



● Announcements

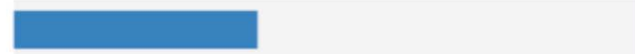
- HW4 due on Thursday
- Mid-term #2 next week
- Today's lecture a special topic...

What should we have as our special topic in PTYS 206?

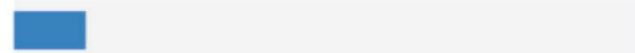
Global warming on Earth

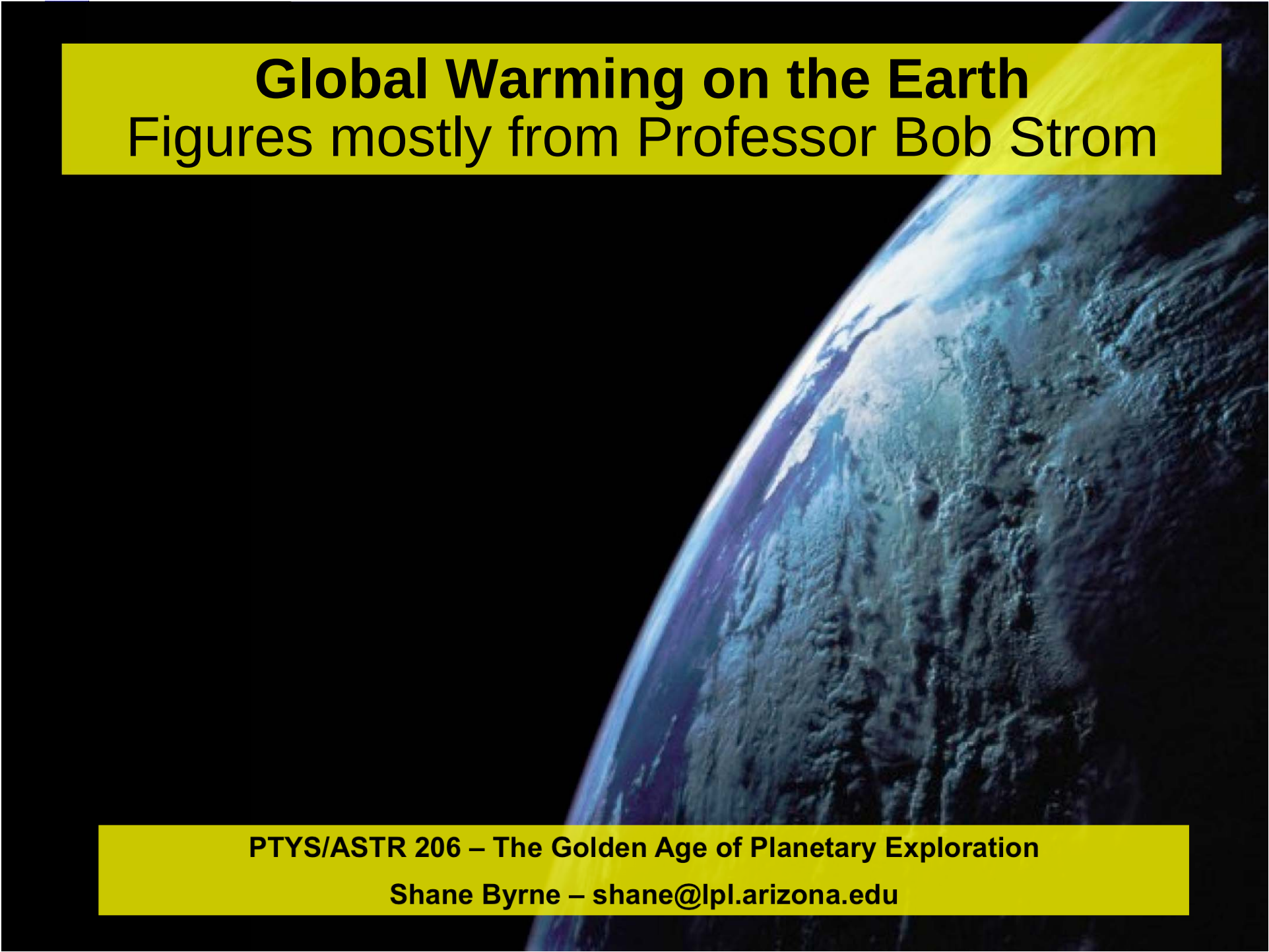


The space race



Mass extinctions on Earth and impacts





Global Warming on the Earth

Figures mostly from Professor Bob Strom

PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu



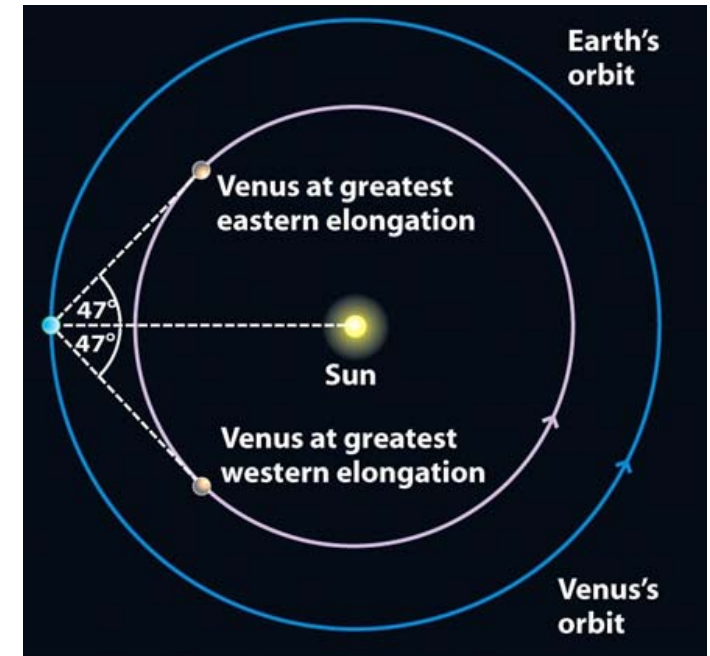
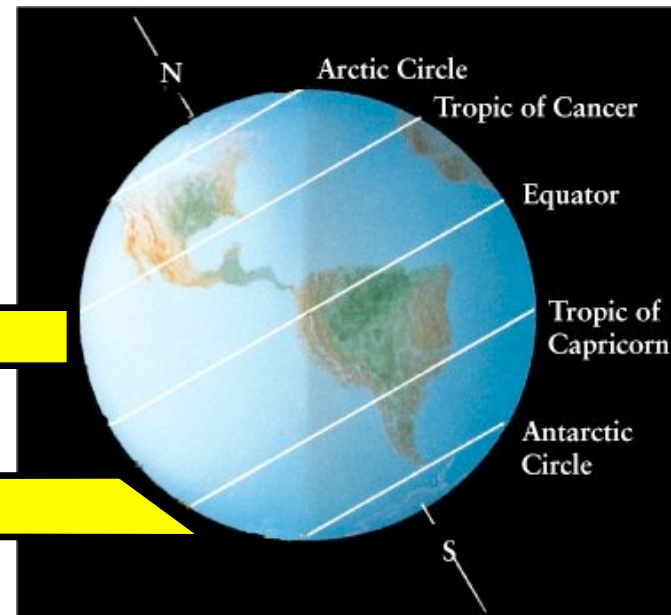
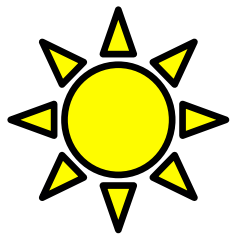
In this lecture...

- What sets the temperature of the Earth?
 - The greenhouse effect revisited
- Earth's carbon dioxide
- Earth's temperature record
- Climate change today
- Feedbacks and tipping points

- Consequences of climate change
- Options at this point?
- Climate change skeptics and alarmists

What sets the Earth's temperature?

- Our position in the solar system
 - Sunlight at 1AU
 - $\sim 1370 \text{ W m}^{-2}$
 - Solar Luminosity slowly grows with time
 - Earth's distance from the Sun is fixed
- Latitude
 - More sunlight when the sun is overhead
 - Tropics are hotter than the poles



- **Reflection**

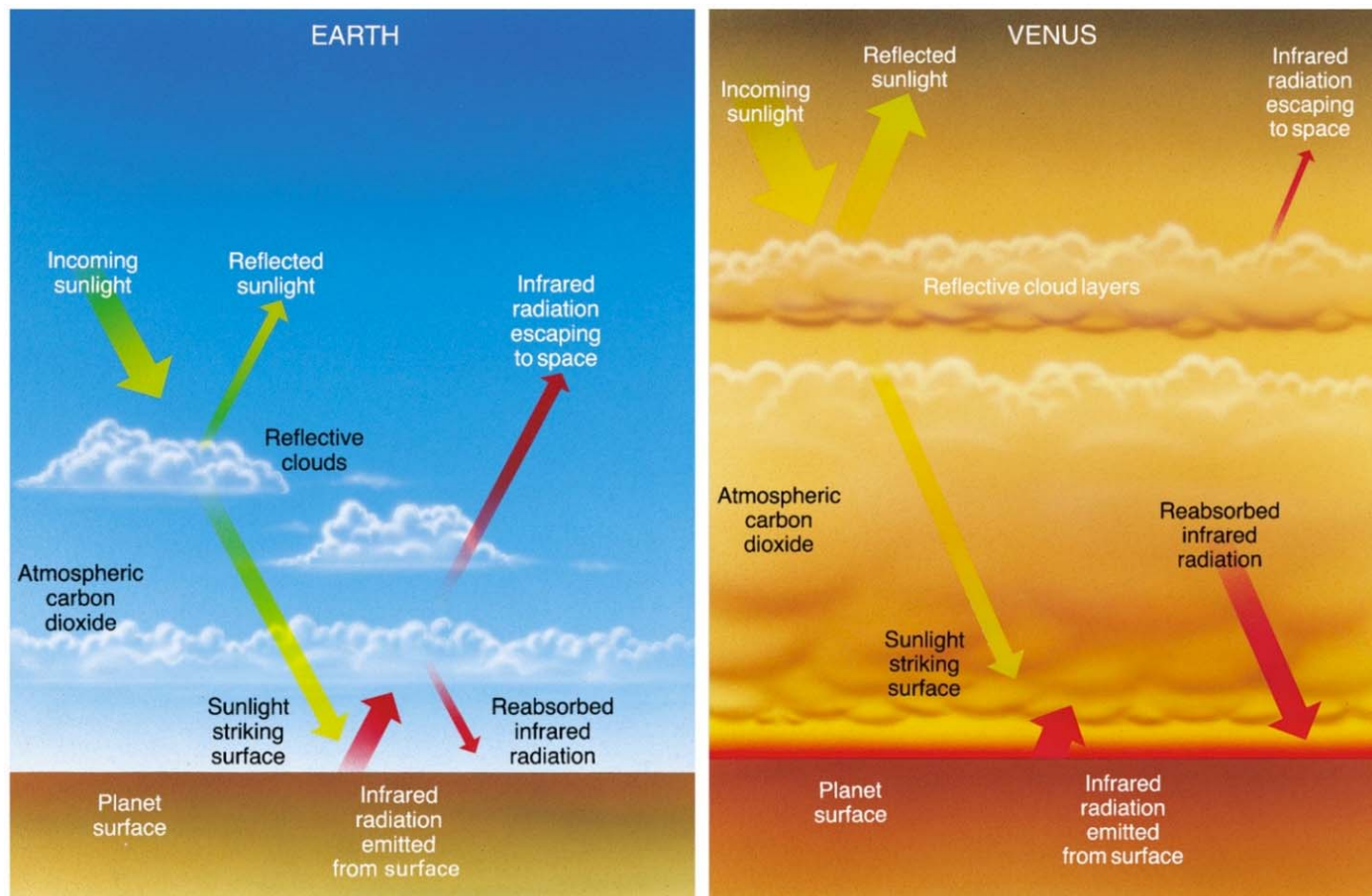
- Icy areas stay cooler
- Dark areas warm up
- Clouds are important in keeping Earth cool

NASA. Photo #: STS045-152-105



● The greenhouse effect revisited

- Visible light hits the planet's surface
- Outgoing infrared light is blocked by greenhouse gases in the atmosphere
- Trapped energy keeps the surface and lower atmosphere warmer



- What are these greenhouse gases?

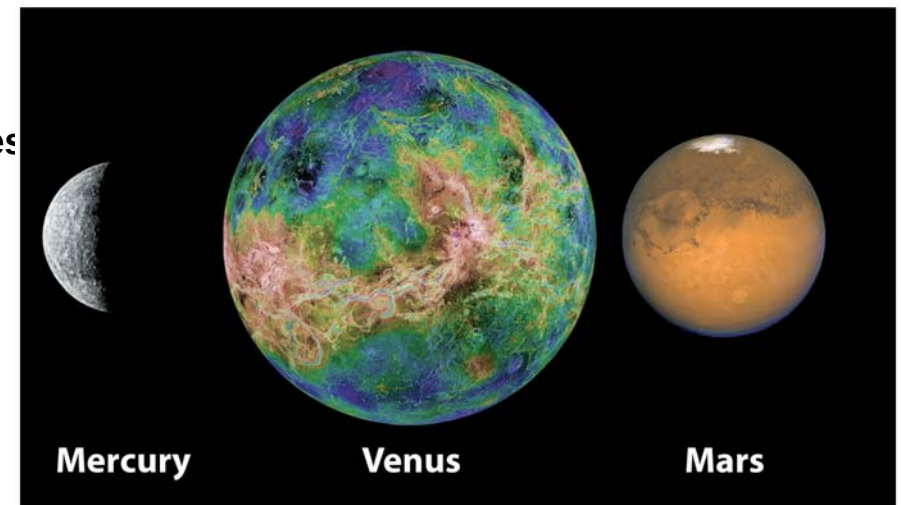
- Carbon Dioxide – CO_2
- Methane – CH_4
- Tropospheric Ozone – O_3
- Halocarbons
- Nitrous Oxide - N_2O



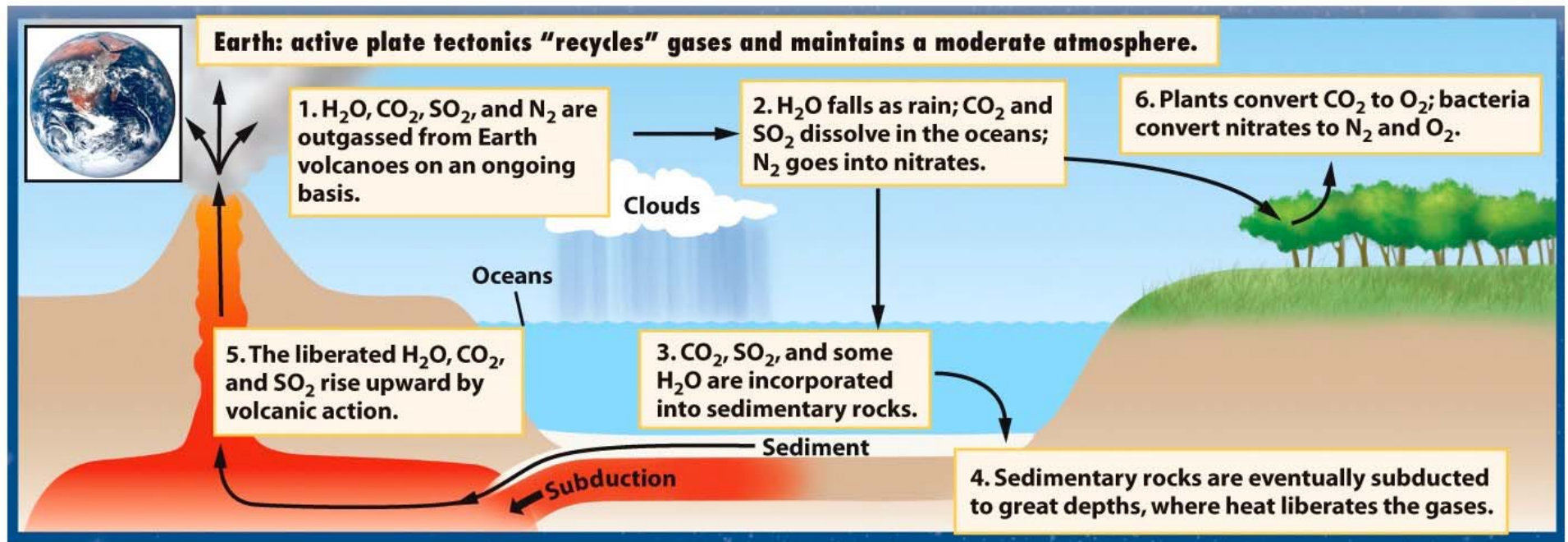
- Methane is much more effective than CO_2 but also much less abundant

- CO_2 is the main greenhouse gas

- Venus has lots of CO_2
 - ▶ Big greenhouse effect - very high temperatures
- Mars has a thin CO_2 atmosphere
 - ▶ Small greenhouse effect – a cold planet



- **CO₂ on the Earth**
 - Earth has water that rains
 - Rain dissolves CO₂ from the atmosphere
 - ▶ Forms carbonic acid
 - This acidified rainwater weathers away rocks
 - Washes into the ocean and forms carbonate rocks
 - Carbonate rocks eventually recycled by plate tectonics
- **The rock-cycle keeps all this in balance**
 - Sometimes this gets out of sync e.g. snowball Earth – stops weathering



Causes of Climate Change

- ***Abundance of Greenhouse Gases***

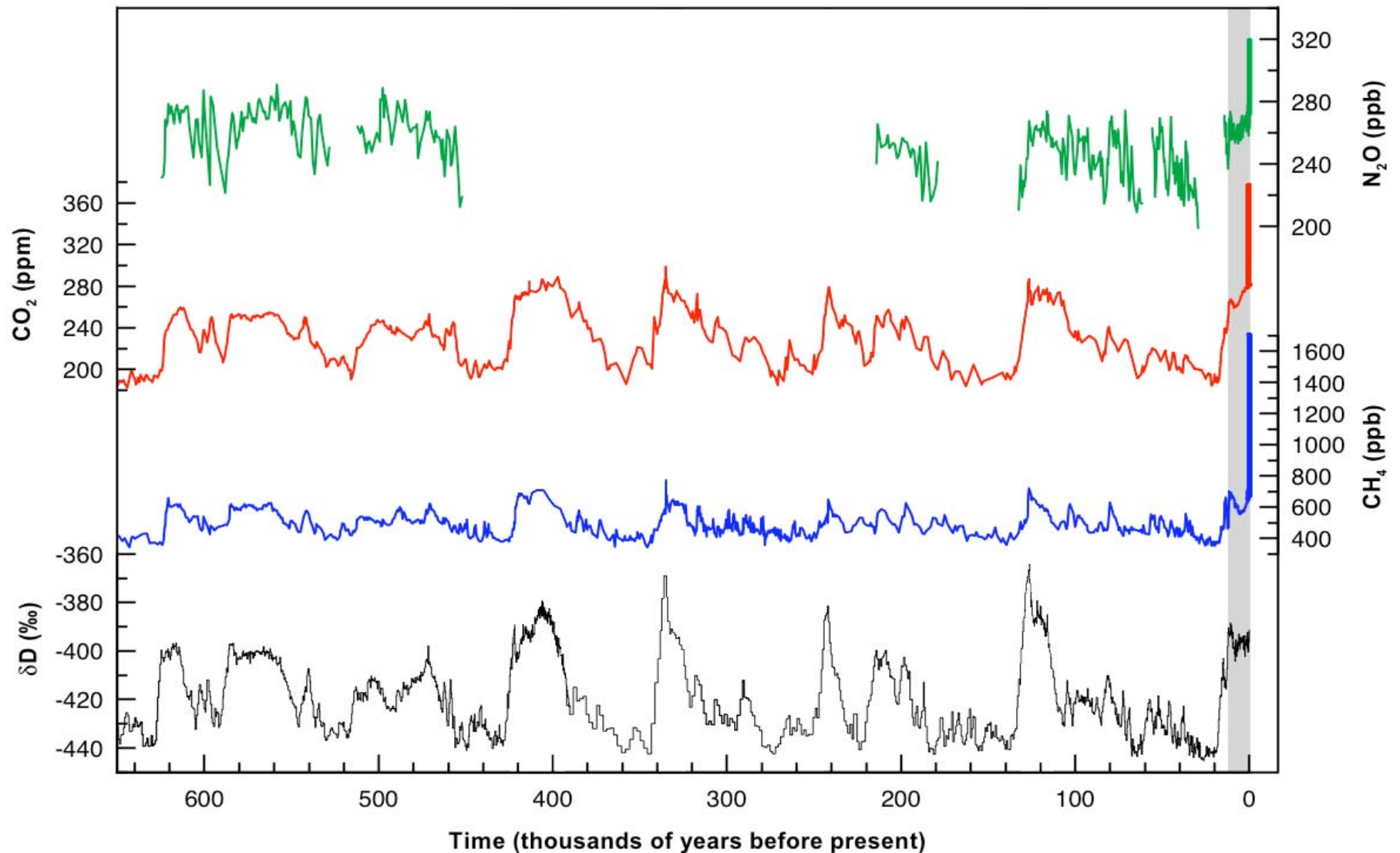
- Major Volcanic Eruptions

{ • Large Asteroid or Comet Impact } **Very Unlikely**

{
• Change in Sun's Irradiance
• Change in Ocean Circulation
• Continental Drift
• Change in Earth's Motions
} **Very Slow**

Greenhouse Gases for the Past 650,000 Years

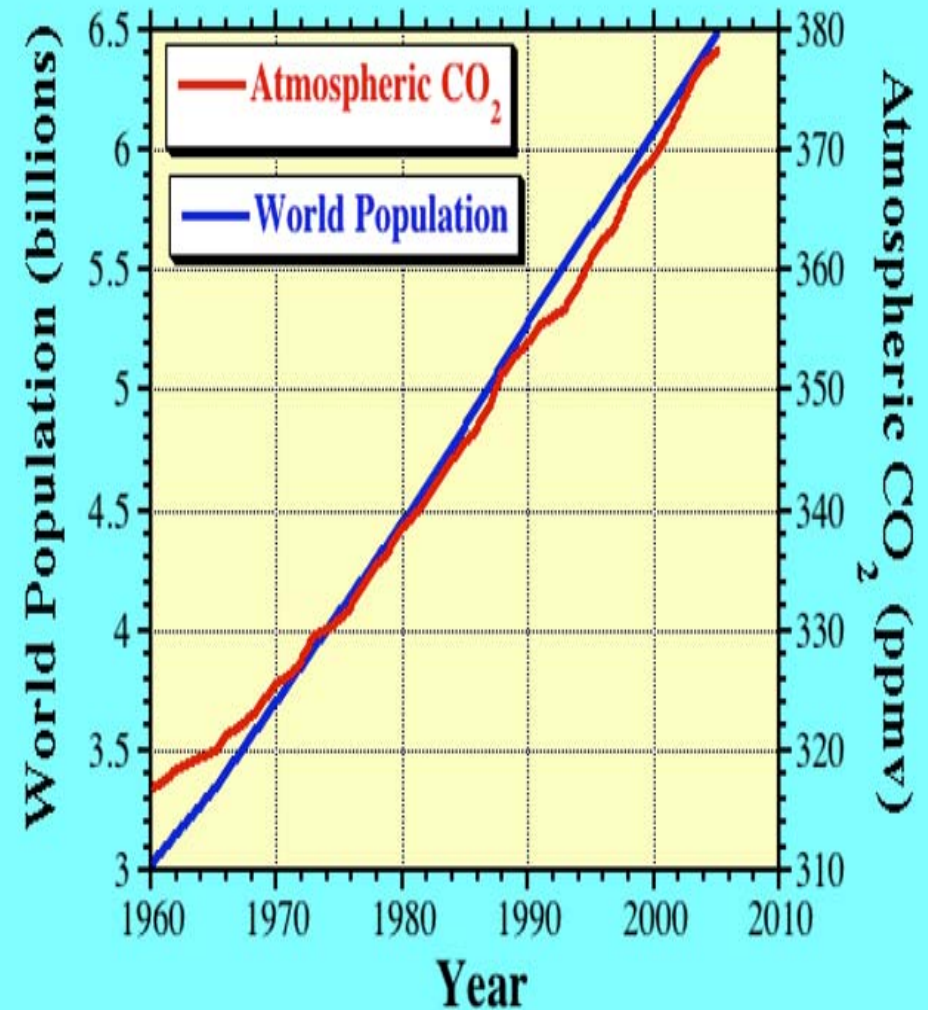
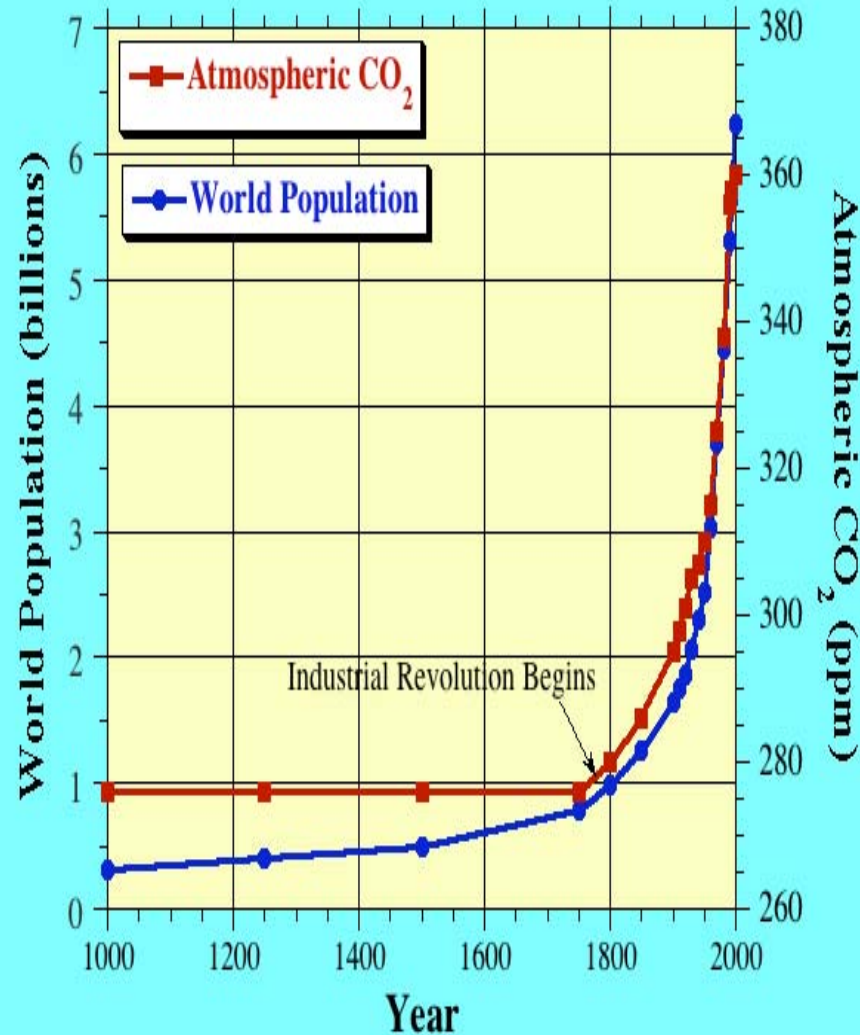
Ice Core Data Showing Greenhouse Gas Concentrations

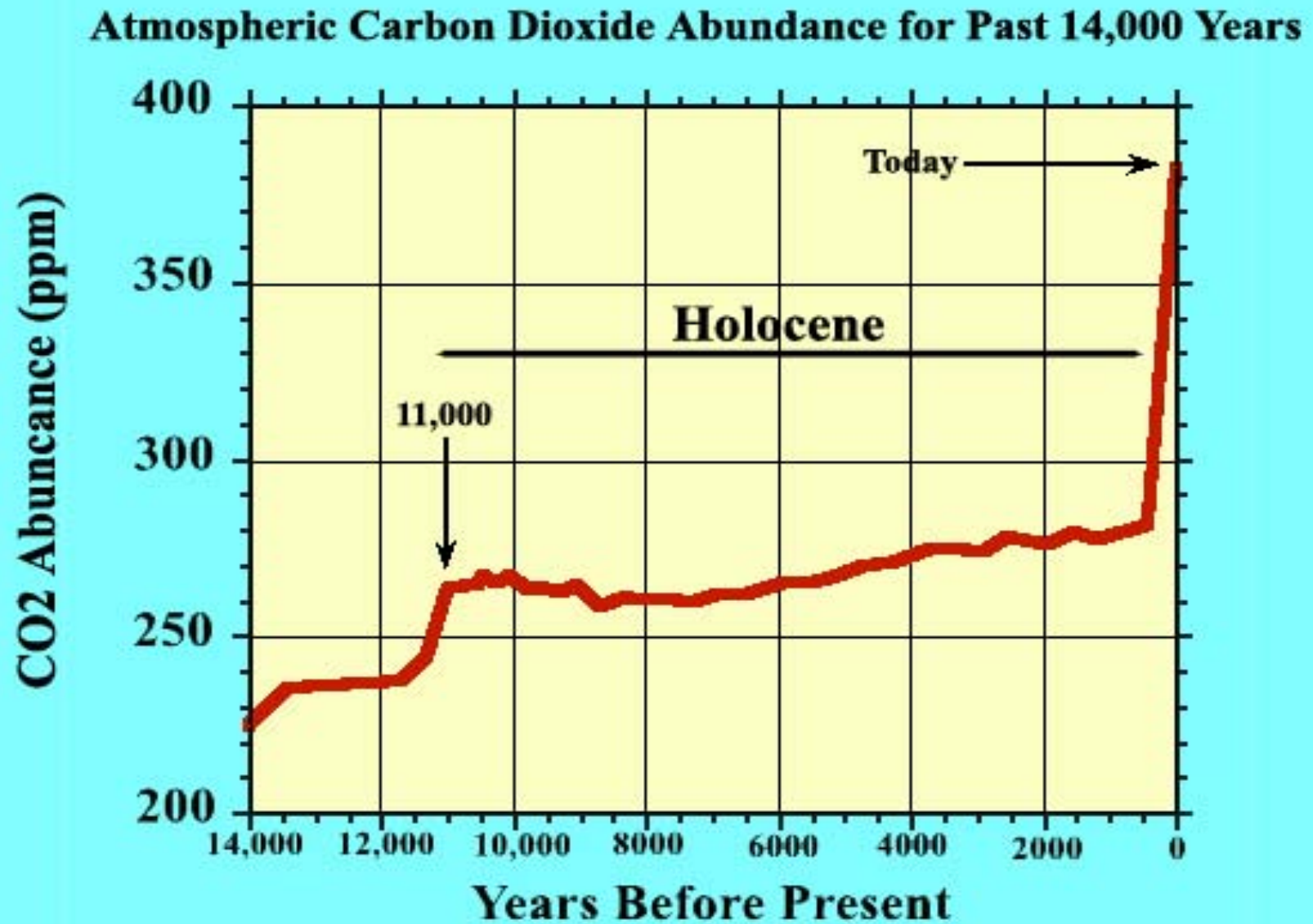




Atmospheric CO₂ and Population Growth

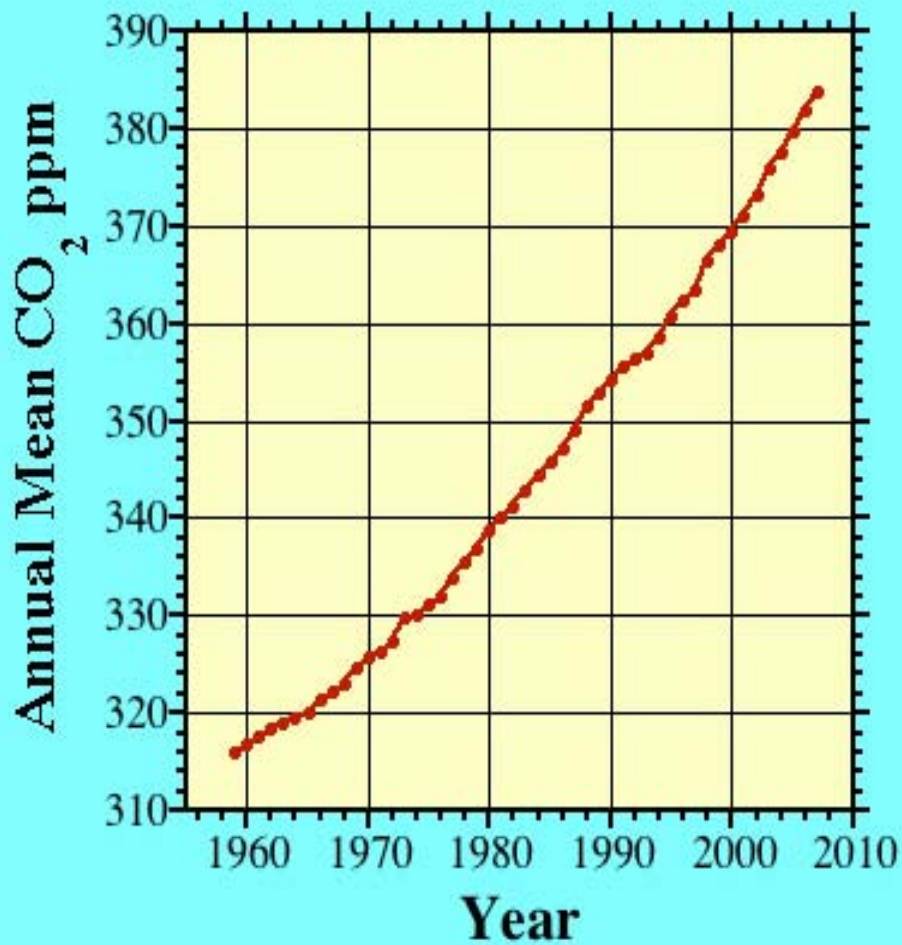
Growth in Population and Atmospheric CO₂



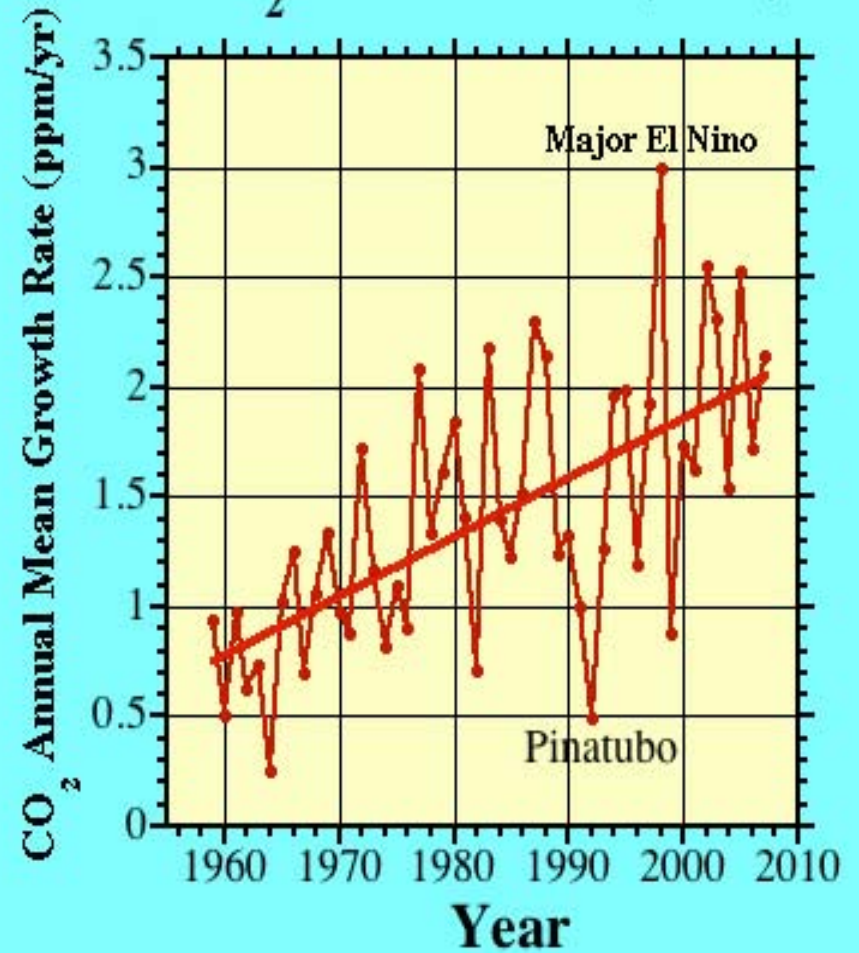


Recent CO₂ Increase (1959 - 2007)

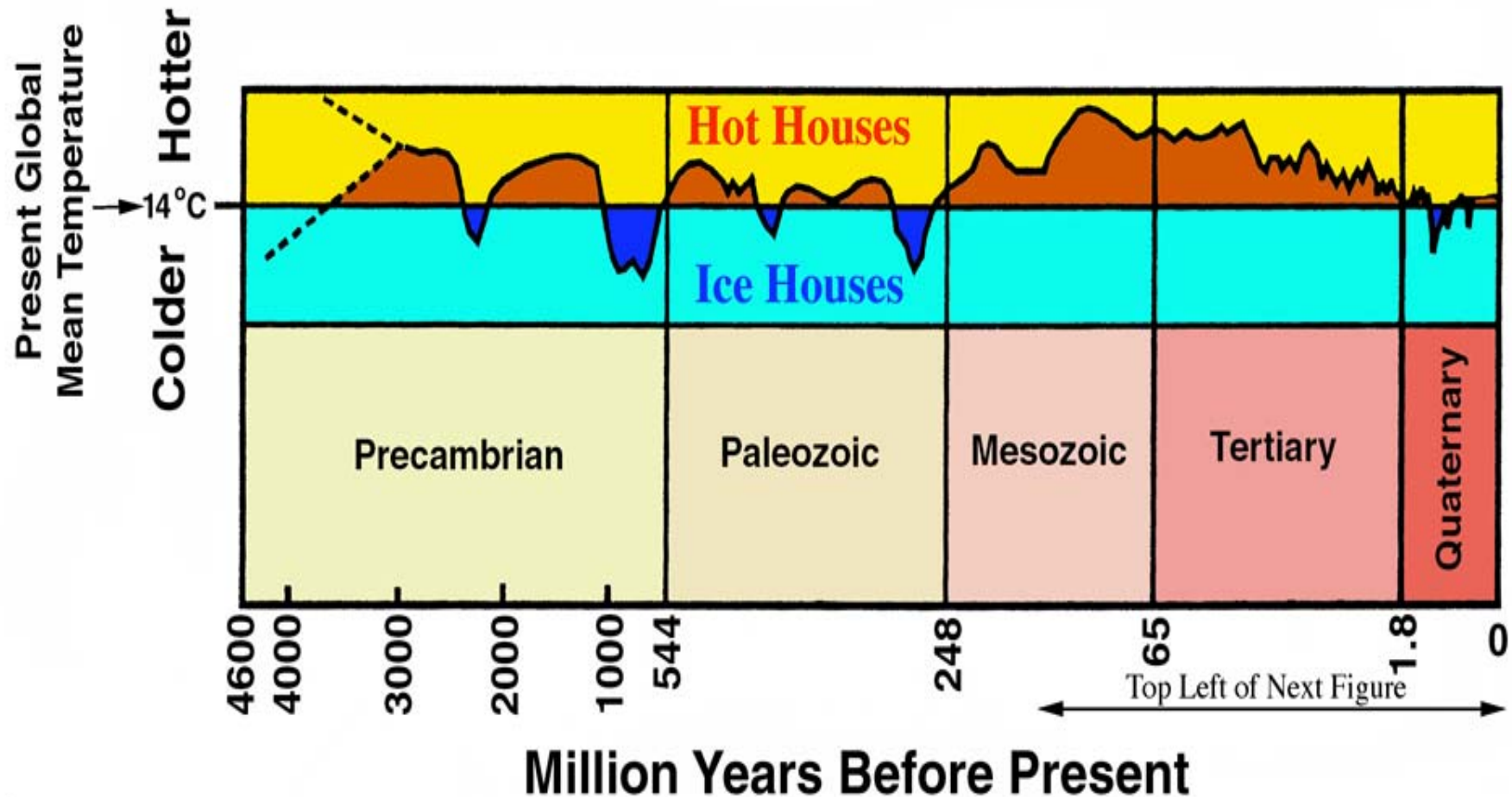
Atmospheric CO₂ Abundance (2007)

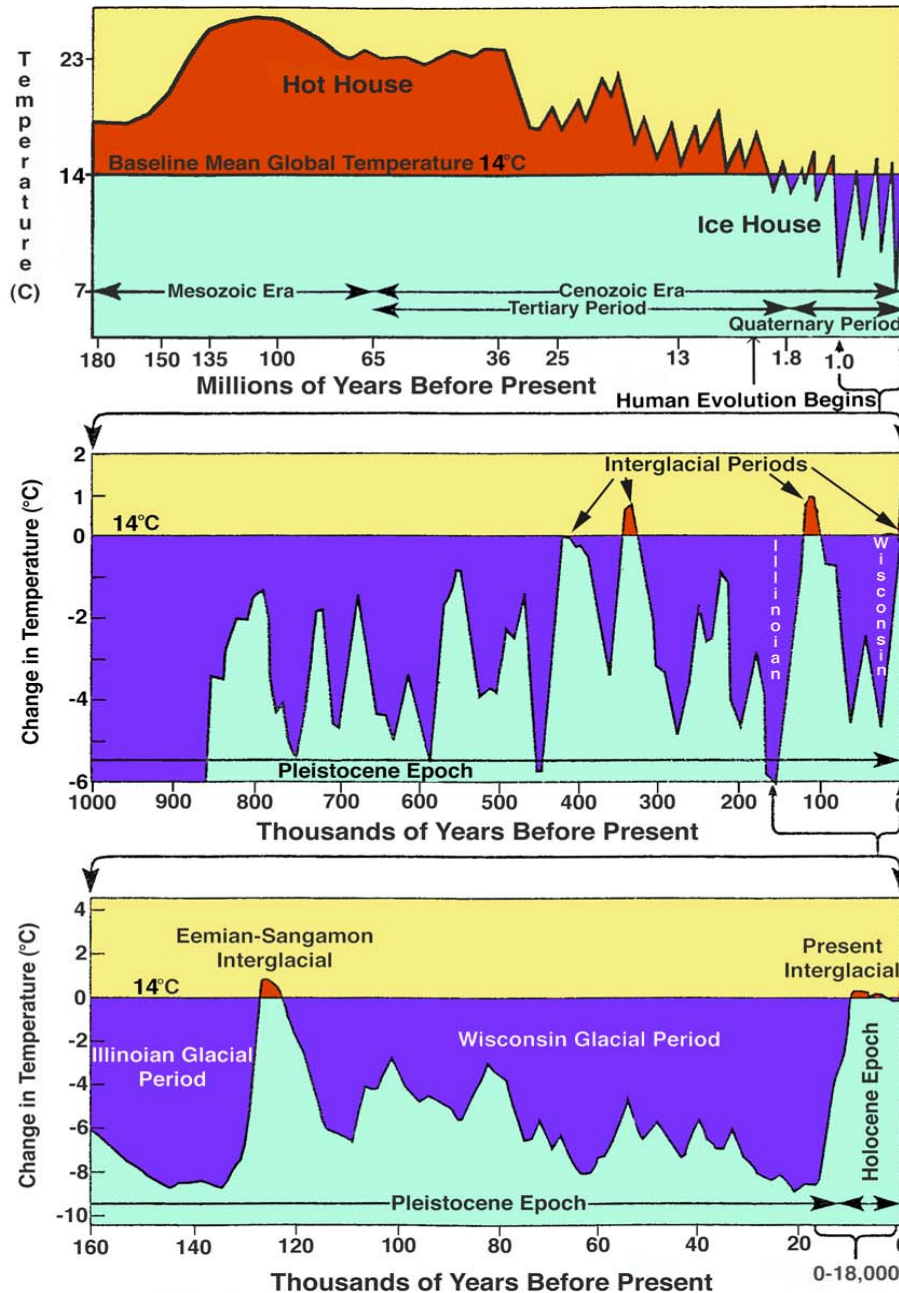


CO₂ Growth Rate (2007)



Generalized Climates for the Past 3 Billion Years





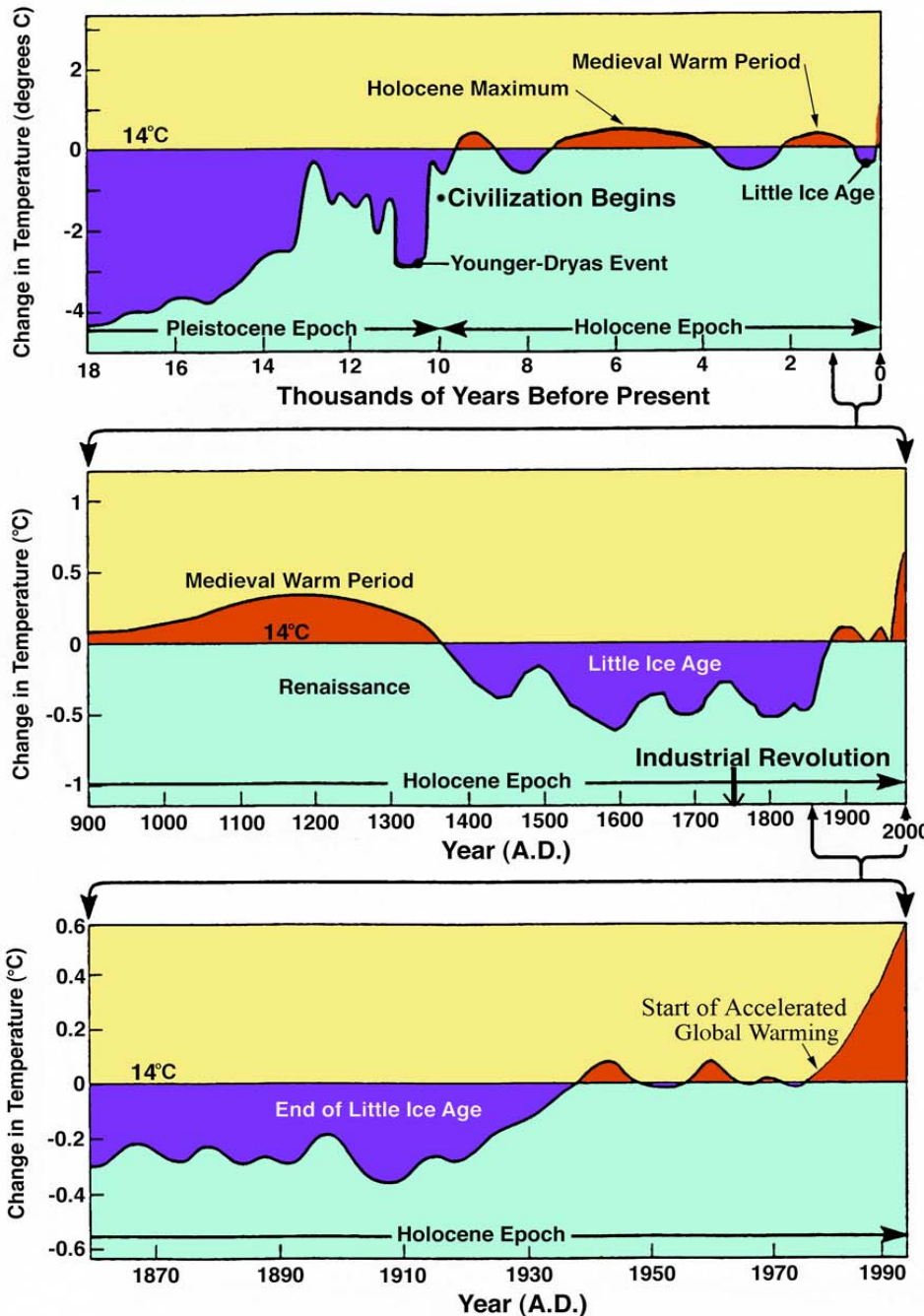
● Hot-house

- Equatorial oceans like a hot-tub
- Arctic ocean like the tropics today
- No ice anywhere on Earth
- Plant life explodes
 - Uses up a lot of CO₂

● Ice house

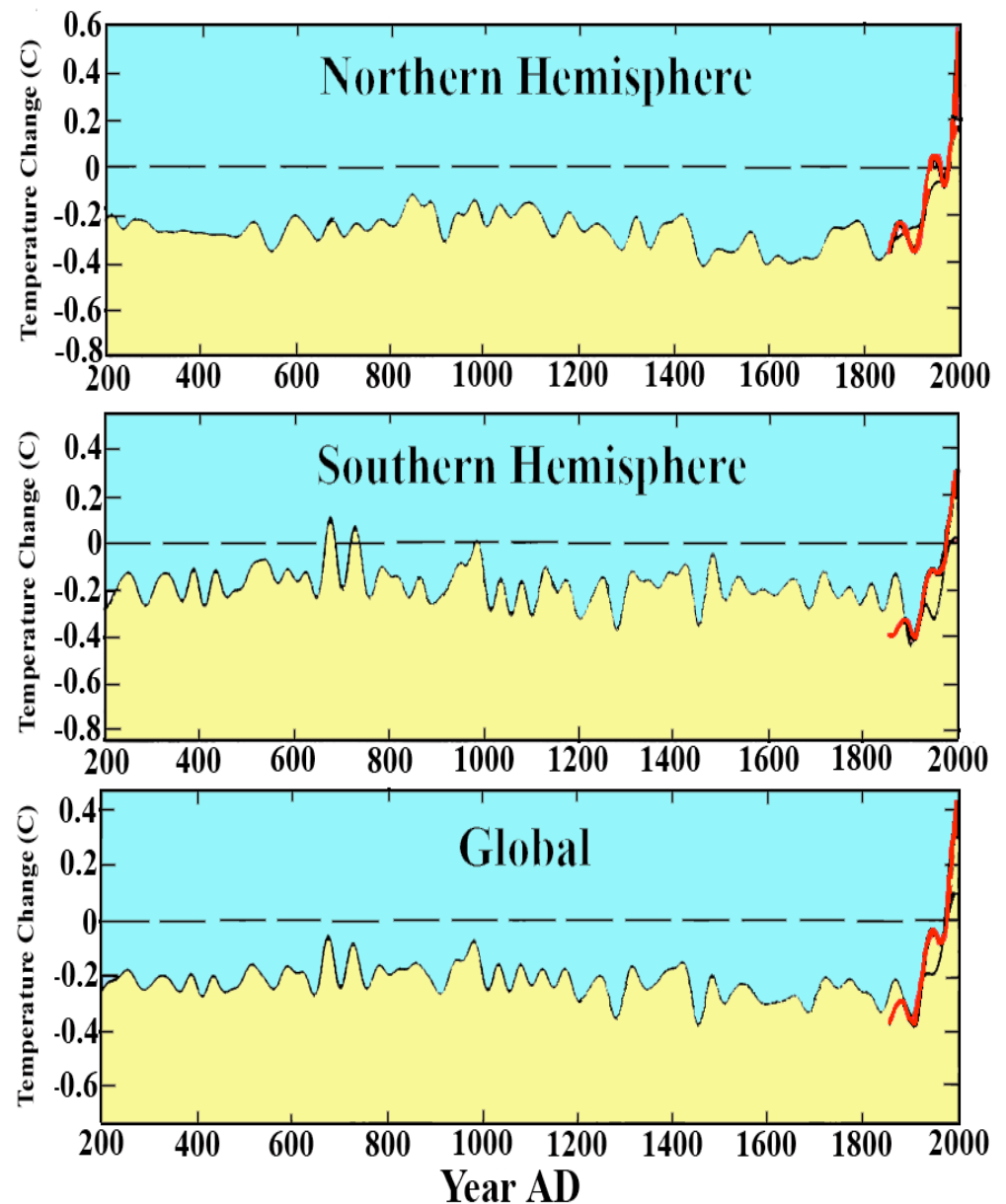
- Ice sheets covering portions of the Earth
- Reduced plant activity
 - Doesn't use up much CO₂

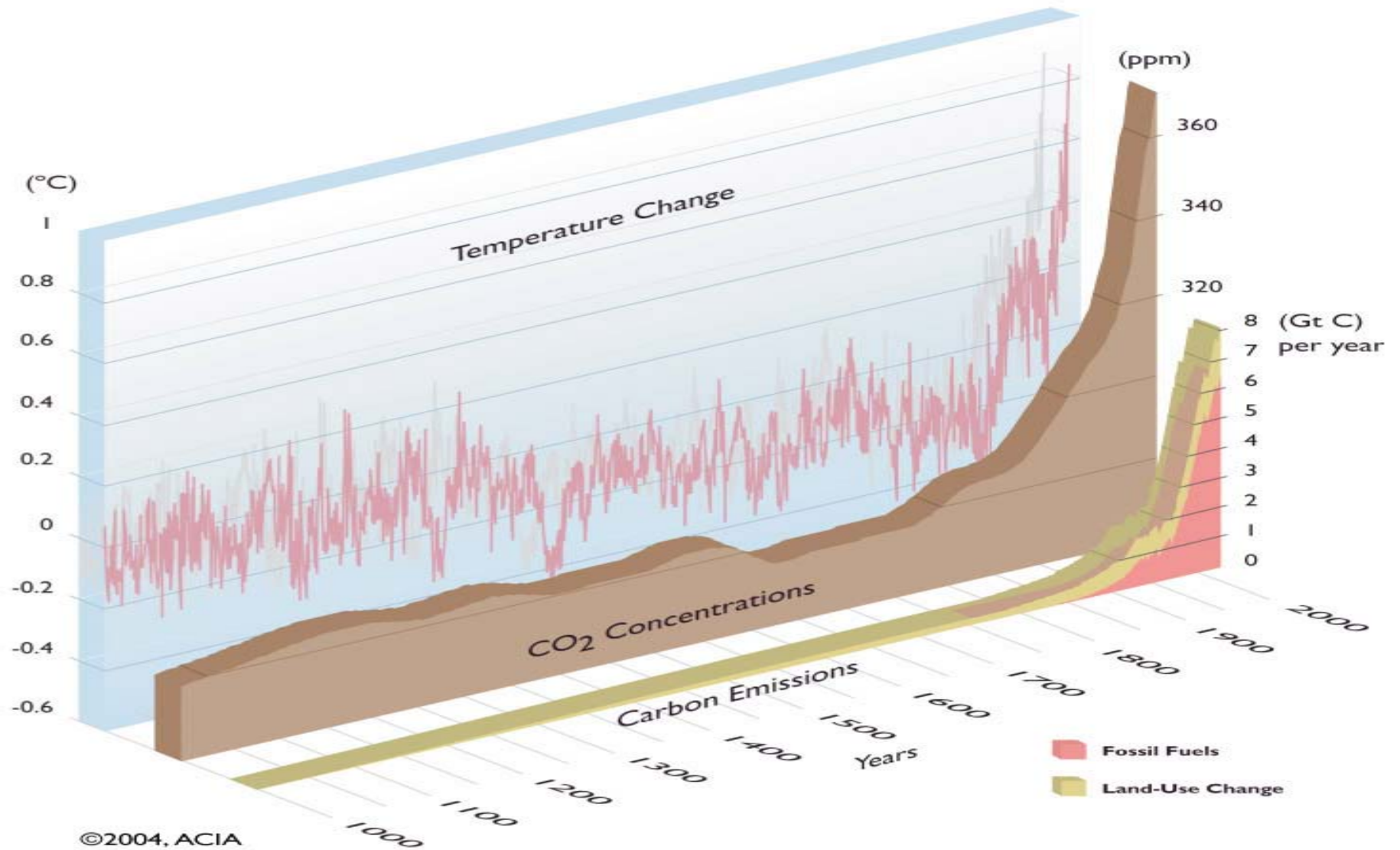
● Recent variations in climate caused by Milankovitch cycles



- Zooming in further
 - Temperatures still going up
 - ...end of last ice age?
 - Unfortunately not... the rate of increase is faster than any time in the past (and still increasing)

- Current global warming coincides with
 - Population explosion
 - Industrial revolution
 - Rapid rise in atmospheric CO₂

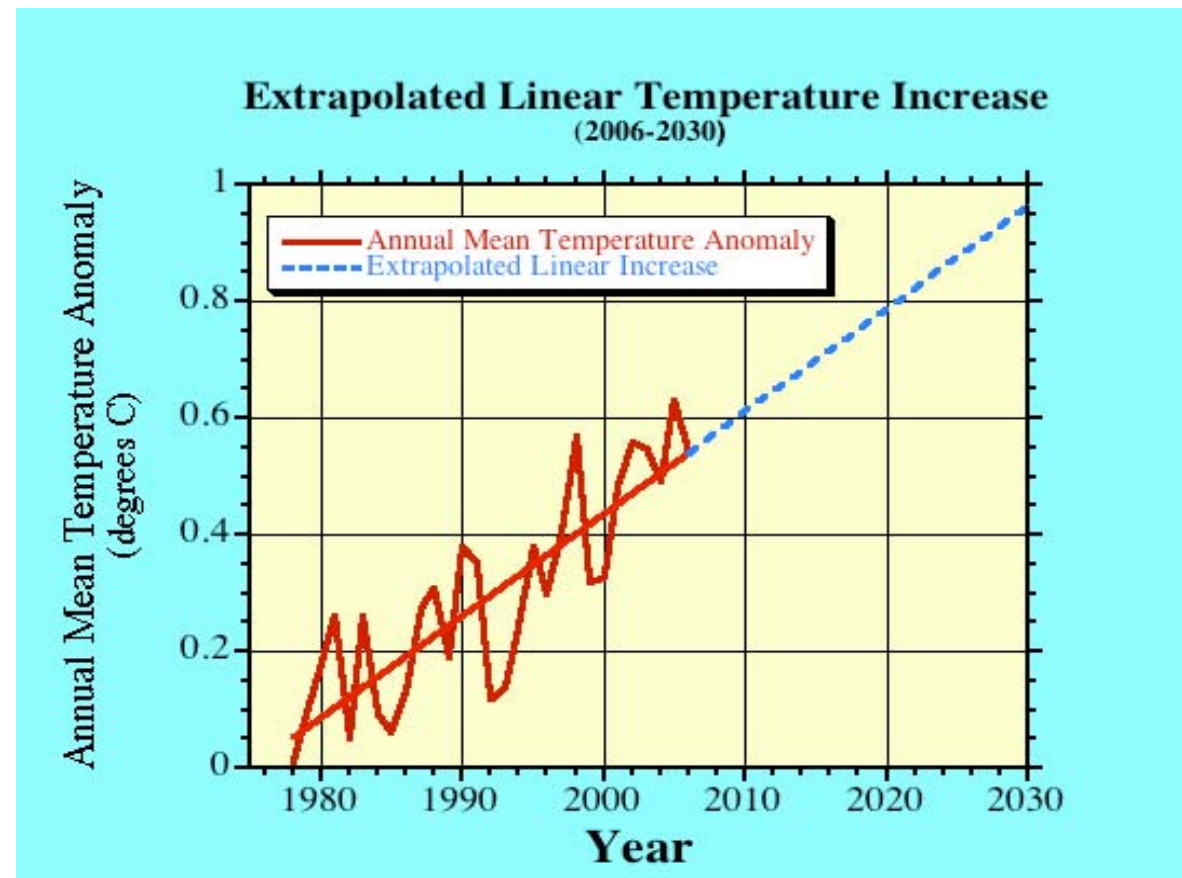




- All this fuss for one or two degrees...
- Really such a big deal ??

■ It's a big deal
because of the
possible
feedbacks

1. Ice
2. Permafrost
3. Methane Hydrate
4. The oceans



- **Feedback #1 – planetary Albedo**

- Ice around the world is retreating
- Ice reflects most of the energy that falls on it
- Less ice means warmer temperatures
- Warmer temperatures mean even less ice etc etc...

NASA. Photo #: STS045-152-105



- **Glaciers around the world are shrinking**
 - **Examples from Alaska**
 - **Vegetation changes also indicate climate change**

- **Glaciers are pretty sensitive to climate and so are good indicators**



Aug. 1941



Aug. 2004



Aug. 1906



Sept. 2003



July 1909



Aug. 2004

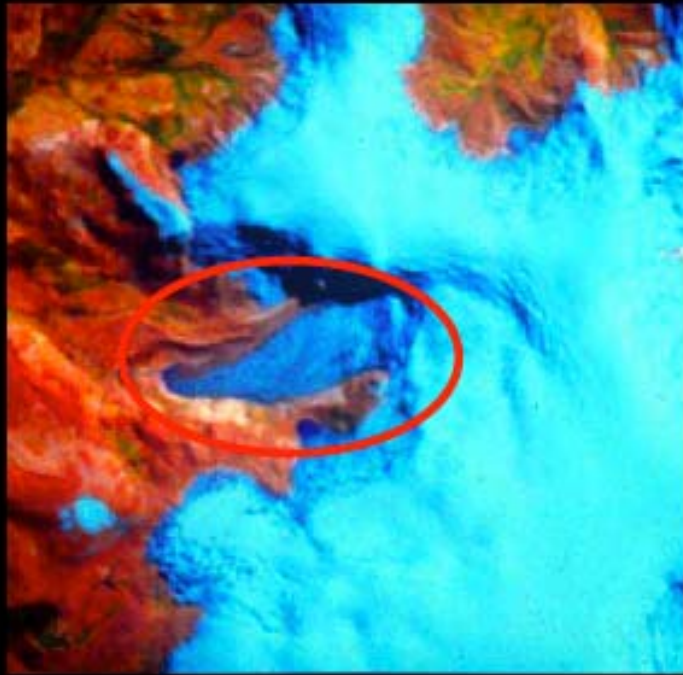
Northwestern Glacier



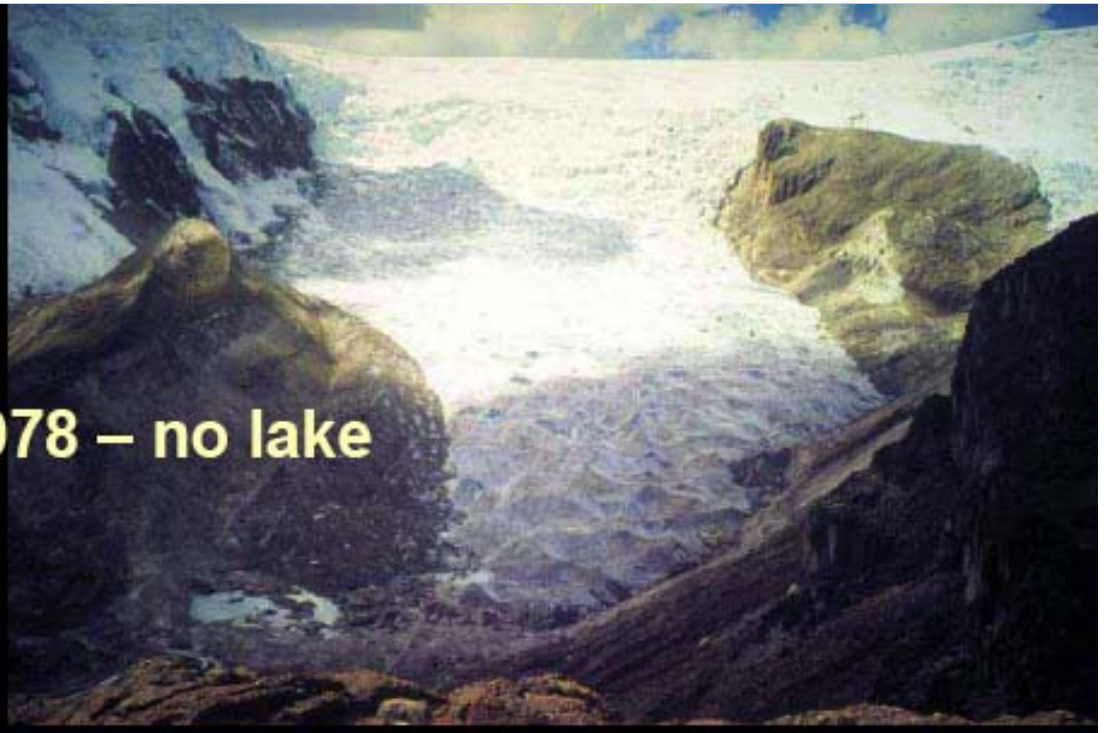
Pedersen Glacier



Retreat of the Qori Kalis Glacier (Peru)

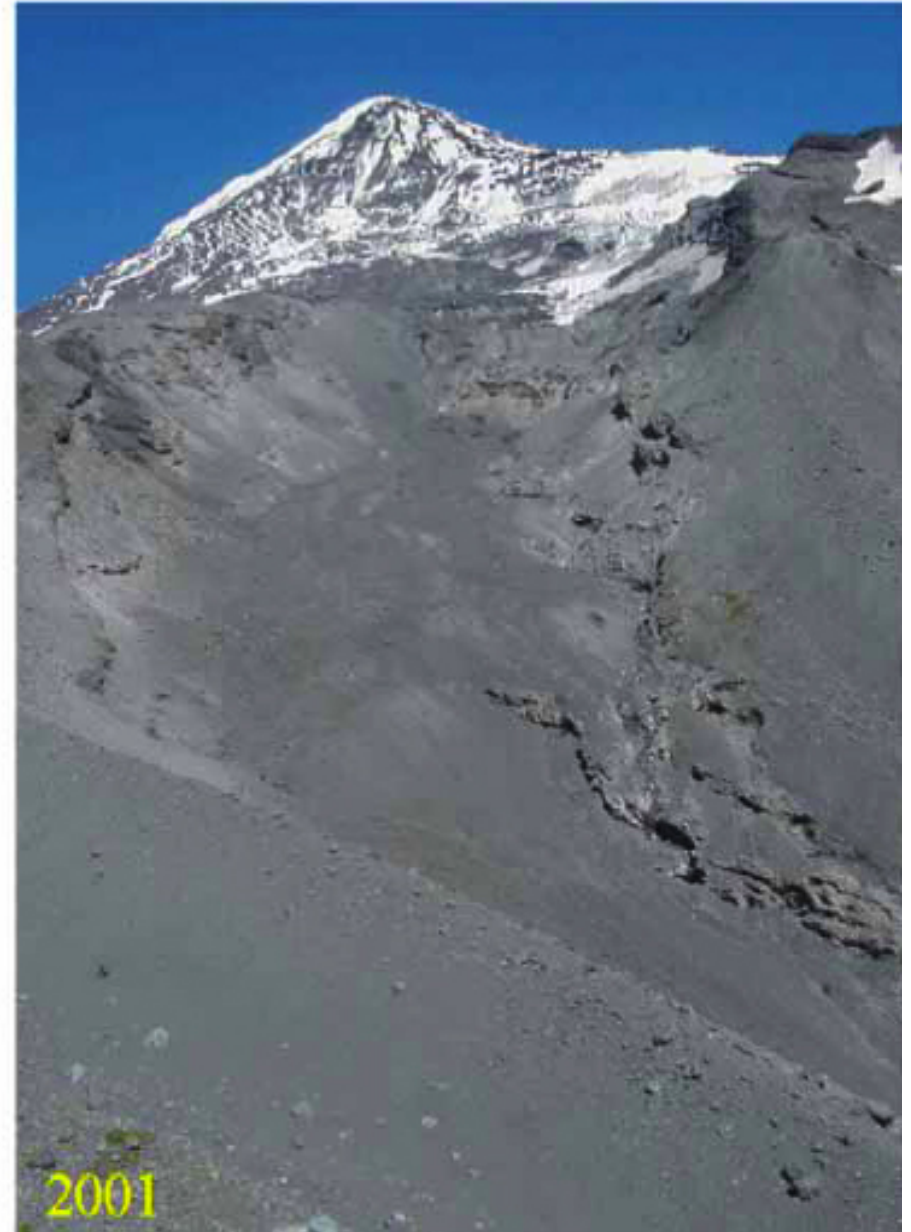


1978 – no lake



2004 –
lake covers 84 acres

Glaciar Lanín Norte Andes

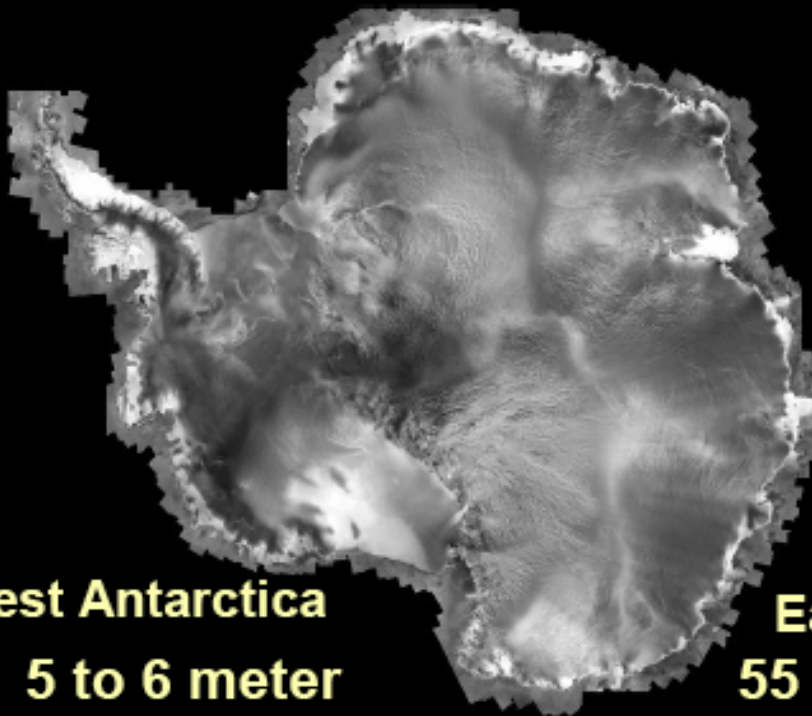


The decline of the Gangotri Glacier in the Himalaya Mts. of India.





Antarctica



West Antarctica

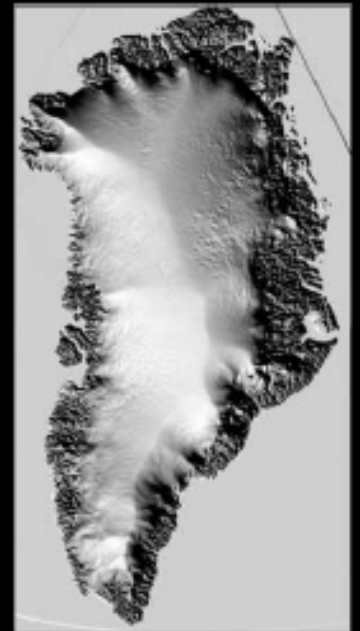
5 to 6 meter
sea level rise
equivalent

East Antarctica

55 to 60 meter
sea level rise
equivalent

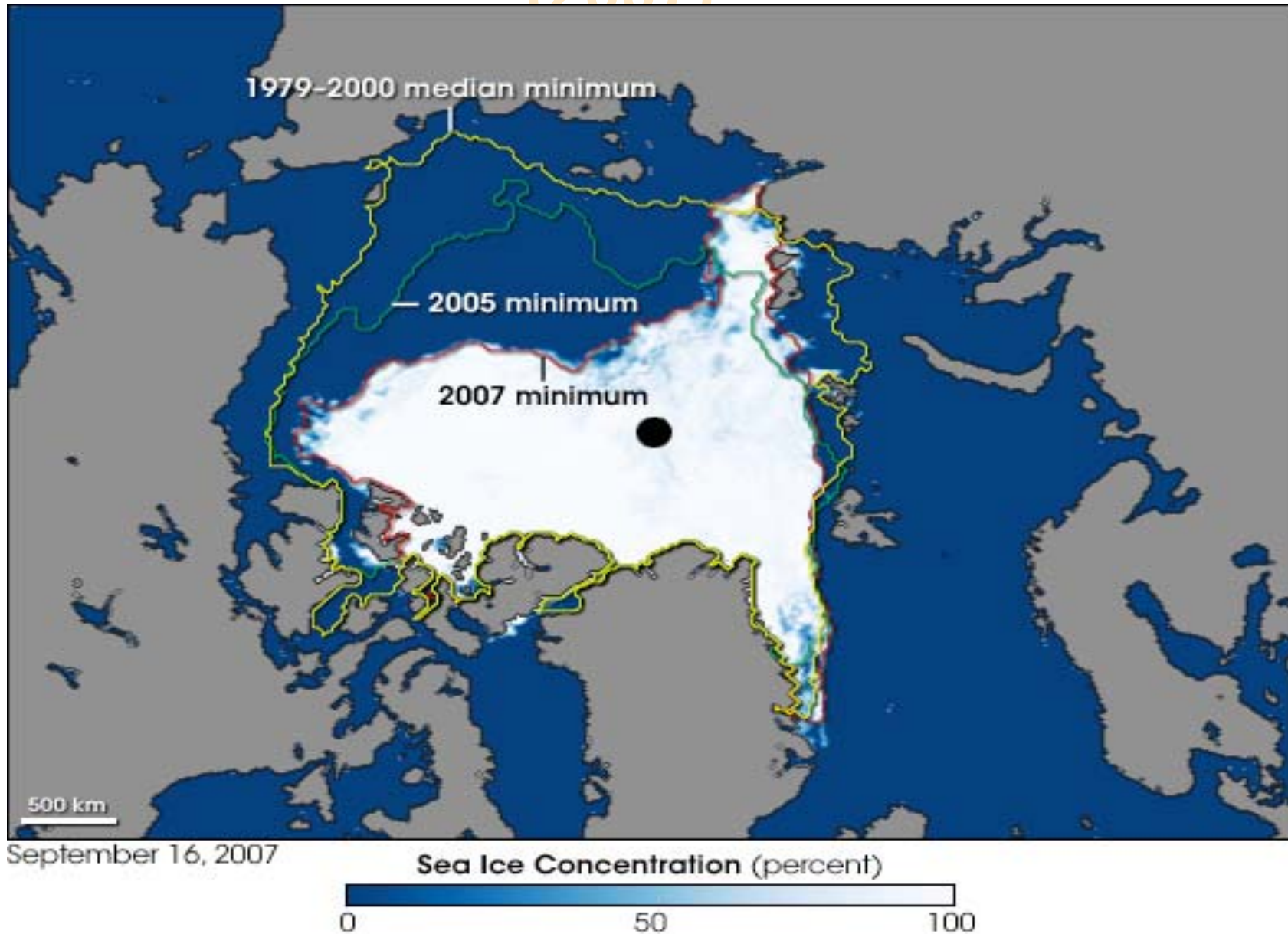
6 to 7 meter
sea level rise
equivalent

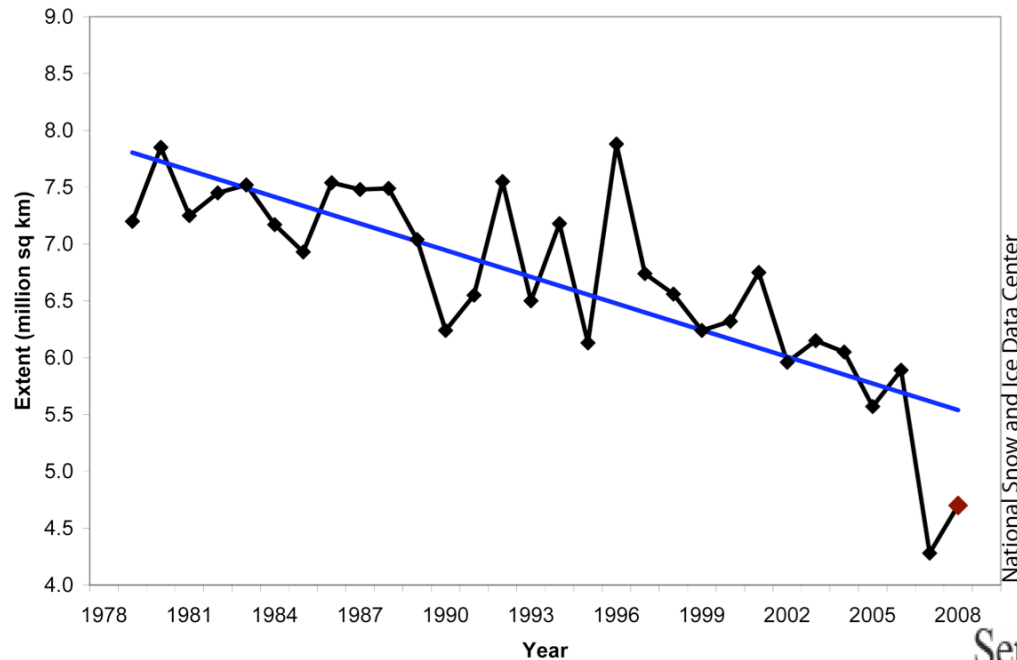
Greenland





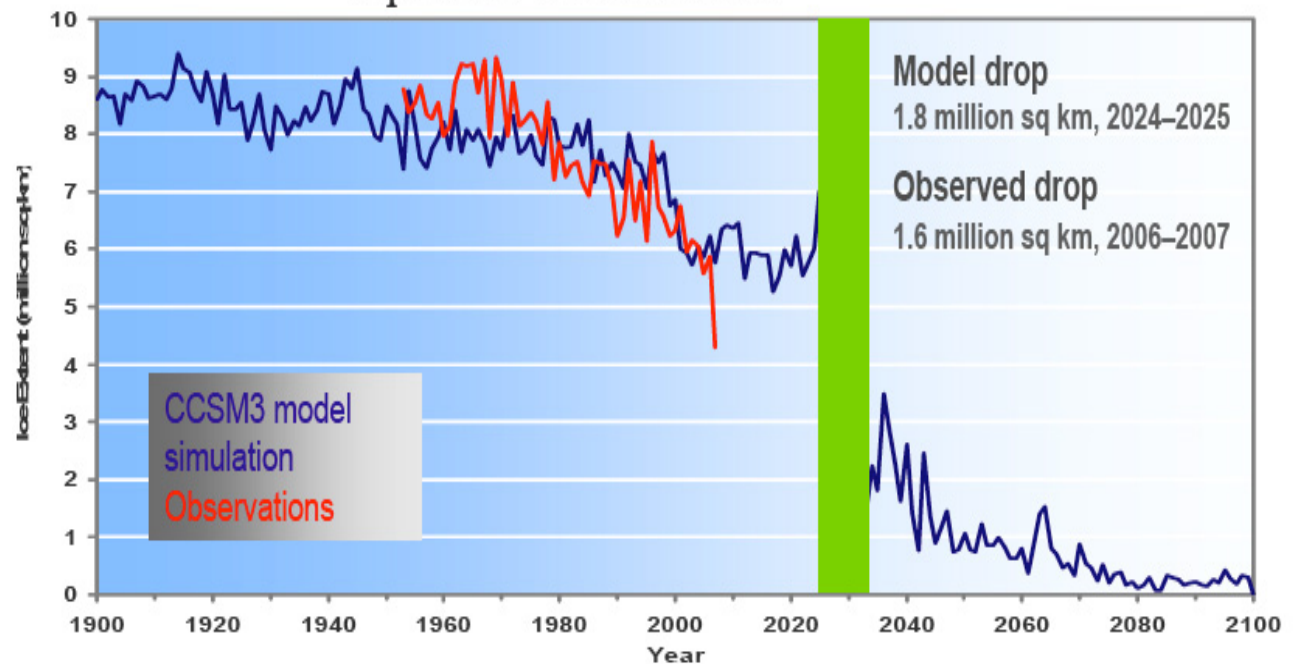
Arctic Summer Sea Ice Record Minimum (2007)





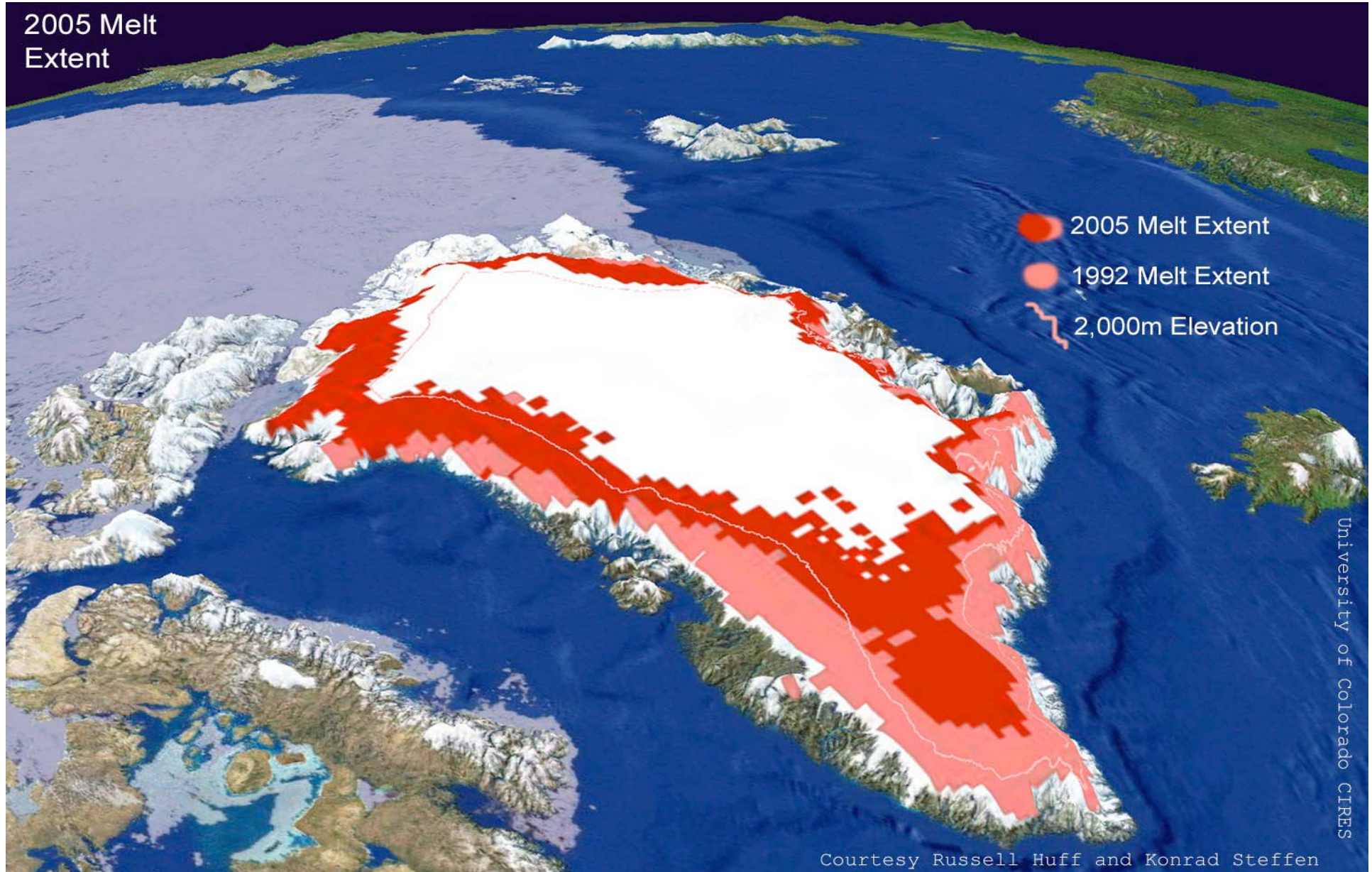
- Volume and area of arctic sea-ice decline precipitously
- 2007 was bad
 - People predicted an ice-free arctic ocean in 10 years

September Sea Ice Extent

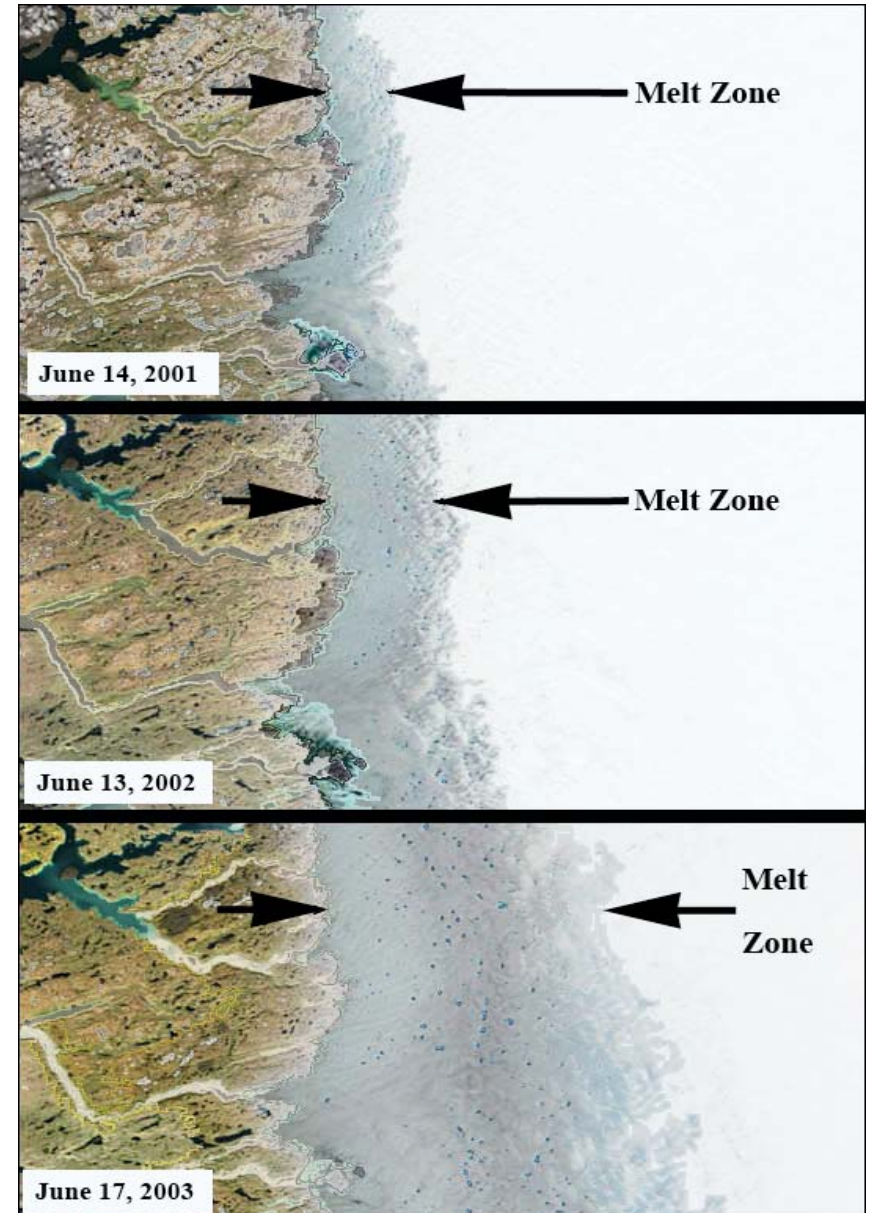


Greenland Melting (1992-2005)

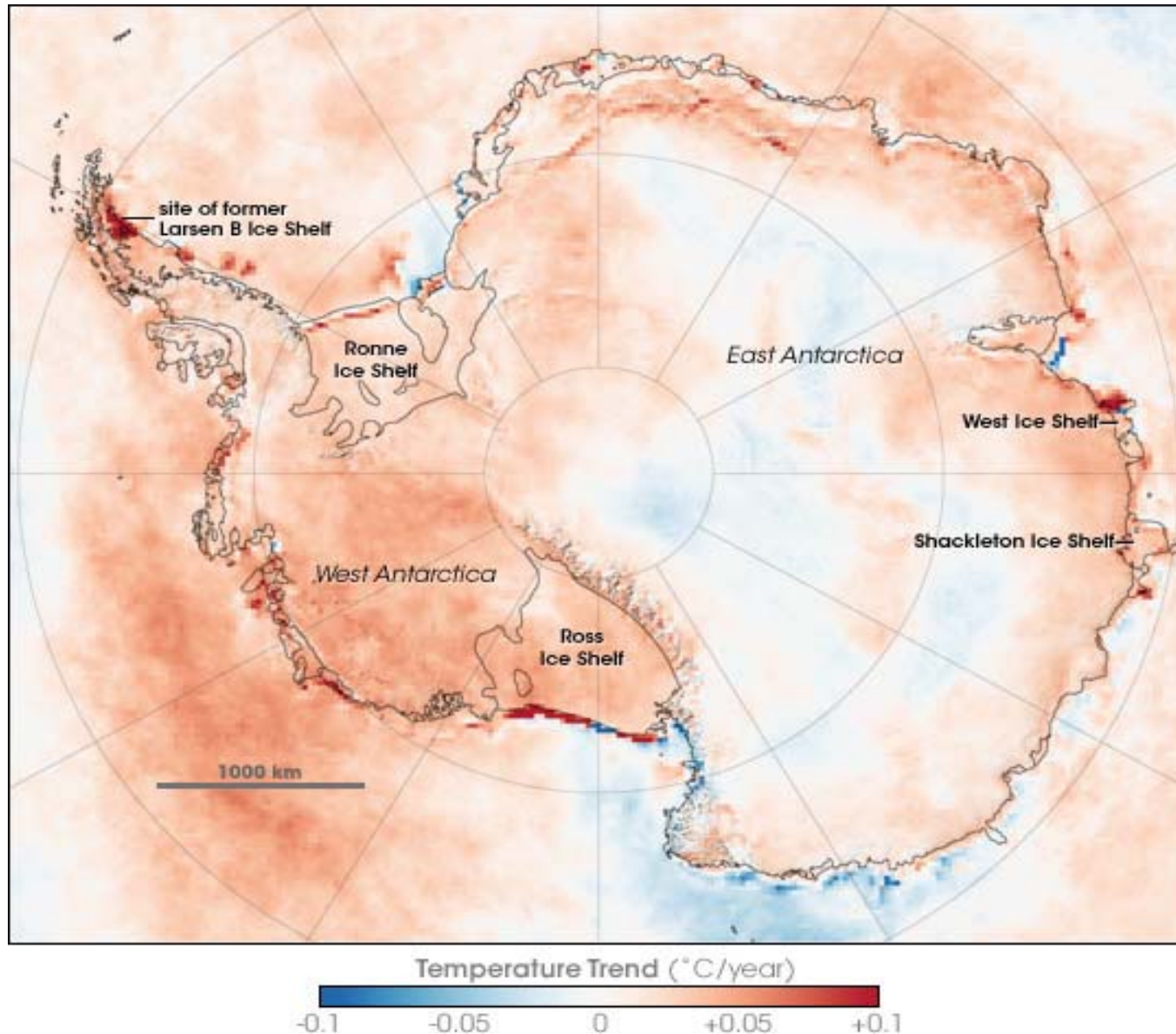
(Volume loss (2005) = 240 km³ per year)

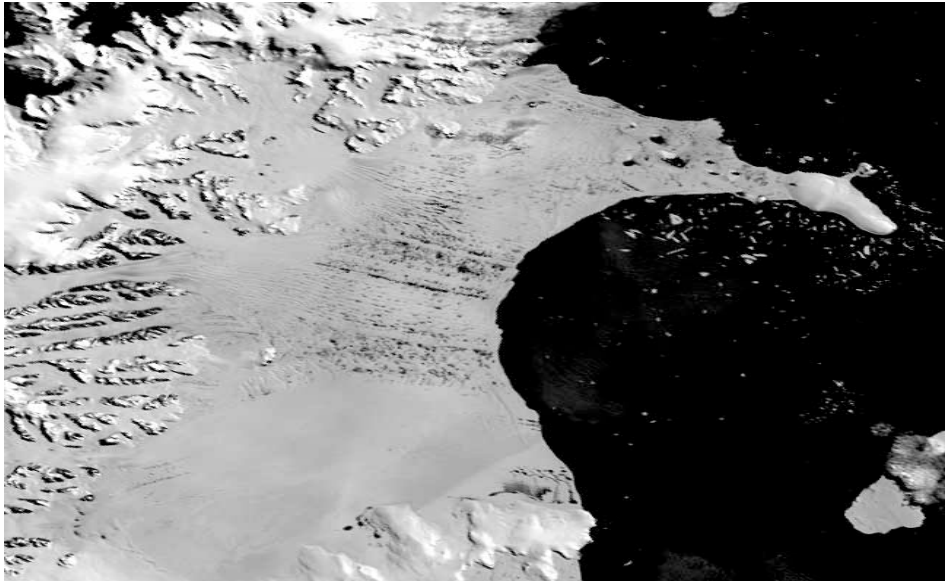


Greenland Ice Sheet Melting

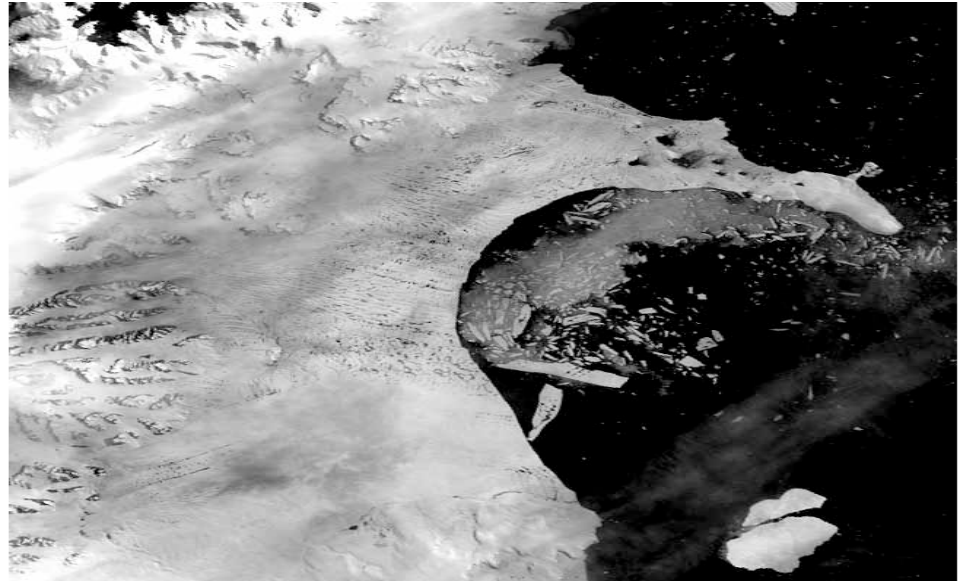


Antarctic Temperature Changes Between 1981 and 2007

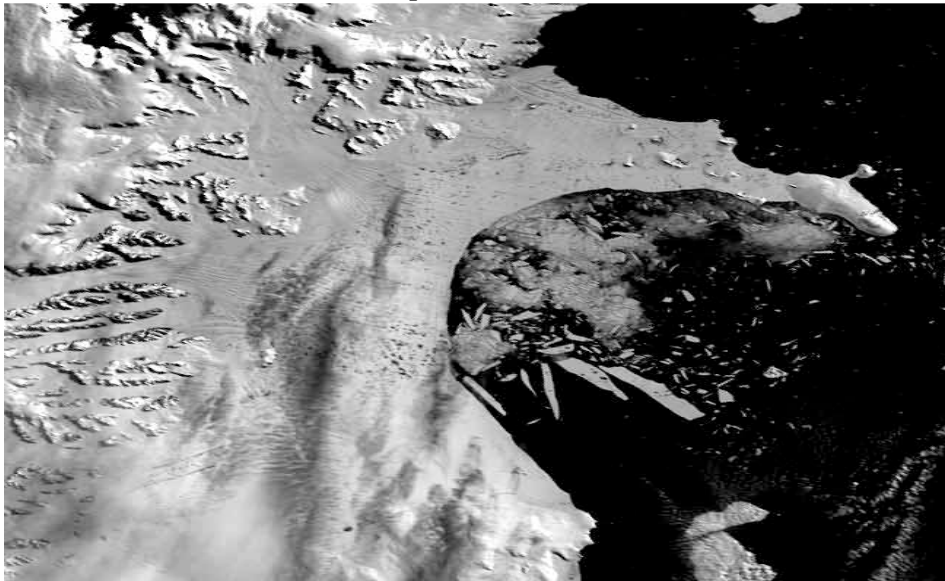




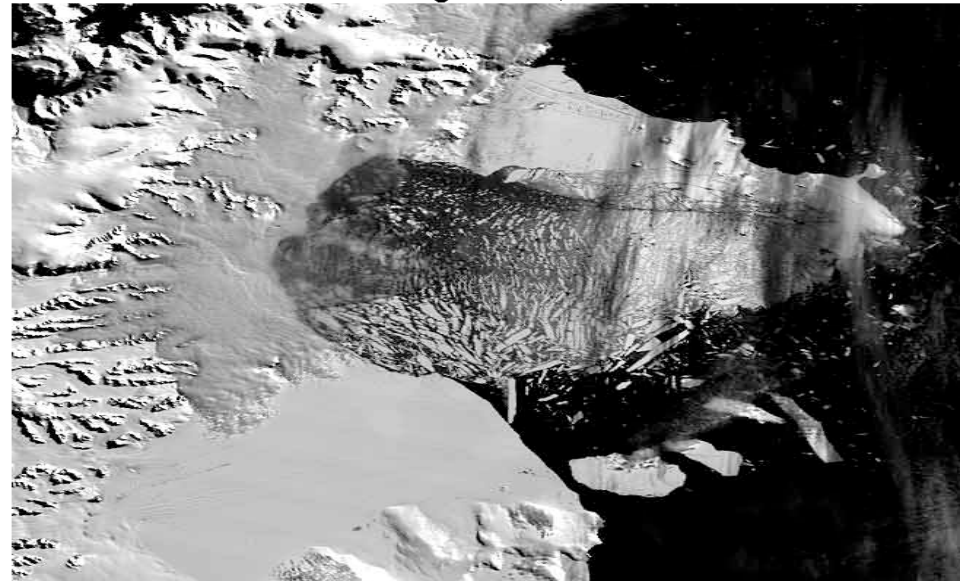
January 31, 2002



February 17, 2002

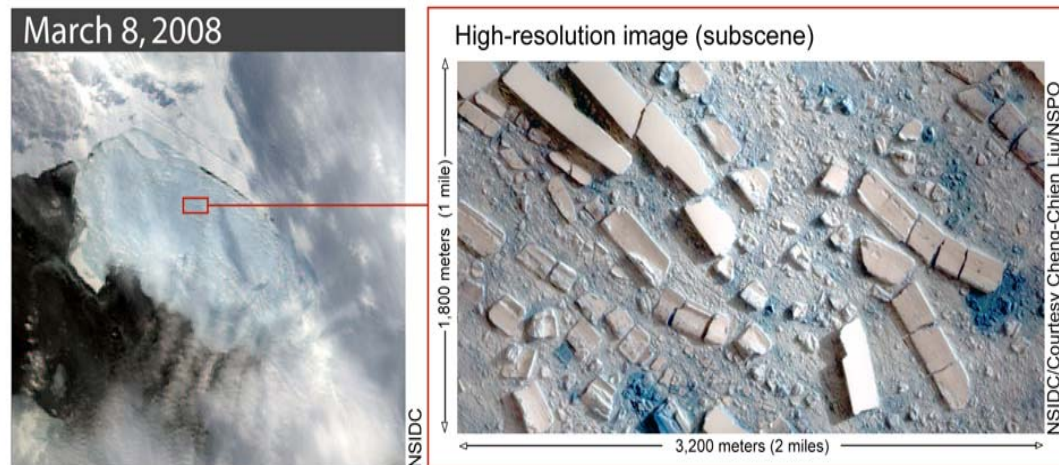
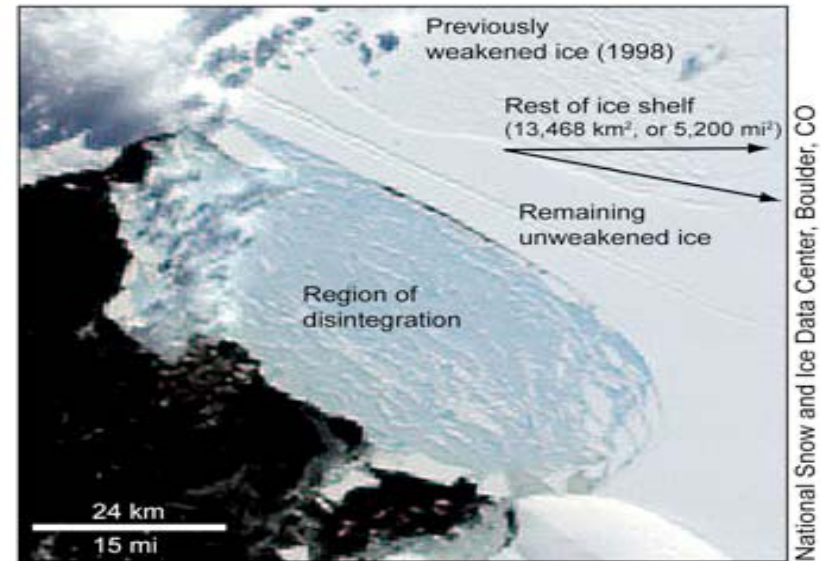
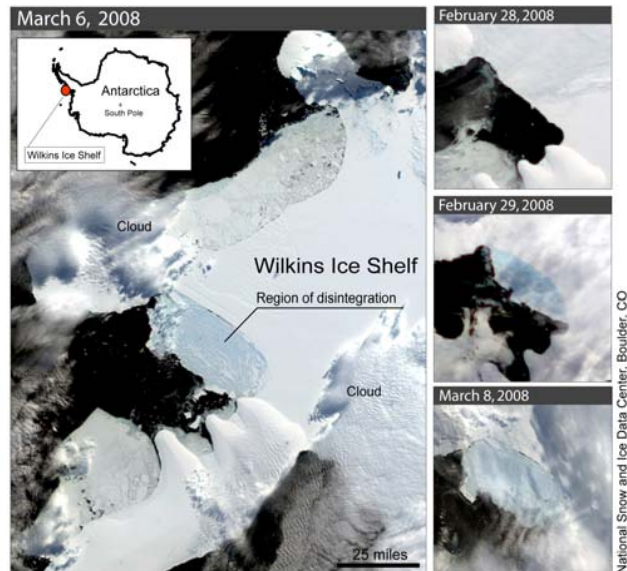


February 23, 2002



March 5, 2002

Breakup of the Wilkins Ice Shelf (2008)

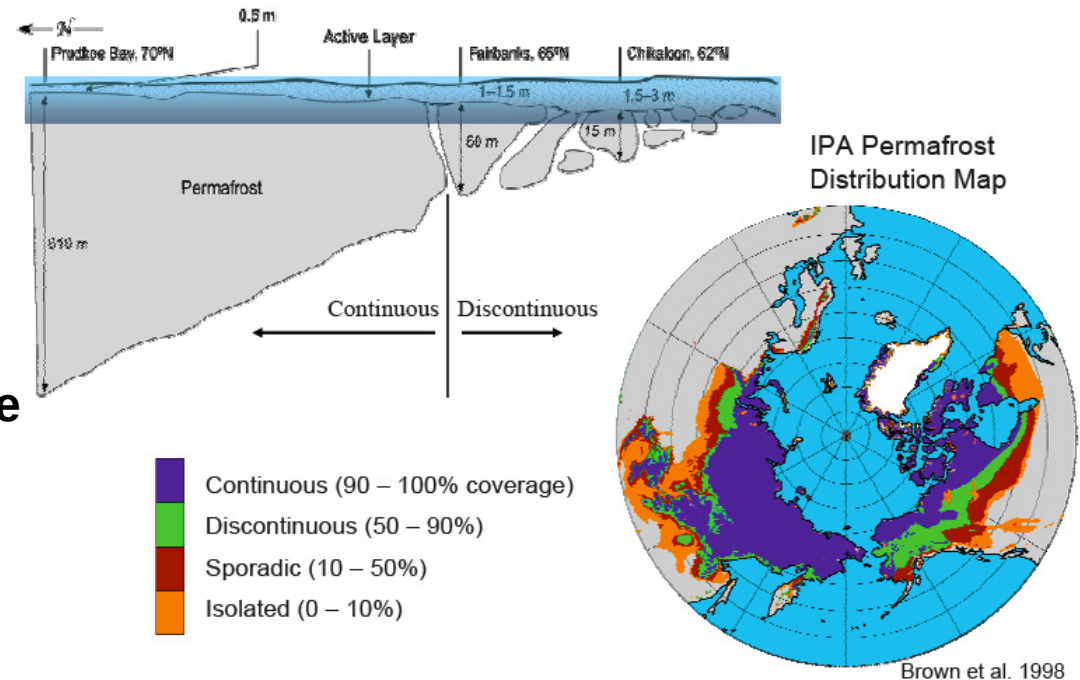


In the past 50 years, the western Antarctic Peninsula has experienced the biggest temperature increase on Earth, rising by 0.5 degree Celsius (0.9 degree Fahrenheit) per decade. Satellite images indicate that the Wilkins began its collapse on February 28, 2008; data revealed that a large iceberg, 41 by 2.5 kilometers (25.5 by 1.5 miles), fell away from the ice shelf's southwestern front, triggering a runaway disintegration of 405 square kilometers (160 square miles) of the shelf interior.

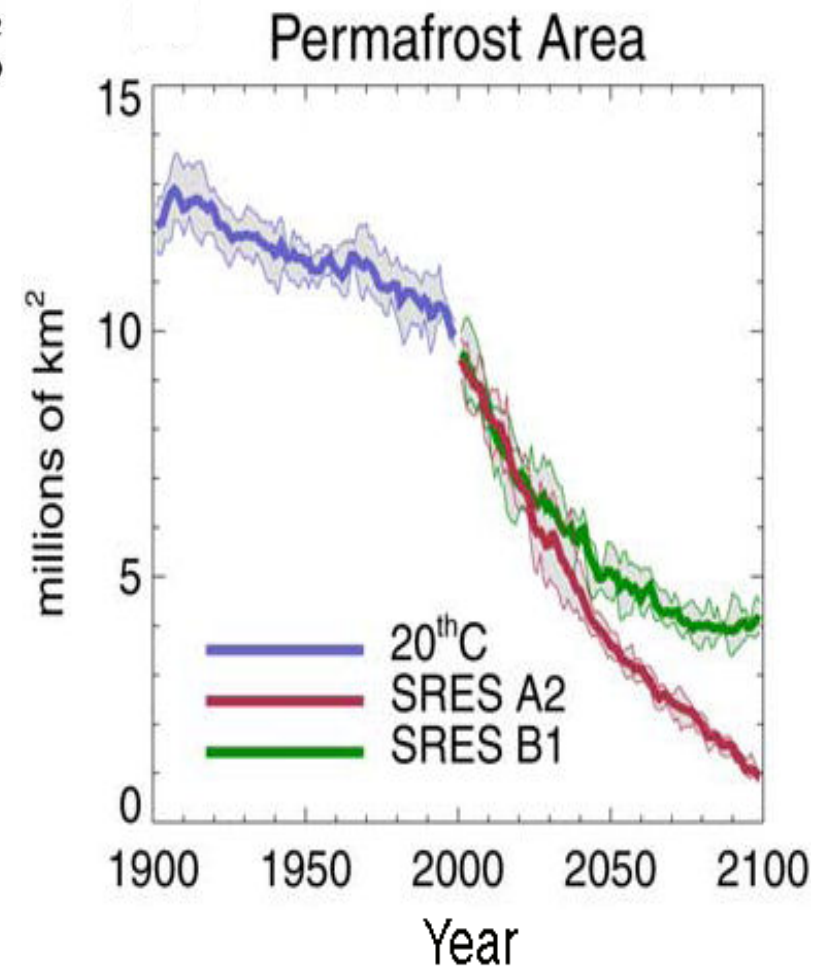
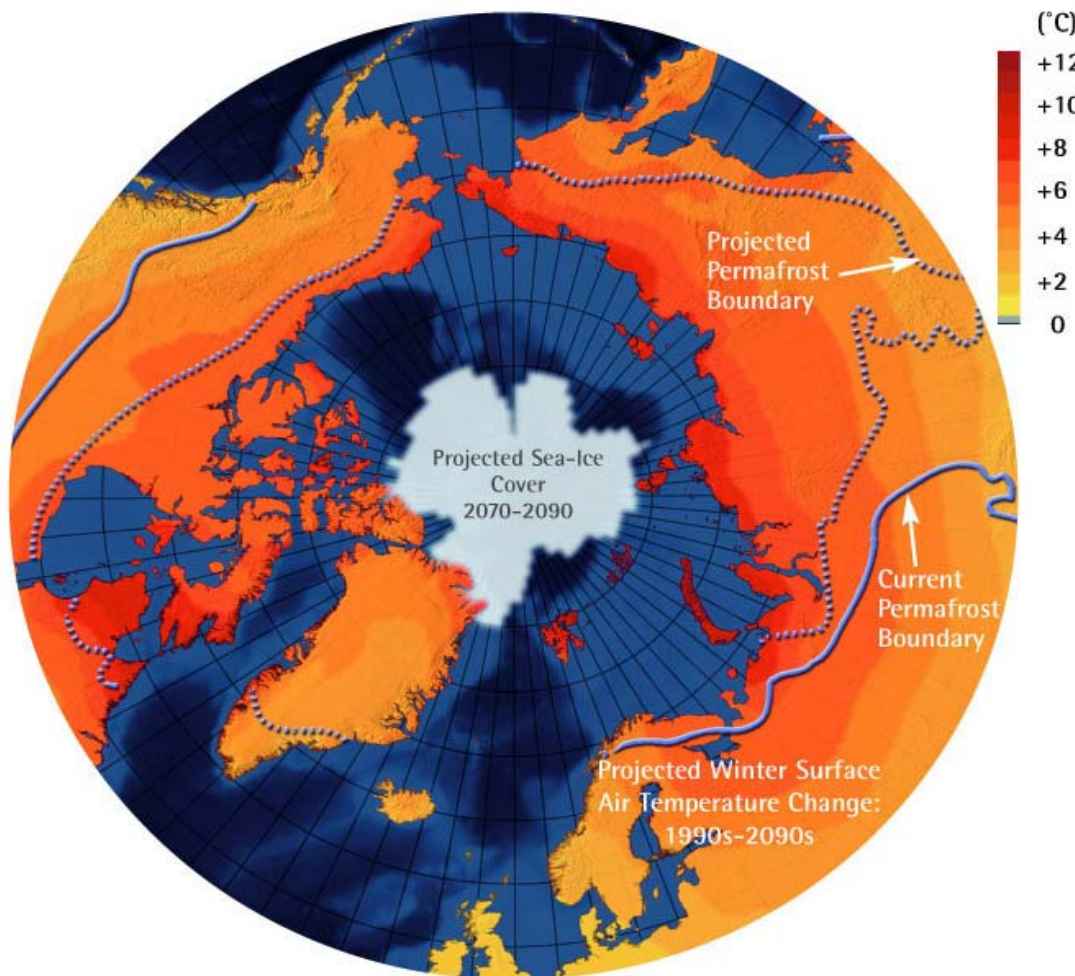
● Feedback #2 – melting permafrost

- Huge amounts of organic material permanently frozen
- Warmer temperatures means this stuff starts to decay
 - Released CO₂ and methane
 - More greenhouse gases means higher temperatures etc...

Permafrost:
Soil or rock that remains below freezing for two or more years

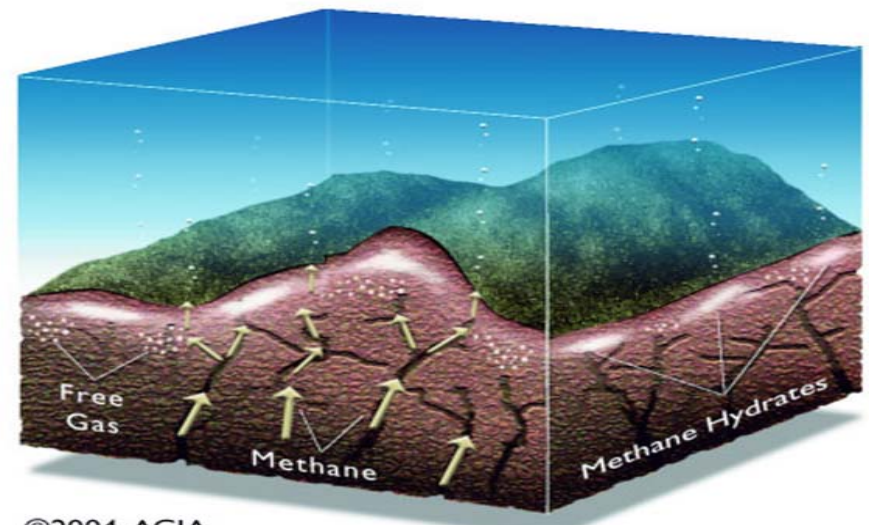
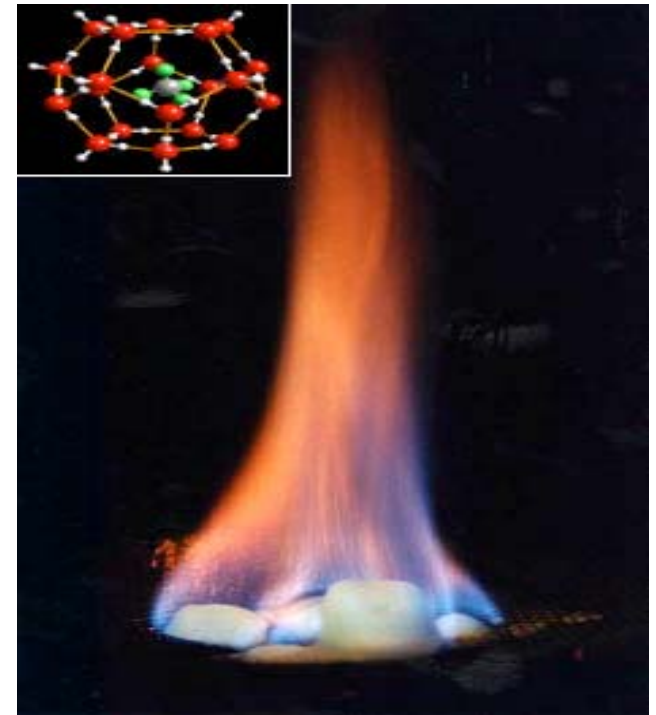


Projected Permafrost Decline by the 2090s

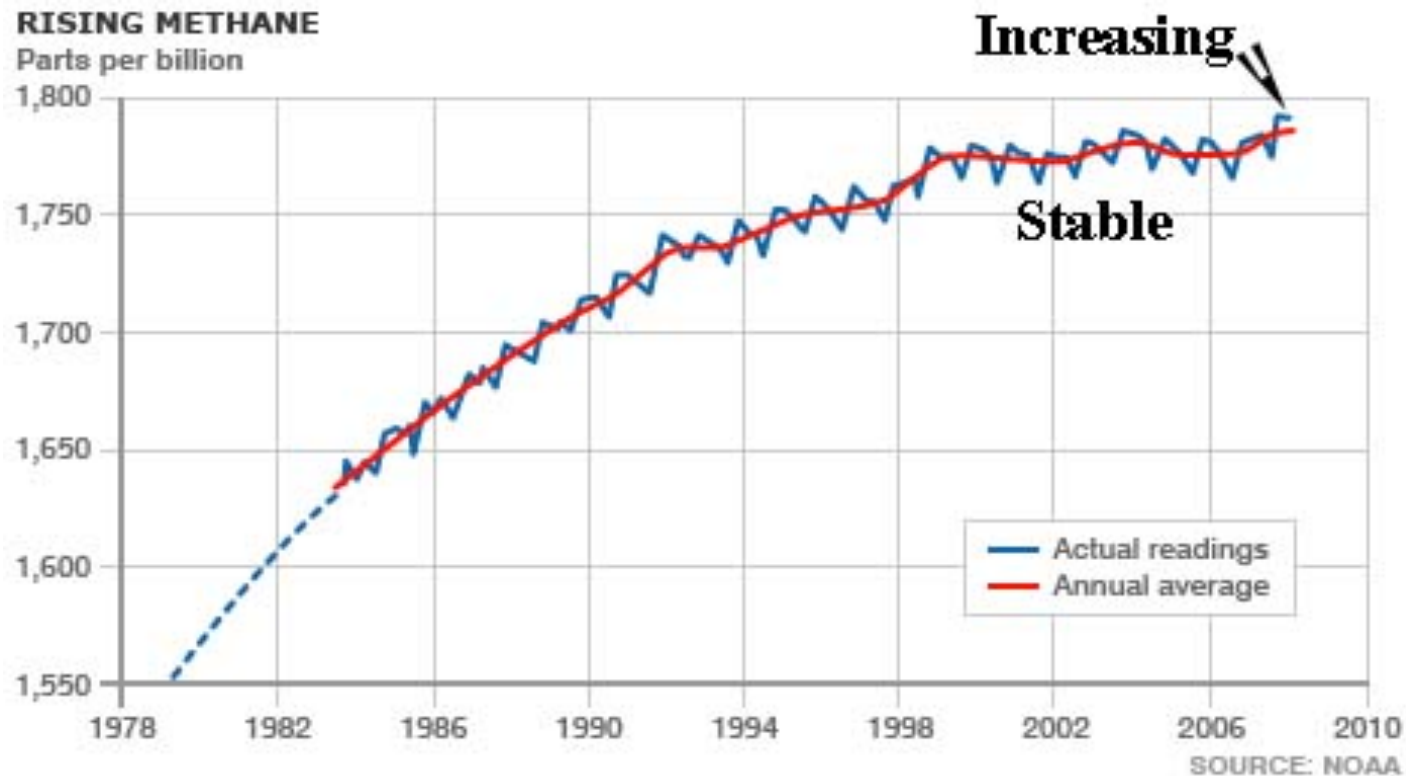


● Feedback #3 – methane hydrate

- Methane molecules trapped inside cages of water ice molecules
 - Found frozen on the seafloor of the Arctic continental shelf
 - CO₂ equivalent of 1.98 trillion metric tons
 - Dangerously close to thawing (within 2 degrees)
 - Reduction in sea ice is causing this to warm up
-
- If thawed and released methane content of the planet's atmosphere would increase twelve-fold
 - Catastrophic rise in temperatures



- Methane has been stable for almost a decade
- Slight rise in last year or two is a big cause for concern
 - Based on carbon isotope analyses the methane is of biogenic origin.
 - The source is probably release from melting permafrost, and possibly the Siberian Arctic continental slope methane hydrates.



- **Feedback #4 – the oceans**

- The oceans soak up about half the CO_2 we pump out
- ...but warmer water absorbs less CO_2
- Ocean warming leads to more CO_2 in the atmosphere
- Causes the oceans to warm more etc...

- **Also increase in windiness (and waves) means that oceans less able to dissolve atmospheric CO_2**

- In 2007 the Antarctic ocean stopped absorbing CO_2 for the first time



Bottom line: We're in an unstable situation where the effects of global warming cause more warming

We should think very carefully about what we do next...

Consequences of global warming

- Sea level rise

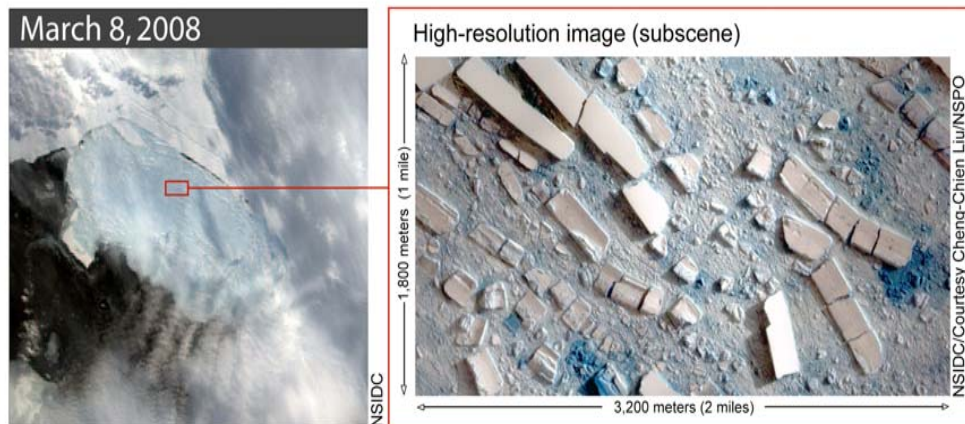


- Natural disasters

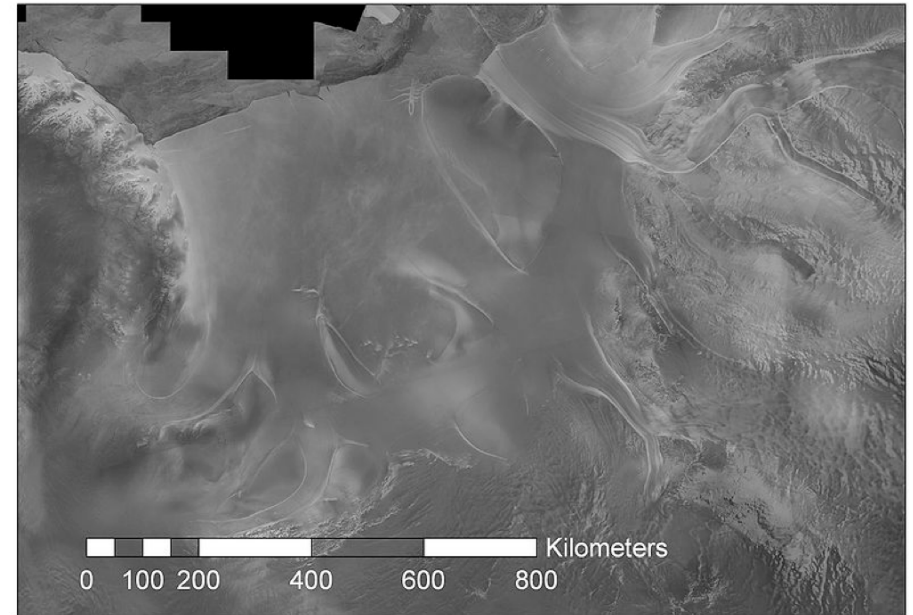
- Floods
- Hurricanes
- Heat waves
- Drought



- Sea level can rise when ice on land melts
 - Melting ice bergs (or ice-shelves) don't raise sea level

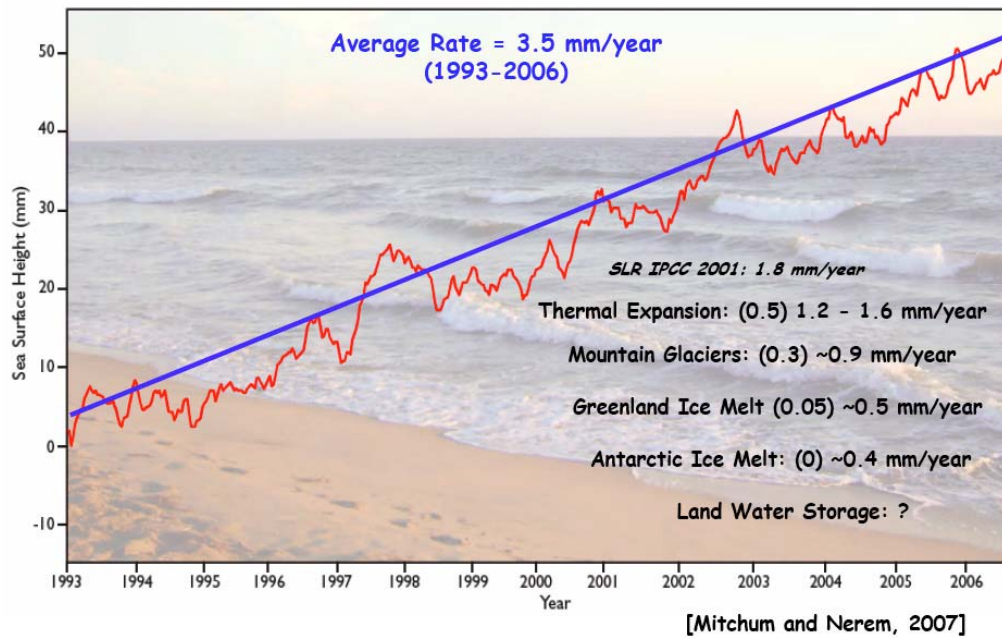


Not a problem directly

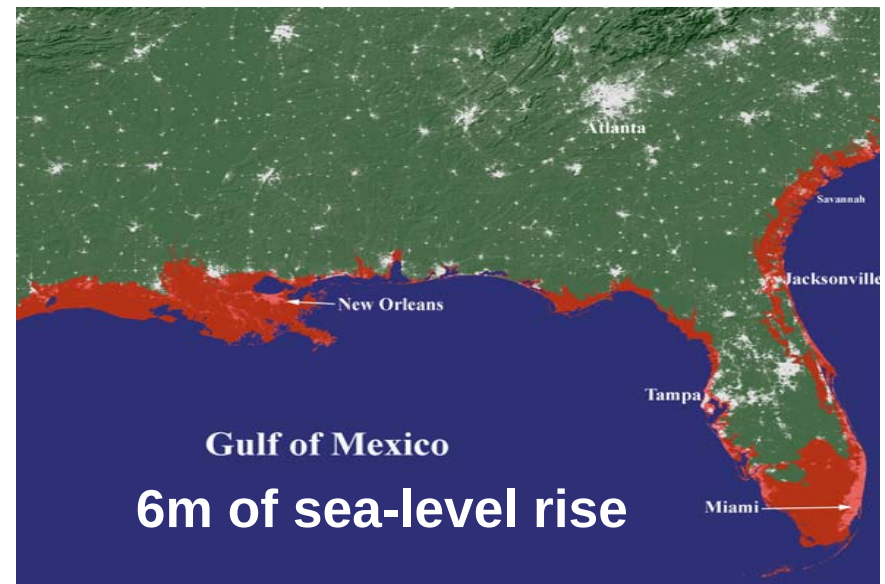
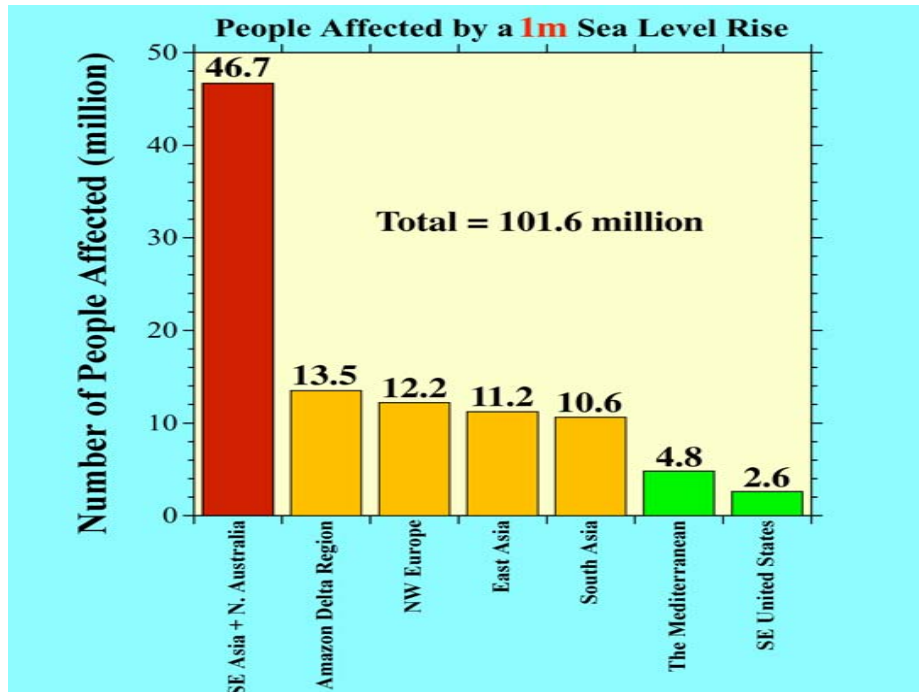
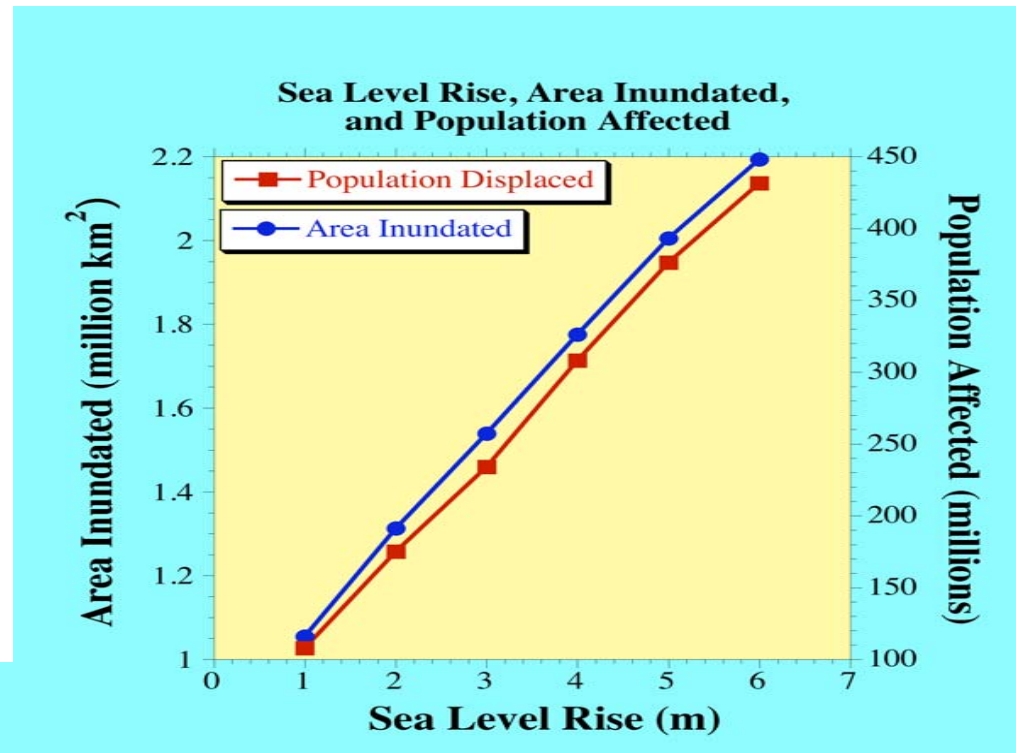


...but it unplugs ice streams than
dump new ice into the ocean

- Sea-level is already on the rise

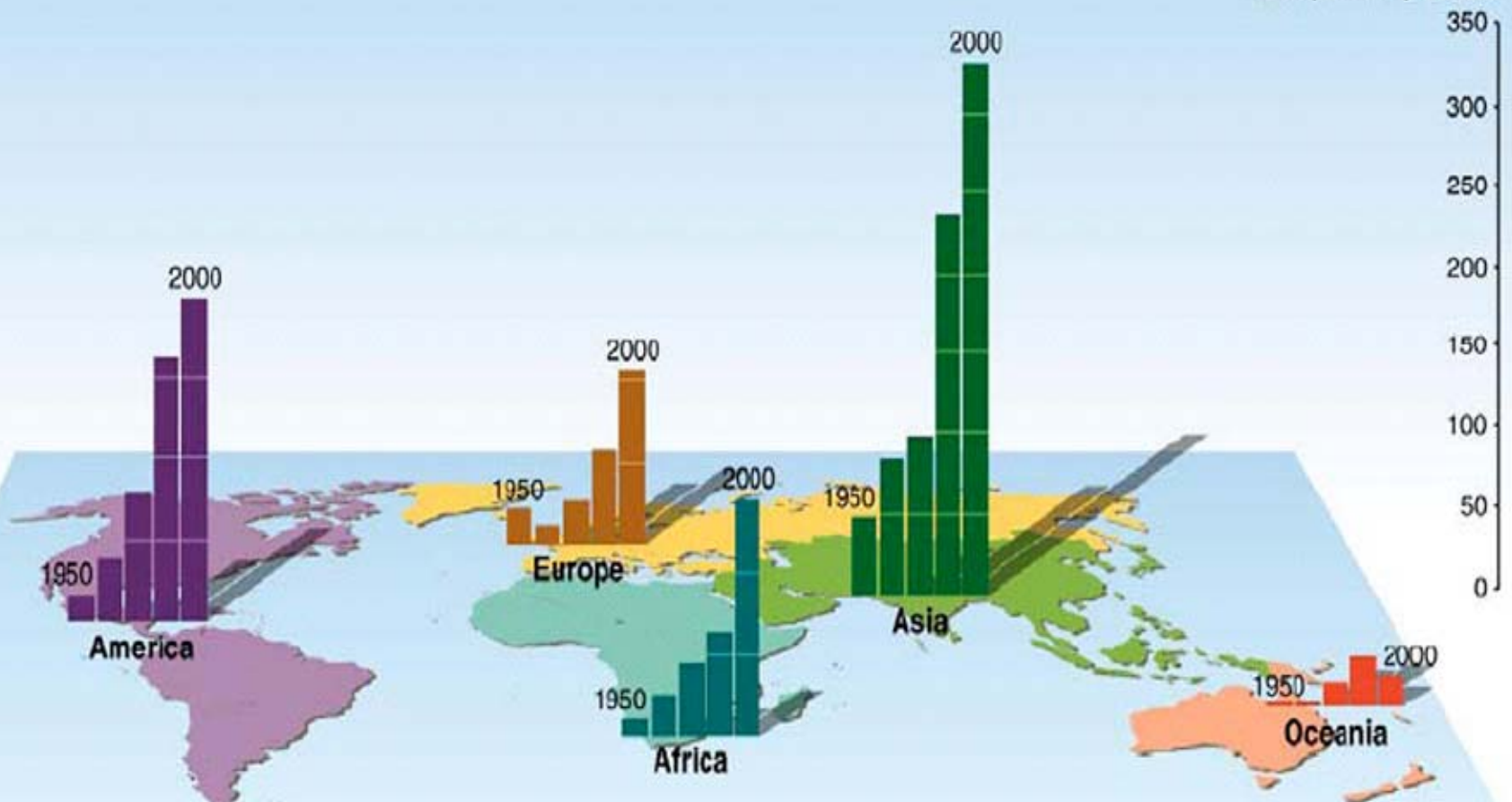


- Sea level rise will add an element of chaos to the 21st and 22nd centuries
 - Massive displacement of people
 - Expensive to relocate infrastructure
 - Expensive to protect existing cities



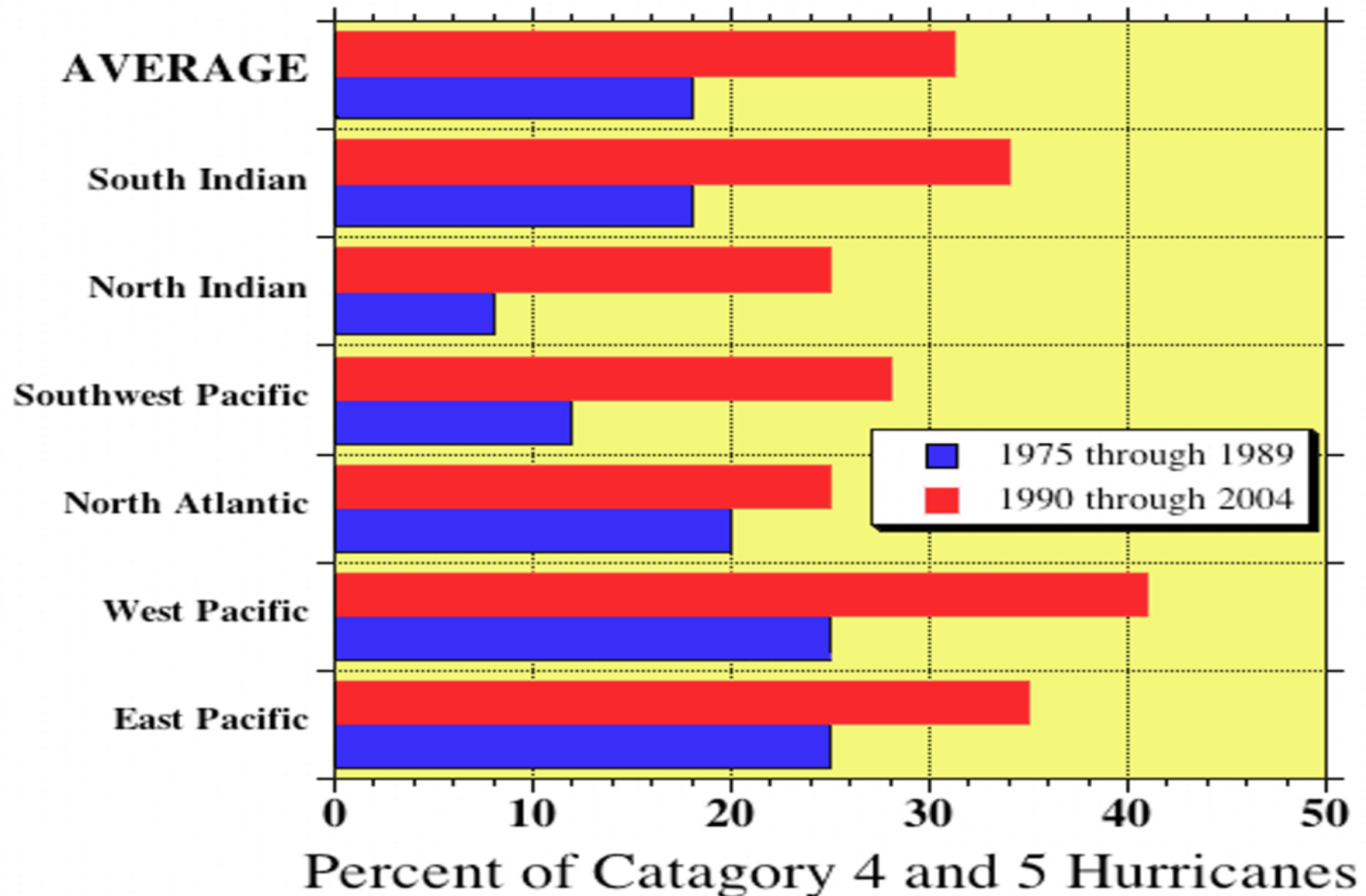
Floods

Number of events
Data plotted by decade



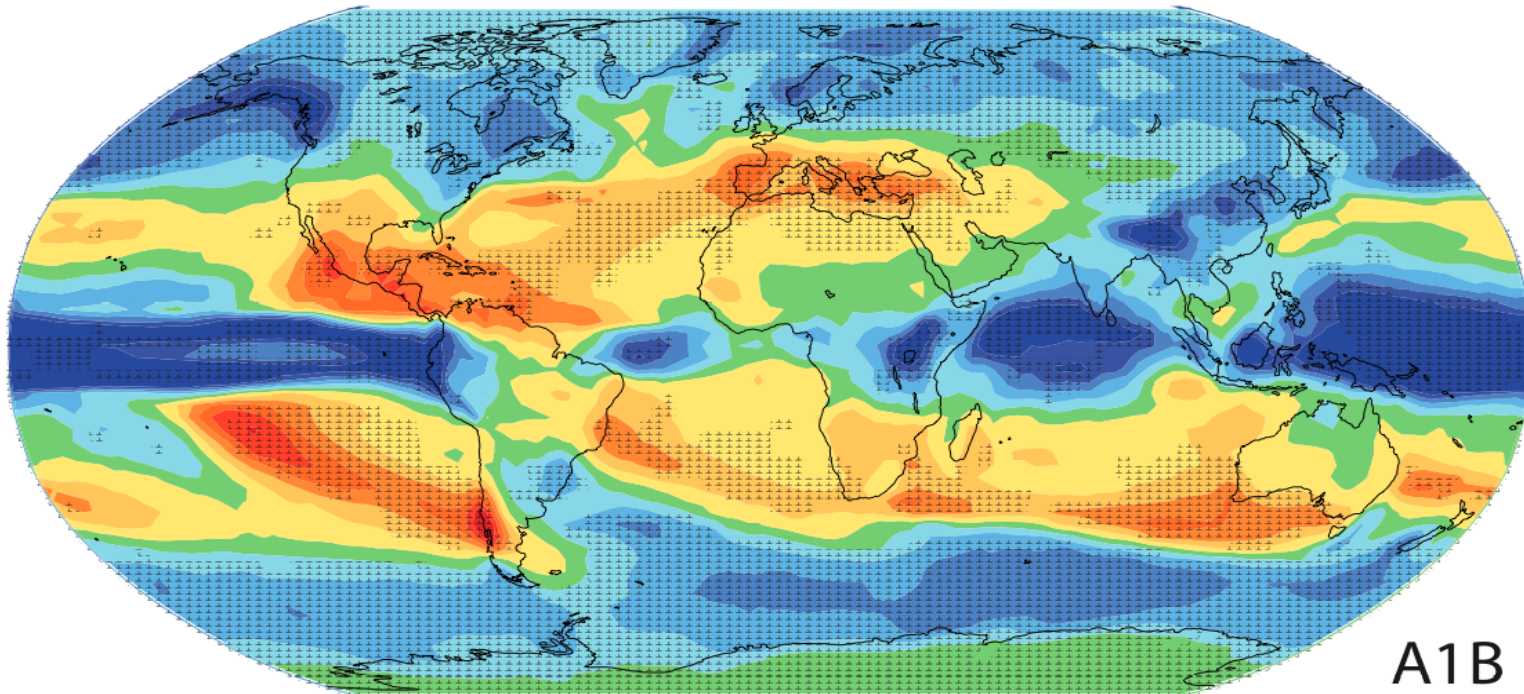
Source: Millennium Ecosystem Assessment

Increase in Hurricane Strength



- Droughts

2080-2099



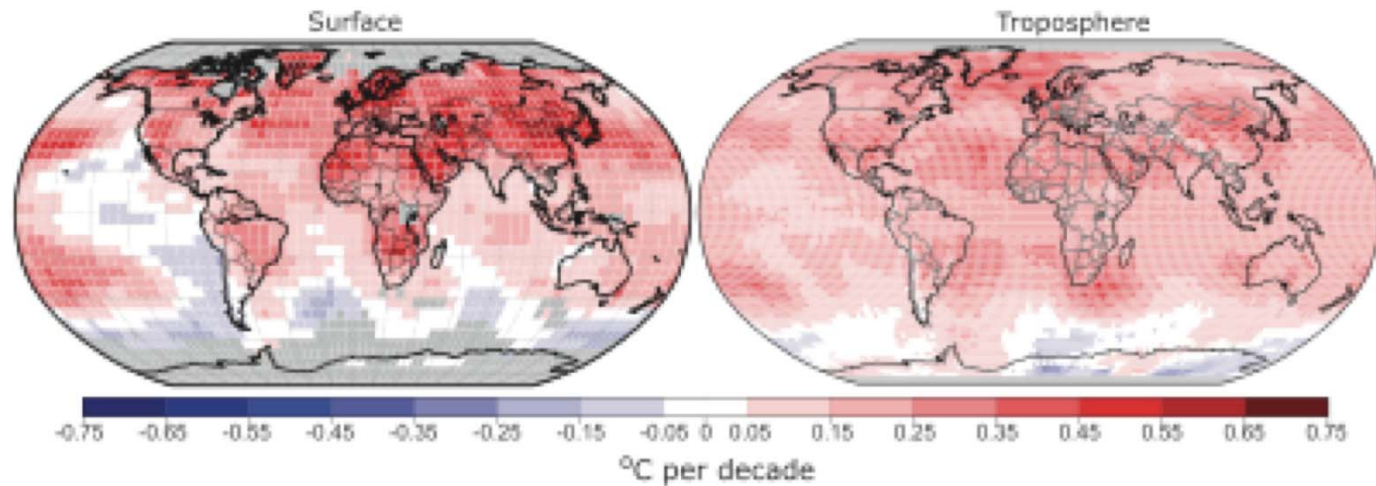
A1B



-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
Annual Mean Precipitation Change (mm/day)

- Heat waves

- Current warming trends



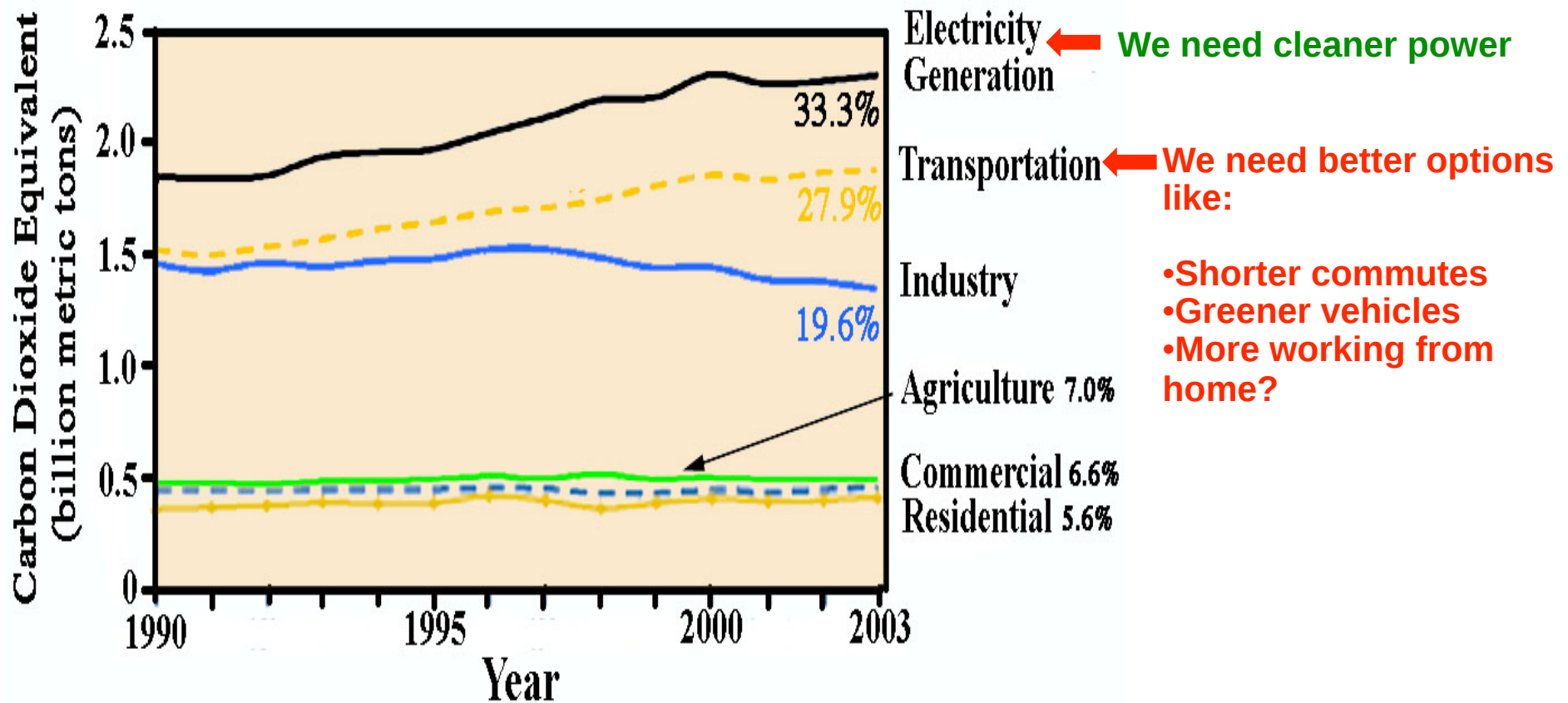
- 2003 European heatwave

- ~35000 dead

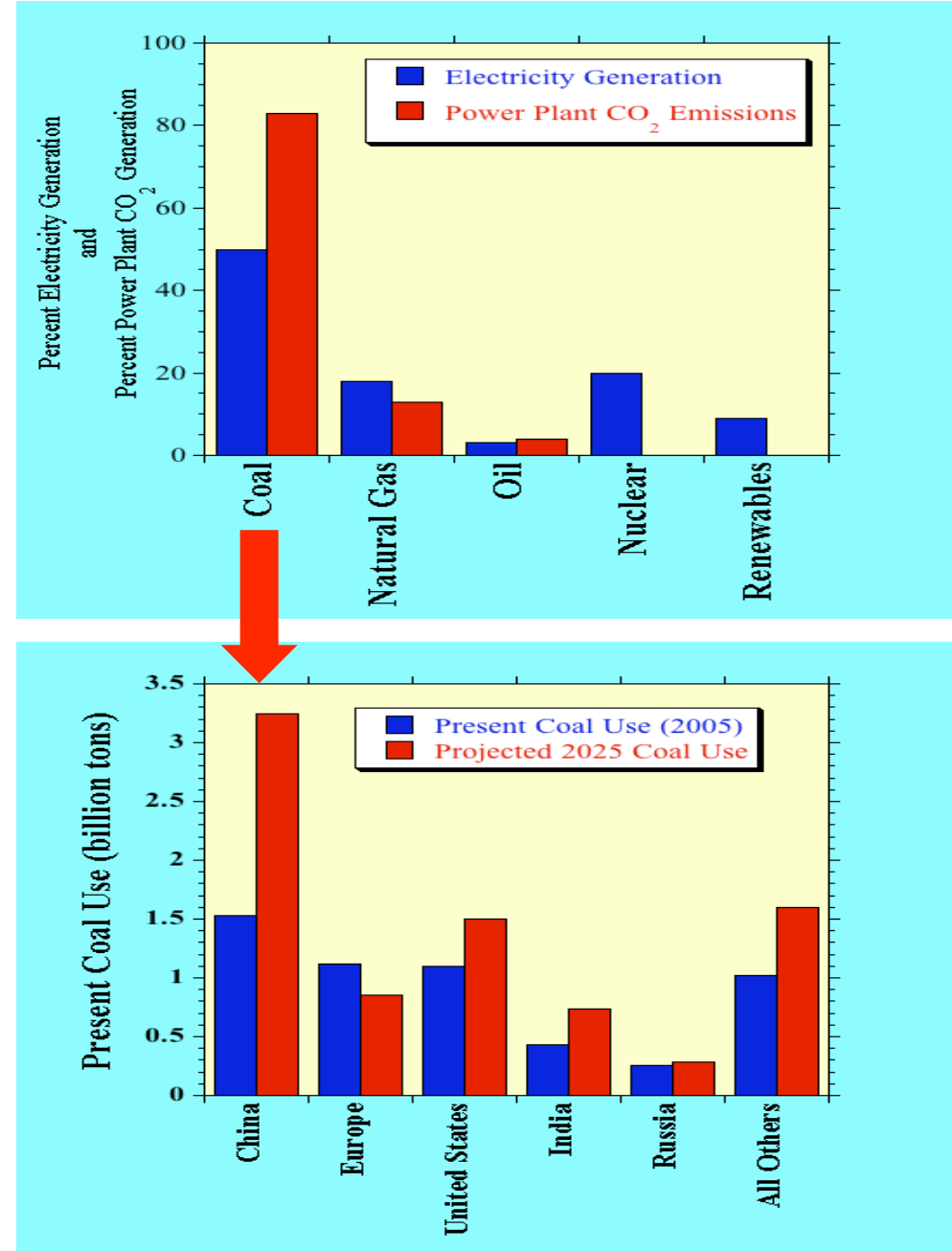
Options ??

- Nothing really easy...
- But it helps to understand the problem

U.S. Emissions by Economic Sector



- Power is the biggest problem
 - Today's options
 - ▶ Conservation
 - ▶ Renewable energy
 - ▶ In reality though it has to be – more nuclear reactors...
 - Options for the future
 - ▶ Nuclear fusion
 - ▶ Hydrogen based transport
- We can't invent our way out of the problem
 - There isn't enough time

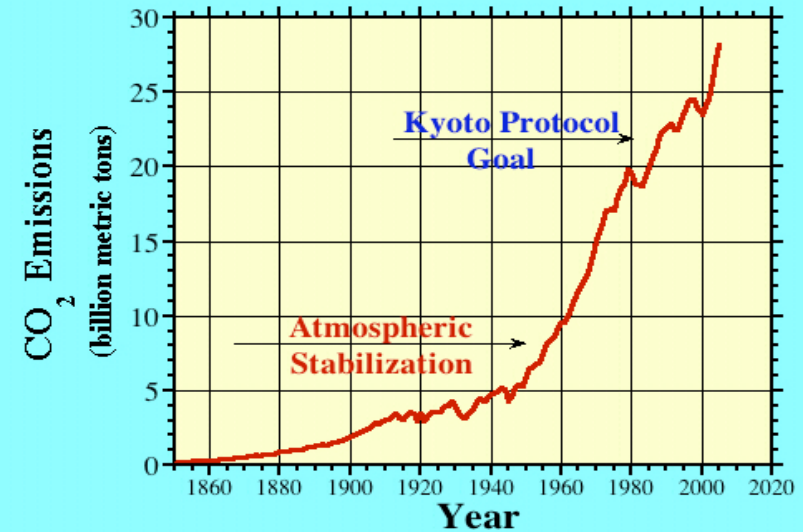


● What about the Kyoto protocol?

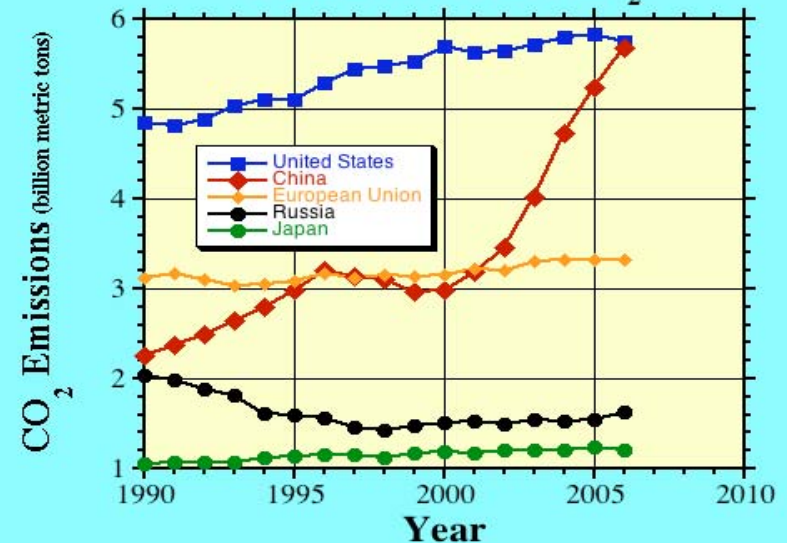
- The US never implemented it
- It was never going to be the final answer
- Now the problems are much more serious and there's less time to solve them

- China is about to overtake the US in CO₂ output
- International agreements necessary
- Kyoto followup is being trashed out this year

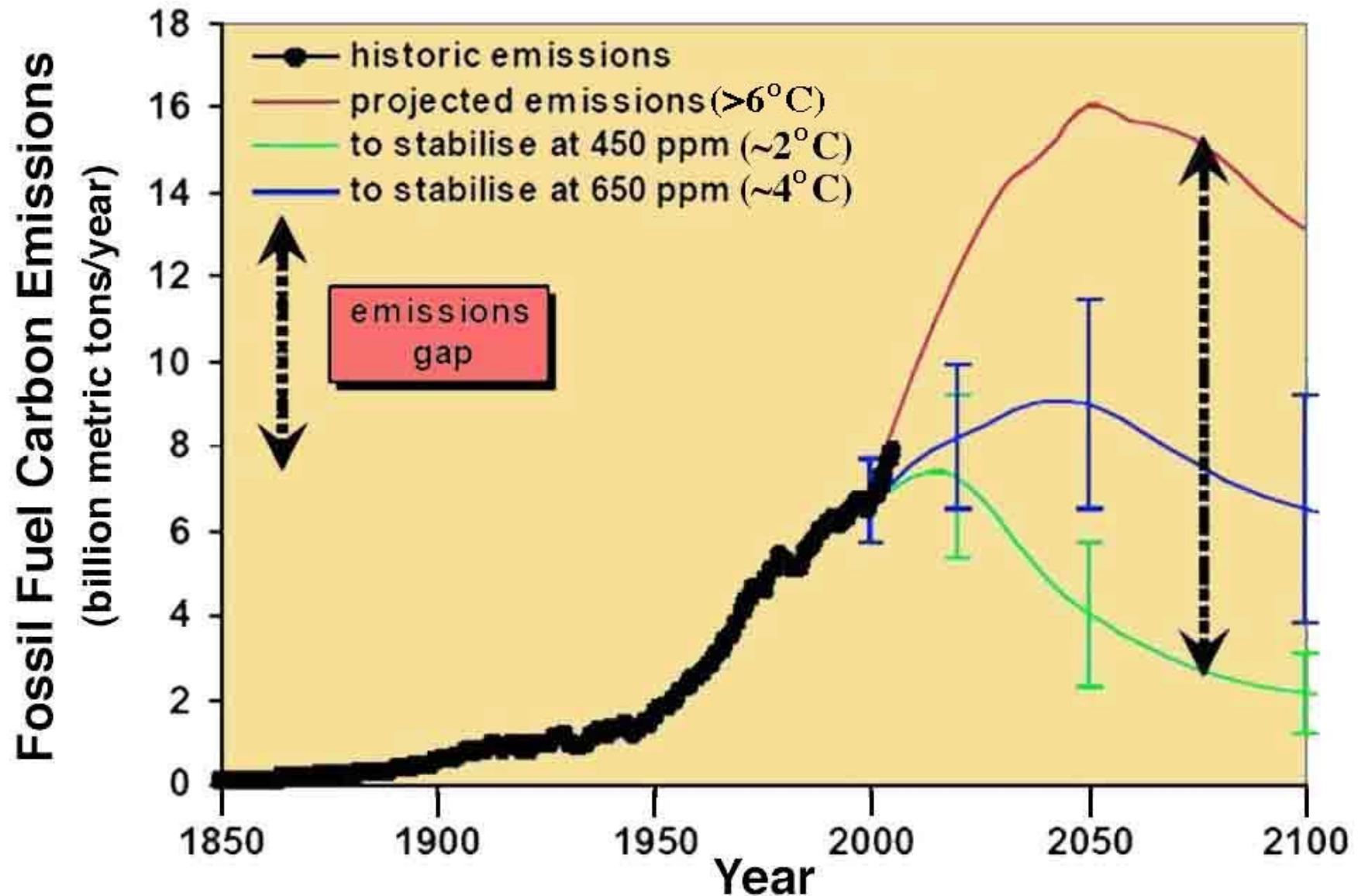
**Current Kyoto Protocol Goal
Will Not Solve Our Problem**



Major Emitters of CO₂



Carbon Emissions for Peak CO₂ Stabilization





Skeptics and Alarmists

- **Why are we still stuck in this rut???**
 - We borrow money from China to keep buying oil from unfriendly regions
 - China expands it's economy and builds ~2 new coal power stations a week
- **Energy efficiency and conservation SAVE money**
- **Creating new greener industries CREATES jobs**
- **Climate skeptics (most paid by the oil industry) worked to maintain the current state of inaction**
- **Climate Alarmists produced dire warnings of imminent catastrophes every day**
- **Some environmentalists lectured people about how bad they were being rather than offering something constructive**

To Date Global Warming Mitigation Has Been a FAILURE

Scientists	Fail to convey seriousness of problem
Media	False “balance”, uninformed and uninterested
Special Interests	Disinformation campaigns and emphasis on short-term profits
Public	Understandably confused, misinformed and uninterested
Government	Affected by special interests and failure to lead



In this lecture...

- Buildup of CO₂ in Earth's atmosphere – greenhouse effect
- Climate change is very real – and already in motion
- Consequences are likely to be bad
 - Extreme weather
 - Sea level rise
 - Increasing Temperatures
- Countering climate change
 - New energy sources
 - Lifestyle changes – conservation
 - International Agreements

Next: Gas Giants: Jupiter and Saturn

- Reading
 - To revise this check out <http://www.lpl.arizona.edu/resources/globalwarming/>
 - Chapter 12 for the next lecture