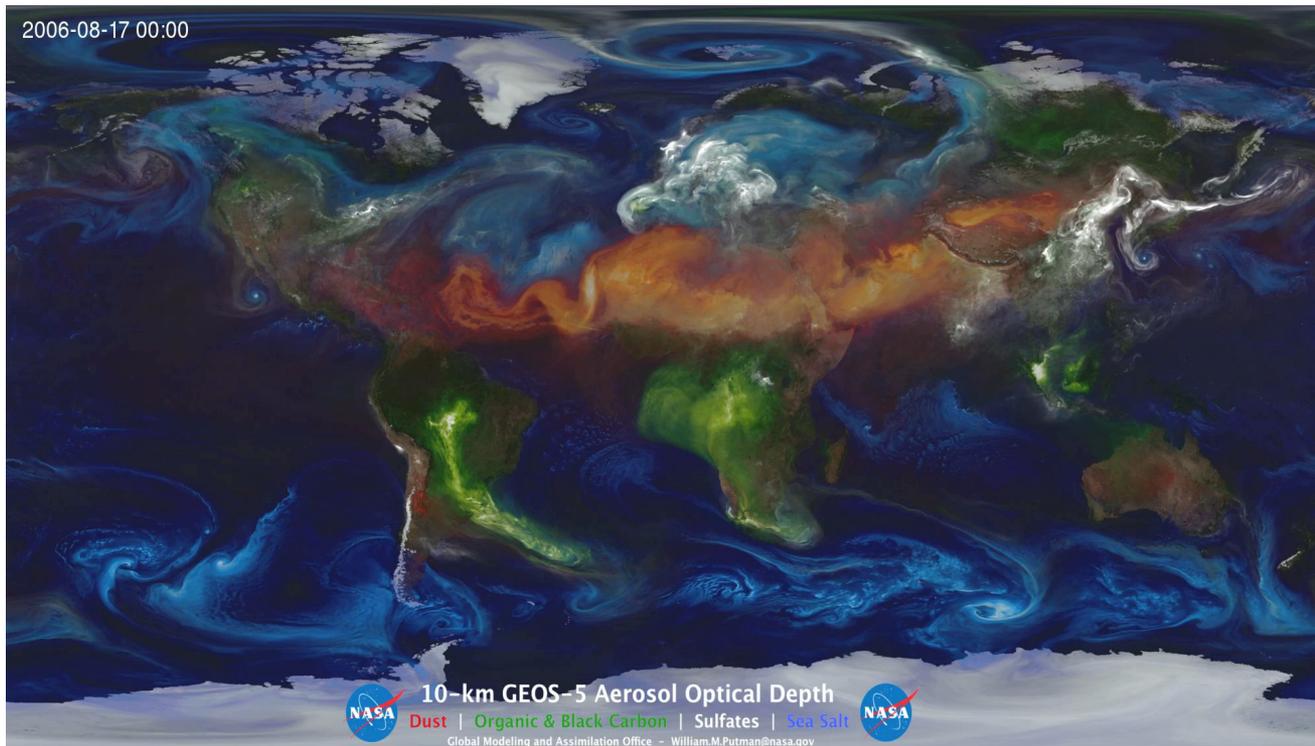


Saturday Morning Physics - February 11, 2017

# The Science of Climate Change

Dr. Erik Ramberg, Fermilab



# Three Key Concepts to Walk Away With:

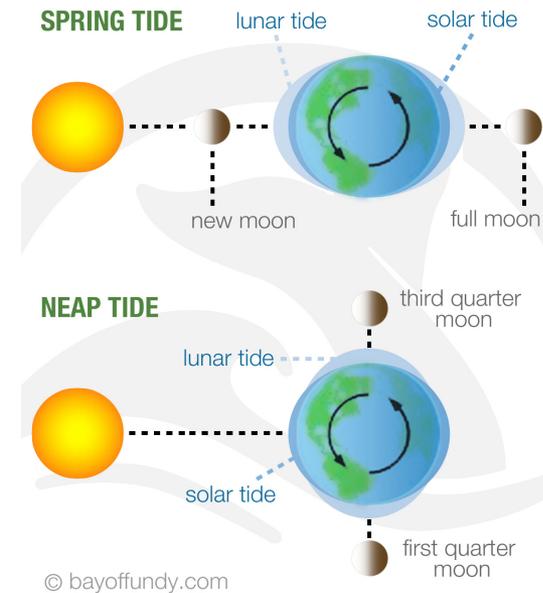
- **The Earth's climate is predictable**
- **The 2 major climate control knobs are:**
  - **The amount of sunlight that is reflected-ICE & DUST !**
  - **The amount of heat that is trapped -CO<sub>2</sub> !**
- **Global temperature is still rising and ice sheets are still melting. There is no pause in the Greenhouse Effect.**

# An Analogy about Predicting Climate:

Nobody can predict what the height of any given wave will be at the seashore:

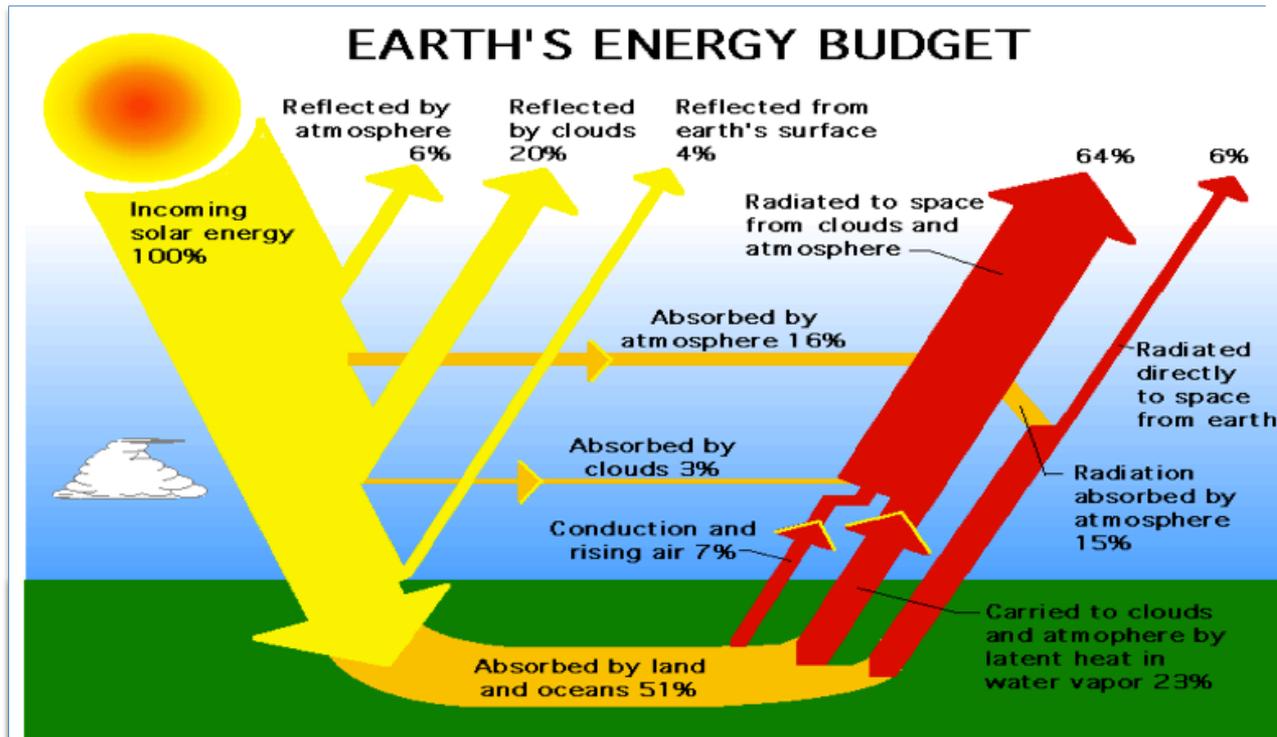


But the timing and magnitude of the tides (the 'average height') is quite predictable:



**Similarly, it is hard to predict the Earth's temperature for any given year, but the slow, steady change of its' climate is quite predictable**

# Energy flow in the Earth system



Without normal greenhouse gases in our atmosphere:

**0° F**

On Earth's surface

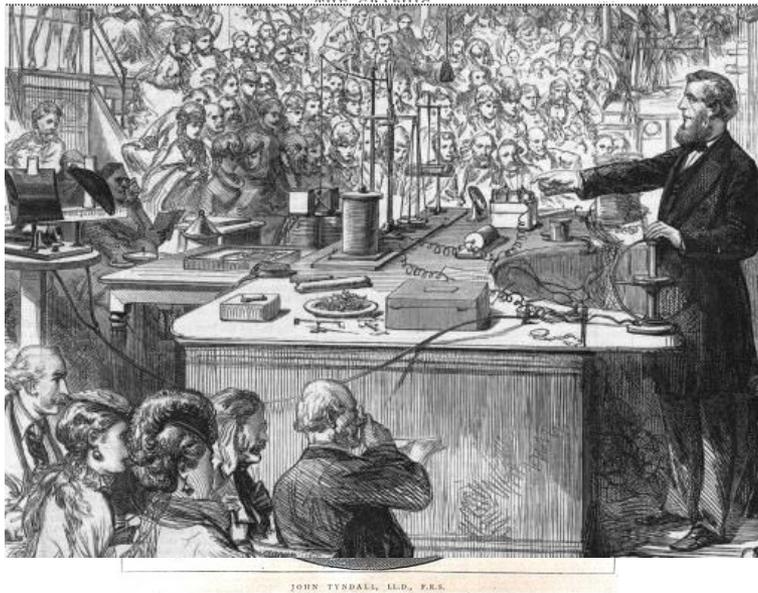
With normal greenhouse gases in our atmosphere:

**60° F**

On Earth's surface

**CO<sub>2</sub> absorbs infrared light by bending and stretching its chemical bonds and then re-emits infrared in all directions.**

***(Discovered by John Tyndall in 1865)***



Tyndall showed that water vapor (H<sub>2</sub>O) and methane (CH<sub>4</sub>) trap heat also

All 3 gases cause trapping of some of the infrared heat coming from the surface of the Earth:  
... the **Greenhouse Effect** !

# Greenhouse Effect predicted in 1896 by Nobel prize winner Svante Arrhenius:

“.. any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4° ...”

**Guess what? His predictions still hold up today, 118 years later!**

**Doubling of CO<sub>2</sub> is expected to raise temperatures between 2.5-4 degrees**

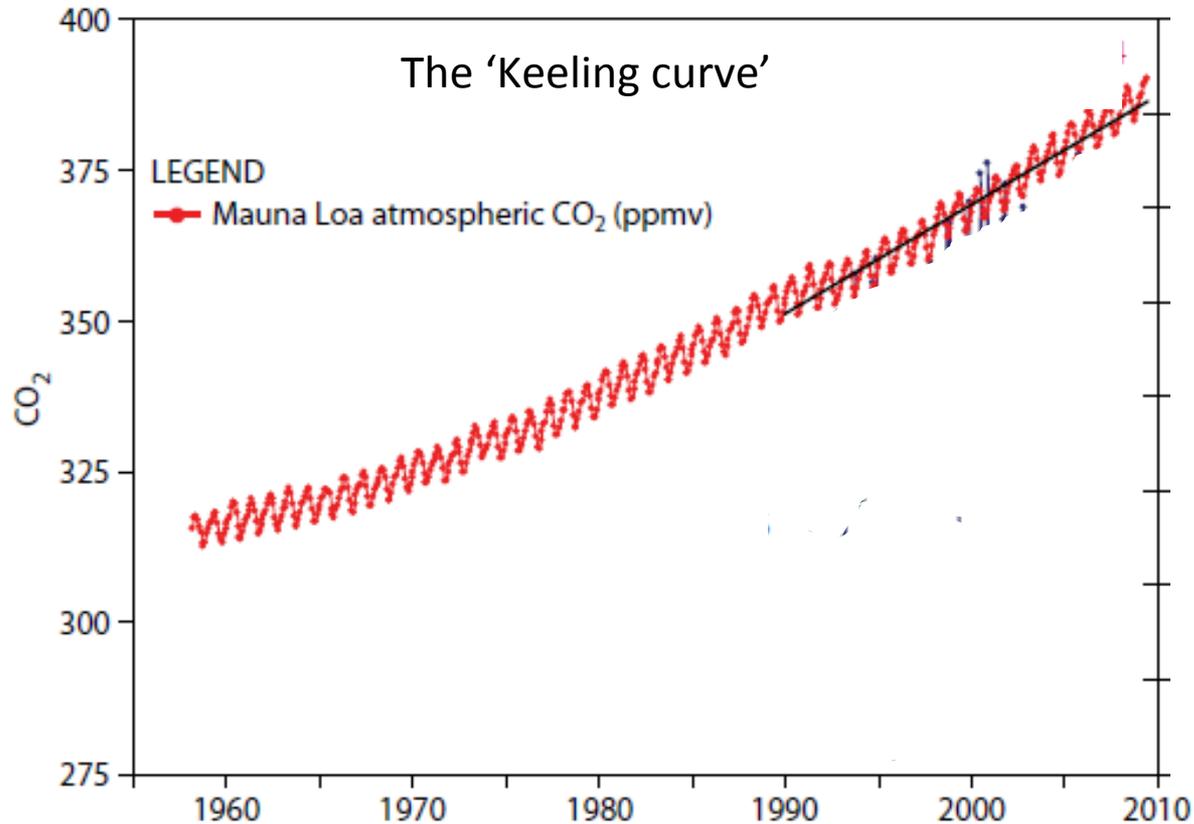


If water vapor is a stronger greenhouse gas than carbon dioxide, then why do we have a CO<sub>2</sub> problem, not an H<sub>2</sub>O problem ?



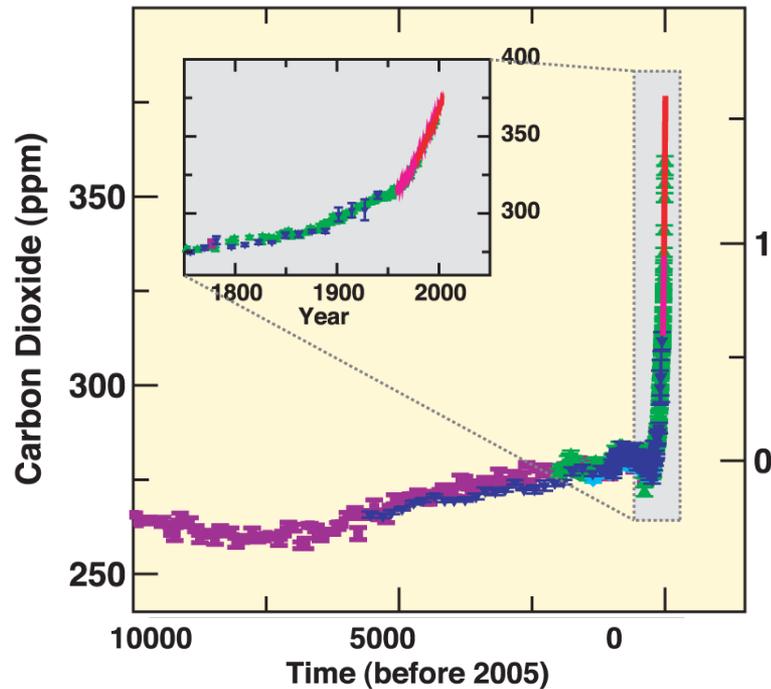
The lifetime of water in the atmosphere is about a week, while the lifetime of CO<sub>2</sub> in the atmosphere is on the order of 100 to 1000 years.

# CO<sub>2</sub> in the Atmosphere

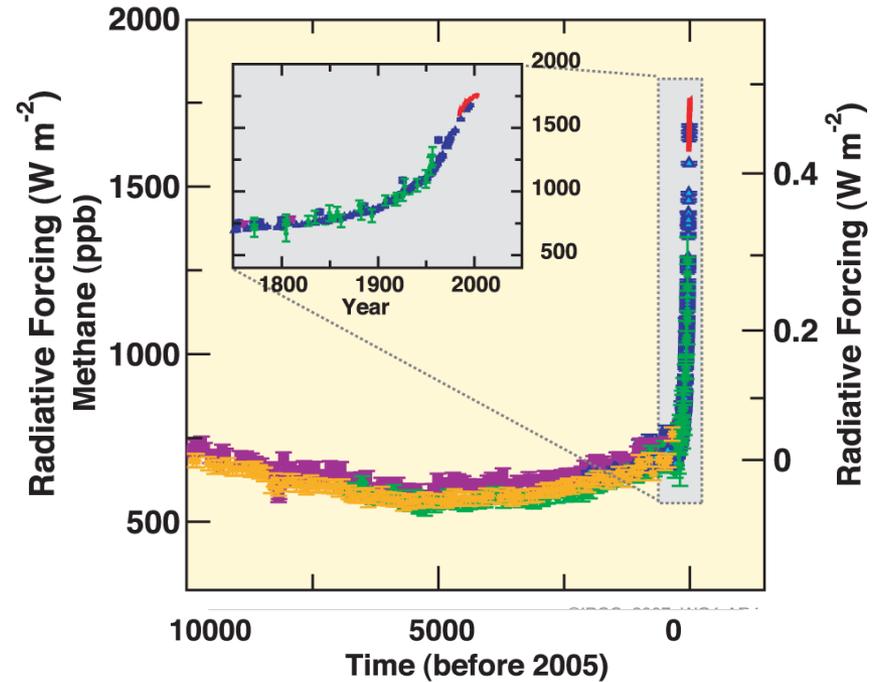


- The burning of fossil fuels is causing the CO<sub>2</sub> concentration in the atmosphere to rise significantly. Isotopes show this is fossil based CO<sub>2</sub>.
- The ocean is getting significantly more acidic as a consequence. This is actually less than what we predict from industrial processes. Where is the rest of the CO<sub>2</sub>?

# CO<sub>2</sub> and other Green House Gases (GHG) are now the dominant elements of climate forcing,

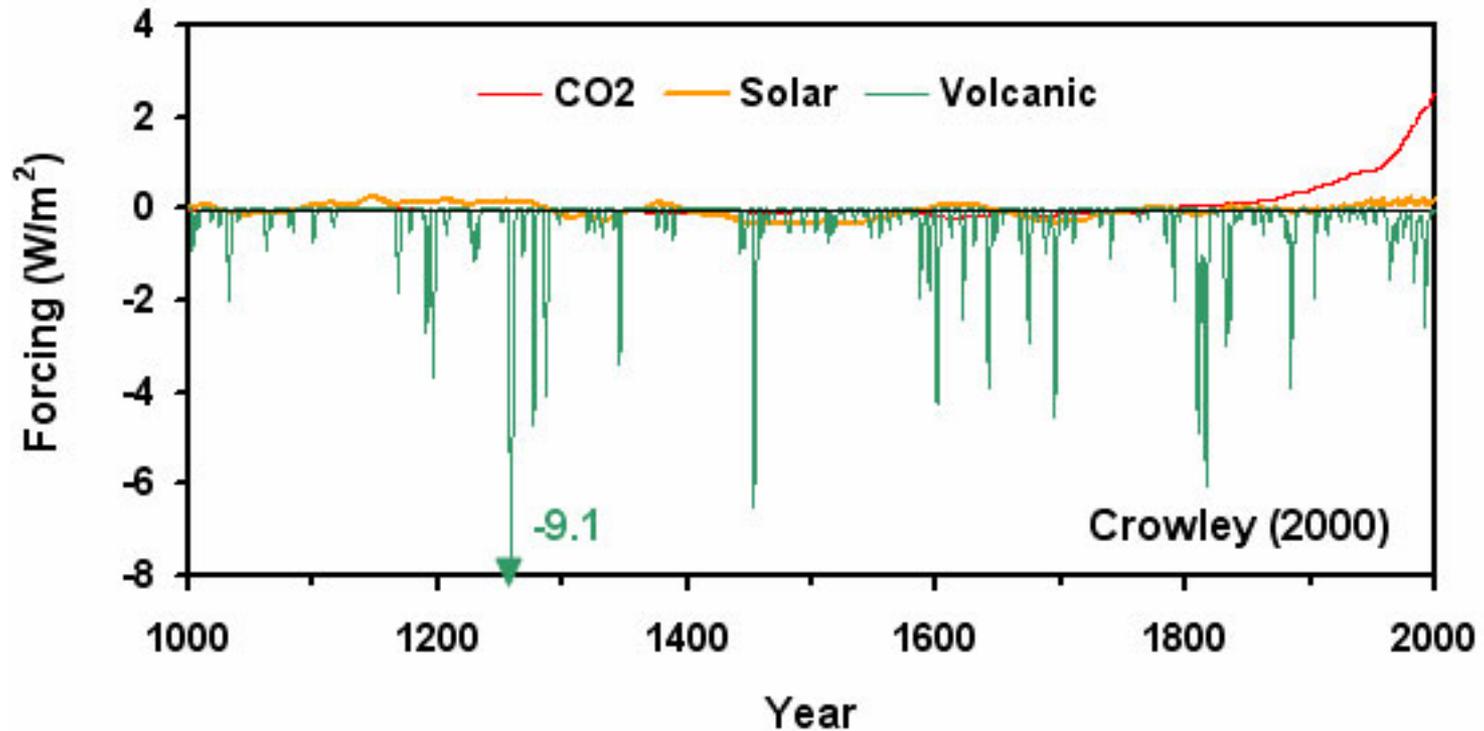


CO<sub>2</sub>



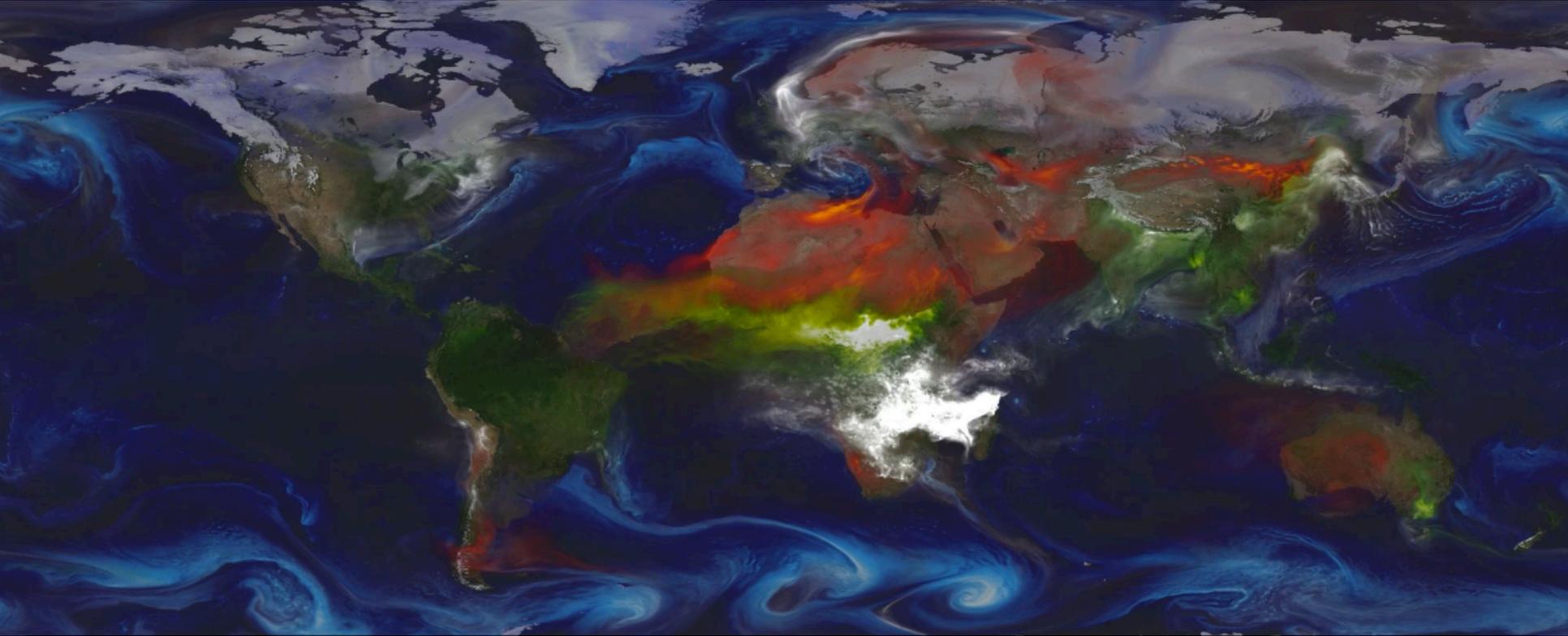
Methane

# Forces acting on the climate



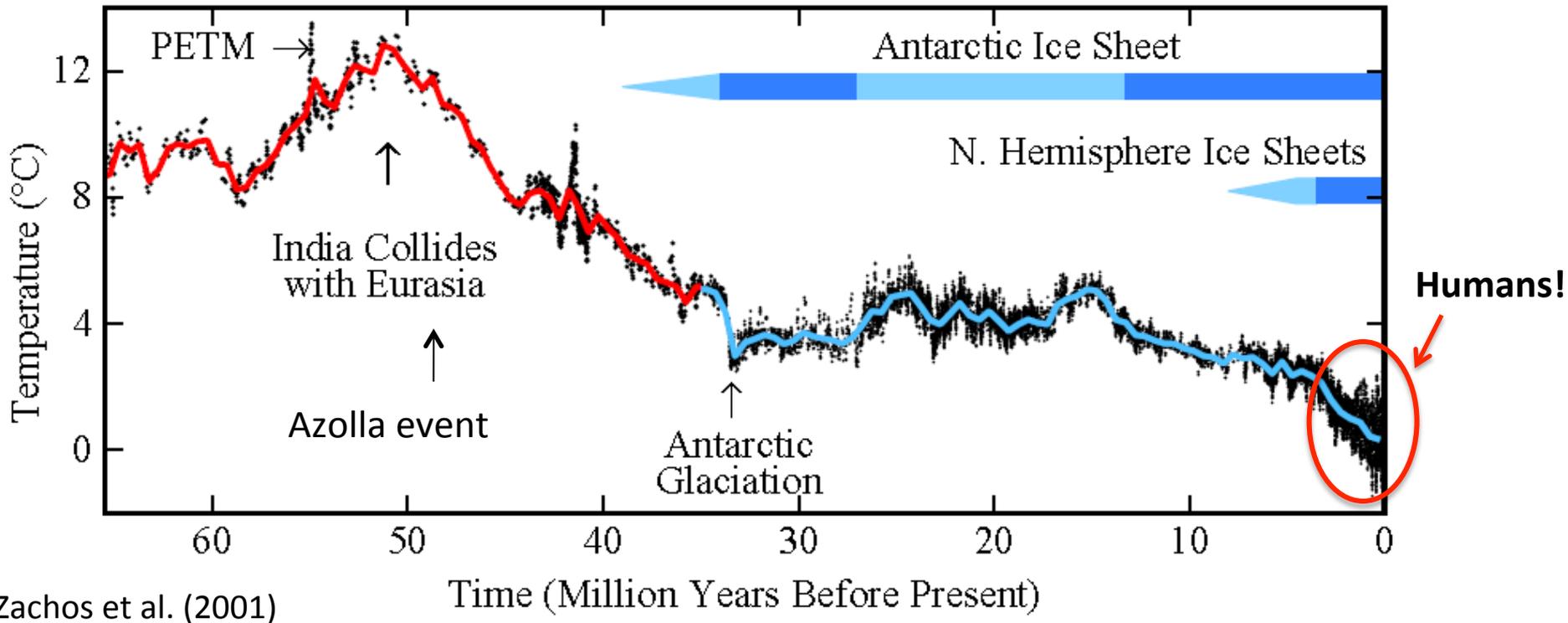
- Volcanoes have a big effect on climate, but last for a very short time
- Variations in sunlight are small
- The biggest effect on the climate is the blanket of CO2 we are putting up into the atmosphere

# Volcano Exploding in Madagascar



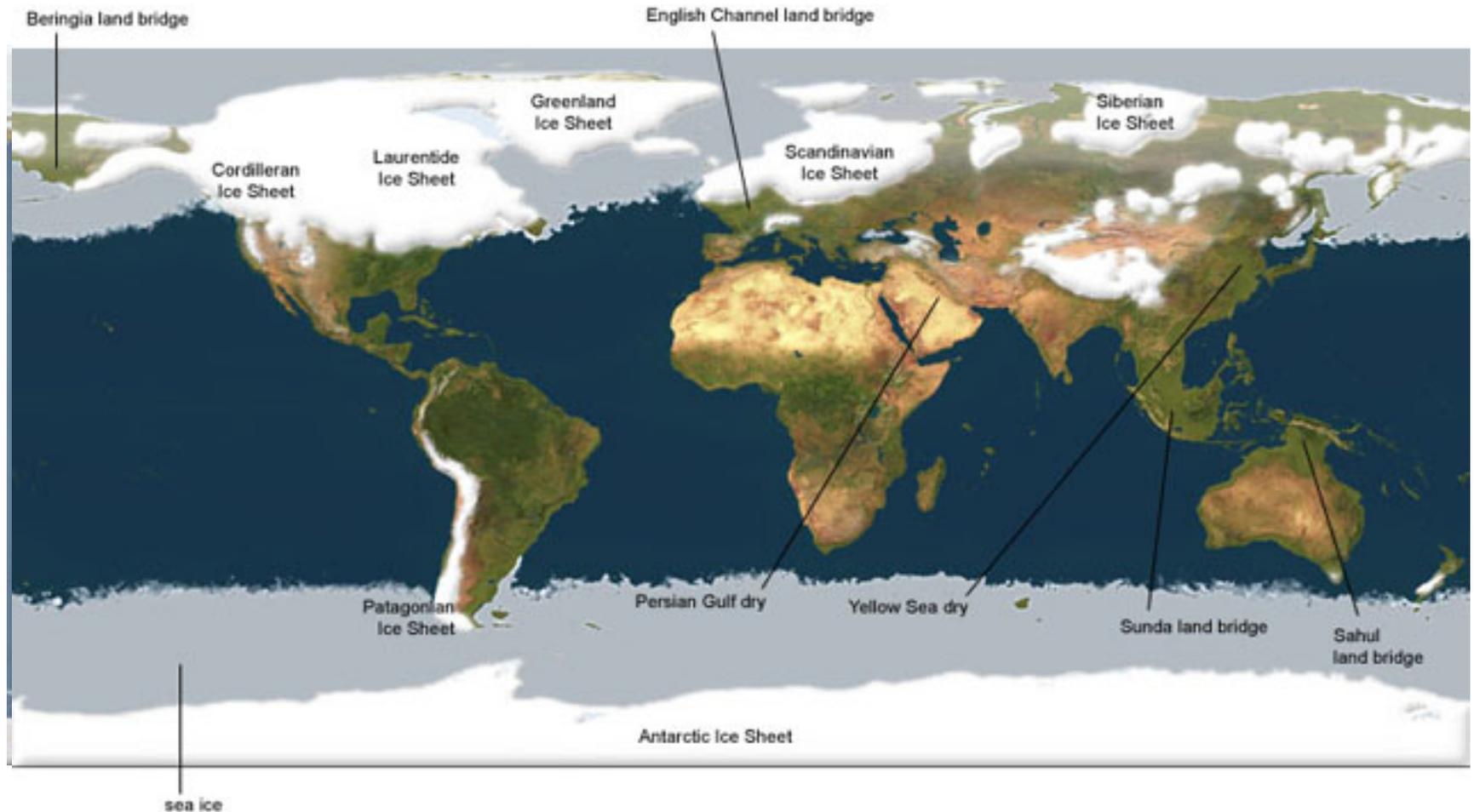
- Volcanic dust (an 'aerosol') has a powerful cooling effect on climate.
- But, like water, the aerosols fall out of the atmosphere - in about 1-2 years

# The Sloooow Change in Climate



- 50 million years ago Earth was hot and ice-free (~12 degrees hotter).
- The change of CO<sub>2</sub> in prehistory was ~1 ppm every 10,000 years  
The change of CO<sub>2</sub> now is ~1 ppm every 8 months

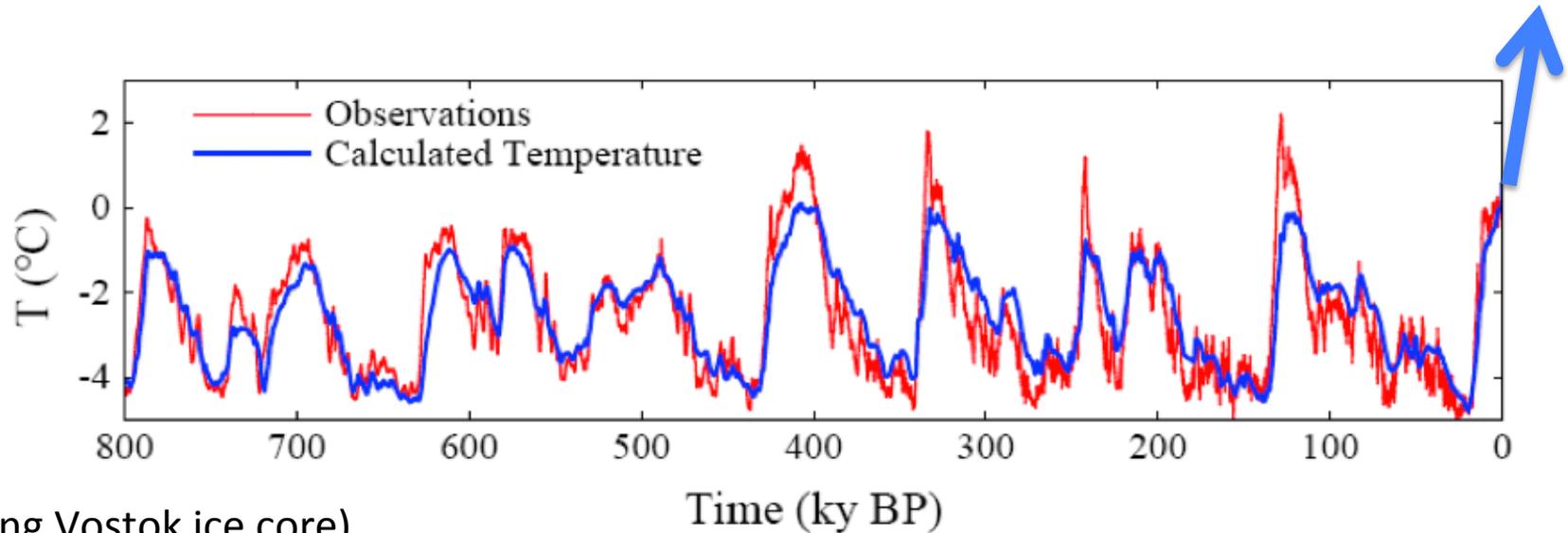
# Ice Sheets During Last Ice Age



Two important changes that accelerate the freezing:

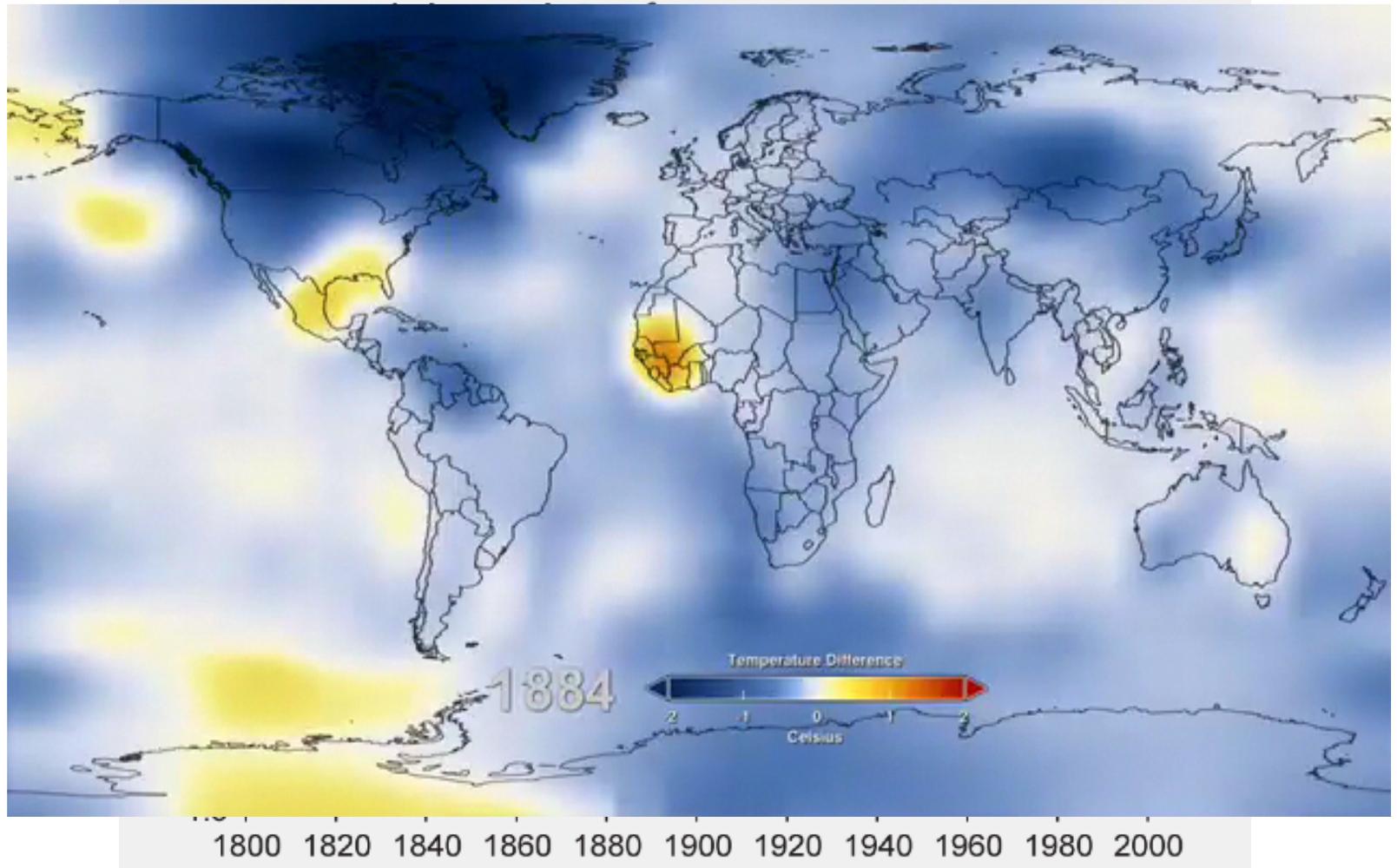
- 1) High reflectivity from the new ice
- 2) The cooling ocean absorbs  $\text{CO}_2$

# The Ice Age Climate is Predictable



- We understand all the cycles and bumps of the last 800,000 years.
- From this data, we now know that mankind will shut off the Ice Ages forever. (Yay!)
- Unfortunately, we will likely start climbing up the temperature curve back into the Eocene Era. (Boo!)

# NASA Gridded Mean Surface Temperatures Over 125 years

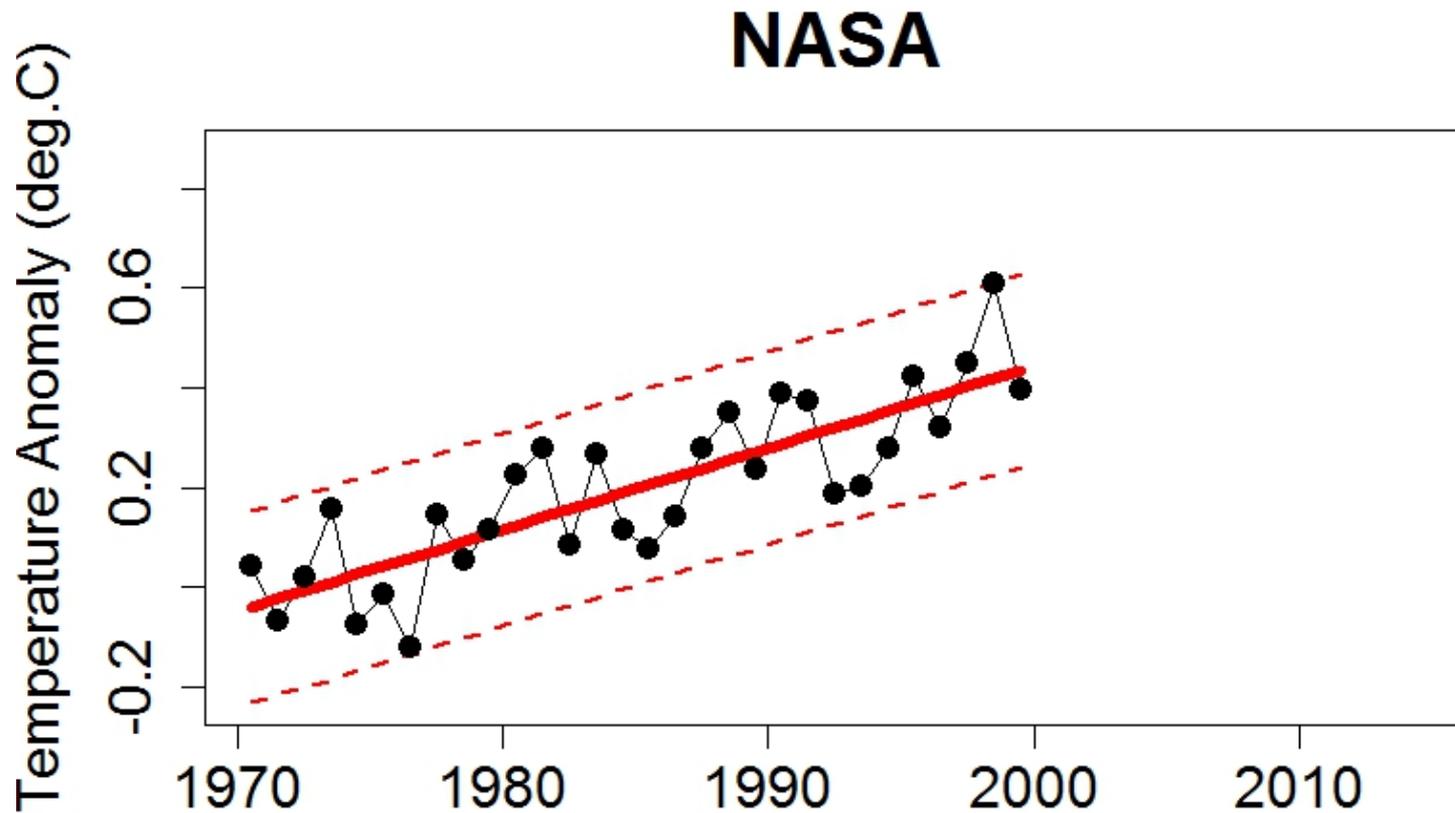


- The increase of heat into the atmosphere, ocean and land (compared to pre-industrial times) is equivalent to 4 Hiroshima size bombs...

every second

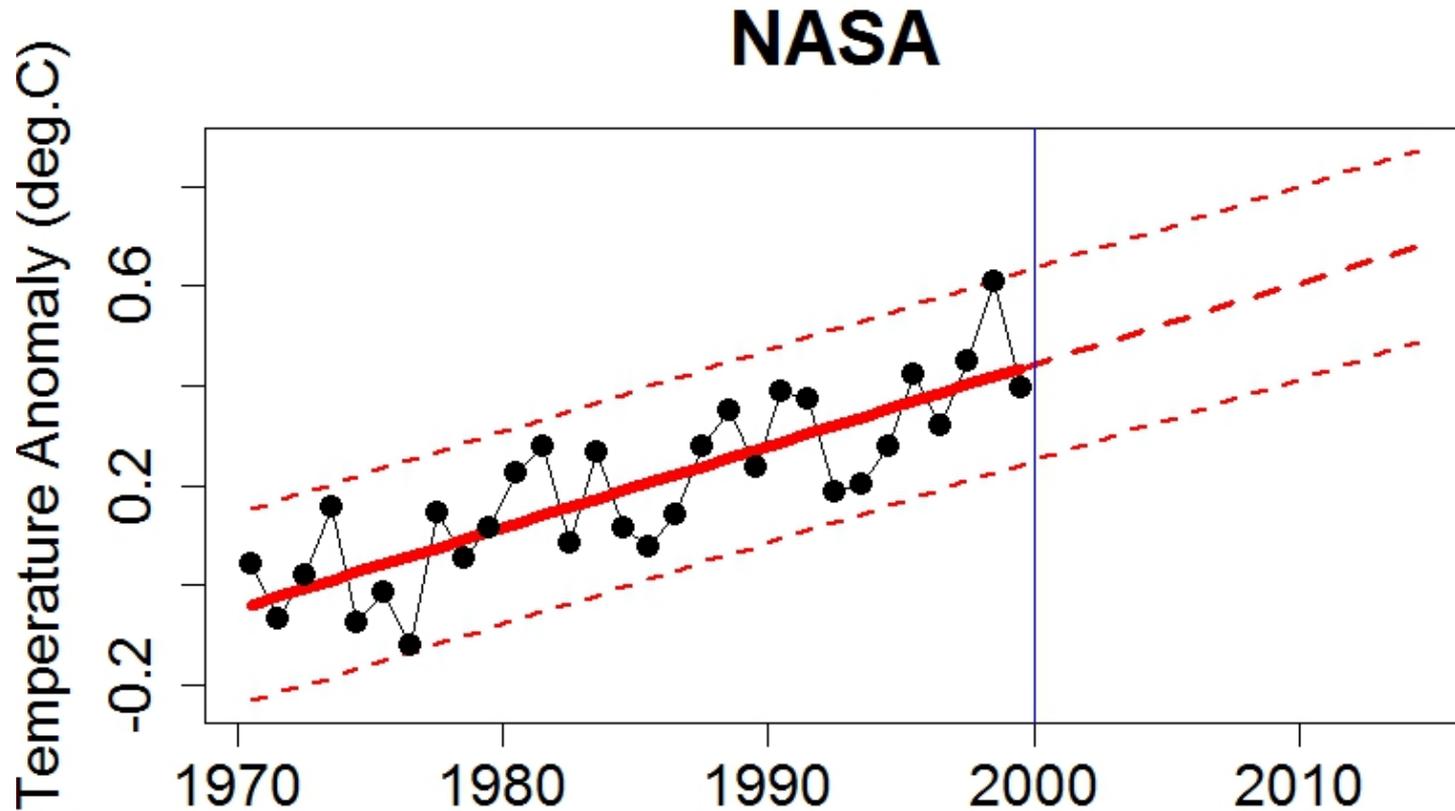
# The famous 'PAUSE' in global warming

- Take NASA's data on global temperatures up to the year 2000:



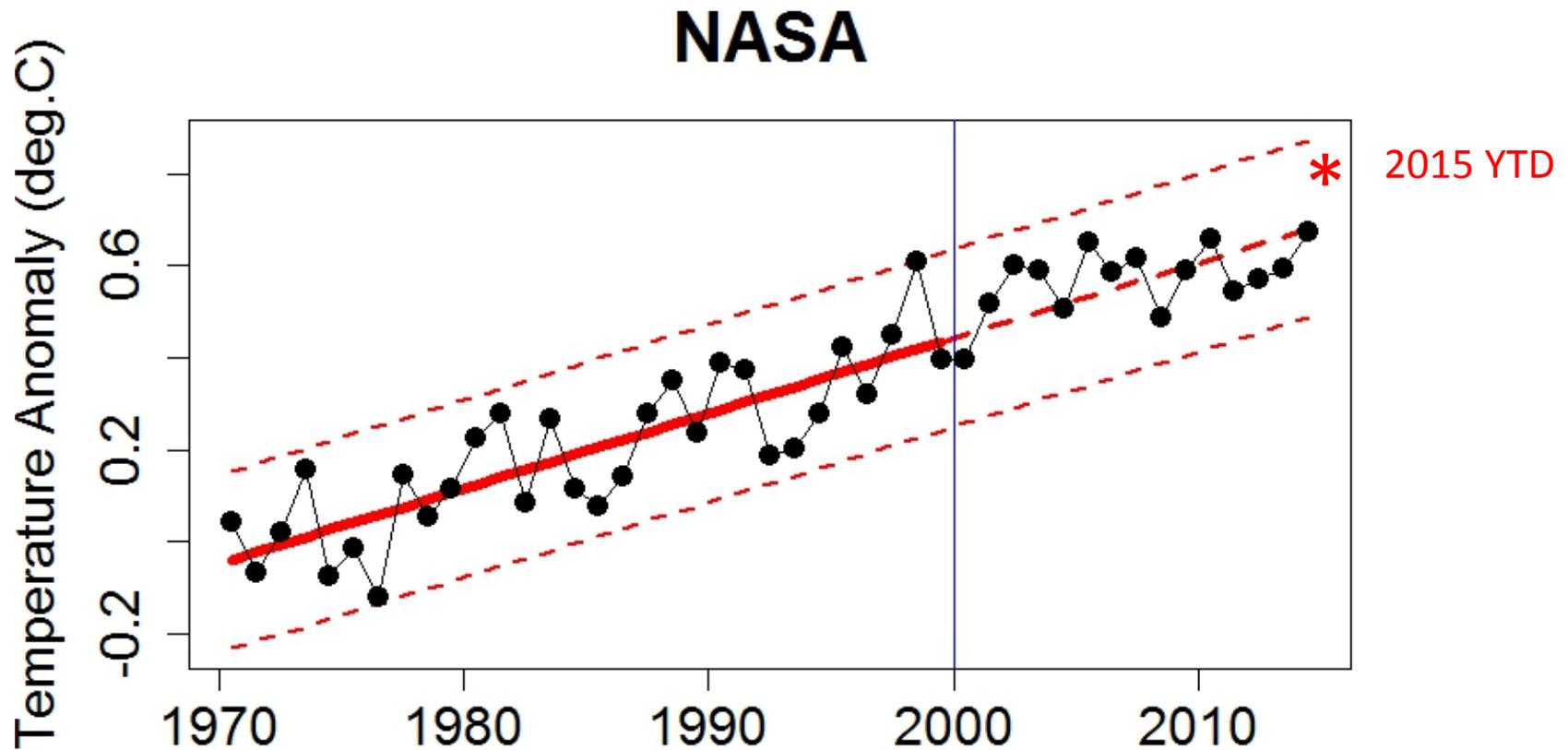
# The famous 'PAUSE' in global warming

- Extrapolate trend to the year 2014:



# The famous 'PAUSE' in global warming

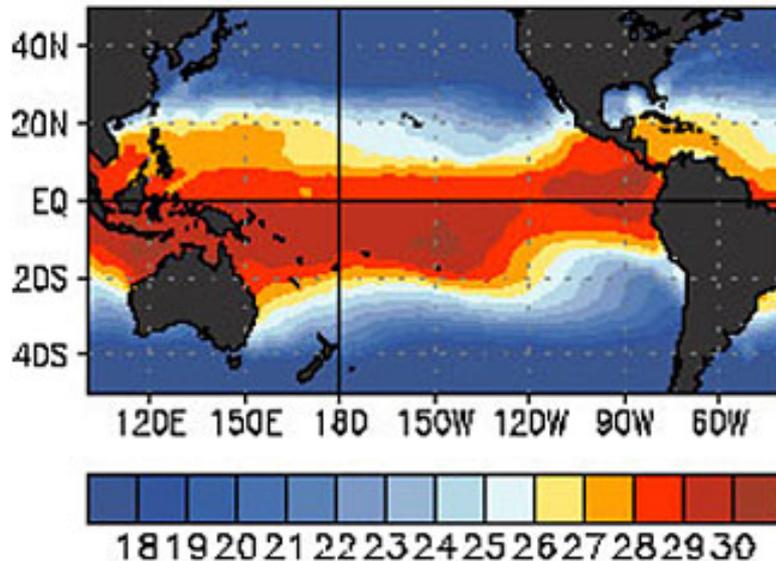
- Add the data since 2000. A 'Pause' never occurred



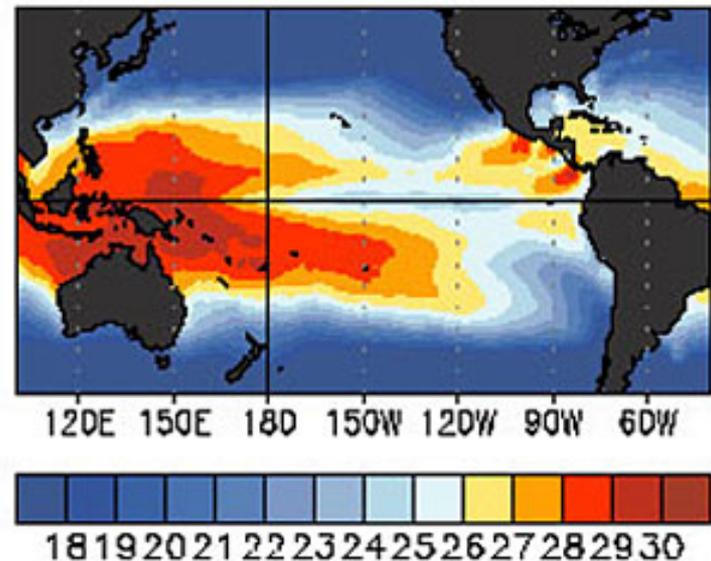
# El Nino (& La Nina) – Southern Oscillation (ENSO)

## OCEAN TEMPERATURES (°C)

**EL NIÑO**  
Jan-Mar 1998



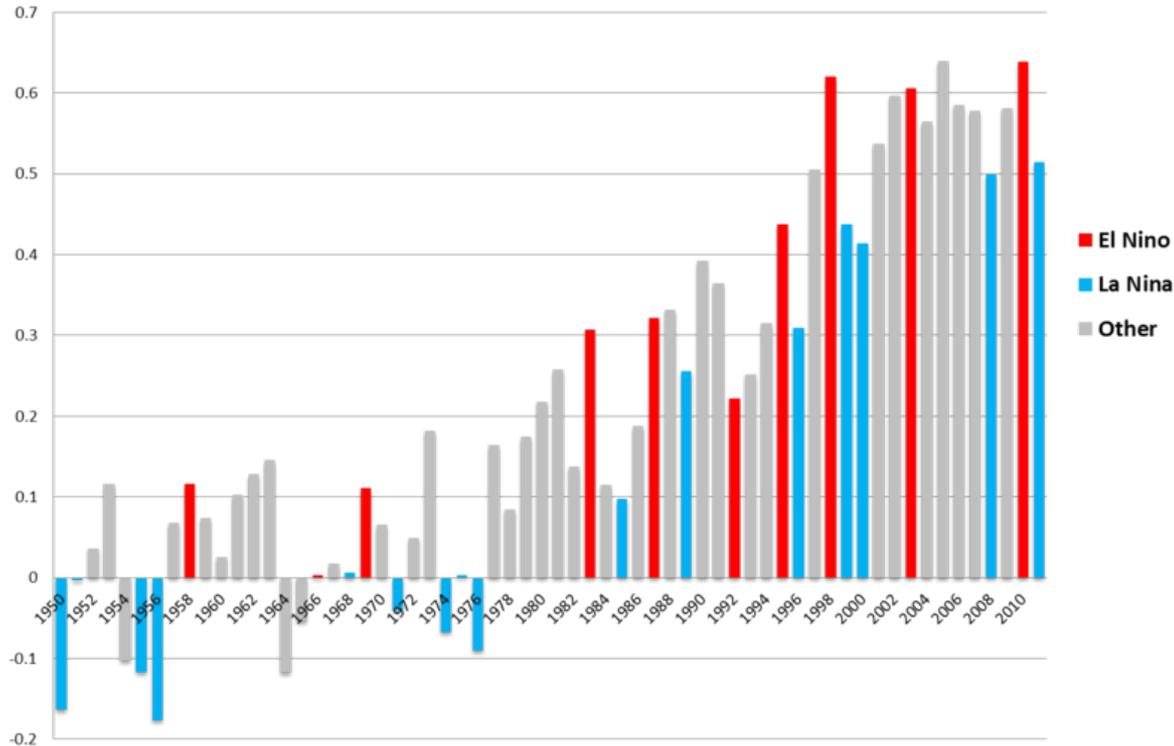
**LA NIÑA**  
Jan-Mar 1989



El Nino: High atmospheric pressure in the western Pacific causes heat flow eastward. La Nina is the reverse.

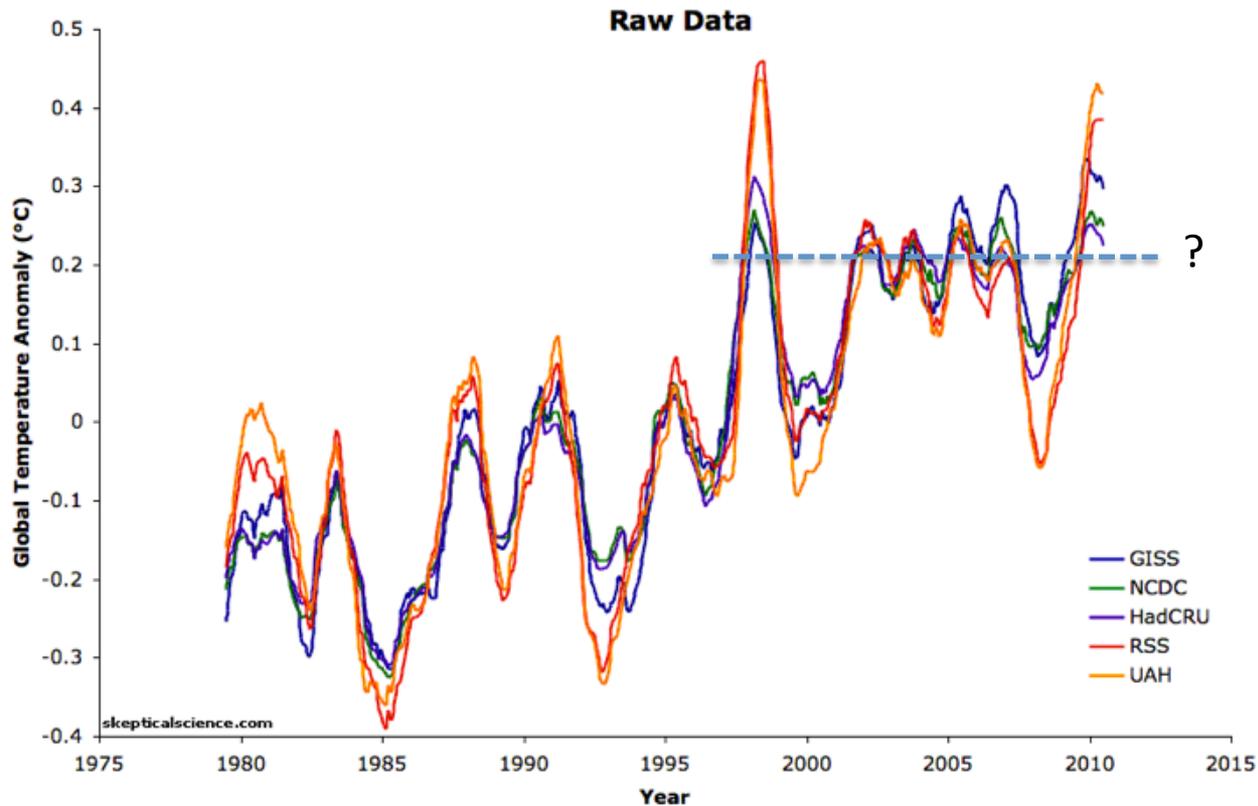
# El Nino (& La Nina) – Southern Oscillation (ENSO)

Annual Global Temperature Anomalies  
1950 - 2011

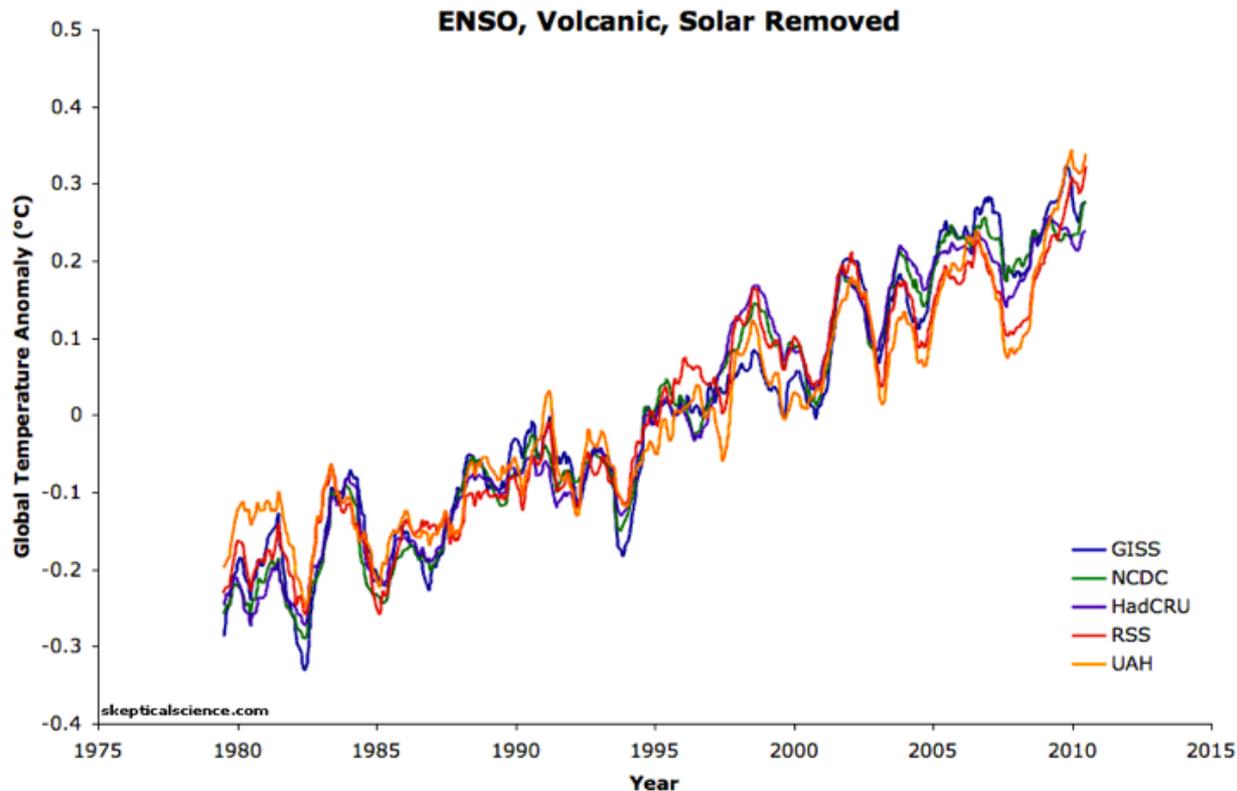


These episodes are correlated to global temperatures at the 0.2° C level and can be corrected for in global averages.

# Has Global Warming Stopped in the last 15 years?



# No. Anthropogenic Global Warming is Continuing at a Steady Pace



Important observation: The El Nino fluctuation and slightly lower solar power in the last few years have given slower temperature rises. But make no mistake about it: the underlying trend will overpower any such noise sources

# An excellent trend calculator (skepticalscience.com)

## Temperature trend calculator

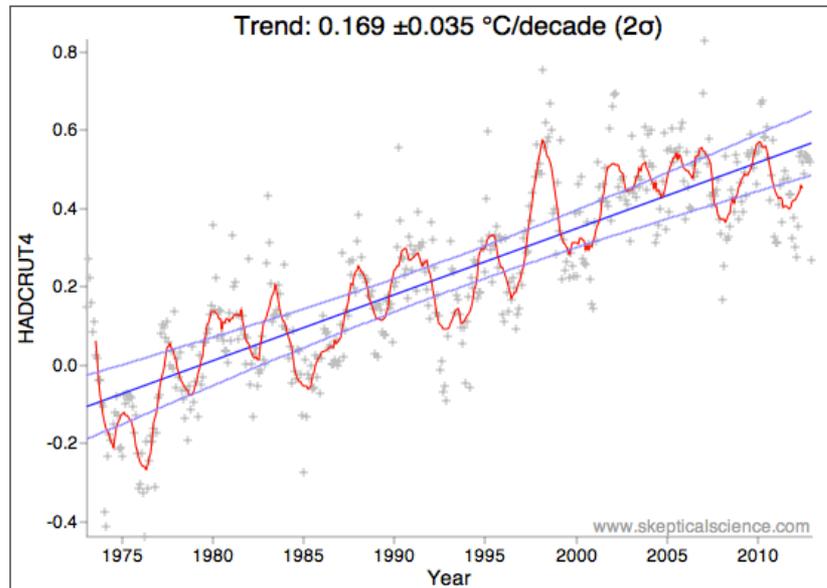
Land/ocean	Land	Satellite
<input type="radio"/> GISTEMP	<input type="radio"/> BEST	<input type="radio"/> RSS
<input type="radio"/> NOAA	<input type="radio"/> NOAA	<input type="radio"/> UAH
<input checked="" type="radio"/> HADCRUT4		
<input type="radio"/> HADCRUT4 hybrid		

Trend calculation: Start date:  End date:

Units:  Moving average:  months

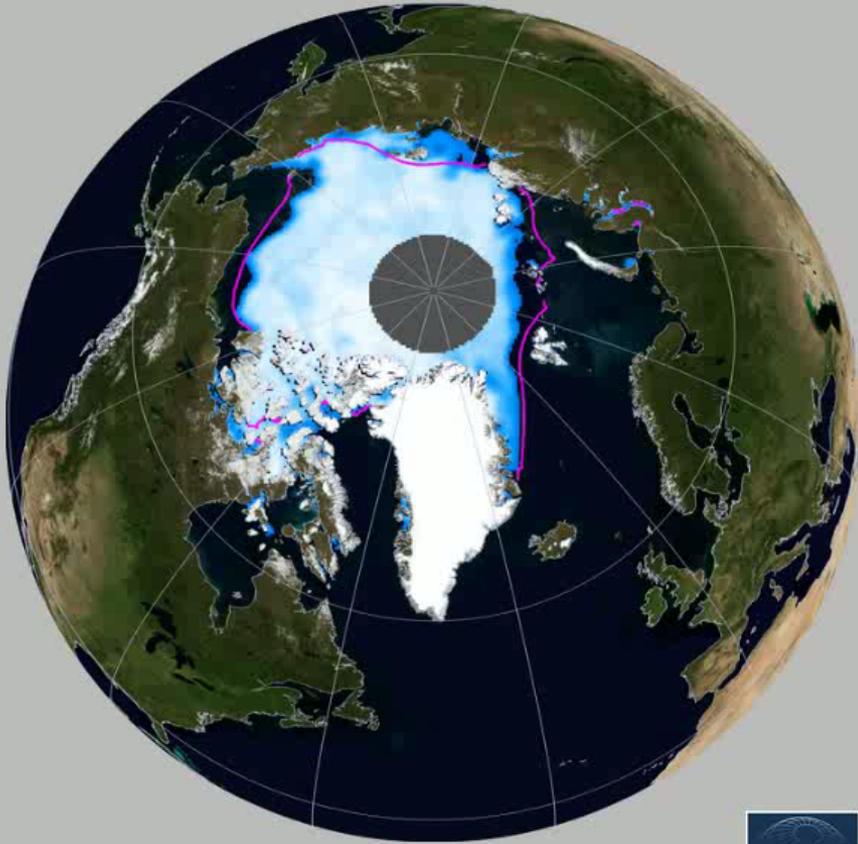
Show advanced options  
 Show appearance options

Calculate



# A Consequence of the Enormous increase in Ocean Heat - Melting Ice !

September Arctic Sea Ice Concentration, 1979 to 2012



September 1979

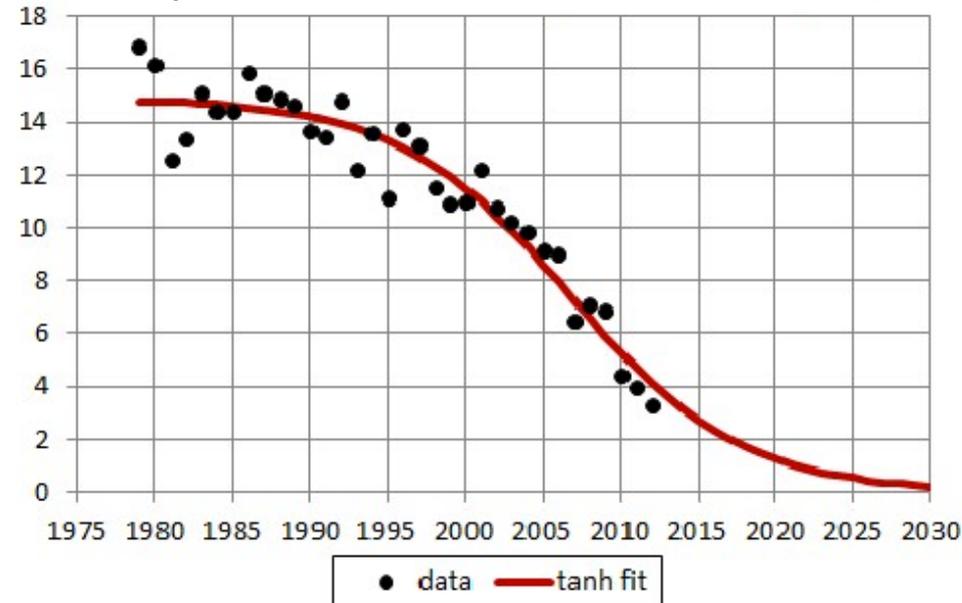


Credit: National Snow and Ice Data Center, NASA Earth Observatory

Pay attention to ice volume, not area. Most of the melting is due to thinning of ice.

These maps show that we are rapidly transitioning to a world without permanent Arctic Ice

September Arctic Ice Volume ( $10^3 \text{ km}^3$ )



# Navigating the Northwest Passage

- Finding a navigable route from Europe to Asia, across the North polar region, had been the dream of adventurers for several hundred years

## *TRACKING THE NORDIC ORION*

*For the first time ever, a bulk carrier is using the North West Passage as a transit trade lane.*

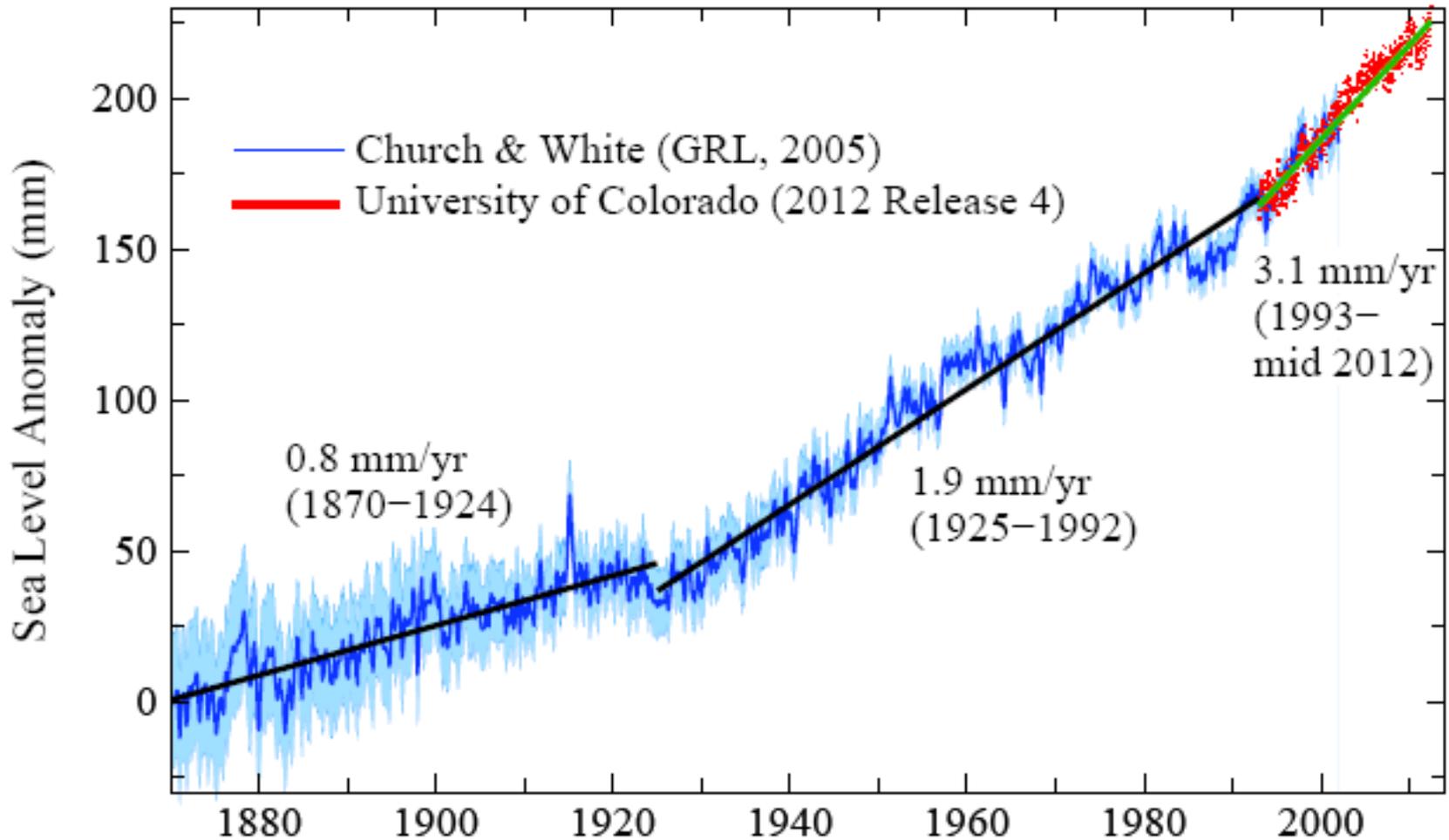


SOURCE: EXACTEARTH.COM

ANDREW BARR / NATIONAL POST

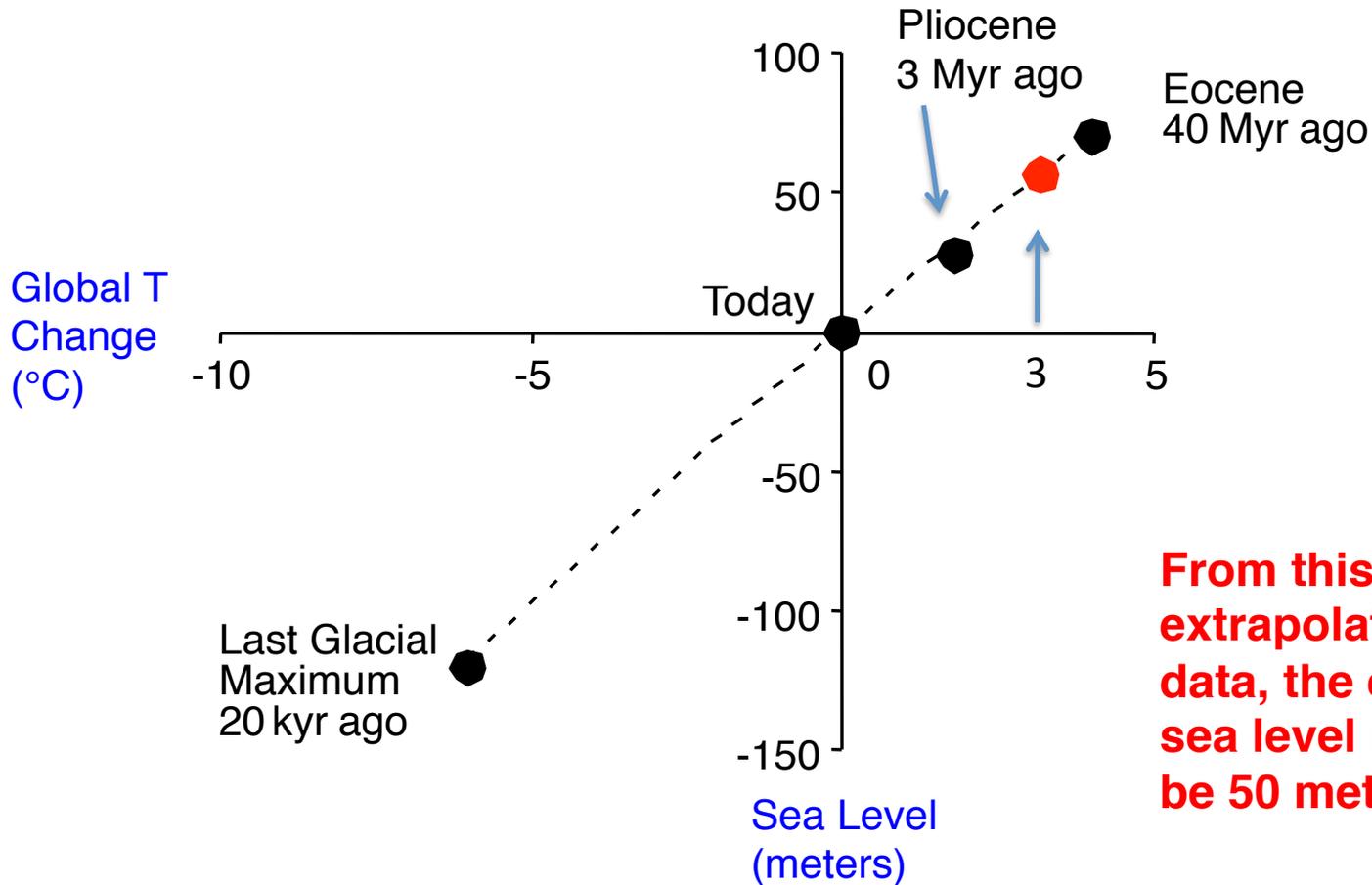


## Global Mean Sea Level Change



Most of the sea level rise is due to the warming of the ocean. Melting ice sheets will continue to contribute to sea level rise.

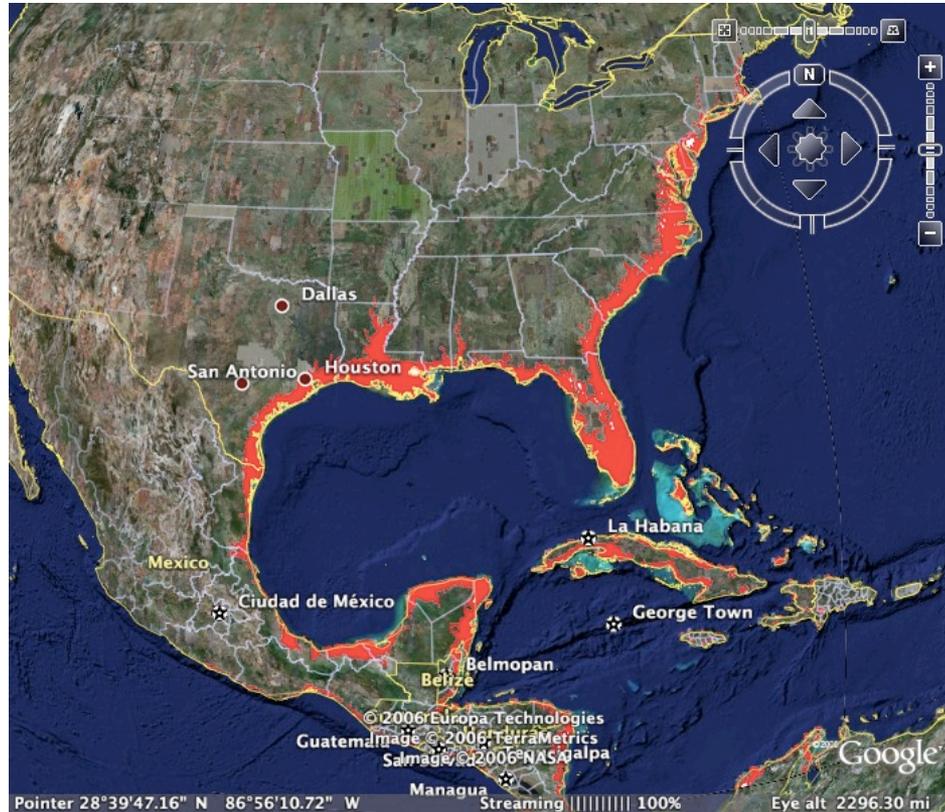
# Simple Sea Level Extrapolation, Using Historical Data, Not Models



**From this simple extrapolation of data, the eventual sea level rise may be 50 meters!**

Source: David Archer, U.C.

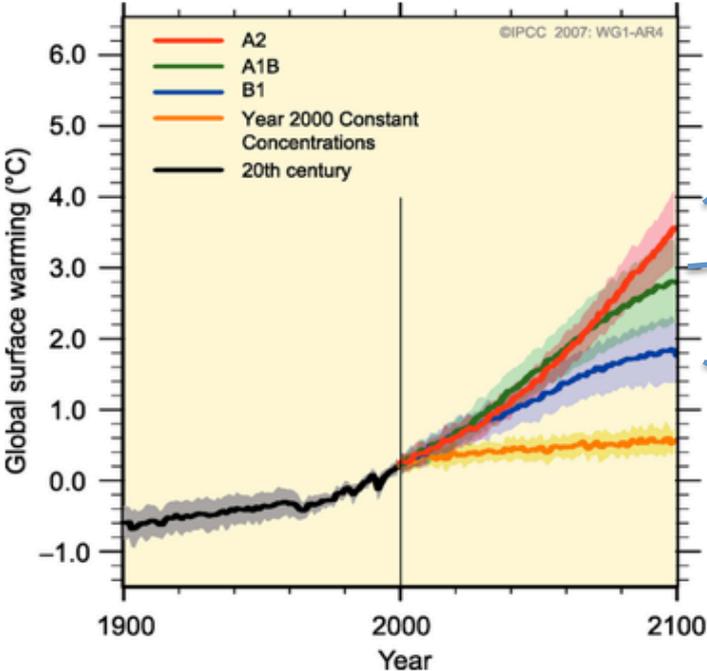
# Map of 20 meter Rise of Sea Level



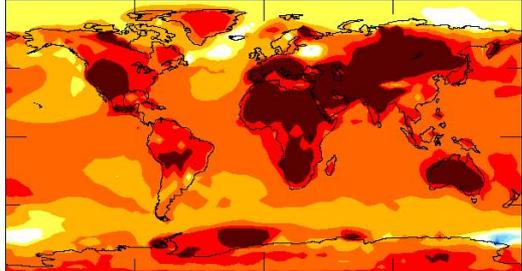
How long will it take? 500 Years? 200 Years? 100 Years? Nobody really knows.

# Predicted 2000-2100 Temperature Change

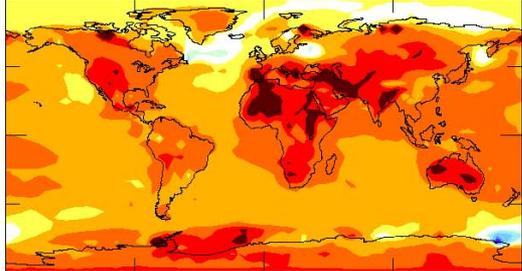
We don't know how hot it is going to get, since we don't know how fast carbon emissions will rise.



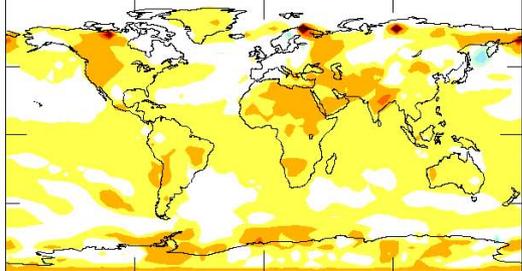
Jun-Jul-Aug  $\Delta T$   
IPCC:A2 2.70



IPCC:A1B 2.03



Alternative Scenario .62



# Summary

- Climate on Earth is predictable
- The two main 'knobs' that control our climate are:
  - CO<sub>2</sub> in the atmosphere
  - Reflectivity of the planet
- Man made CO<sub>2</sub> emission from fossil fuels is the dominant climate force now and is predicted to lead to a 5° F rise in temperature compared to pre-industrial times.
- Temperature measurements are very clear that the global temperature has risen already about 2.7° F and that the greenhouse effect has not stopped.

# Climate Science is for everyone

Feel free to email me about the wonderful world of climate science  
RAMBERG@FNAL.GOV

**But for the best information, please contact the real experts at:**

- NOAA** – National Oceanic and Atmospheric Administration
- NASA** – National Aeronautics and Space Administration
- AGU** – American Geophysical Union
- EPA** – Environmental Protection Agency
- APS** – American Physical Society
- NAS** – National Academy of Sciences

# Here is what change looks like!



James Hansen was the head of the climate branch of the NASA Goddard Institute for Space Studies.

Since the 1980's he has been giving a clarion call for action.

He recently quit NASA to devote full time to environmental advocacy.

*“Every major national science academy in the world has reported that global warming is real, caused mostly by humans, and requires urgent action. The cost of acting goes far higher the longer we wait — we can't wait any longer to avoid the worst and be judged immoral by coming generations.”*

*James Hansen, New York Times, May 9, 2012*

What kind of courageous change can you engender? That's easy: **Vote!**

**Thank you so much  
for your kind attention !**

**Any more questions?**