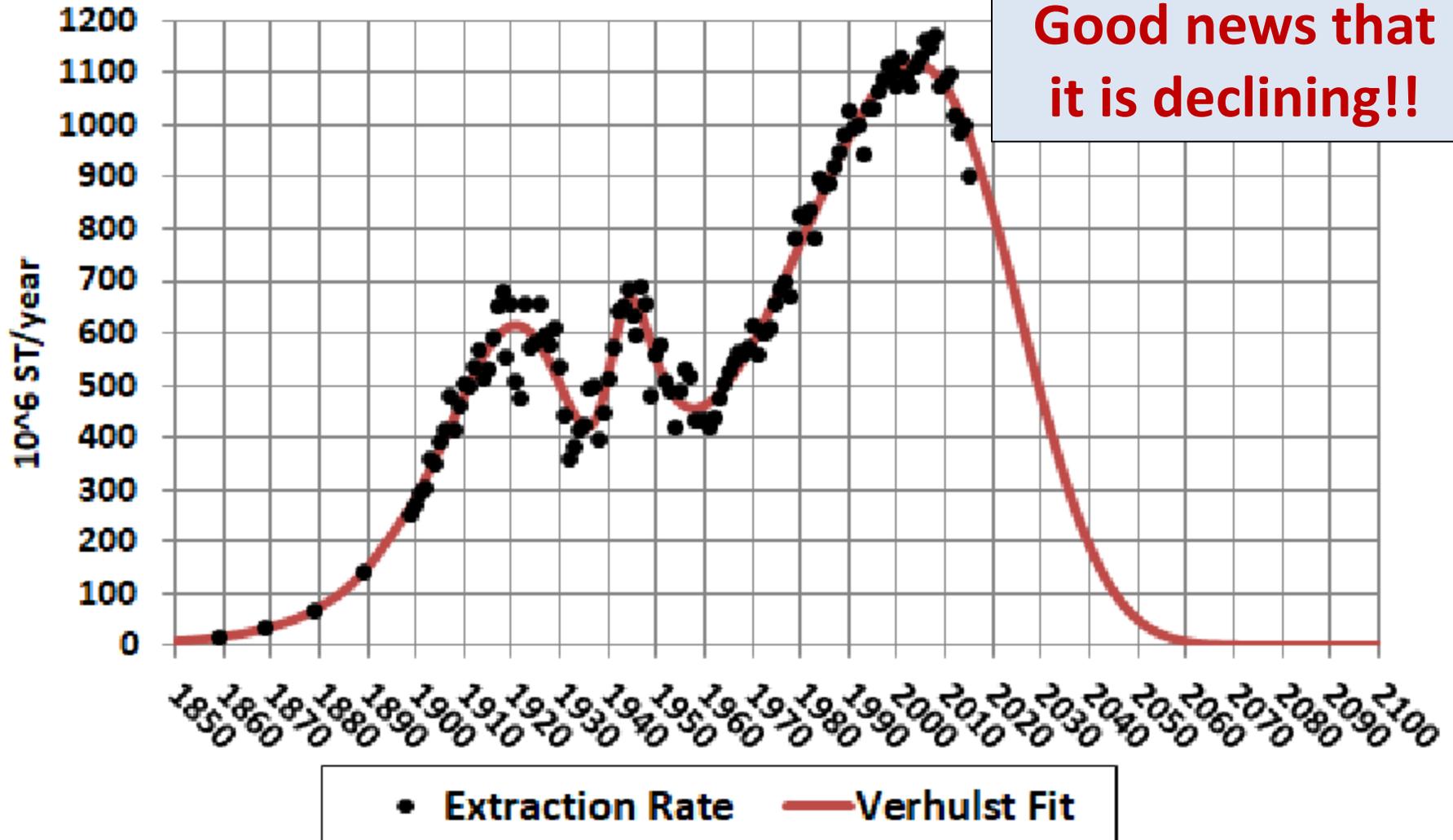
# United States Natural-Gas Extraction



# World Natural-Gas Extraction

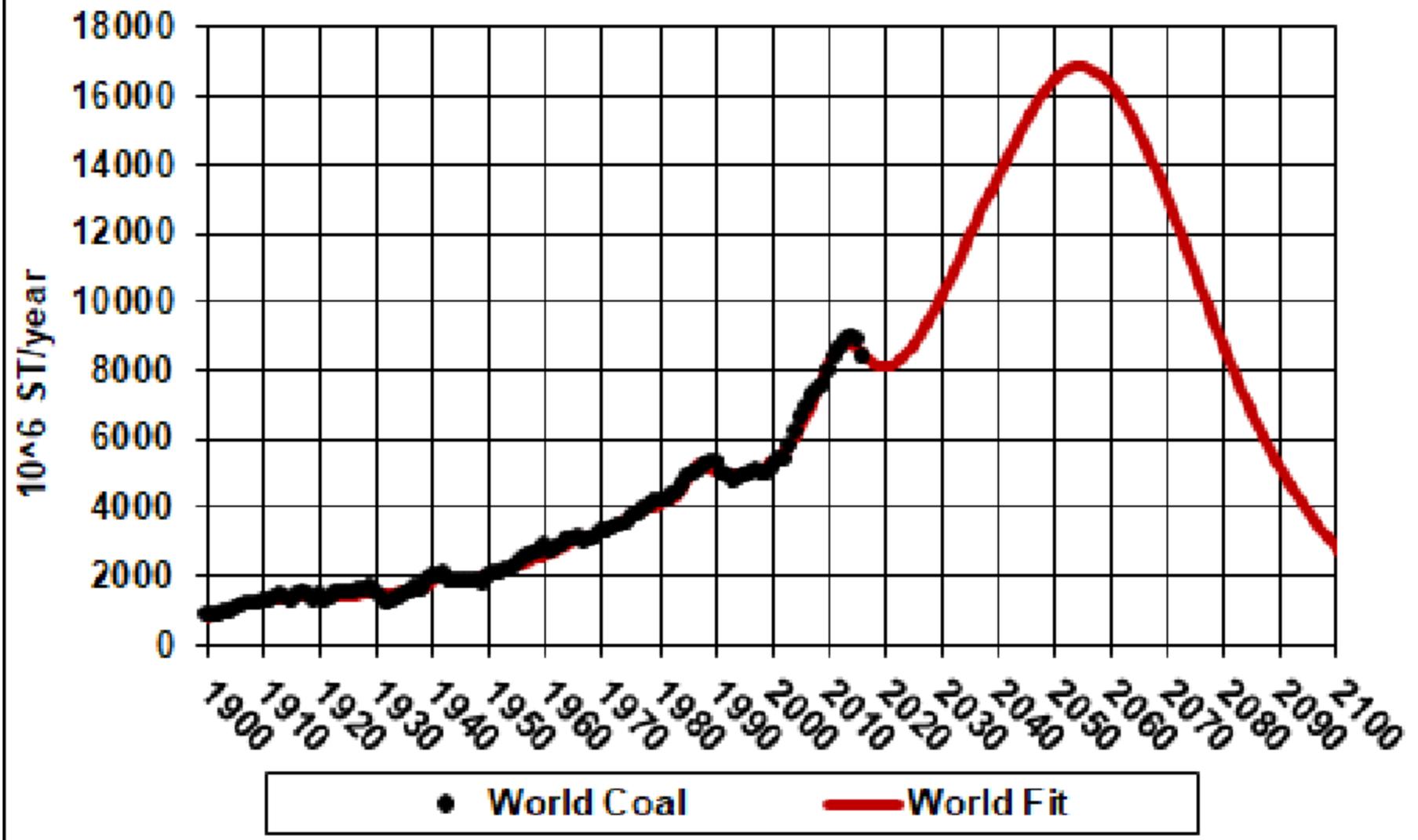


# US Coal Extraction



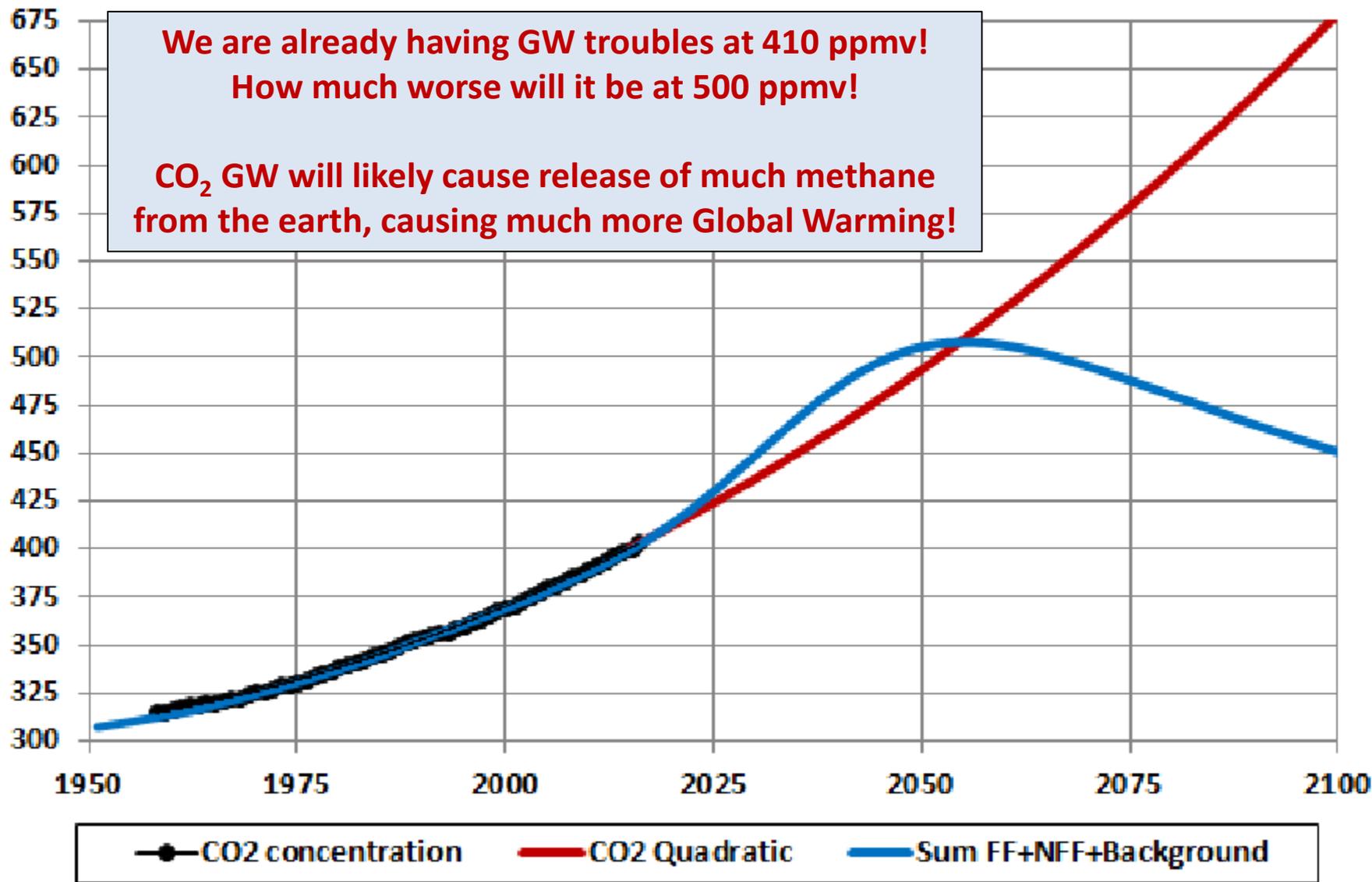
**Bad news!**

# World Coal Extraction



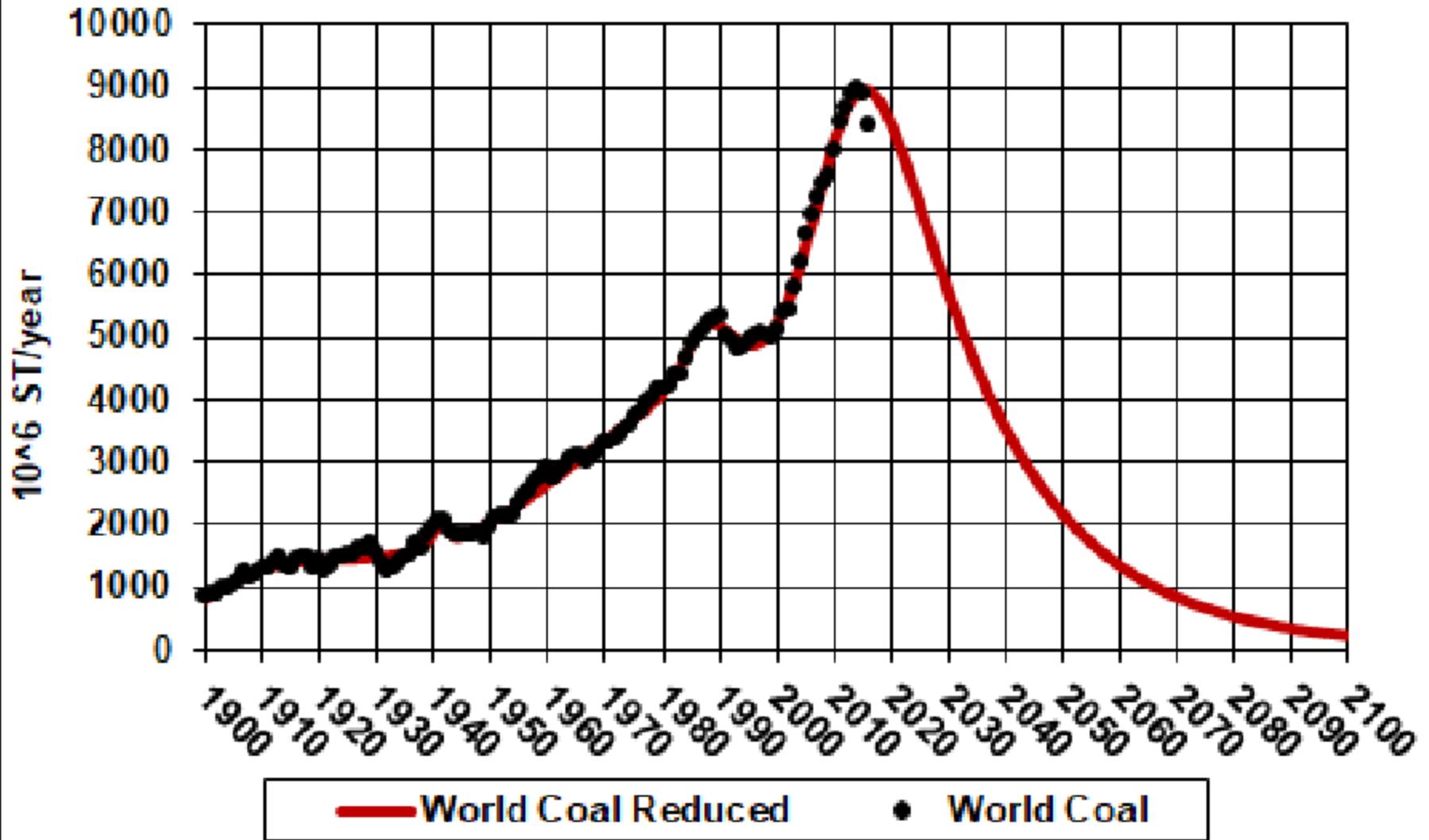
**Bank of America and Deutsche Bank are committed to end financing of coal mining and coal-fired power plant construction; and coal plants are shutting down.**

# Atmosphere CO<sub>2</sub> Concentration (ppmv)

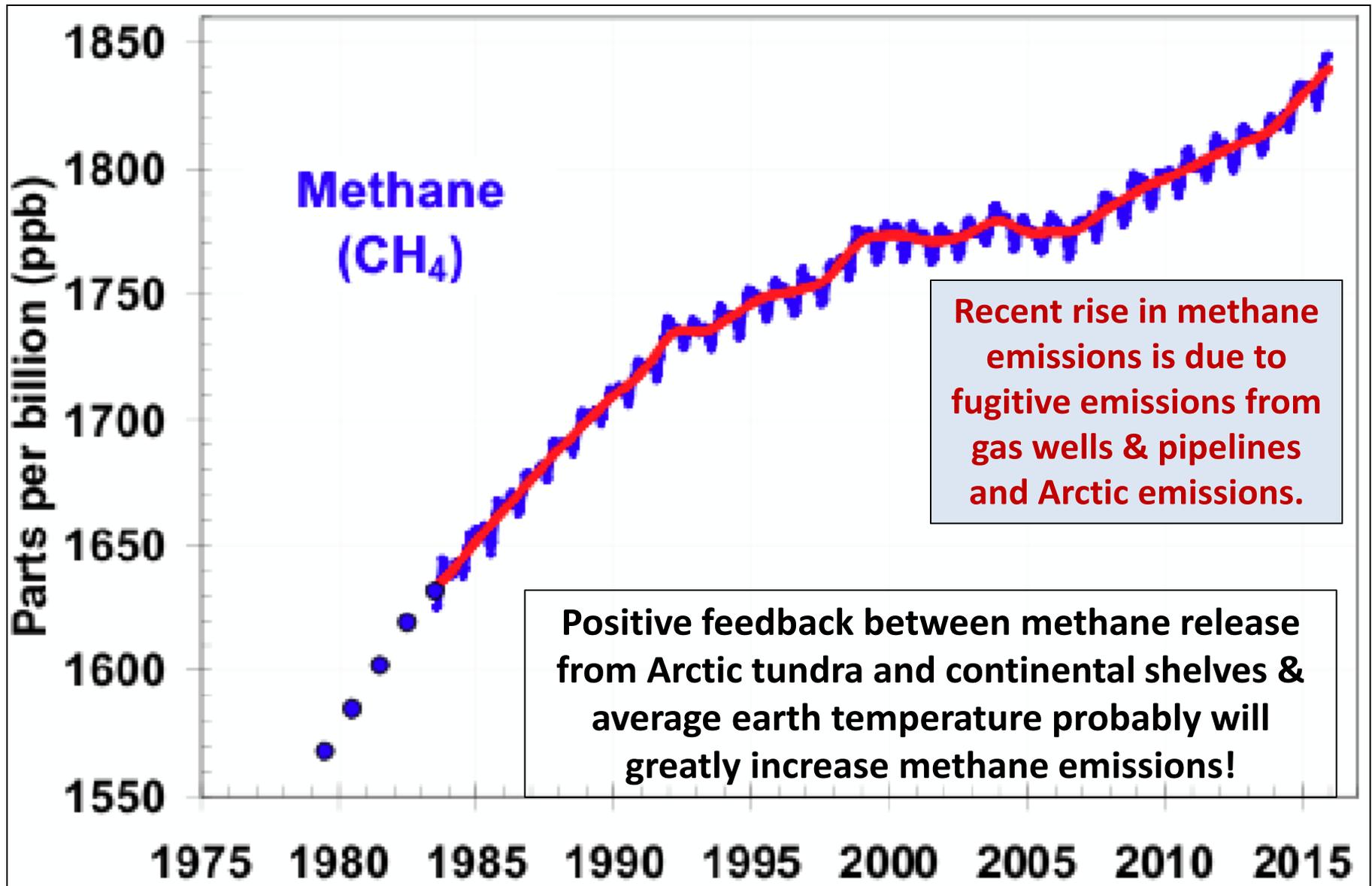


**Red curve** is quadratic data extrapolation into the future.  
**Blue curve** is CO<sub>2</sub> concentration accounting for fossil-fuels depletion.

# World Coal Extraction

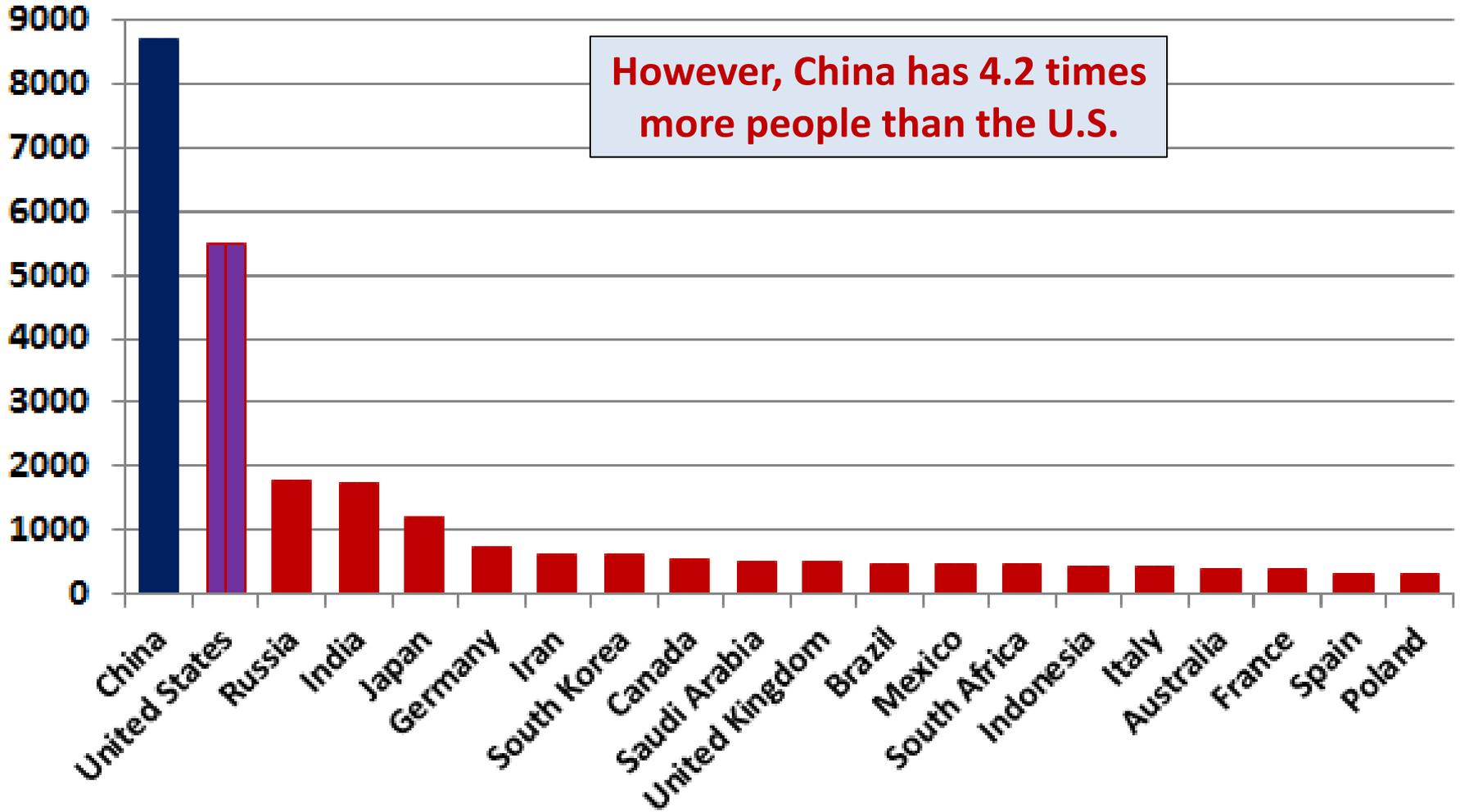


This **reduction in coal extraction** would lower the CO<sub>2</sub> emissions peak from ~500 ppmv to ~425 ppmv and from year ~2050 to ~2025.



1 tonne = 1.102 ton

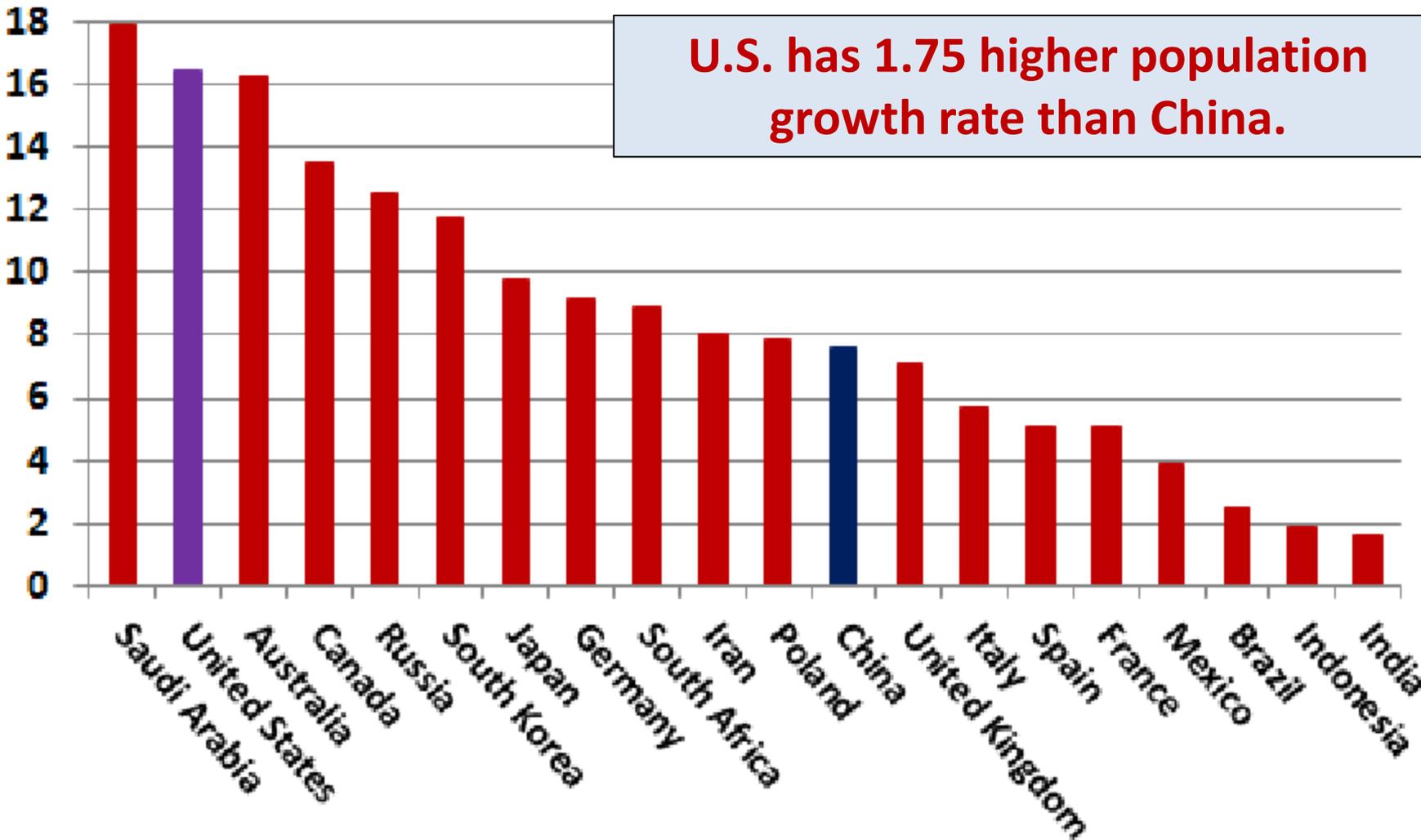
## Total Carbon-Dioxide Emissions ( $10^6$ tonnes)



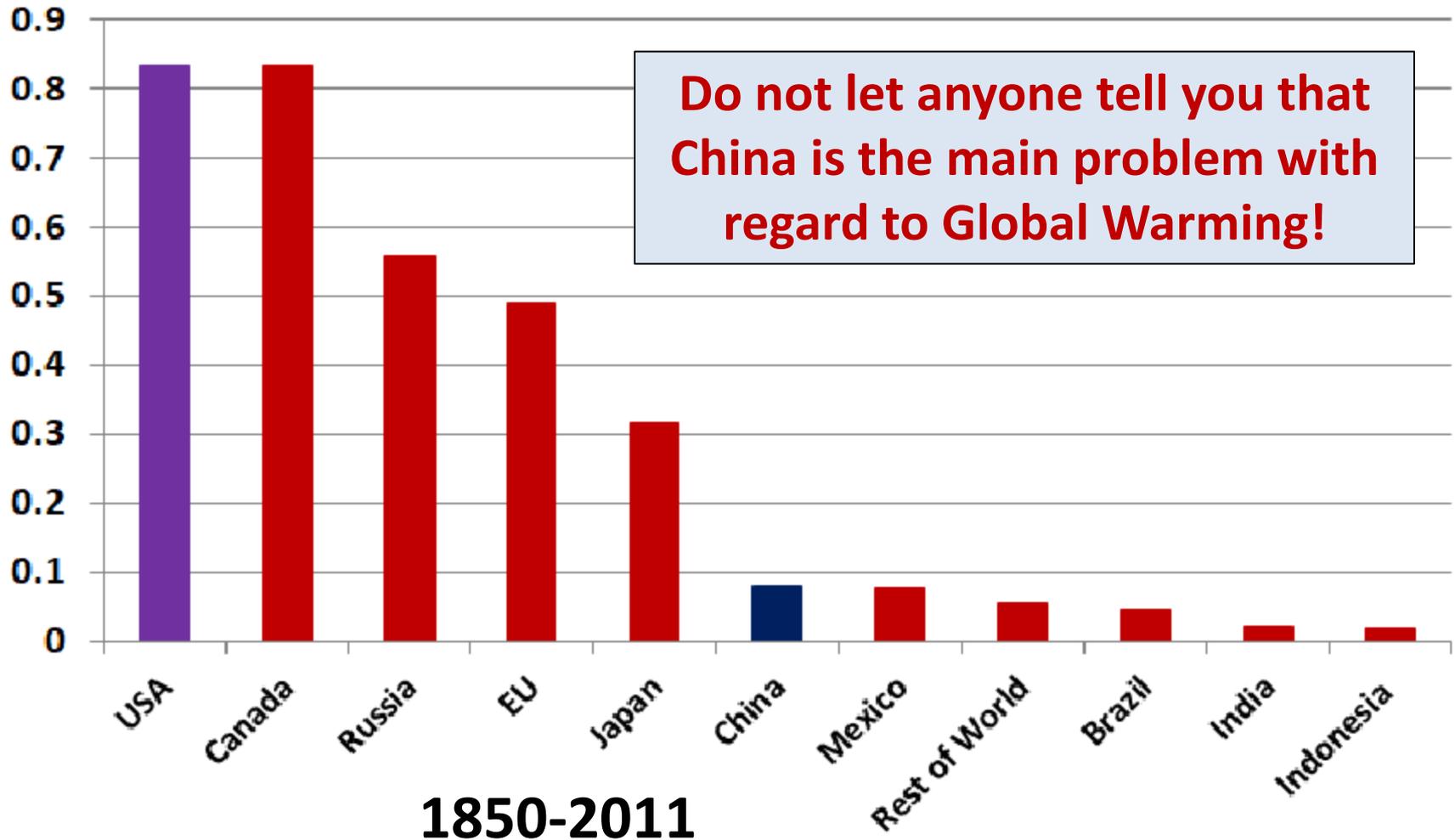
1 tonne = 1.102 ton

### Per Capita Carbon-Dioxide Emissions (tonnes/person)

U.S. has 1.75 higher population growth rate than China.

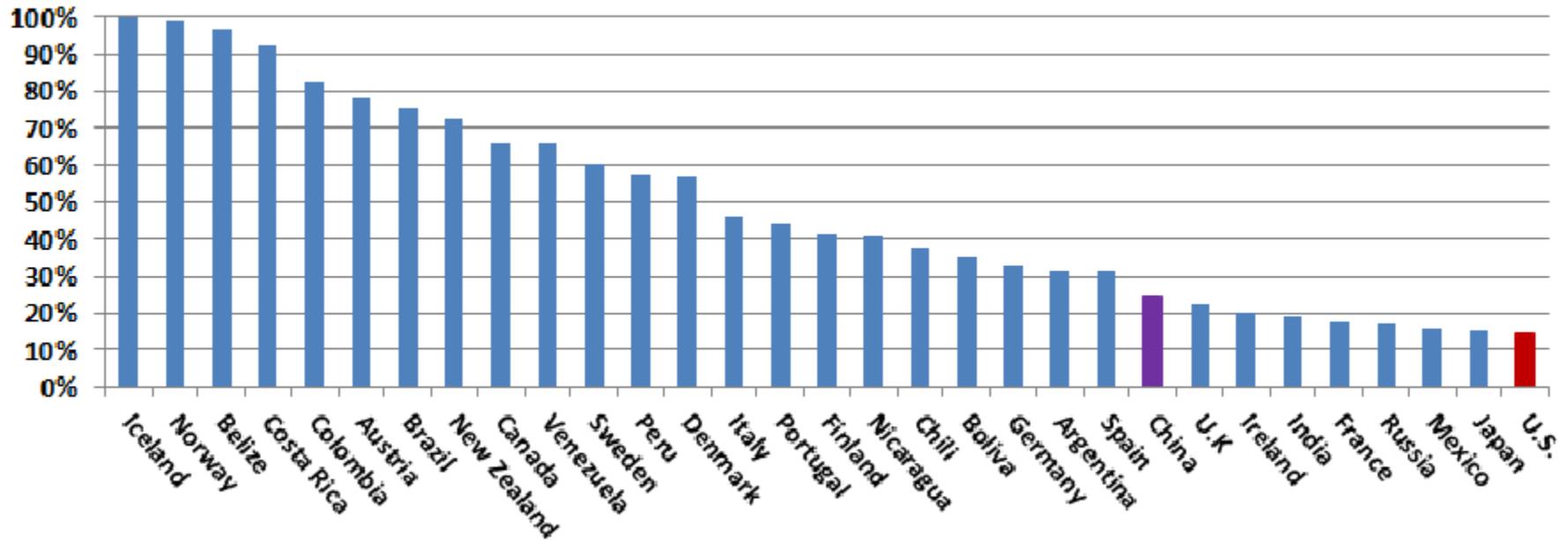


## **%( $\times 10^{-6}$ ) of Total CO<sub>2</sub> Cumulative Emissions/Population**



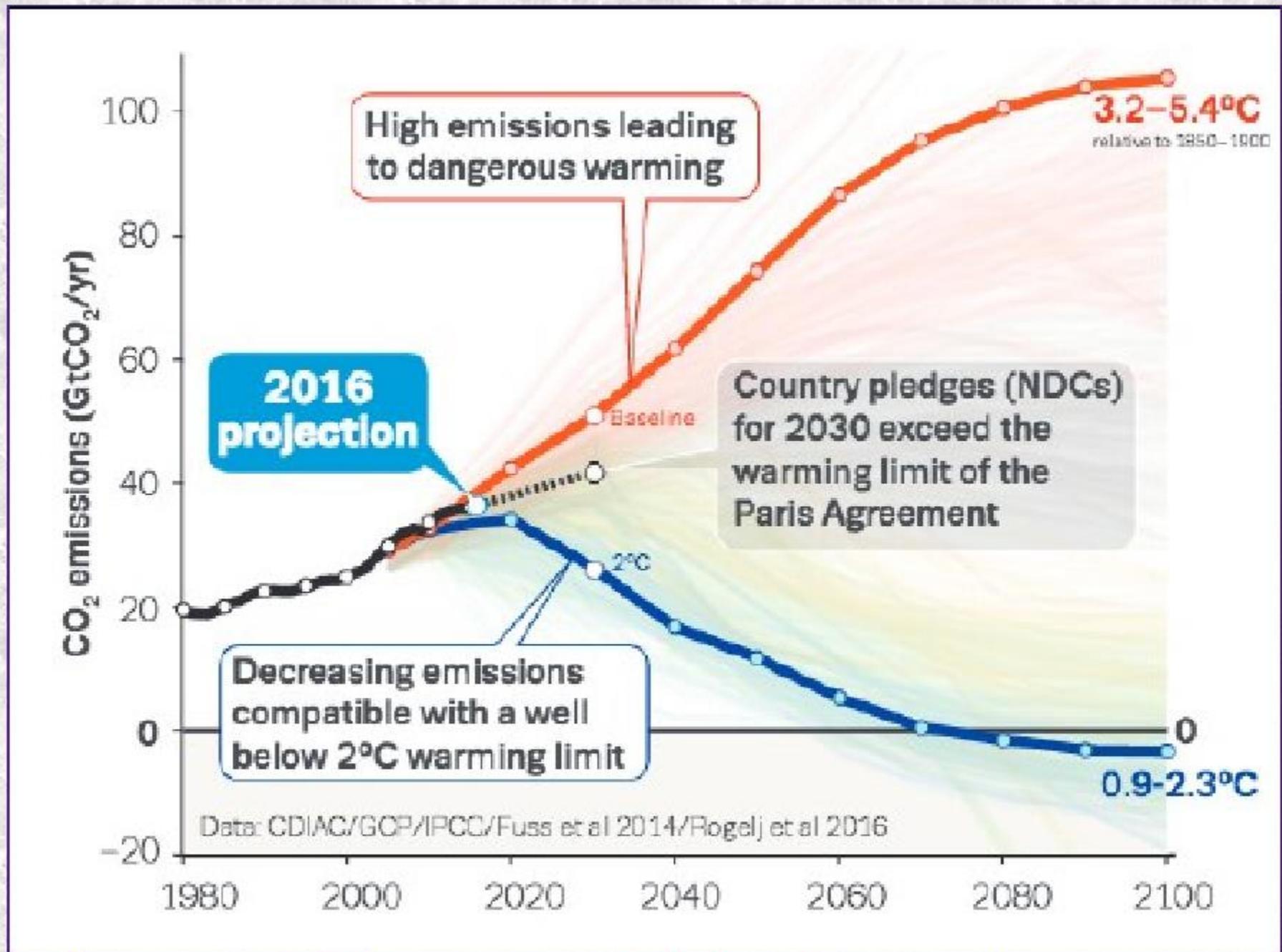
**Do not let anyone tell you that China is the main problem with regard to Global Warming!**

**Renewable Energy % of Total Electric Energy**



# Immediate Action Needed!

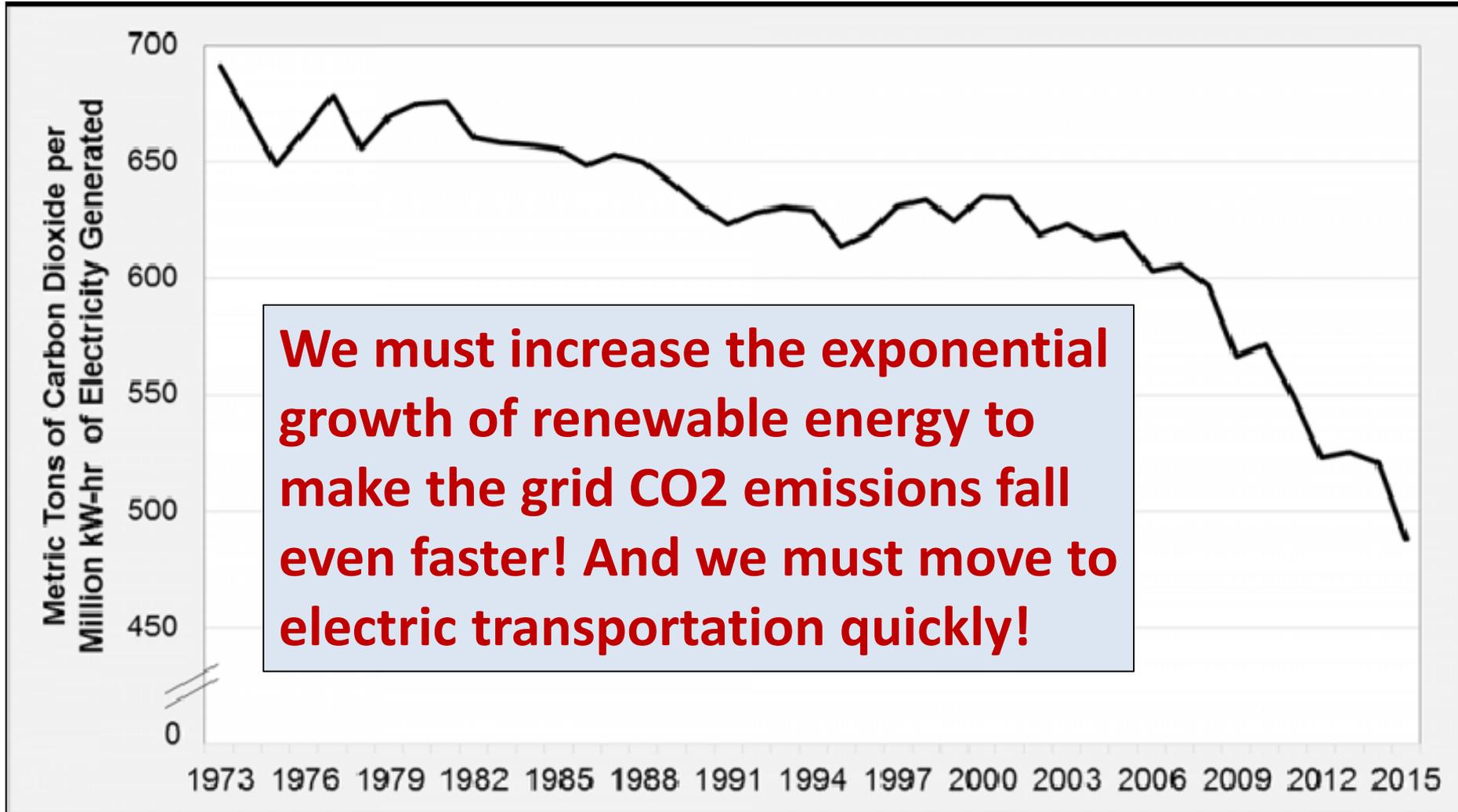
- Do not build any more coal power plants and stop current ones.
- Build distributed wind and solar energy and smart grid.
- Move to electric rail transportation for freight and mass people movement asap.
- Change personal transportation to electric vehicles and biofueled plug-in hybrid vehicles asap.
- Change trucks to fuel cells with hydrogen fuel made by solar.
- Make biofuels from non-food plants, such as algae and kudzu.
- Build all new buildings and remodel old buildings with high energy efficiency and with solar collectors and gardens on their roofs.
- Cover parking lots with solar panels and build community solar.
- Use petroleum and natural gas only for chemicals, not burning for fuel.
- Use coal to make carbon fibers to make vehicles lighter.



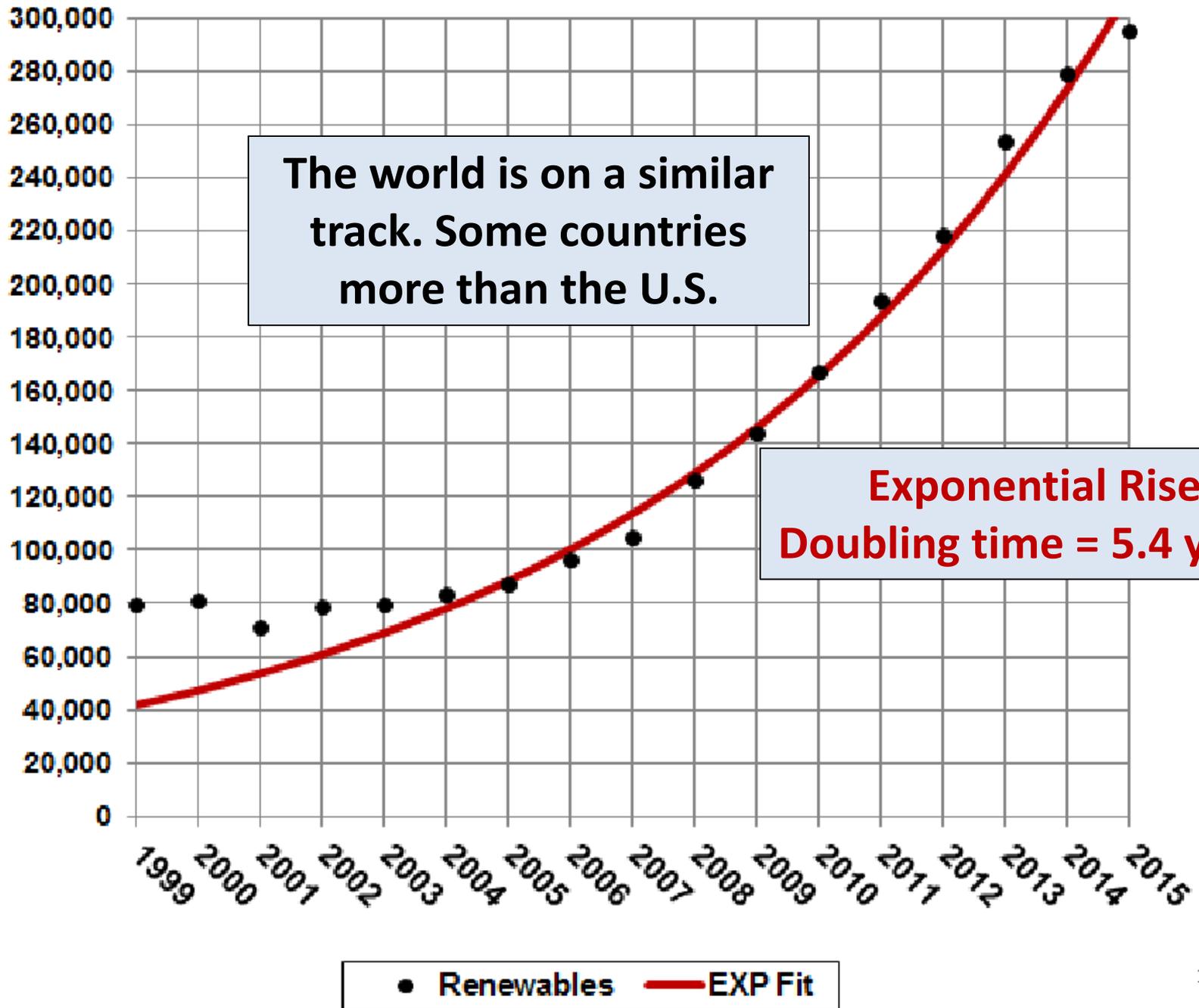
The y-axis is for CO<sub>2</sub> emissions; divide by 3.67 to get carbon emissions. <sup>103</sup>

# U.S. Reduced Grid CO<sub>2</sub> Emissions

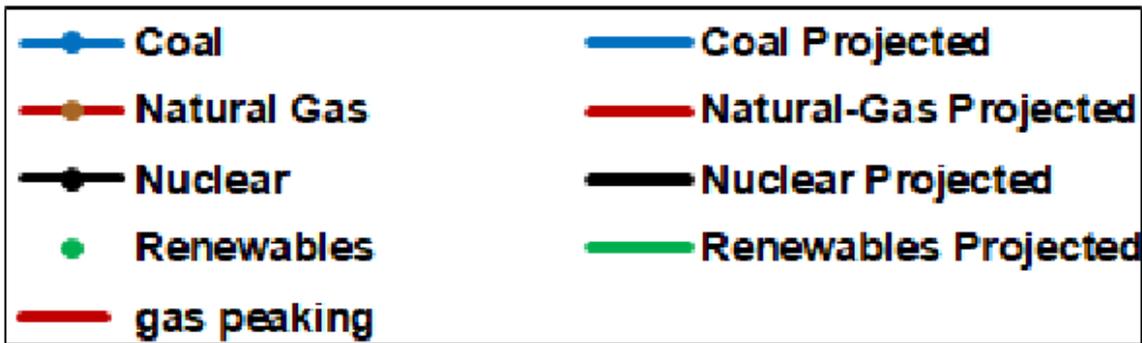
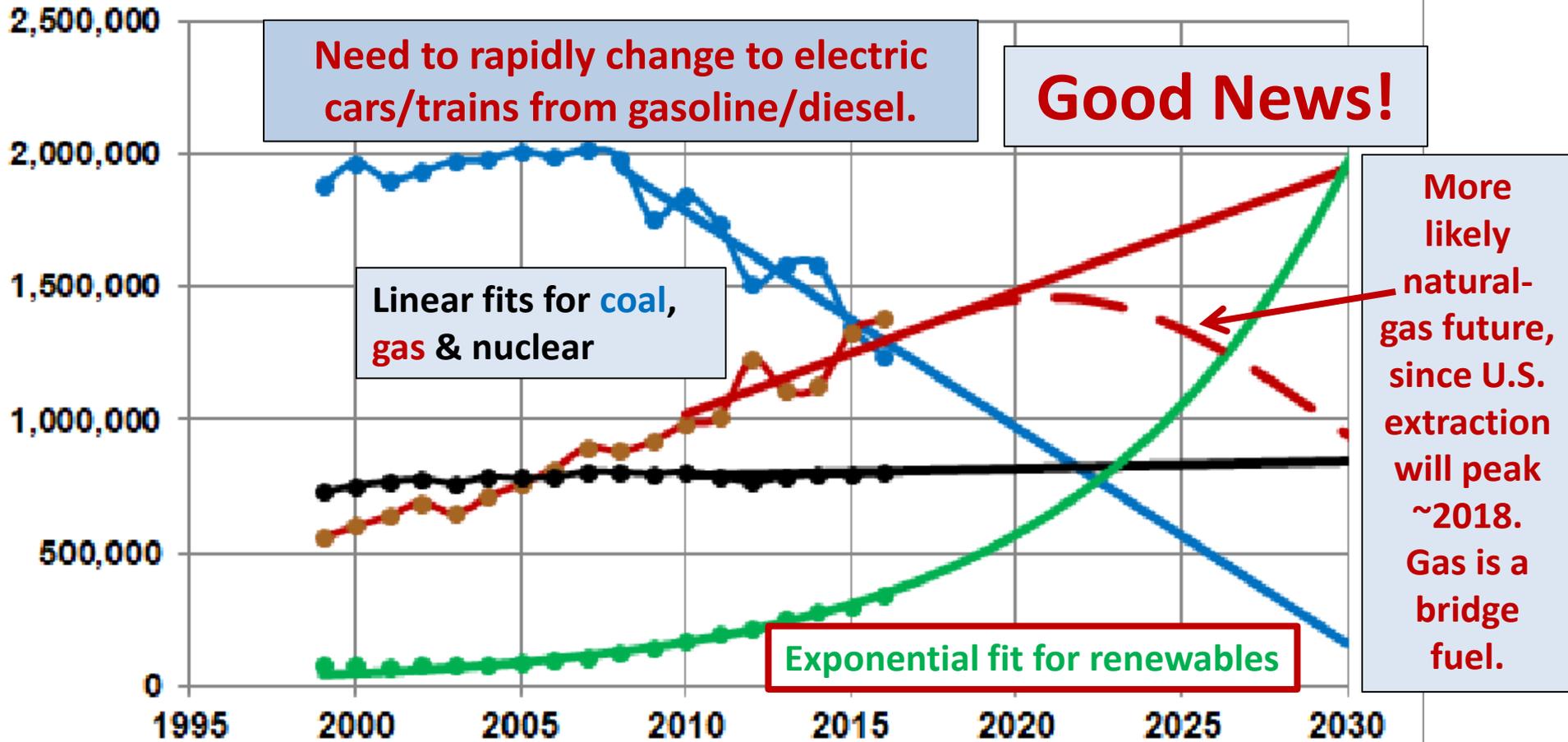
## Good News!



# U.S. Electricity from Renewables (GWhours)



# U.S. Electricity Projection (GWhours)



# Citizens' Climate Lobby

- Carbon Fee and Dividend
- Start with \$15/ton of CO<sub>2</sub>-equivalent at entry point (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, SF<sub>6</sub>, etc.).
- Methane leakage fee after initial fee @20-year GWP charged to entities responsible for leakage.
- Fee increase of \$10/ton/year until CO<sub>2</sub>e emissions are reduced to 10% of 1990 value.
- Emissions calculations will be done by U.S. Department of Energy.
- Fee will be collected by U.S. Treasury Department.

# Citizens' Climate Lobby

- Dividend (Rebates)
- Equal monthly dividend for all persons above 18-years age.
- One-half dividend for persons under 18-years age.
- Dividends limited to two children per family.
- Total monthly dividends = total monthly carbon fees.
- Administered by U.S. Treasury Department.

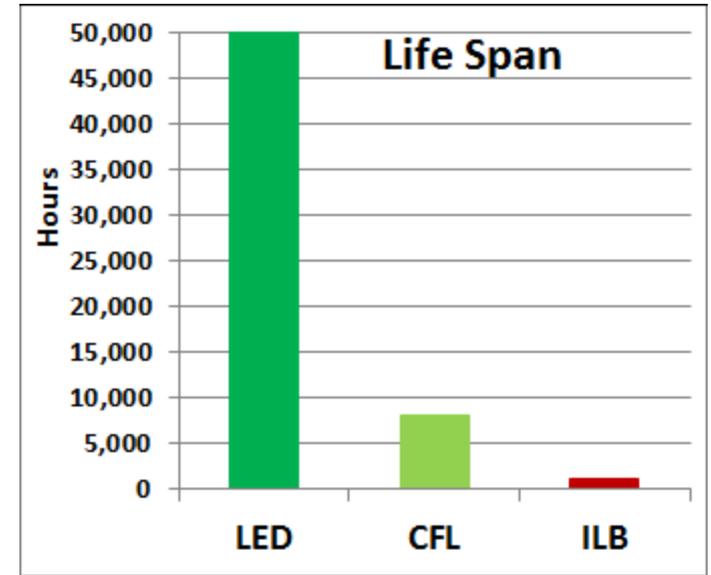
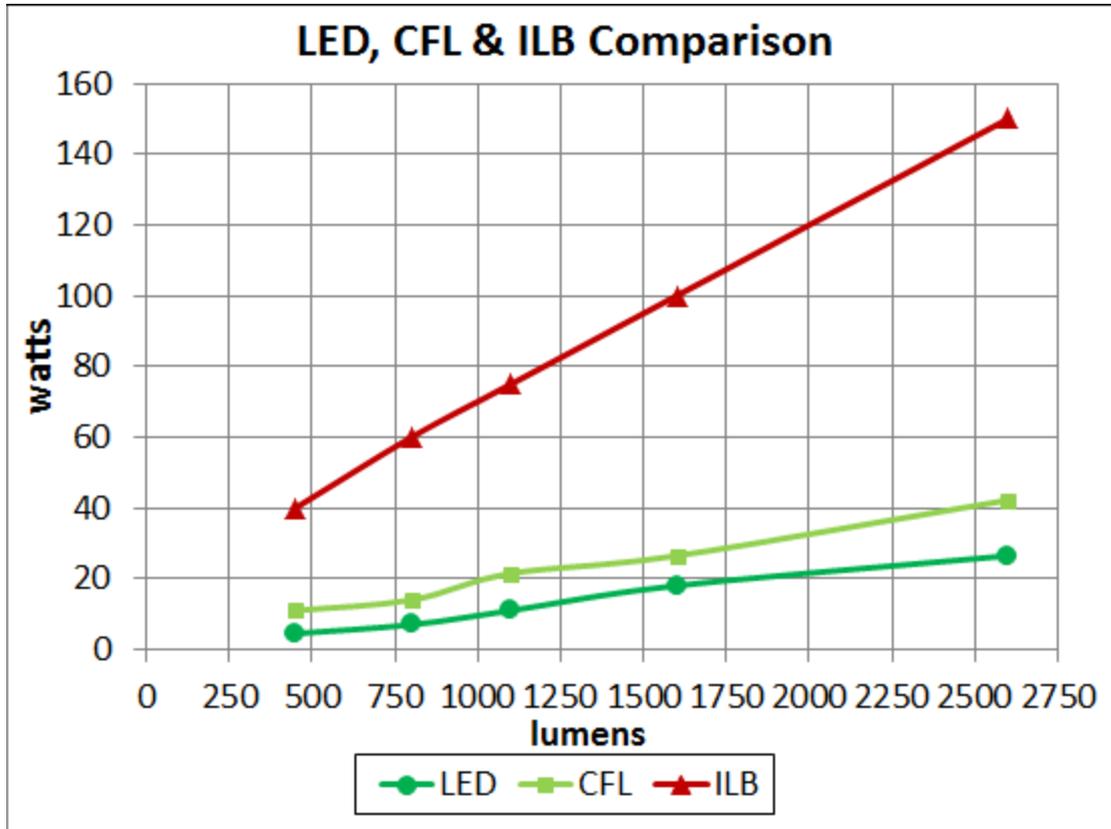
# Citizens' Climate Lobby

- Tariffs and Rebates
- Tariffs on imports from countries without equivalent controls on emissions.
- Rebates to companies that export to countries without equivalent controls on emissions.
- U.S. State Department will determine the tariffs and rebates.

# What Individuals can do

- Energy renovate your house and business.
- Install efficient heating and cooling.
- Change all lighting to LEDs. (7W = 60W-equivalent for \$1.50!)
- Install solar energy on your house and business .
- Lease a >200-miles electric car and promote fast charging.
- Advocate a fee for emitting carbon into the atmosphere.
- Advocate power companies to convert to renewable energy.
- Travel using less energy.
- Eat local food.
- Eat less meat.
- Compost food and yard waste.
- Don't drink carbonated drinks.
- Recycle everything possible.
- Donate items to thrift shops and ReStores for reuse.

# Comparison of LED, CFL & ILB Bulbs



**efficiency = lumens/watt**

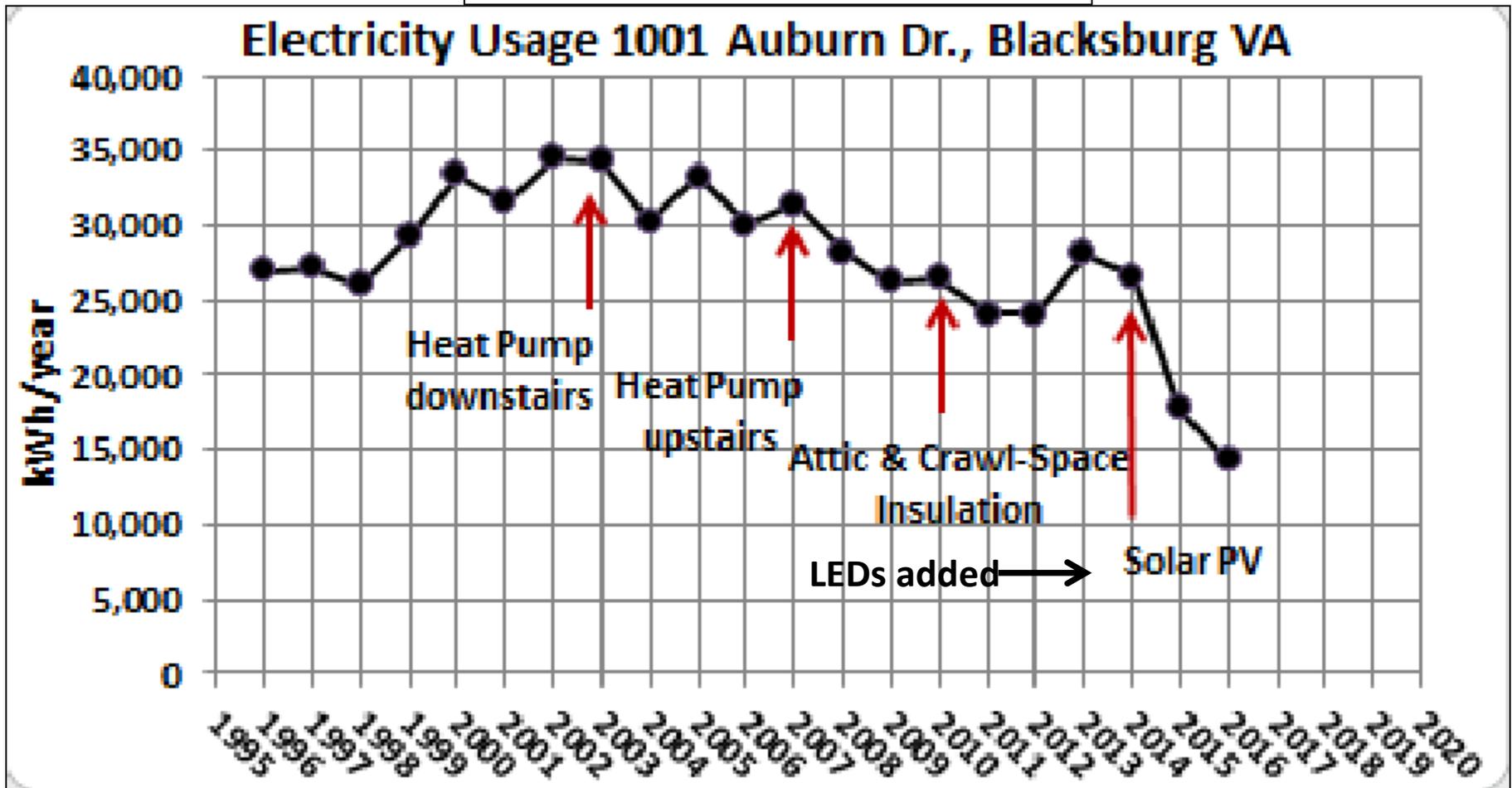
**goodness = efficiency × life-span (lumens × hours/watt)**

**LED = 41 × ILB, CFL = 6.6 × ILB**

LEDs are available in White Light (2700K) & Daylight (5000K). 111

## What my family is doing:

- Driving electric and hybrid cars
- Composting food and yard waste
- Recycling
- All LED light bulbs
- Solar PV on roof of house:



The installation of the 28 solar panels had a much larger effect than other changes.

# Midsize >200-Miles BEVs in 2017-8

[tinyurl.com/BoltEVManual](http://tinyurl.com/BoltEVManual)

[Chevrolet Bolt EV](#) (238-miles)(2017)(\$37,500)



**60-kWh battery**  
**119 MPGe EPA**  
**ECO: 140 MPGe**  
**\$7,500 federal**  
**tax credit**

**Don't confuse the Chevy Bolt EV, a BEV,  
with the Chevy Volt, a PHEV.**

# Midsize >200-Miles BEVs in 2017-8

Tesla Model 3 (>215 miles)(2018)(\$35,000)



~55-kWh battery  
15" horizontal &  
Heads-Up displays

Often called Model ≡

I expect Tesla to increase the battery size to compete with the Chevy Bolt EV range.

## Options:

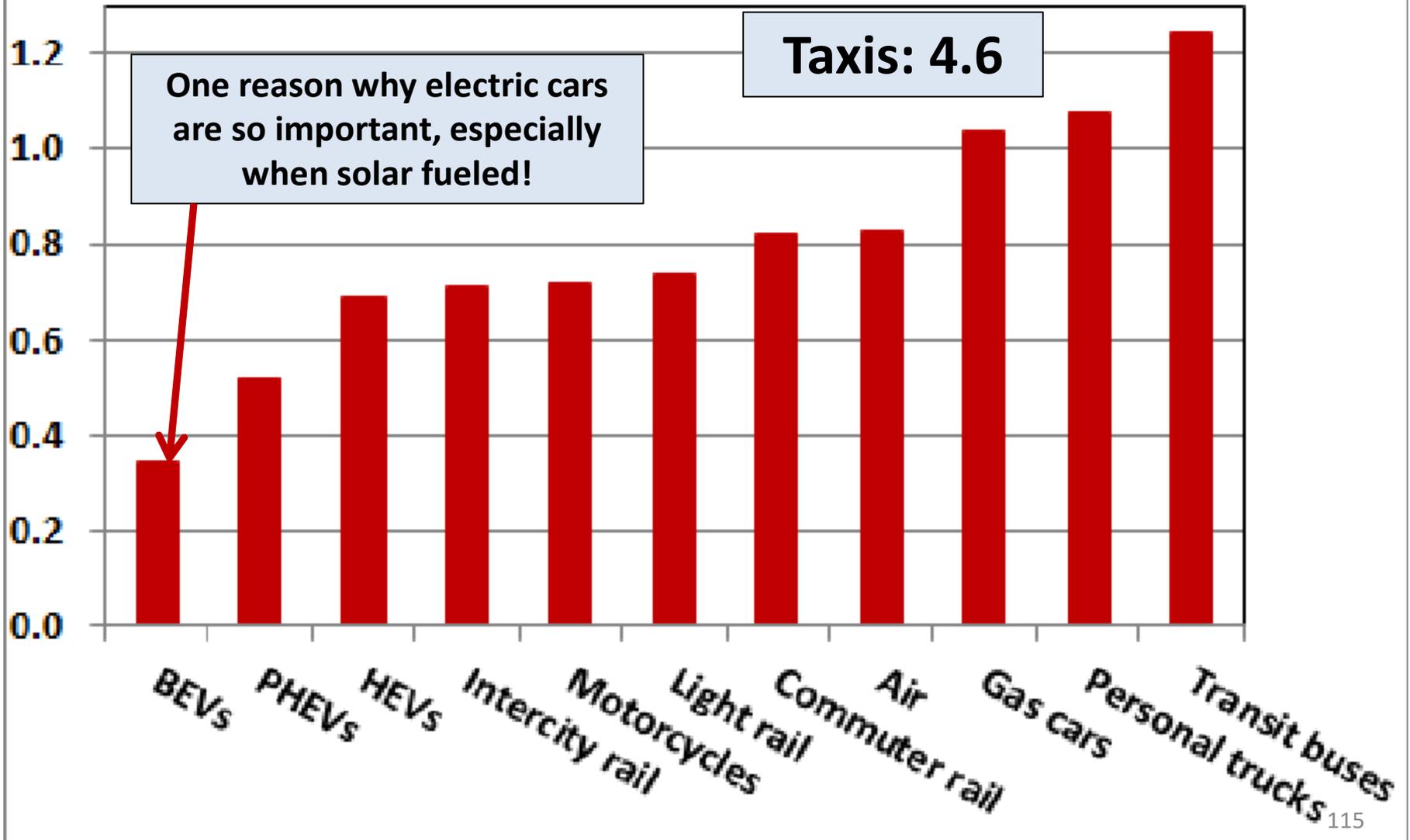
- Larger battery
- AWD
- Autopilot
- Glass roof
- Superchargers access

Establish a Grayson County electric-vehicles organization to encourage leasing BEVs or buying PHEVs.

Work with [Virginia Clean Cities](#) to get public charging stations in Grayson County.

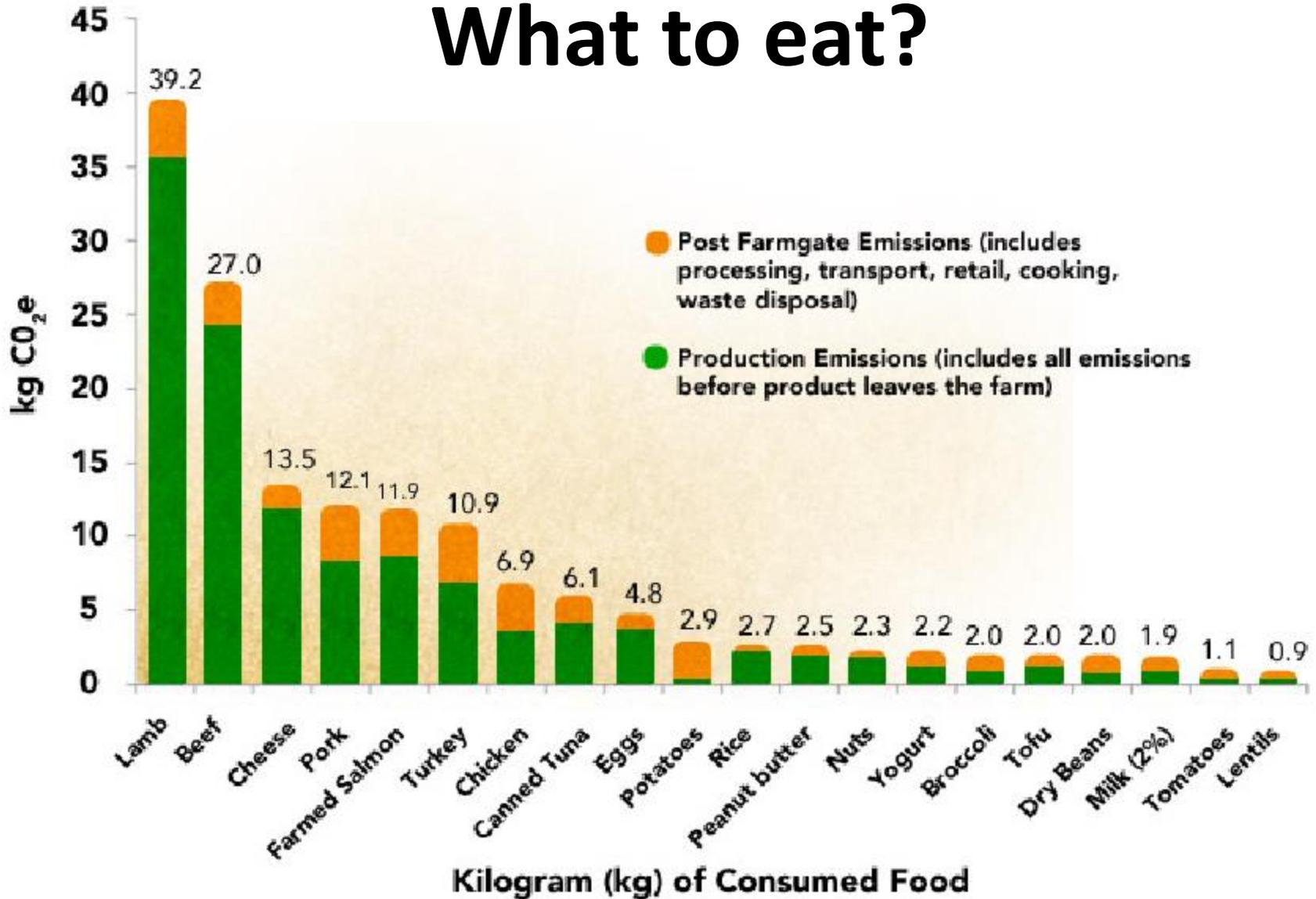
# Passenger Travel Energy Use

kWh/passenger/mile



Agriculture causes ~9% of greenhouse gases.

# What to eat?



# UN Framework Convention on Climate Change

- Keep global temperature **below 2°C above pre-industrial value.**
- Pursue efforts to **limit the temperature rise below 1.5°C.**
- Nationally Determined Contributions to reduce carbon emissions to be reported regularly.
- Global analysis every 5 years of progress.
- 55 countries responsible for 55% of emissions have ratified the UNFCCC (Paris Agreement)(U.S. & China)

# U.S. & China Cooperation on Climate Change

- Both ratified the Paris Agreement.
- **“China announced it was cancelling plans to build 103 new coal-fired plants. China is the world’s largest importer of coal, but even it is cutting back on fossil fuels and investing in renewables.”**  
**21 Jan 2017, The Roanoke Times**
- Domestically transition to low-carbon economies.
- Pledge to increase use of renewable energy.
- Organized to increase cooperation to reduce climate change.

**Global Warming may be the greatest challenge that humans have encountered in the last 10,000 years, and its effects will extend for many centuries!**

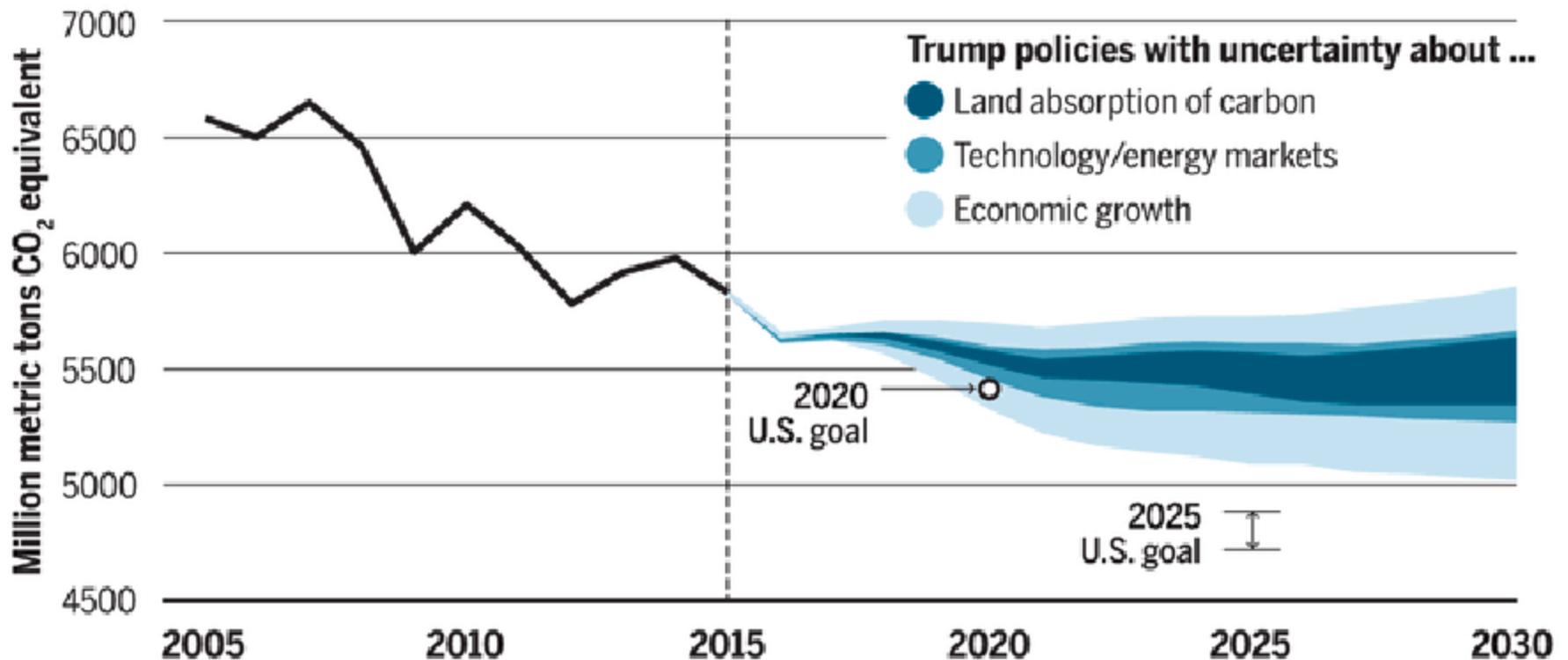
Human-made Global Warming is challenging our *Homo-sapiens*-brain and society to **recognize the truth of climate science, make plans to mitigate Global Warming and put the plans into action.** We are having trouble doing all three.

**The underlying problem is too many people wanting too many resources. Free global birth control is needed!**<sup>119</sup>

# Need for U.S. GW-Reduction by 2020

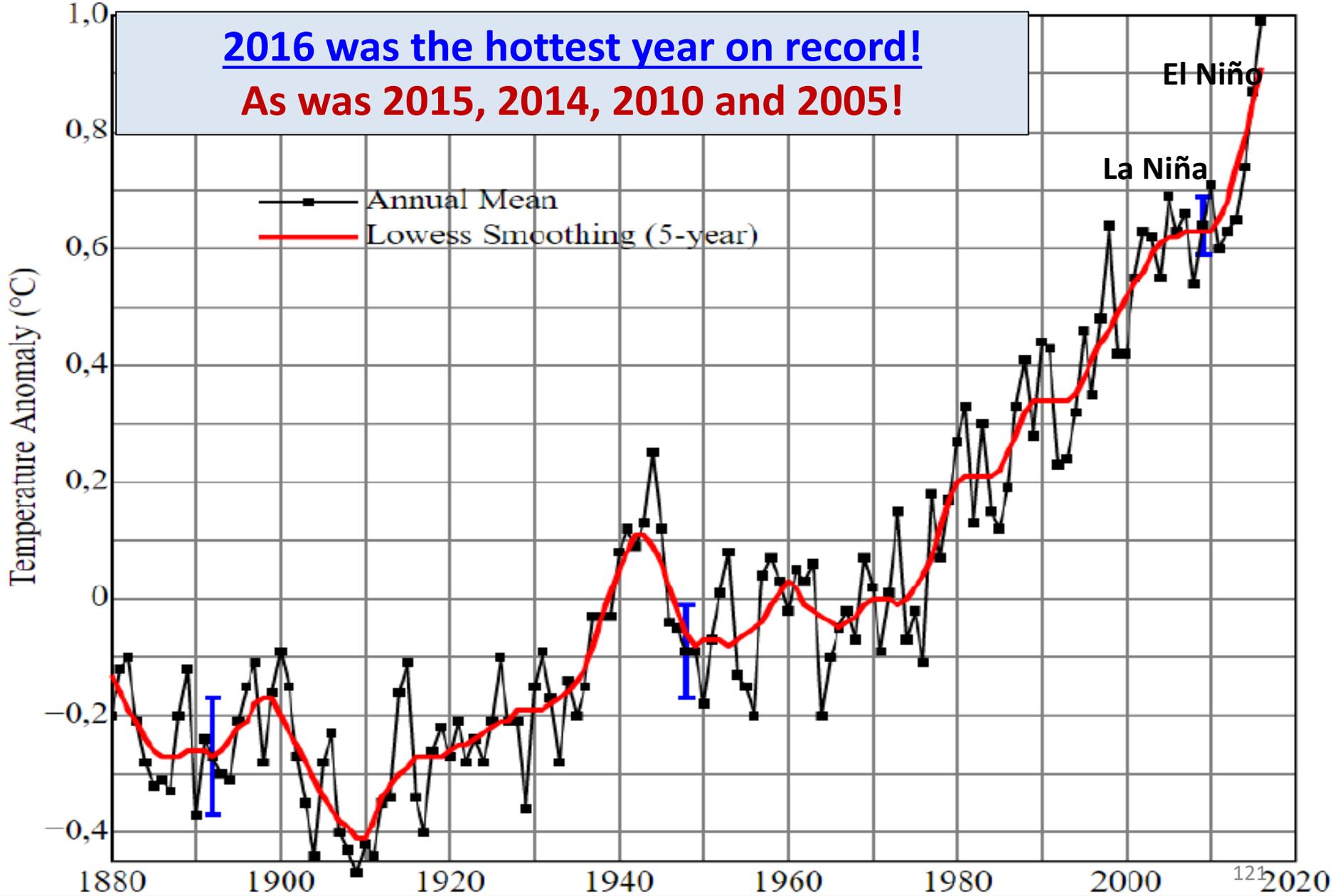
## No road to Paris

Even if many major Obama administration climate policies are eliminated, U.S. emissions are projected to fall over the next few years. After that, uncertainties about technological change, economic growth, and how much carbon terrestrial ecosystems can absorb affect projections, but the 2025 U.S. goal is out of reach in all scenarios.



# Global Land–Ocean Temperature Index

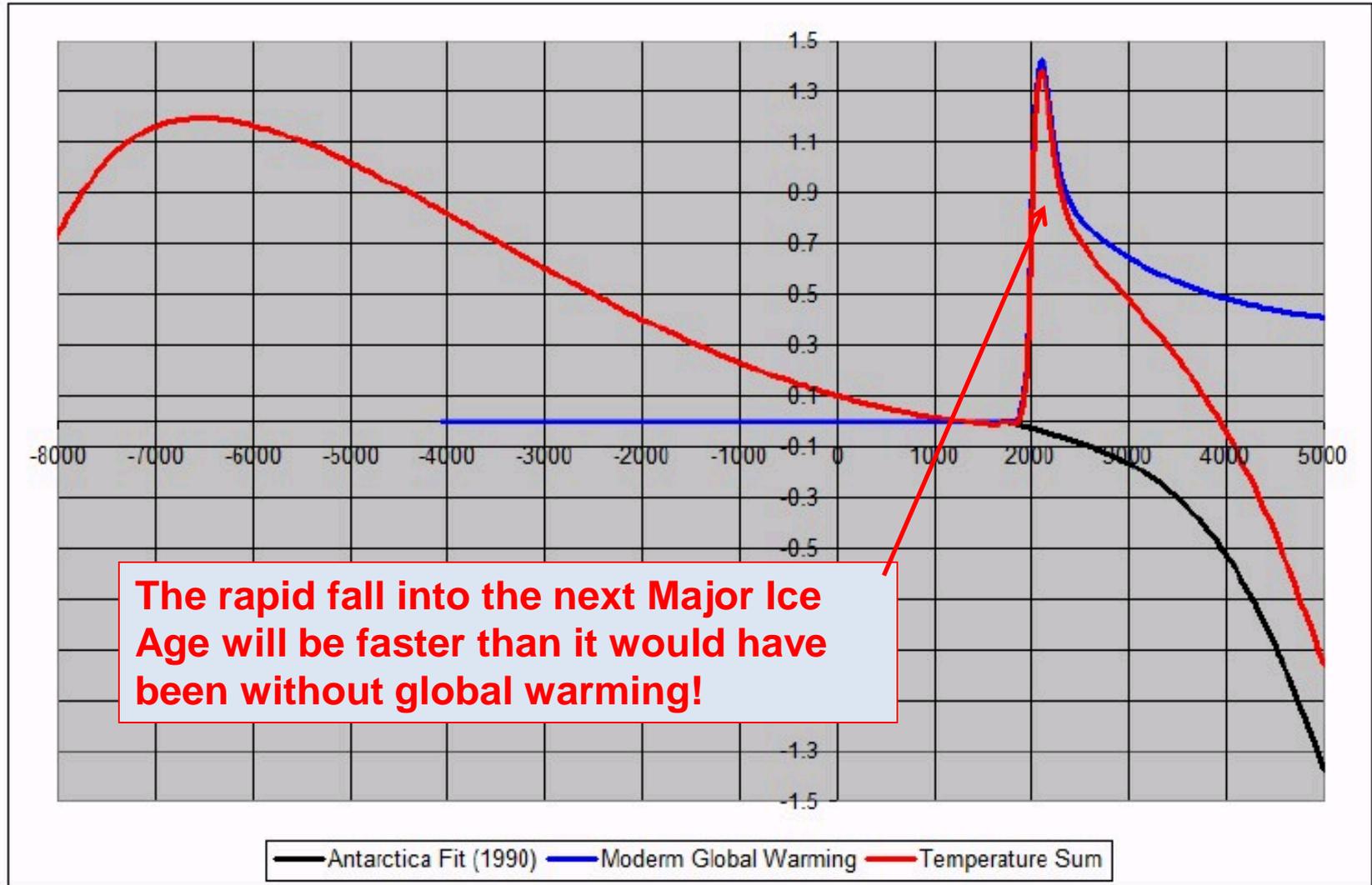
**2016 was the hottest year on record!**  
**As was 2015, 2014, 2010 and 2005!**



# Far Future

- Without global warming the global temperature would be dropping the Earth into the **next ~120,000-years ice age.**
- After fossil fuels are gone, the **temperature drop into the next major ice age will be faster** than it would have been without global warming.
- If a **nuclear war**, say between Pakistan and India, occurs or a large asteroid collides with the Earth, a “nuclear winter” may cause global cooling for a decade or longer and **may trigger the next ice age.**
- Should we be **storing the carbon dioxide due to burning fossil fuels** to release it later to slow down the entry into the next ice age?

# Adding Modern Global Warming to Neolithic Global Warming and Fall into the Next Major Ice Age



Temperatures are normalized to 0 at year 1700.

Will probably be much more global warming than shown here.