Lec. 9: Climate Change Projections

Climate Change Projections

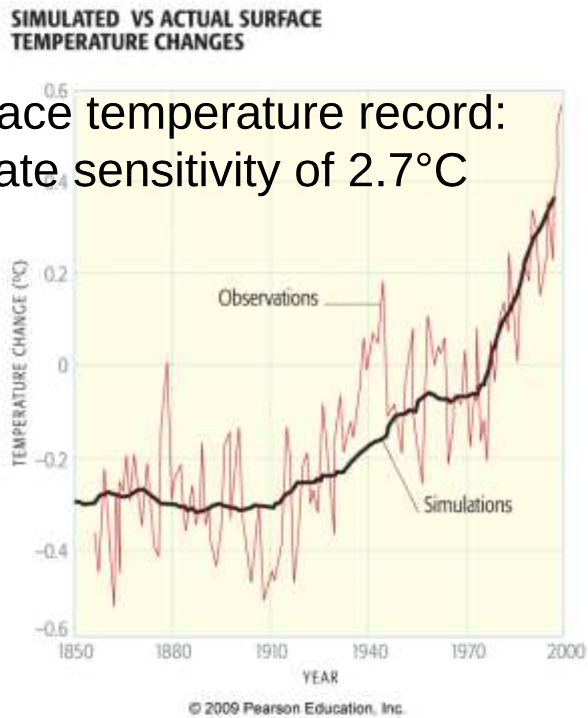
- Climate projections (i.e. predictions) depend on
  - The unknown future trajectory of green house emissions
  - The uncertain response of the climate to these emissions
- Certain conclusions can be drawn from
  - Best guess scenarios of fossils-fuel burning.
  - The average predictions of theoretical climate models.

How sensitive is the climate?

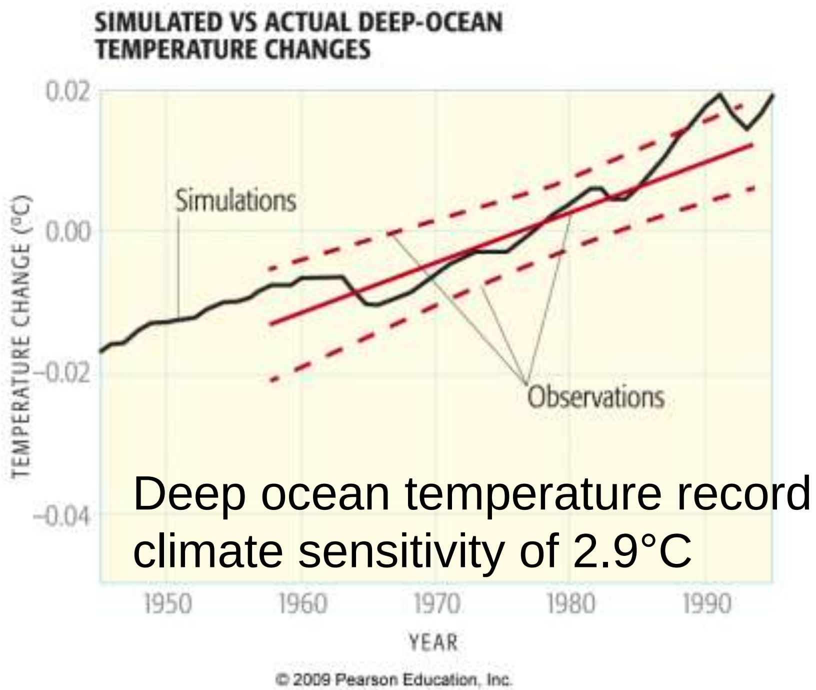
- **Climate sensitivity** defines the amount of warming (in degree Celsius) that we expect to occur in response to future increases in greenhouse gas emissions. It is typically expressed in terms of the expected surface warming that will occur in response to a doubling of atmospheric CO_2 level from their pre-industrial level of 280 ppm.
- **Equilibrium climate sensitivity:** due to sluggish ocean warming, the full amount of warming in response to an increases in greenhouse gas concentrations may not be realized for many decades. So if we say equilibrium climate sensitivity is 3 °C, we mean that Earth will eventually warm by 3 °C if CO_2 level reach 560 ppm.

How do scientists estimate climate sensitivity?

- **By tuning to different climate sensitivity values**, scientists compare observed temperature changes (from the instrumental record of the past 150 years) with climate model simulations over the same time frame.
- **Results based on modern instrumental observations:** an equilibrium climate sensitivity of about 3 °C (3 °C warming if CO_2 doubling) .



Surface temperature record: climate sensitivity of 2.7°C

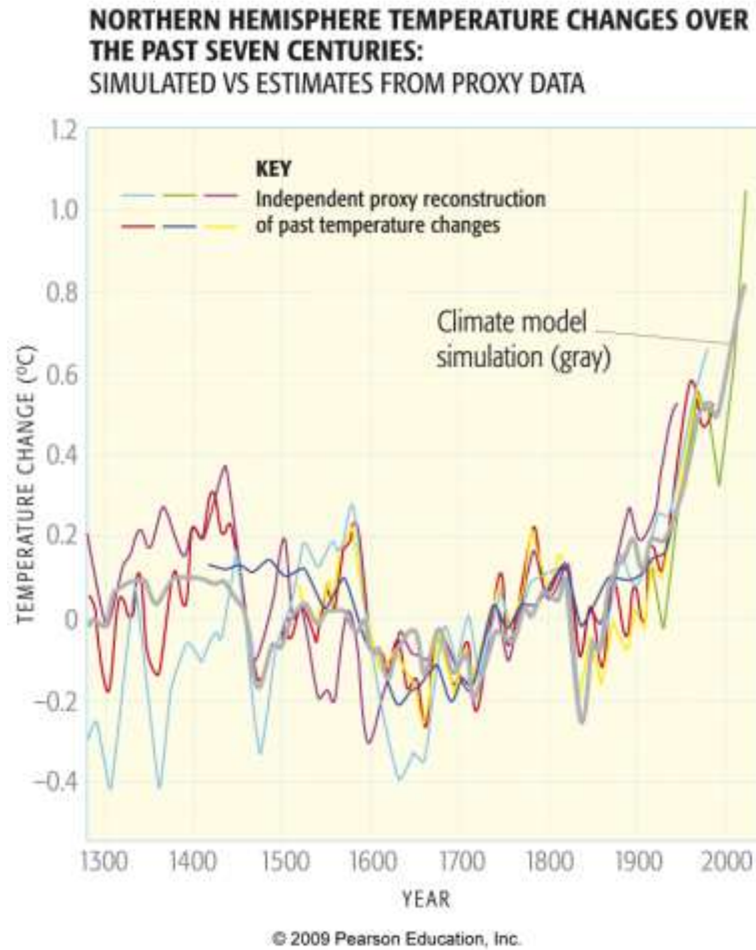


Deep ocean temperature record: climate sensitivity of 2.9°C

Evidence from past centuries: proxy data

- **By studying responses to changes in natural factors governing climate in previous centuries:** sunspot record and volcanic eruptions

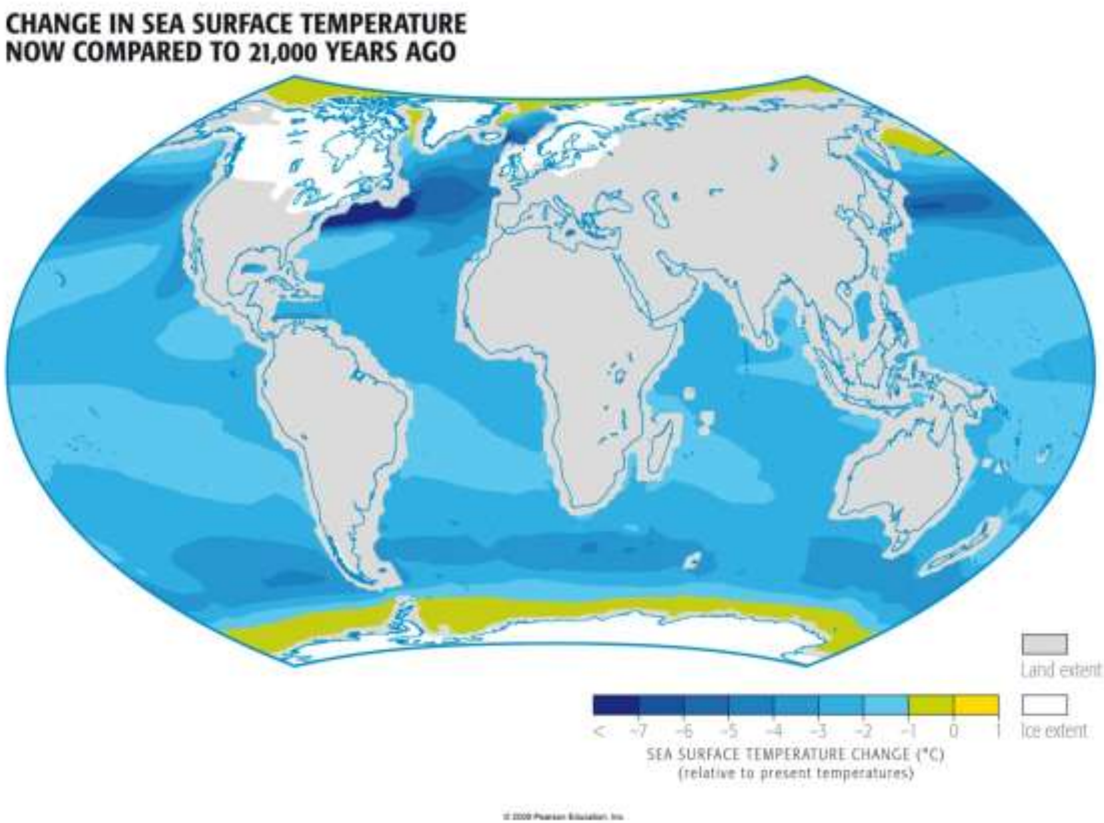
- **Results based on proxy data:** an equilibrium climate sensitivity of about 2-3 °C (2-3 °C warming if CO_2 doubling) .



NH Surface temperature change from proxy date during the past 7 centuries: climate sensitivity of 2-3°C

Evidence from deep time: last ice age

- **Last Glacial maximum (LGM):** 21,000 years ago, the global average temperature was 5 °C cooler than today (due to changes in Earth’s orbit and CO_2 feedbacks), the CO_2 levels were much lower (180ppm).
- **Resulting** an equilibrium climate sensitivity for the LGM of 2.7-3.7 °C, very close to other estimates.



LGM temperature minus current temperature

Intergovernmental Panel on Climate Change (IPCC)

The IPCC is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

The IPCC is a scientific body. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters.

The IPCC is an intergovernmental body. It is open to all member countries of the United Nations (UN) and WMO. Currently 194 countries are members of the IPCC.

Fossil-fuel emissions scenarios

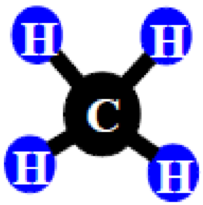
- **Future levels of global GreenHouse Gas (GHG) emissions** are driven by forces such as population growth, socio-economic development, and technological progress; thus to predict emissions accurately is virtually impossible. However, near-term policies may have profound long-term climate. Consequently, policy-makers need a summary of what is understood about possible future GHG emissions.

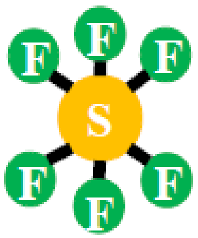
- **Definition of scenario:**
  - Image of future
  - Neither forecast nor prediction
  - Each scenario is one possible future– Set of scenarios are possible future developments of complex systems
  - Useful tool for not fully understood complex systems, whose prediction is impossible, e.g. population growth, use of fossil fuels and GreenHouse Gases (GHG) emissions

Emission

Scenarios include anthropogenic emissions of all relevant GHG species:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Hydroclorofluorocarbons (HCFCs)
- Chlorofluorocarbons (CFCs)
- Sulfur dioxide (SO_2)
- Carbon monoxide (CO)
- Nitrogen oxides (NO_X)
- Non-methane volatile organic compounds (NMVOCs)





Possible Scenarios by recent IPCC assessment

- **Four storylines:**
  - **A1: one global family**
  - **A2: a divided world**
  - **B1: global utopia**
  - **B2: local utopia**

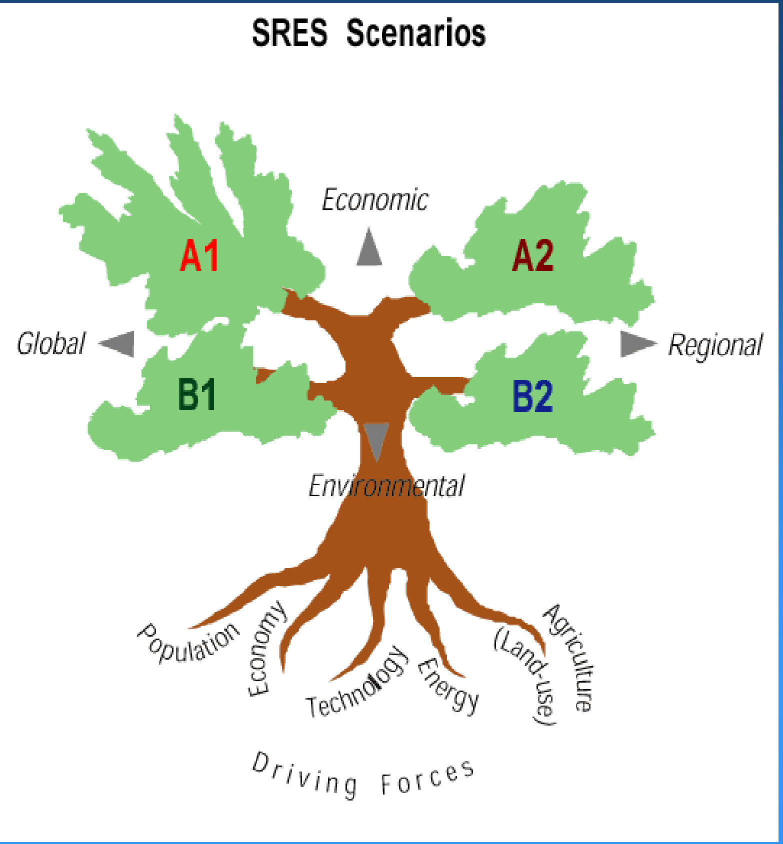
Storylines of scenarios

A1:
- Rapid economic growth.
- Peak population mid-21st century, then, declining.
- Rapid introduction of new and more efficient technologies.
- Substantial reduction of regional difference in per-capita income.

A2:
- Regional solutions to environmental and social equity issues.
- Continuously rising world population.
- Slow per-capita income growth technological development

B1:
- Rapid changes in economic structures.
- Peak population mid-21st century, then, declining, as in A1.
- Reduction in intensity of demand for materials.
- Introduction of clean and resource efficient technologies.
- Global solutions to environmental and social equity issues.

B2:
- Intermediate economic development.
- Moderate population growth.
- Less rapid and more diverse technological change than in the B1 and A1.
- Regional solutions to environmental and social equity issues.

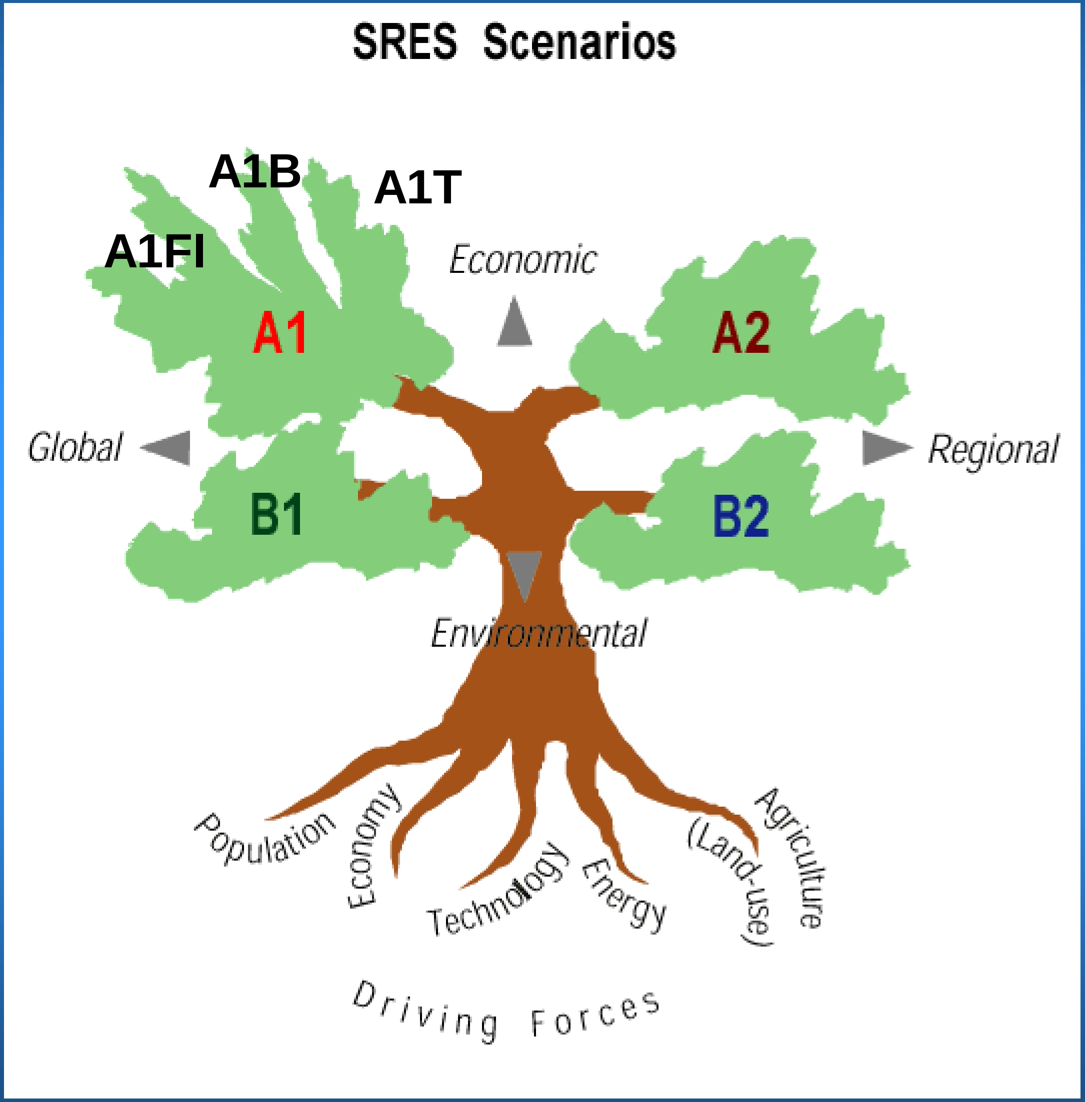


A1 Storyline

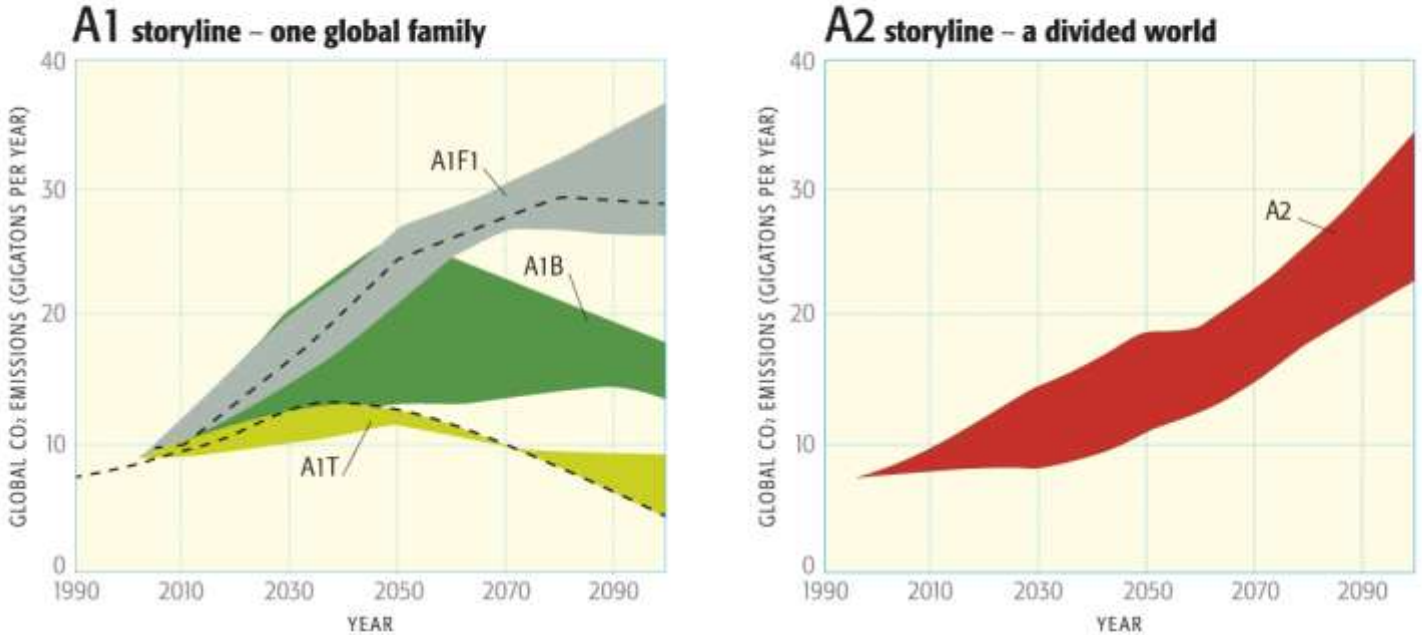
A1FI: Fossil fuel intensive

A1B: Assumes **a b**alanced use of both fossil and non-fossil fuels. **The A1B scenario is a "middle of the road" scenario often used as a basis of comparison in the IPCC report.**

A1T: Non-fossil fuel intensive



POSSIBLE CO_2 EMISSIONS SENARIOS FOR THE FUTURE



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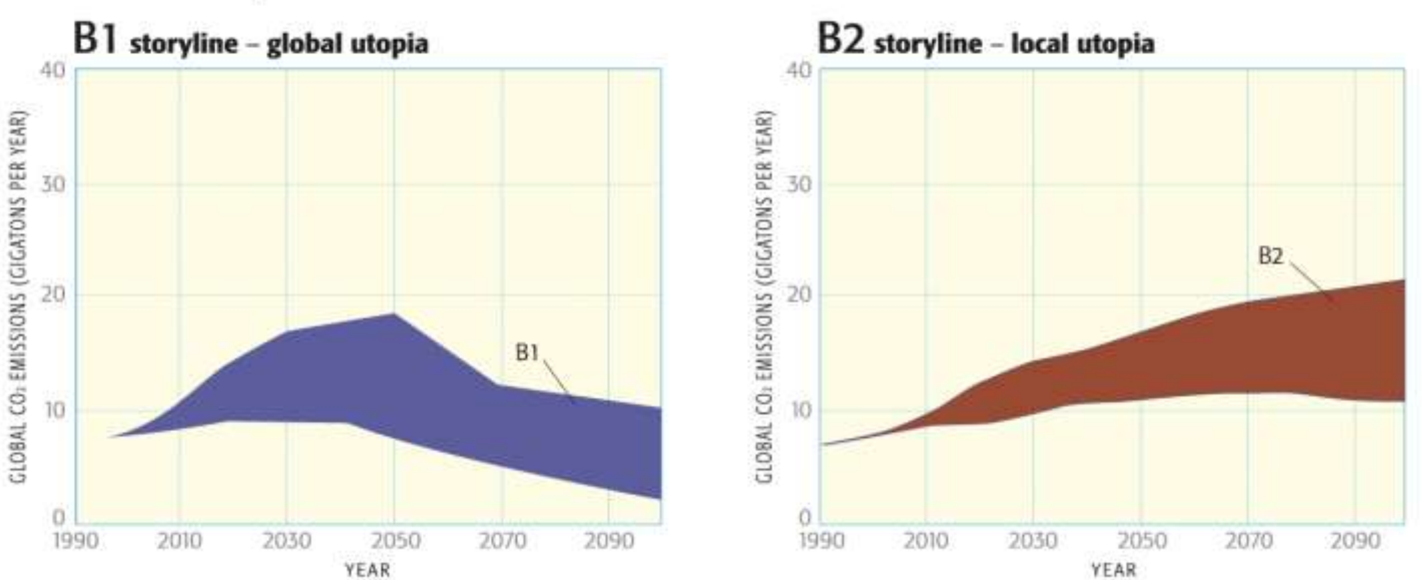
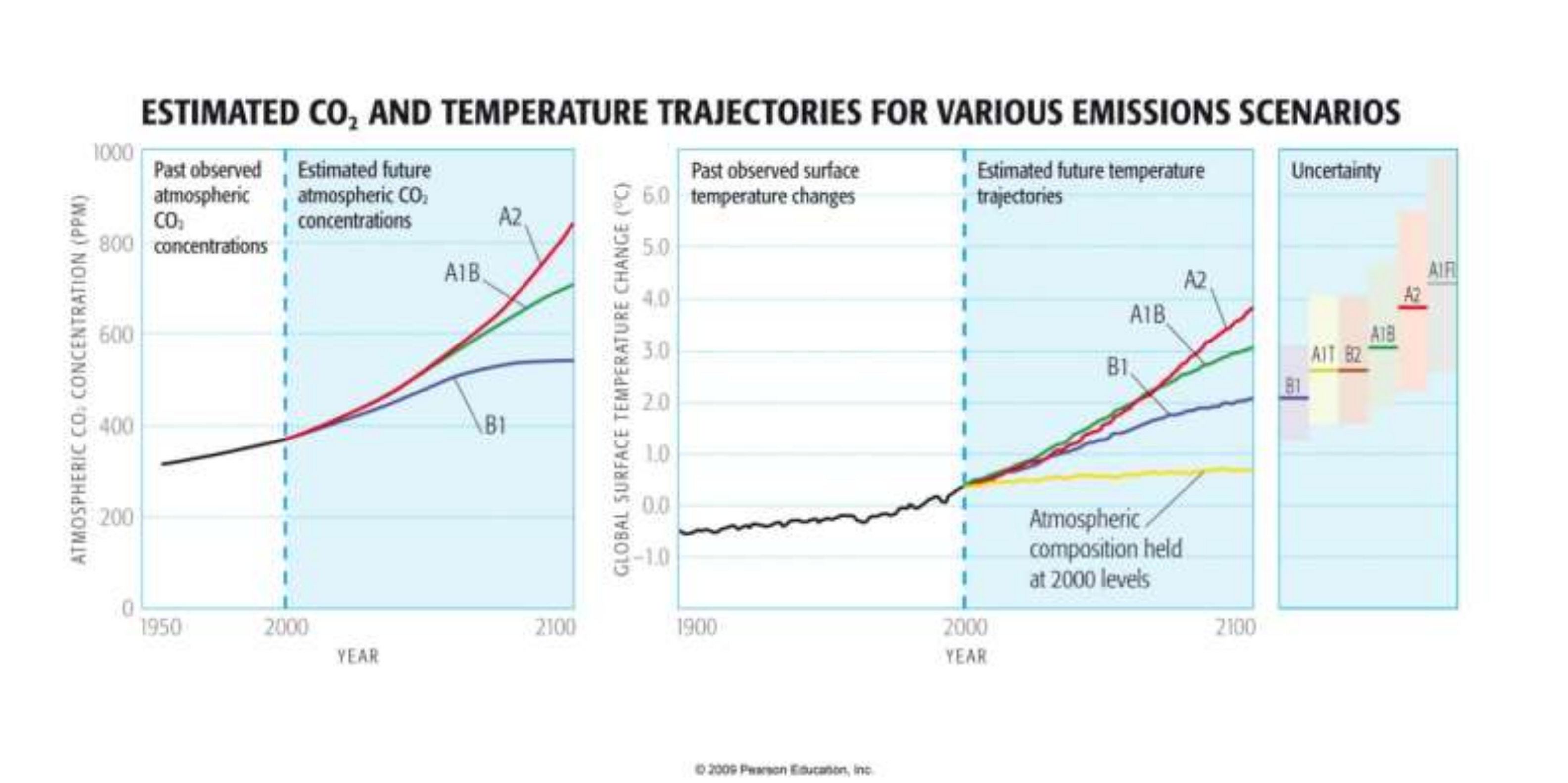


How will the climate change?

- Temperature changes
- Precipitation changes
- More drought, more flood
- Uncertain ENSO
- Future changes in extreme weather
  - Fewer frosty days
  - More heat waves
  - Possible more sever storms
  - Likely more stronger hurricanes

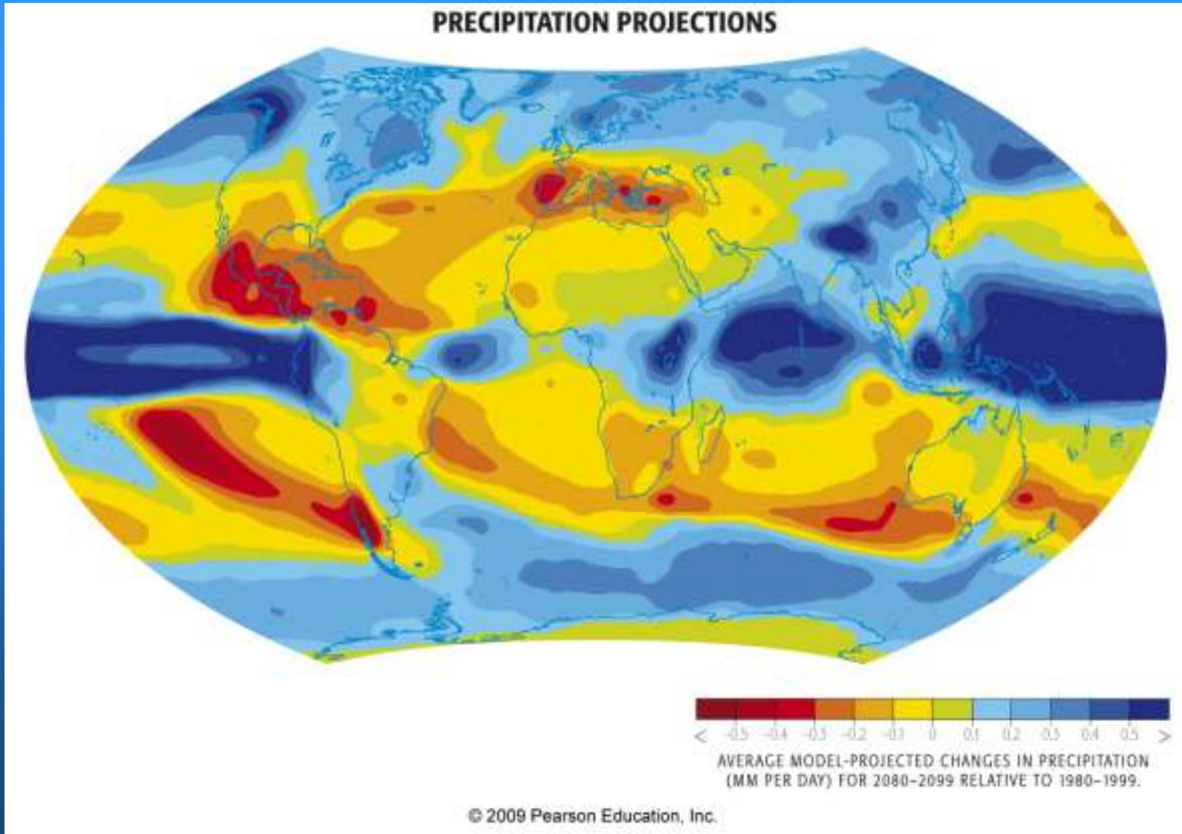
Temperature changes from climate simulations using different emission scenarios

- The predicted increase in global average temperature from 2000 to 2100 is roughly:
  - 1-3 °C for the most aggressive emission reduction (B1)
  - 1.5-4.5 °C for the "middle of the road" scenario (A1B)
  - 2.5-6.5 °C for the least aggressive scenario (A1FI)



Precipitation changes

- Increased precipitation near the equator (caused by a warmer atmosphere) and in subpolar regions (by the poleward shift of jet streams)
- Decreased precipitation in the subtropical (poleward expansion of the tropical Hadley circulation) and mid-latitude regions (by the poleward shift of jet streams).

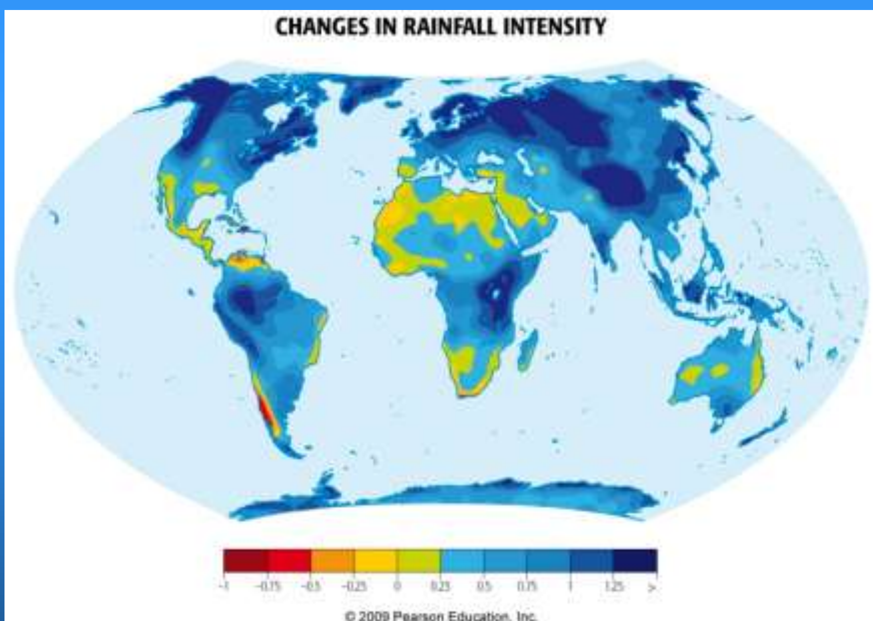


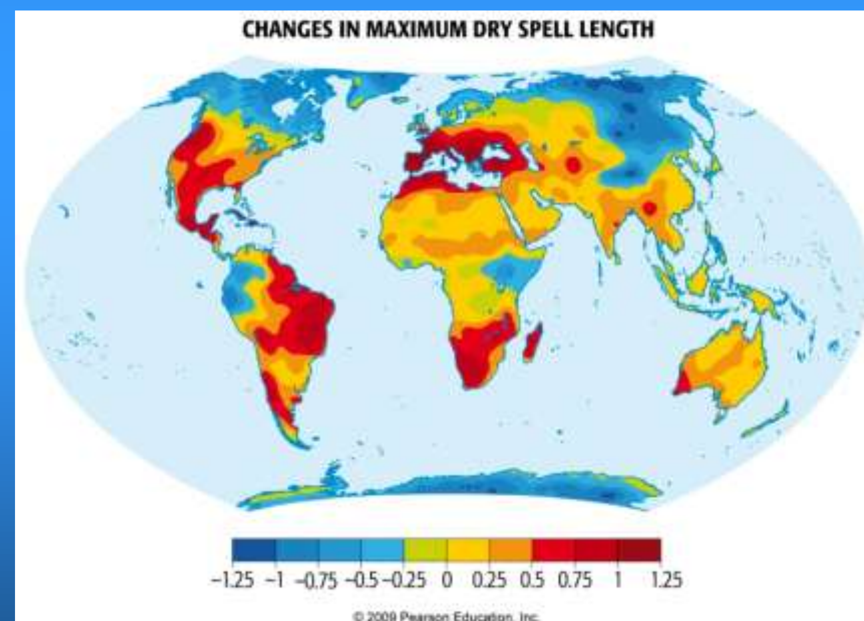
A1B "middle of the road" scenario

2100 projection relative to 1980-1999

More drought, more flood

- More intense rainfall: Increases are to be expected in the frequency of very intense rainfall events & flooding.
- Longer dry spells between intense rainfall events.

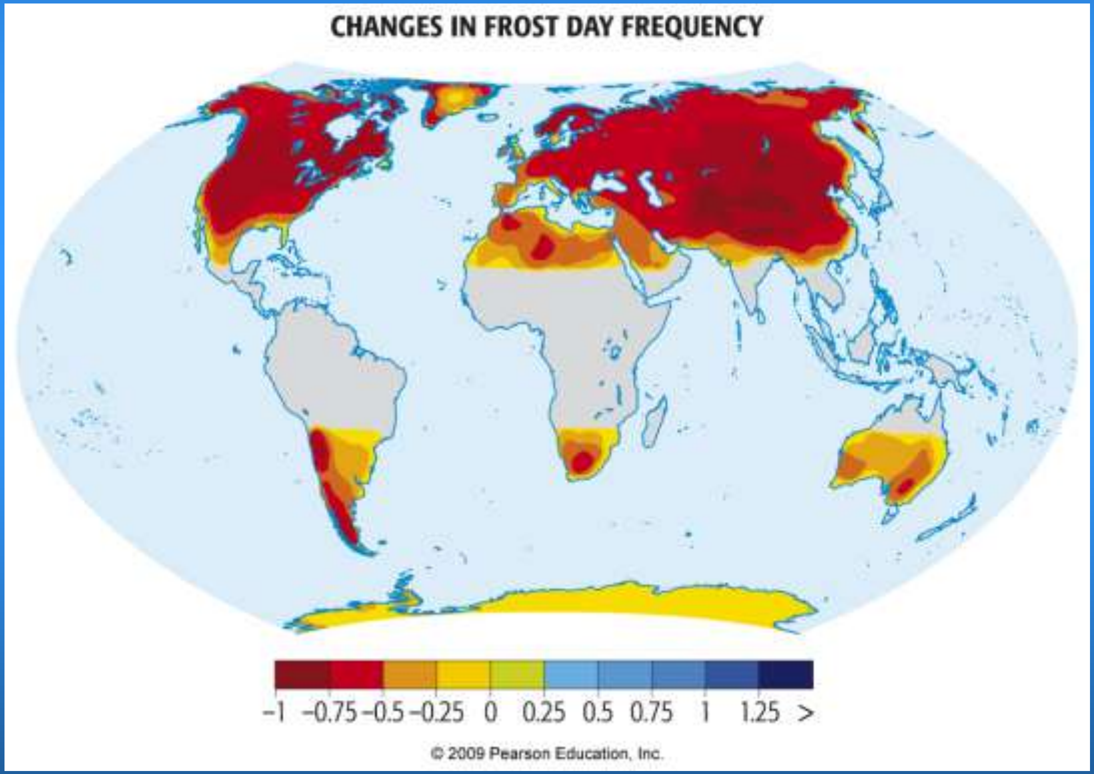




Projected changes by 2100 relative to 1980-1999. A relative scale is used, where a single unit "1" represents the typical range of year-to-year variations.

Fewer frosty days

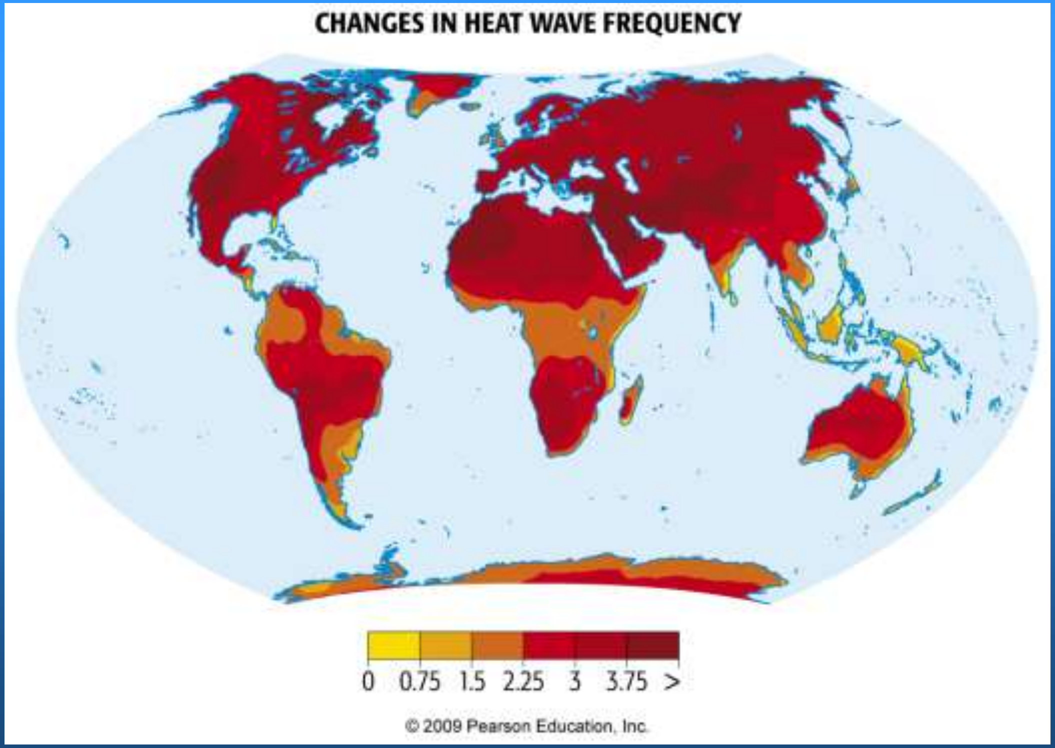
- As temperature warm, the probability of frosts (nights when temperatures dip below freezing) will decrease markedly.



Projected changes by 2100 relative to 1980-1999. A relative scale is used, where a single unit "1" represents the typical range of year-to-year variations.

More Heat Waves

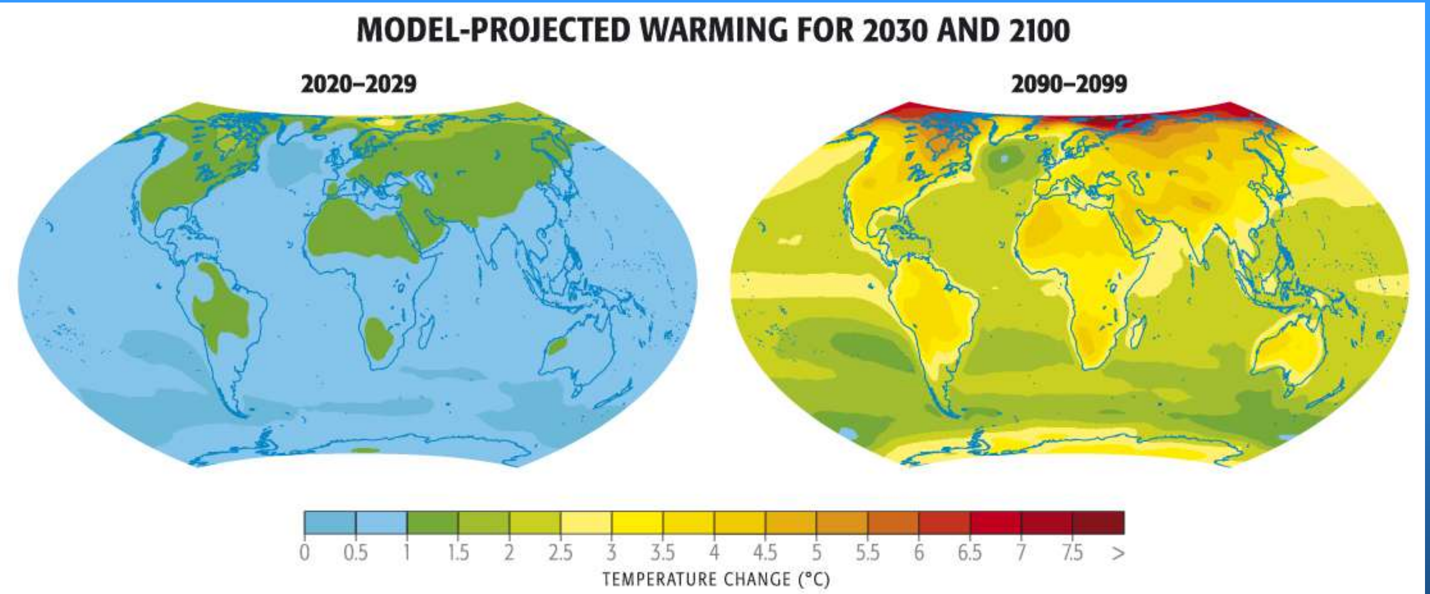
- Heat waves (very high temperatures sustained over a number of days) are likely to become more intense, more frequent, and long-lasting.
- The greatest increase in heat waves is predicted to occur in areas such the western US, North Africa, and the Middle East.



Projected changes by 2100 relative to 1980-1999. A relative scale is used, where a single unit "1" represents the typical range of year-to-year variations.

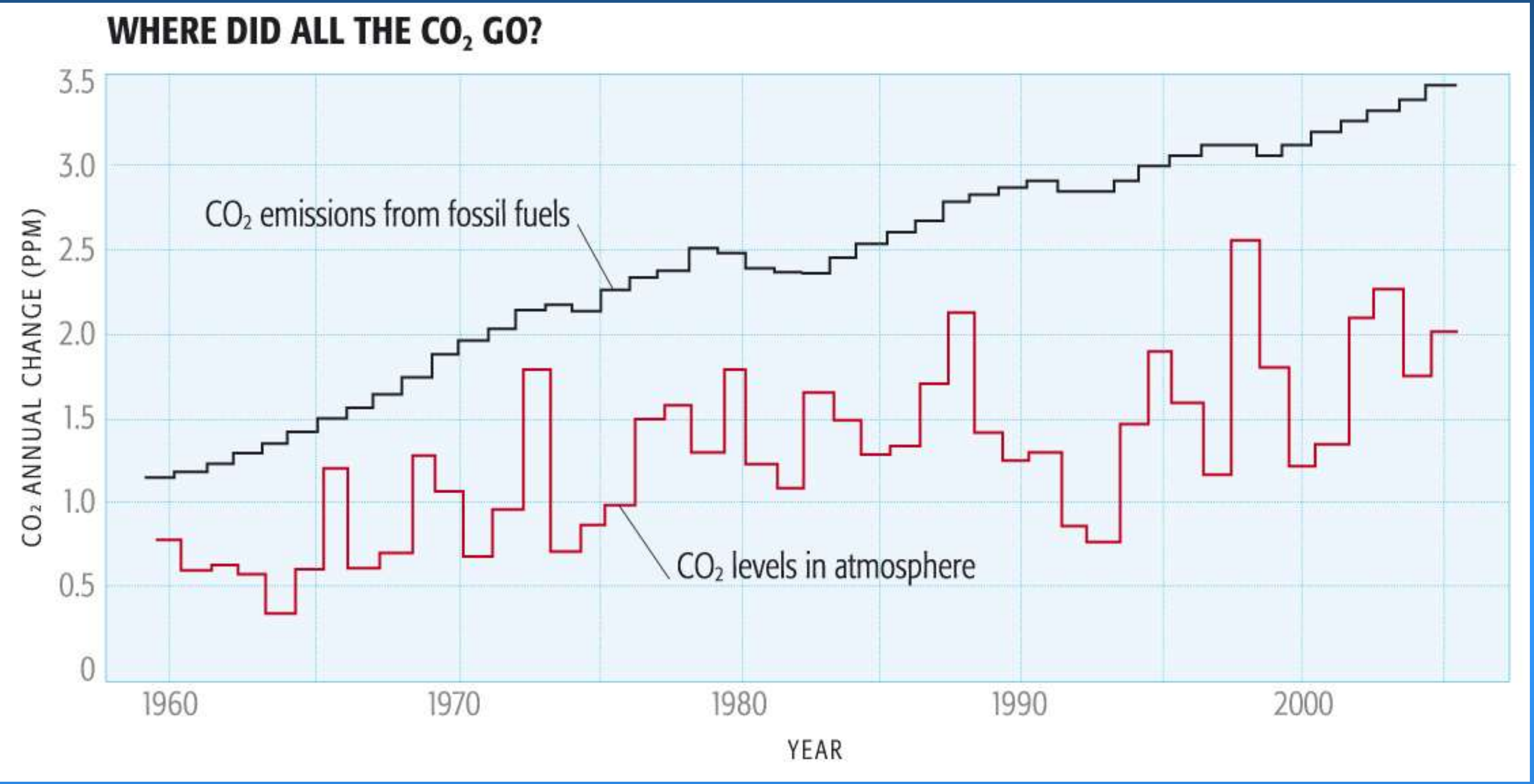
The geographical pattern of future warming

- Non-uniform warming globally.
  - The greatest warming over the polar regions due to positiove feedbacks associated melting sea-ice.
  - Greater warming for land than ocean, due to the fact that water tends to warm or cool more slowly than land.
  - Greater warming in Northern Hemisphere (NH) than SH (more land mass in NH)
  - Little warming over The North Atlantic ocean just south of Greenland due to weakening ocean currents and shifts in the pattern of the NH jet stream.

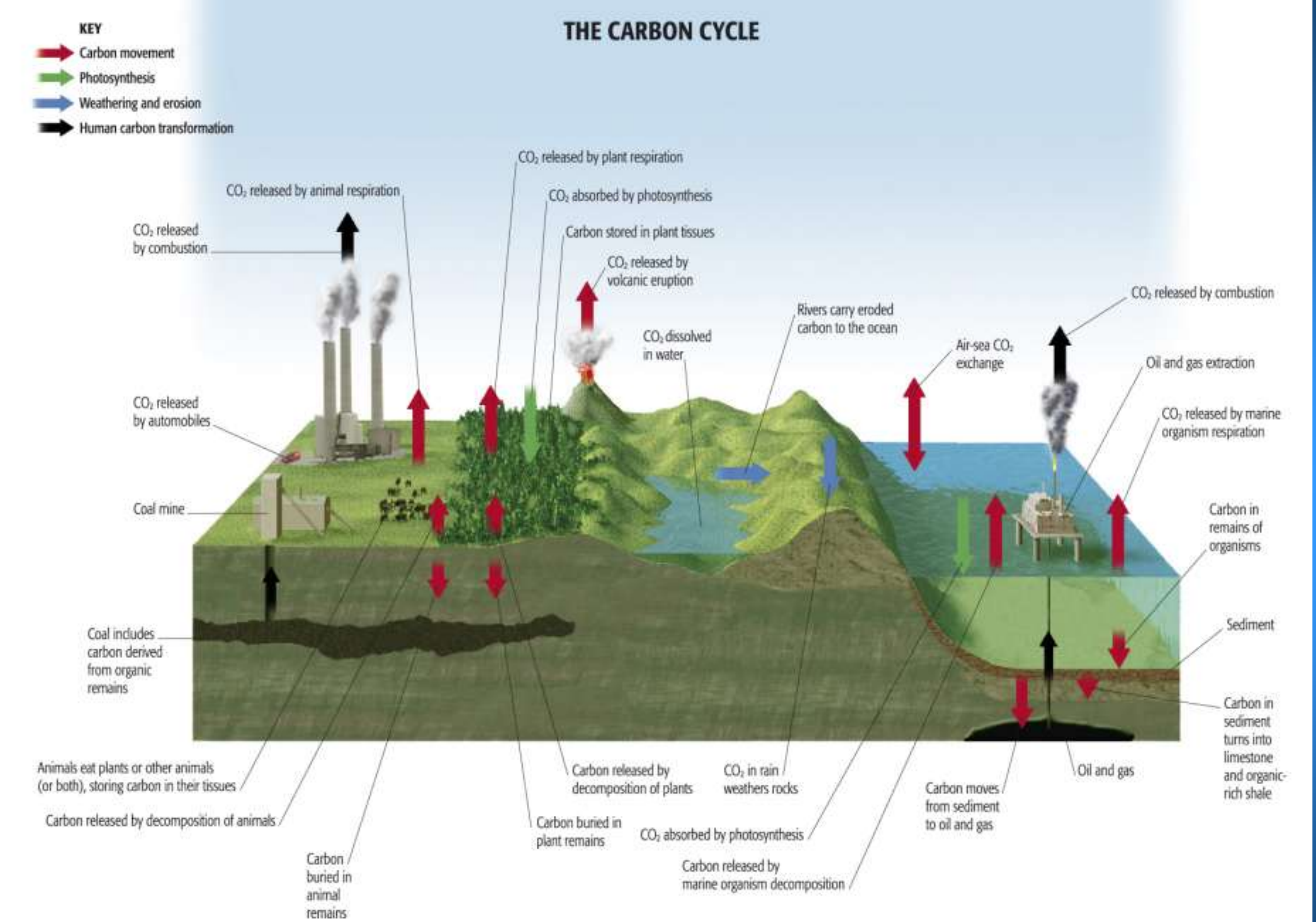


A1B "middle of the road" scenario

Carbon-cycle feedbacks



45% CO2 that is pumped into the atmosphere since 1959 has "disappeared" (dissolved into the ocean or go into biomass through photosynthesis). Nature has responded to fossil-fuel burning a certain degree, and somewhat reduced the human impact on climate. But nature has its limits.



KEY
Carbon movement
Photosynthesis
Weathering and erosion
Human carbon transformation
THE CARBON CYCLE
CO_2 released by plant respiration
CO_2 released by animal respiration
CO_2 absorbed by photosynthesis
Carbon stored in plant tissues
CO_2 released by combustion
CO_2 released by volcanic eruption
CO_2 dissolved in water
Rivers carry eroded carbon to the ocean
CO_2 released by combustion
Air-sea CO_2 exchange
Oil and gas extraction
CO_2 released by automobiles
CO_2 released by marine organism respiration
Coal mine
Carbon in remains of organisms
Coal includes carbon derived from organic remains
Sediment
Carbon in sediment turns into limestone and organic-rich shale
Animals eat plants or other animals (or both), storing carbon in their tissues
Carbon released by decomposition of plants
CO_2 in rain weathers rocks
Oil and gas
Carbon moves from sediment to oil and gas
Carbon released by decomposition of animals
Carbon buried in plant remains
CO_2 absorbed by photosynthesis
Carbon released by marine organism decomposition
Carbon buried in animal remains

Various Carbon-cycle feedbacks- warming reduces the nature's ability to absorb CO_2

Warmer land

1. Positive feedback: soil microorganisms increase their growth and respiration rates in a warmer climate. One of the waste products of their metabolism is CO_2. As a result, carbon in soil is being converted to CO_2 at increasing rates.

2. Negative feedback: Plants respond favorably in their growth to elevated CO_2 levels.

Warmer ocean

Positive feedback: a warmer ocean has less ability to absorb CO_2.

Ocean acidification

Negative feedback: When organisms such as corals and plankton grow their calcium carbonate (limestone) skeletons, CO_2 is released into water, so calcification reduces the ocean's ability to take up CO_2 in the atmosphere. However, it is predicted that some calcifying organisms will be extinct as temperature rises. The reduced rate of calcification will increase the ocean's ability to take up CO_2.

Pump problems

Positive feedback: Calcium carbonate acts as ballast once organisms die, carrying the decaying tissues to deep ocean. This “pump” effect removes CO2 from surface waters, allowing CO2 in the atmosphere to be absorbed. Loss of ballast via ocean acidification reduces the once’s ability to take up CO2.

A sluggish ocean

Positive feedback: A slowing of ocean circulations in a warmer climate reduces the mixing up of nutrients at the ocean surface, which weakens the action of biological pump of ocean, leading to the reduction of the ocean’s ability to absorb CO2.

Rock weathering

Negative feedback: Increased temperature and rainfall stimulate the rock weathering, a process that removes CO2 from the atmosphere,

$CaCO_3+CO_2+H_2O \longleftrightarrow Ca^{2+}+2HCO_3^-$ (1) for limestone

$CaMg(CO_3)_2 +2CO_2+2H_2O \longleftrightarrow Ca^{2+}+Mg^{2+}+4HCO_3^-$ (2) for dolomite.

Overall, positive feedbacks prevail!

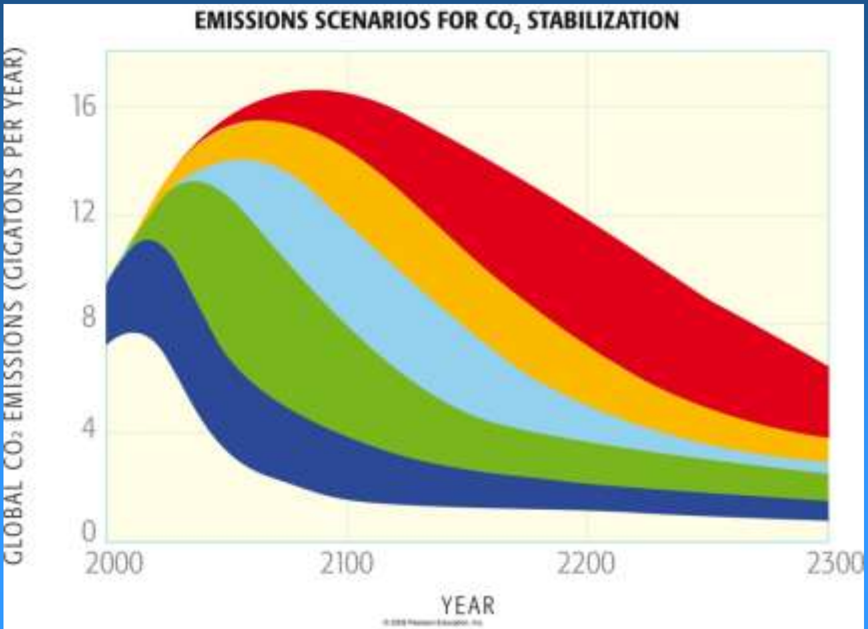
Stabilizing atmospheric CO2 level

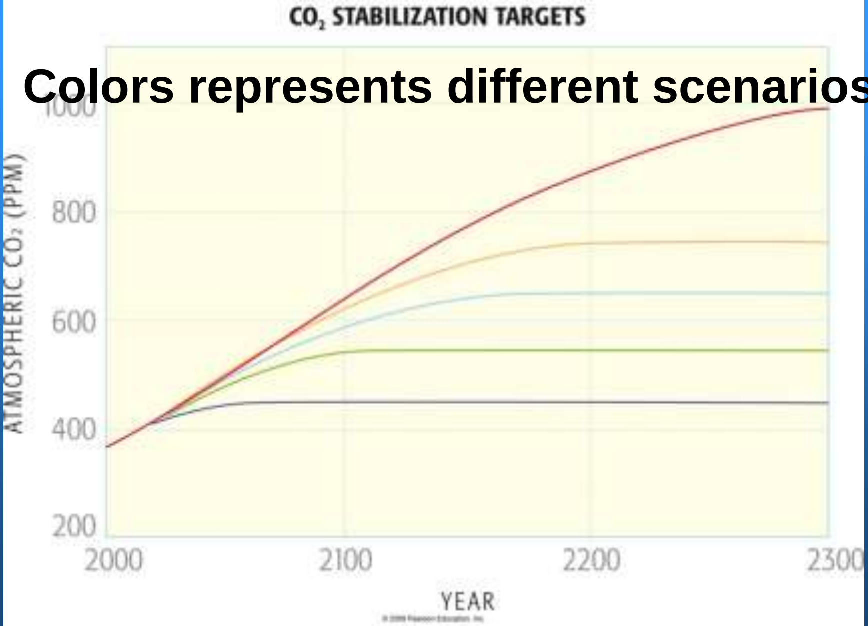
1. The lower the stabilization target, the sooner peak emission of CO2 must occur, or we must cut back on fossil-fuel use, e.g., to stabilize CO2 level at 450 ppm, we would reach peak usage before 2020.

2. Lower stabilization levels can be achieved only with lower peak emission.

3. All stabilization targets require sharp reductions in CO2 emission after the peak. Low stabilization targets require that the emission rates fall below the current rates within a few decades.

4. Even with atmospheric CO2 level at 450 ppm, global temperature will increase by about 2^{0}C and sea level will rise by half a meter or more.





Is a greenhouse world a better world?

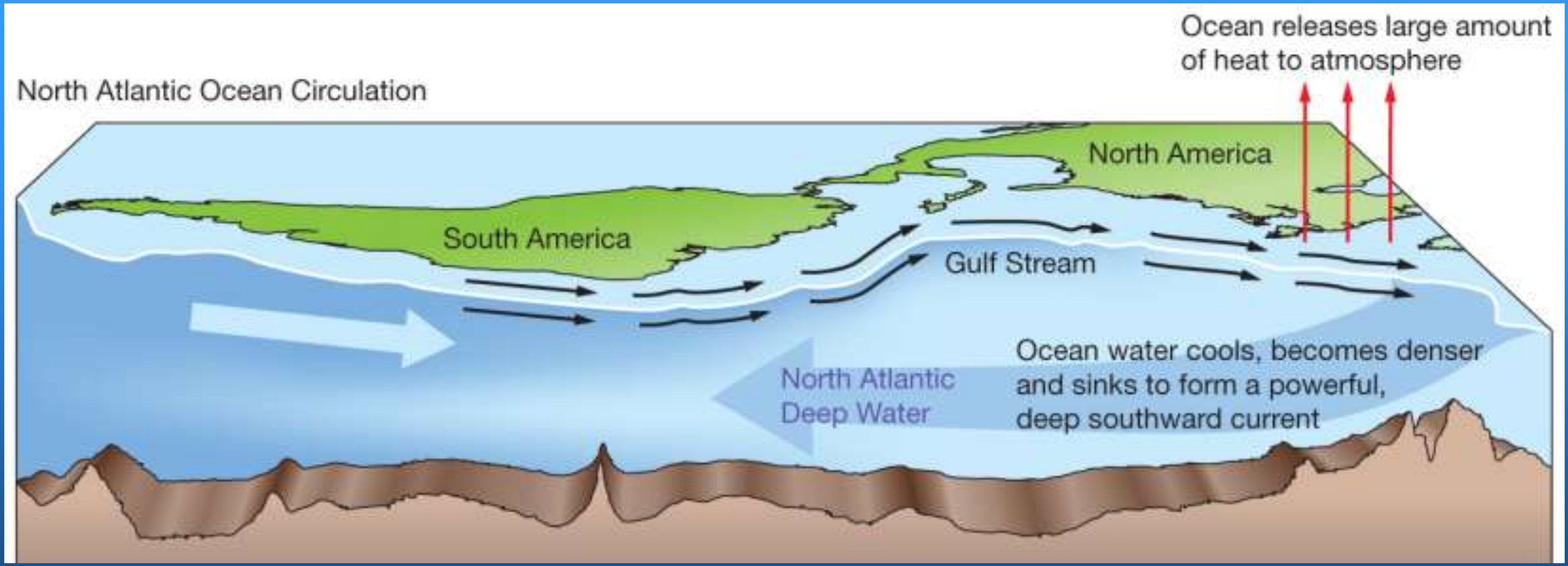
High level CO2 may benefit plants (CO2 fertilization) since plants do not have open their pores as wide as that in a low level CO2 climate. This reduces water loss and infection by germs. However, these benefits cannot be fully realized in nature if other factors, such as lack of nutrients or inadequate soil, are limiting growth.

The growth limiting factors combined with other negative factors, such as ocean acidification and loss of coral reefs, suggest that the “greening of planet Earth” may not be achievable as an outcome of fossil-fuel burning!

Changes in the Oceans

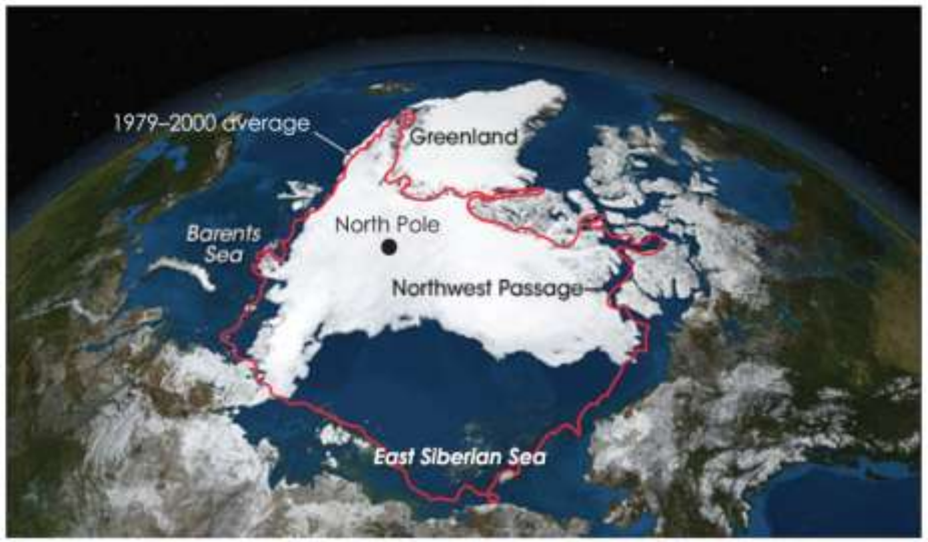
Increasing ocean temperature (Sea surface temperatures risen mostly since 1970)

Deep-water circulation slows down in a warm climate.



Polar Ice Melting

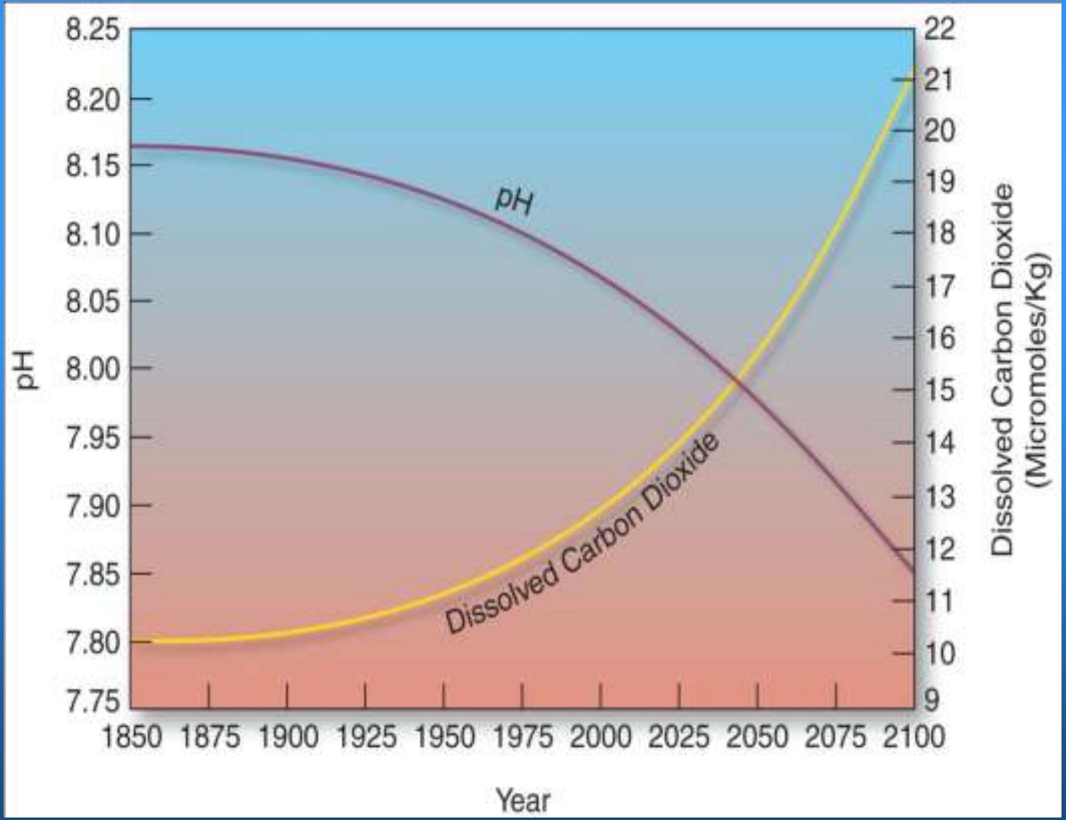
- Loss of more than 2 million square kilometers (800,000 square miles) of Arctic sea ice in last decade. Antarctica shrinking, glaciers thinning.
- Loss of ice enhancing further warming due to lower albedo



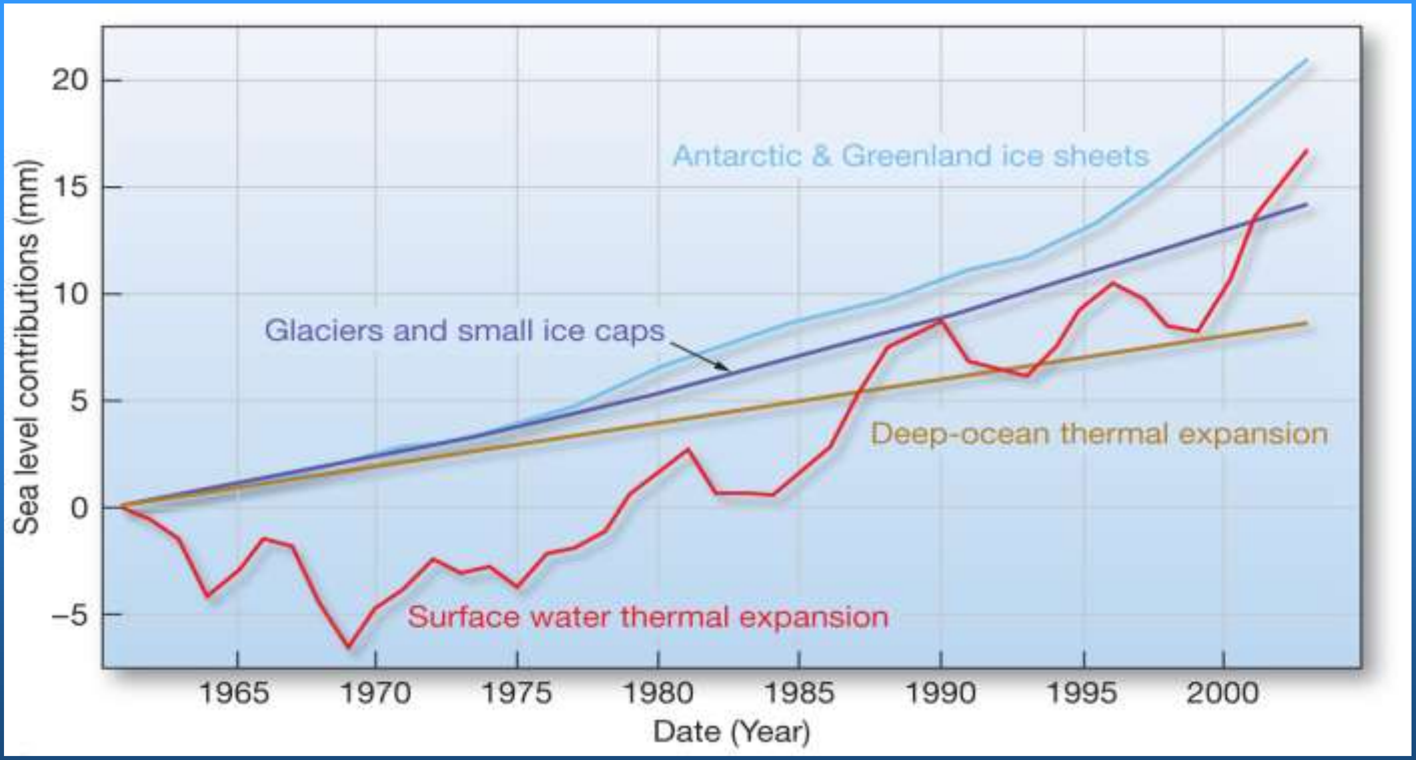
- Arctic ice melting affects polar bear survival.
- Food sources are dwindling for Arctic dwellers

Ocean acidity increase

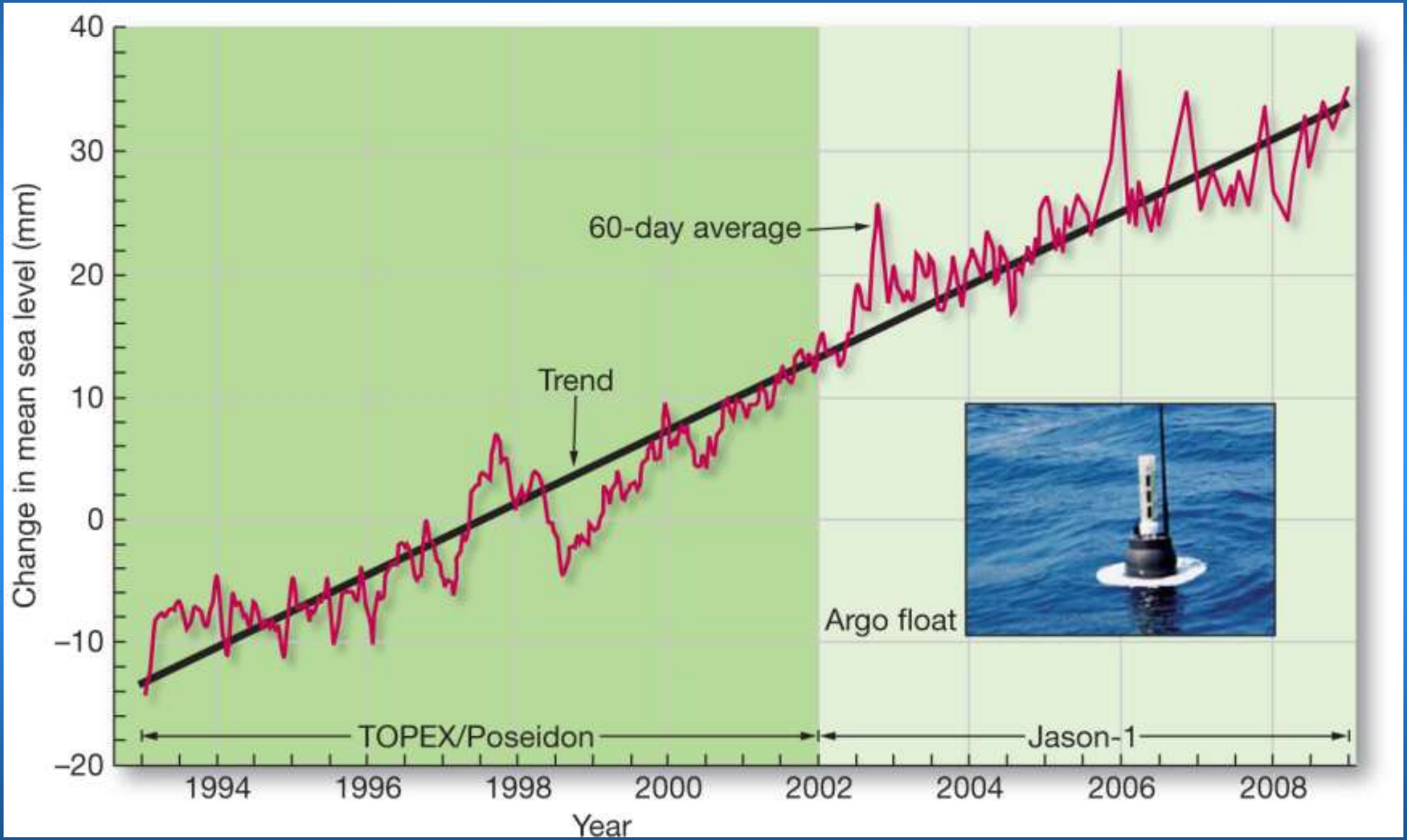
- Some atmospheric carbon dioxide dissolves in ocean water.
  - Acidifies ocean
- Threatens calcifying organisms
  - Coccolithophores
  - Foraminifers
  - Sea urchins
  - Corals



- Rising Sea Level – already occurring
- Main contributors:
  - Melting of Antarctic and Greenland ice sheets (most important)
  - Thermal expansion of ocean surface waters
  - Melting of land glaciers and ice caps
  - Thermal expansion of deep-ocean waters

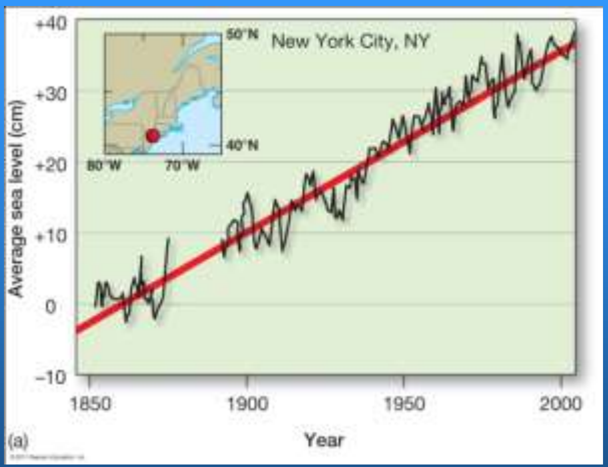


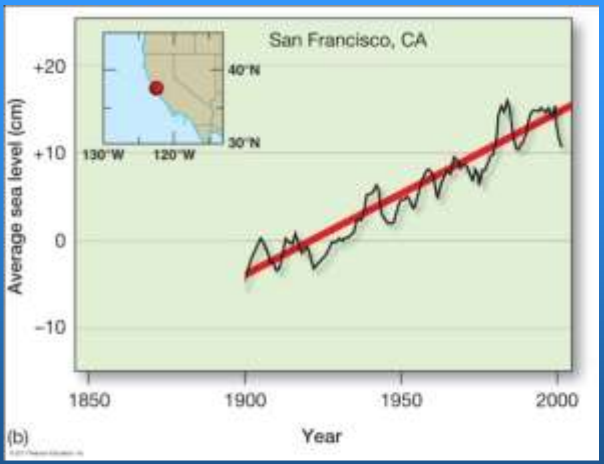
Global Sea Level Rise

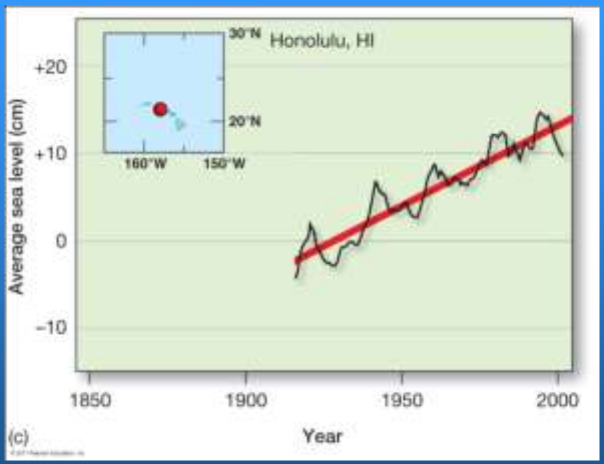


Rising Sea Level

- Severely affect areas with gently sloping coastlines
  - U.S. Atlantic and Gulf Coasts
- Models predict rise between 0.5 and 1.4 meters (1.6 and 4.6 feet) by year 2100







Key West Tidal data 1920 to 2006