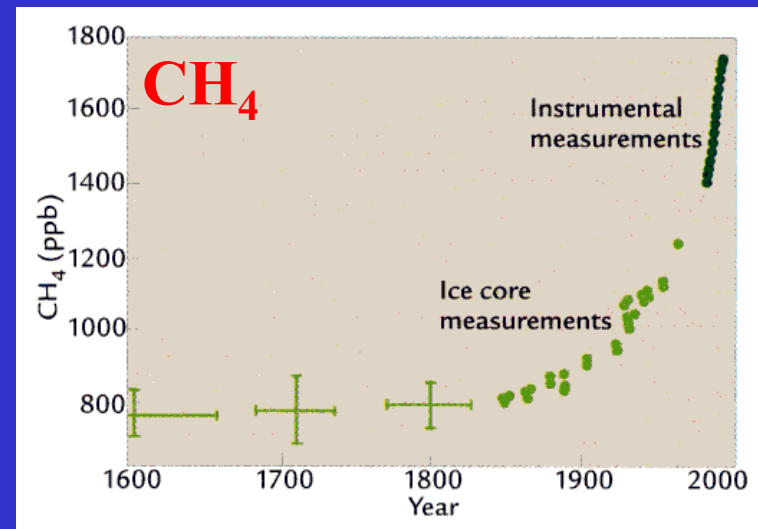
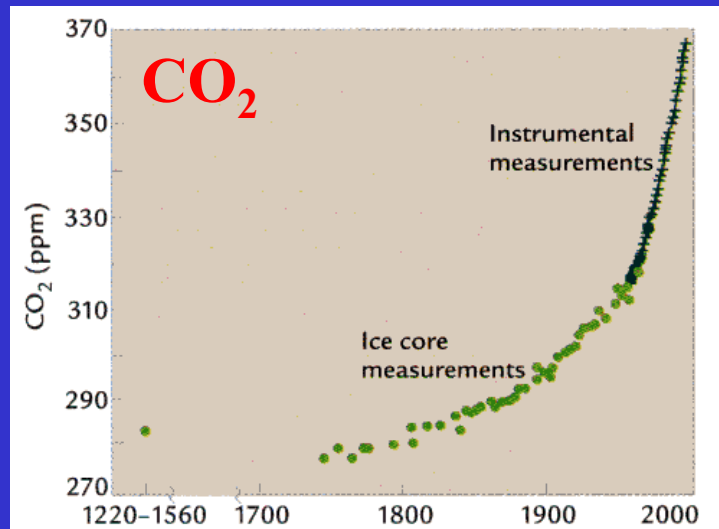


# Lecture 11: Global Warming



- How much of the global warming is caused by Natural climate change and by human activities?
- What is the sensitivity of Earth's climate to the increases of greenhouse gases (CO<sub>2</sub> and CH<sub>4</sub>) and sulfur dioxide (SO<sub>2</sub>)?
- What is the projection of the future climate change?

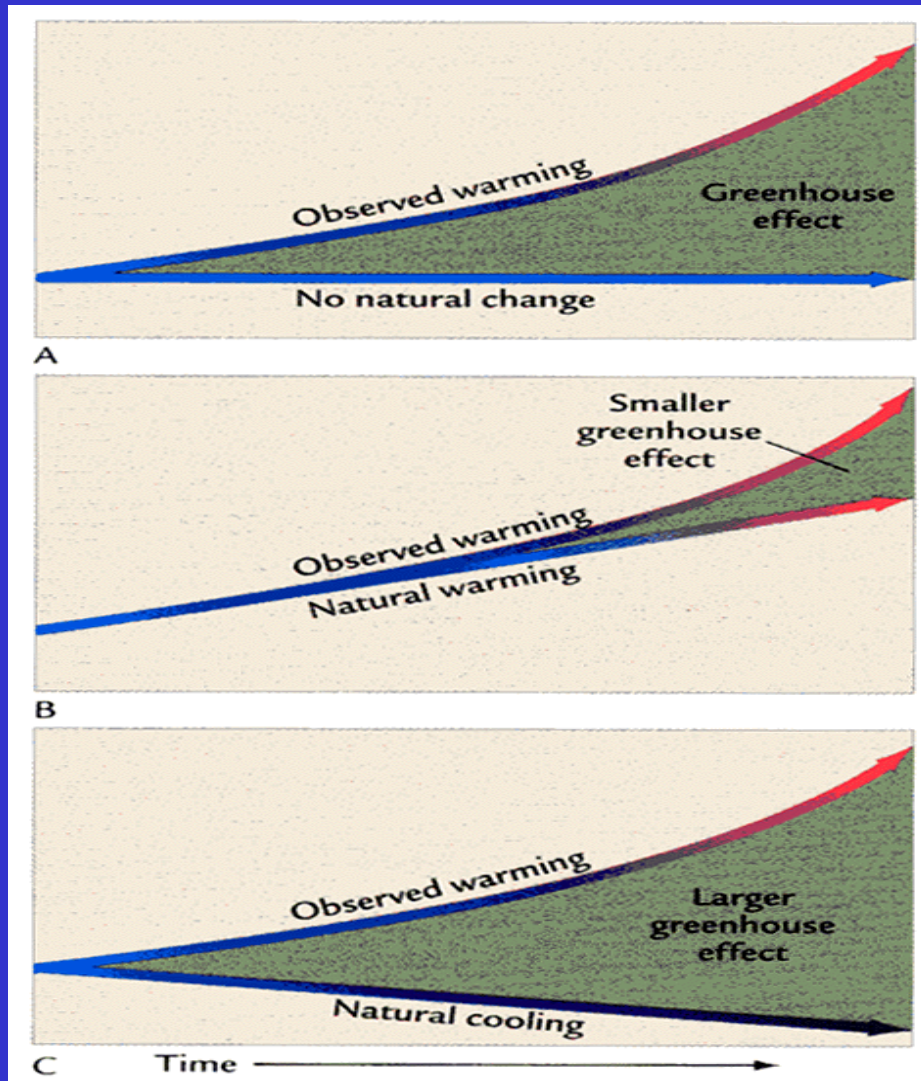


# Human Activities

- ❑ The initial appearance of human species: *last 100,000 to 200,000* years
- ❑ Development of the first civilization: the *last 10,000* years
- ❑ The arrival and growth of the industrial era: the *last few hundreds* years



# Global Warming: Natural or Man-Made

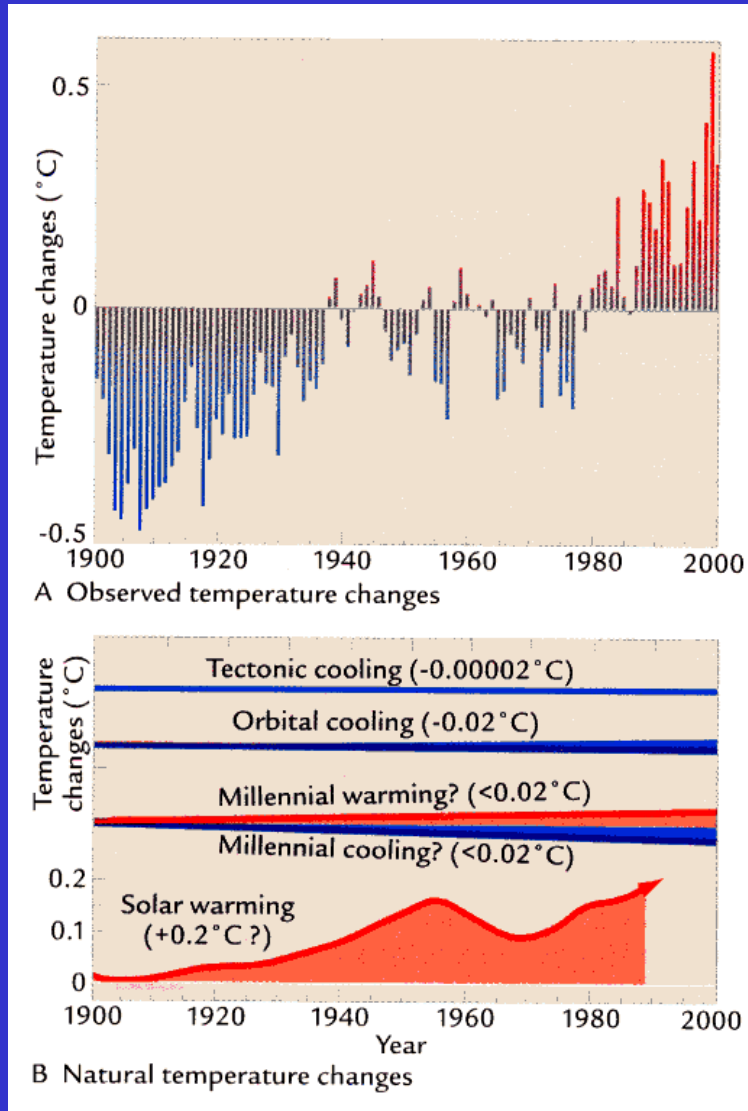


(from *Earth's Climate: Past and Future*)

- Global surface temperature has **warmed by  $0.6^{\circ}\text{C}$**  in the last century.
- Is the global warming caused by natural climate change or by human activities?



# Natural Climate Changes

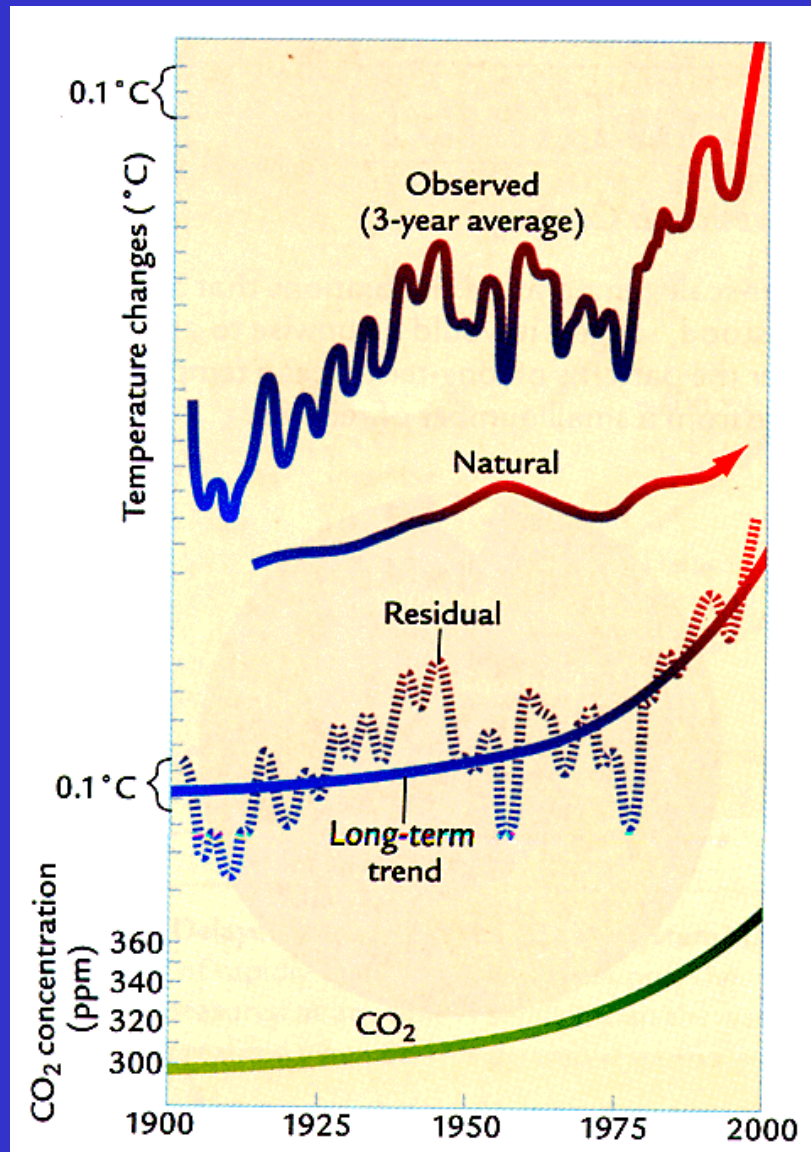


(from *Earth's Climate: Past and Future*)

- ❑ **Observed warming**  
0.6°C in the last 100 years.
- ❑ **Tectonic Scale**  
Cooling by 0.00002°C within 100 years
- ❑ **Orbital Scale**  
Cooling by 0.02°C within 100 years
- ❑ **Millennial Scale**  
Uncertain, but probably on the order of 0.02°C (such as the net cooling into the Little Ice Age)
- ❑ **Solar Activities**  
May cause 0.2°C warming



# Global Warming: Is it Man-mad?



*Observed Warming*

*Orbital + solar warming*

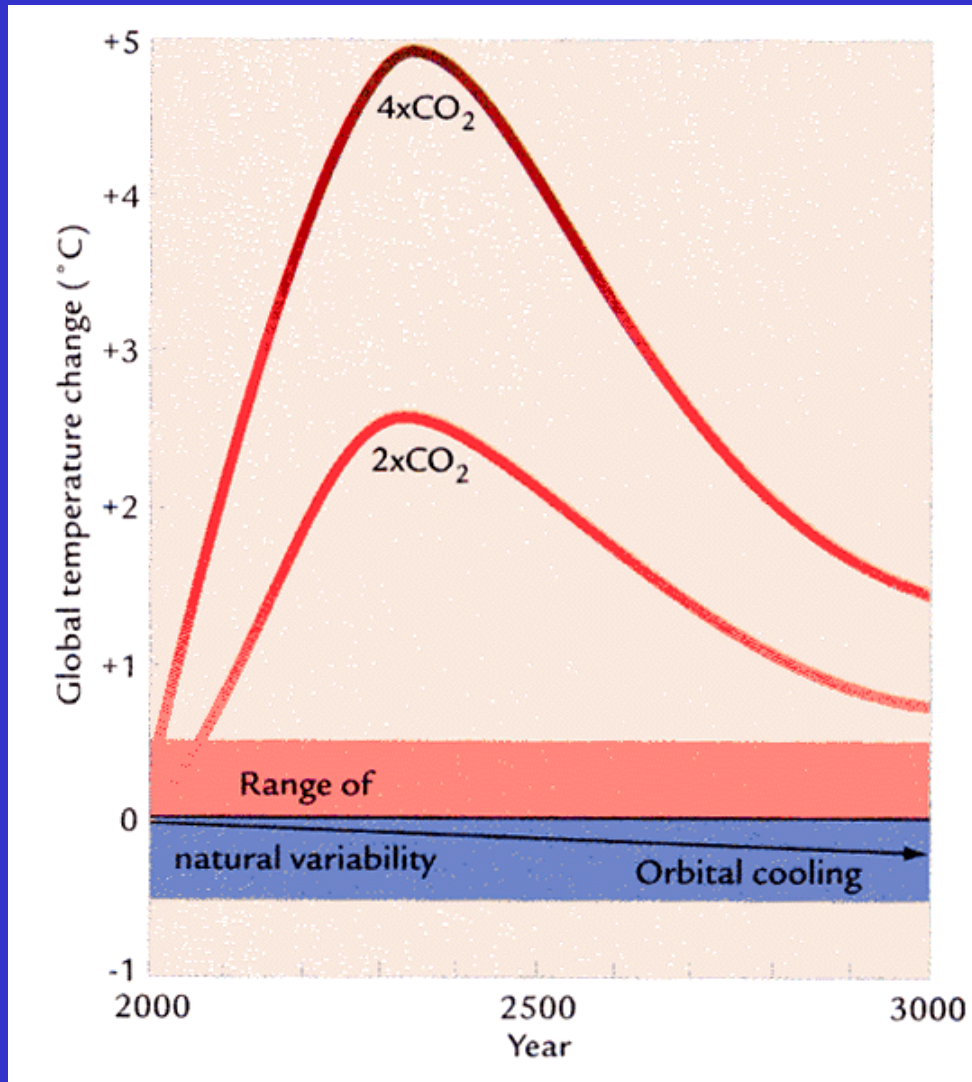
*Man-made warming (?)*

(from *Earth's Climate: Past and Future*)



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# Future CO2 Change

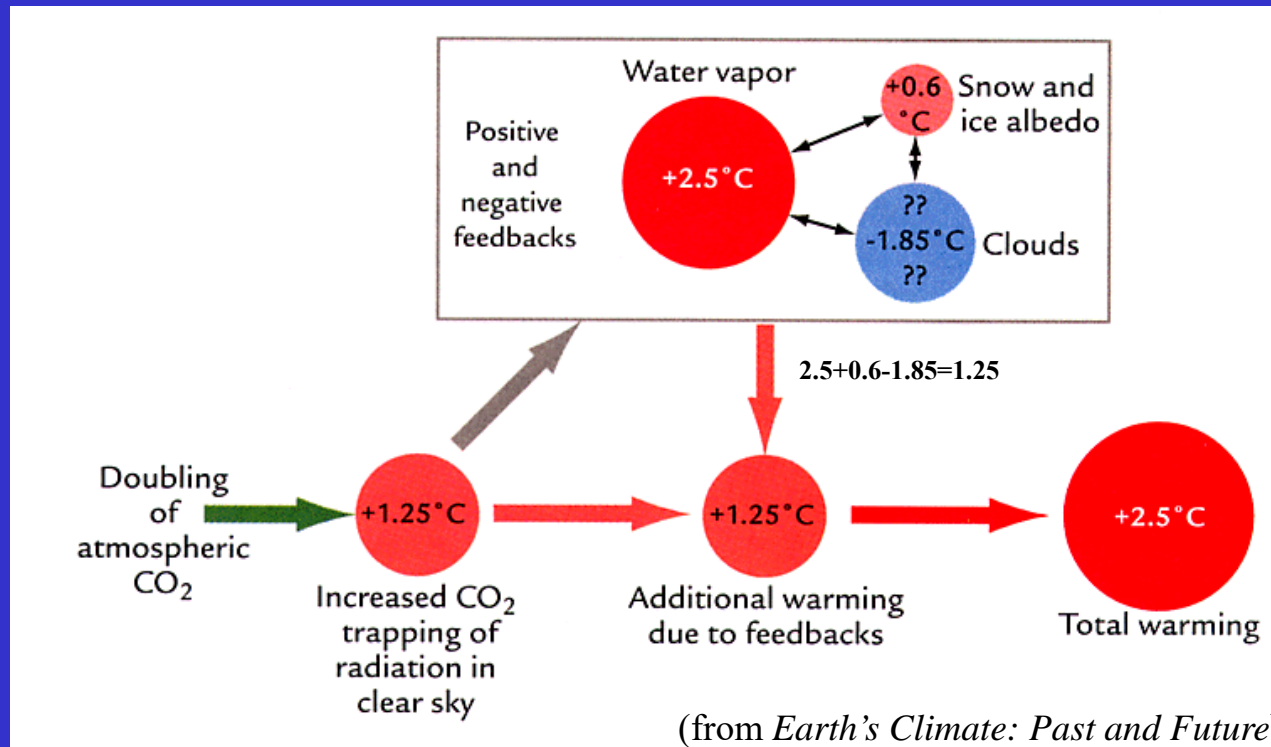


(from *Earth's Climate: Past and Future*)

- Atmospheric CO<sub>2</sub> will increase within two centuries to levels at least two and possibly four times higher than those that existed before humans made their influence felt.



# Global Warming Due to 2xCO<sub>2</sub>

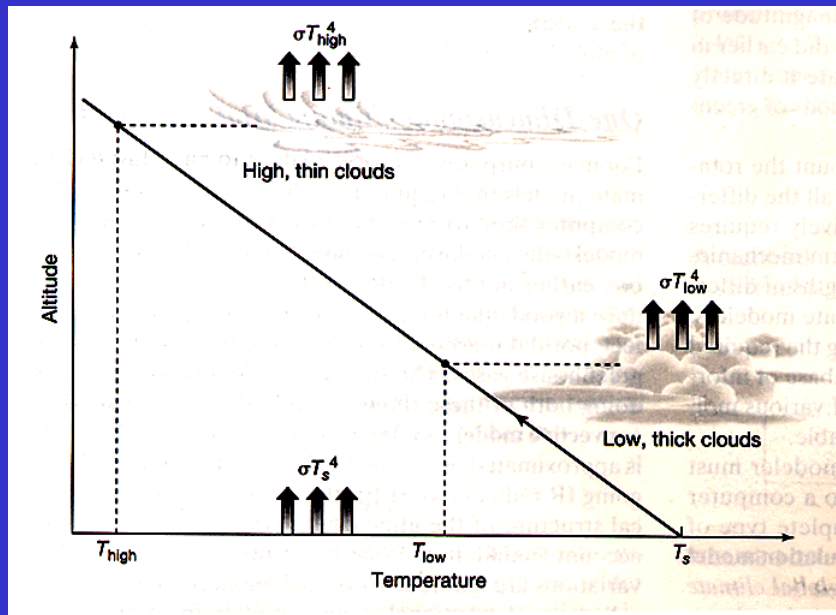


□ Estimated by computer models:

- (1) Direct Greenhouse effect: warms up global surface temperature by 1.25°C
- (2) Water vapor feedback produces another 2.5°C warming
- (3) Snow-Albedo feedback produces another 0.6°C warming
- (4) Cloud feedback is uncertain.



# Clouds – A Major Uncertainty



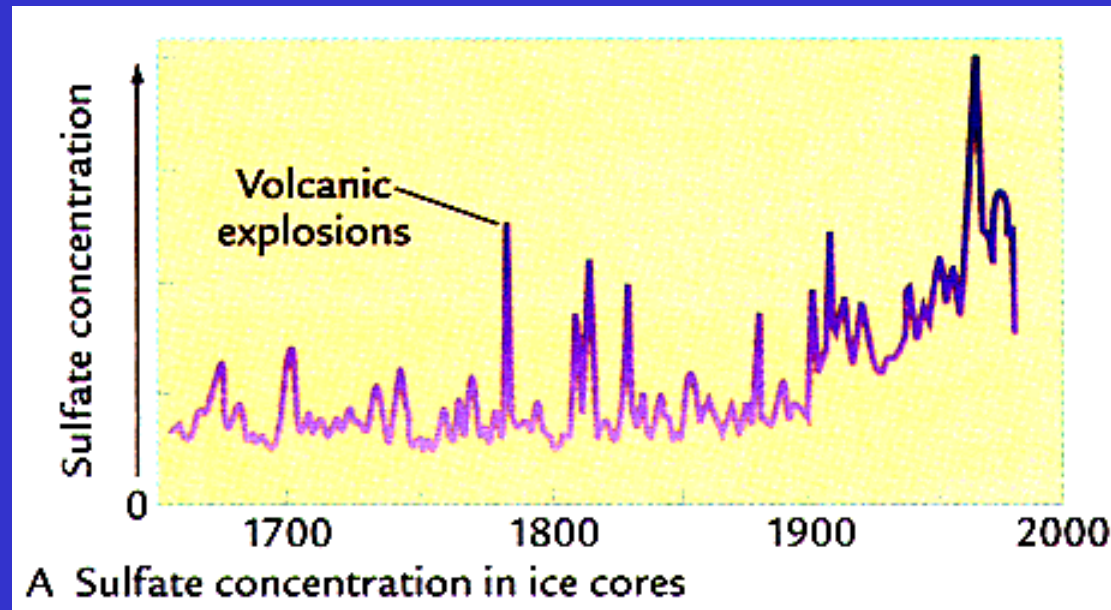
(from *The Earth System*)

- How do all types of clouds (high and low clouds) respond to global warming?
- **Possibility 1: more clouds during global warming**
  - Global warming
  - More water vapor available to form clouds
  - More clouds
- **Possibility 2: less clouds during global warming**
  - Global warming
  - A warmer atmosphere can hold more water vapor
  - Reduce the condensation of water vapors to clouds
  - Less clouds





# Cooling Effects of SO<sub>2</sub>



(from *Earth's Climate: Past and Future*)

- ❑ SO<sub>2</sub> produced by smokestacks exceeds natural emissions.
- ❑ SO<sub>2</sub> reacts with water vapor to produce sulfate aerosols.
- ❑ Sulfate aerosols can block solar radiation and cool the climate.

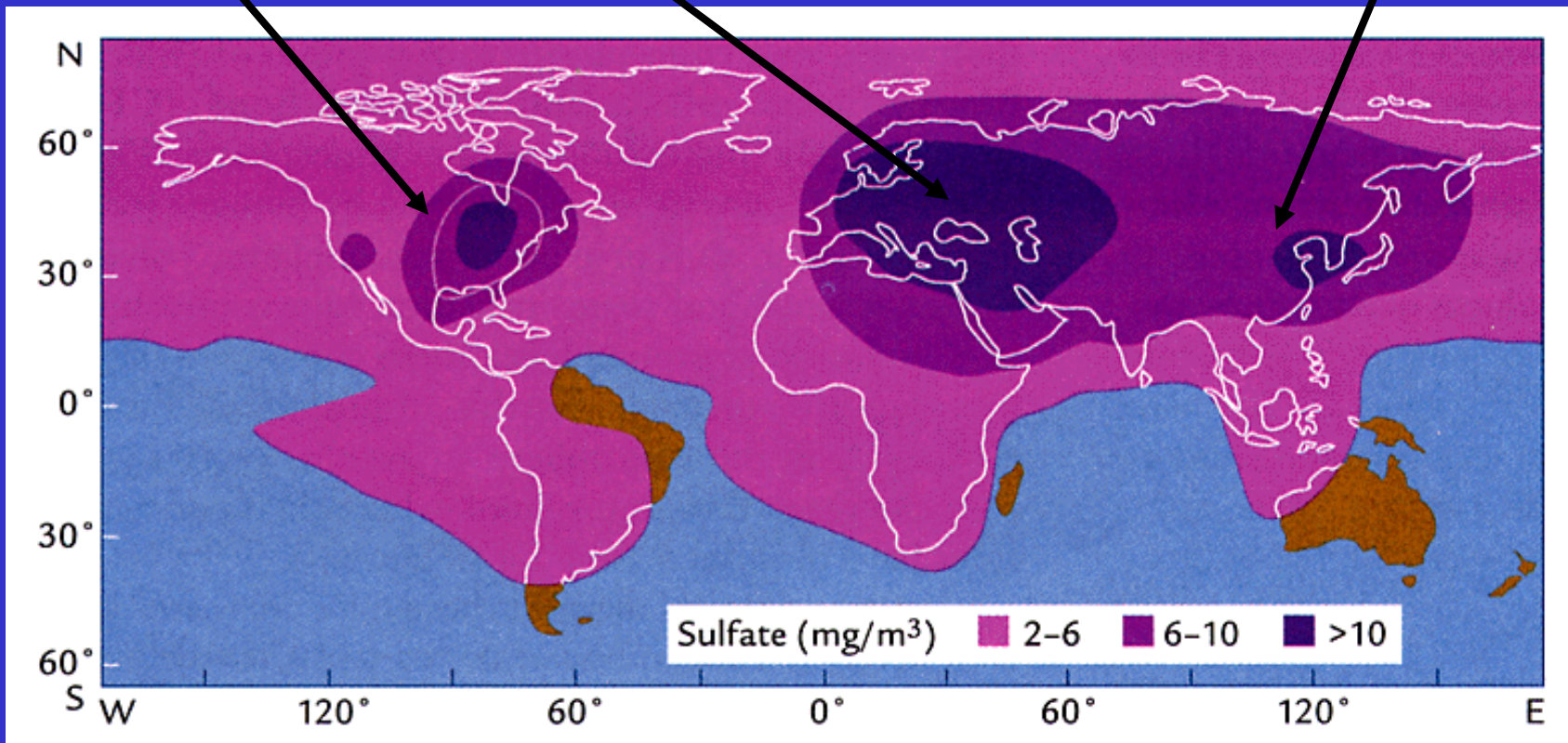


# Sources of SO<sub>2</sub> Emissions

USA

Europe

China

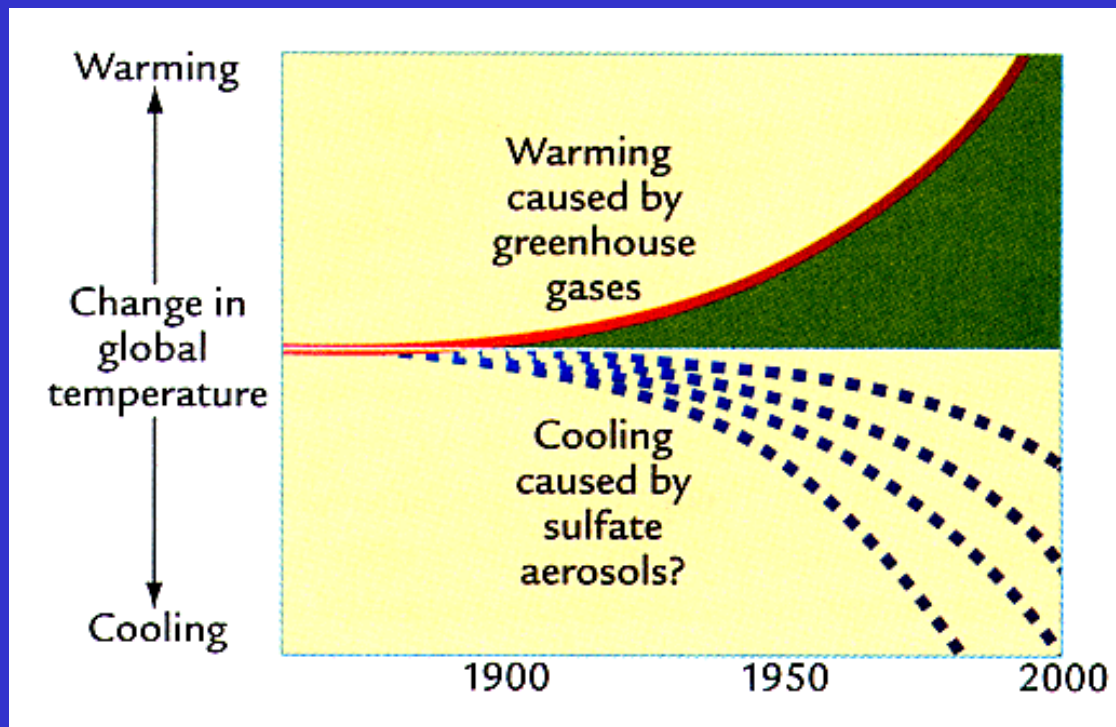


(from *Earth's Climate: Past and Future*)



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# SO<sub>2</sub> Cooling and CO<sub>2</sub> Warming

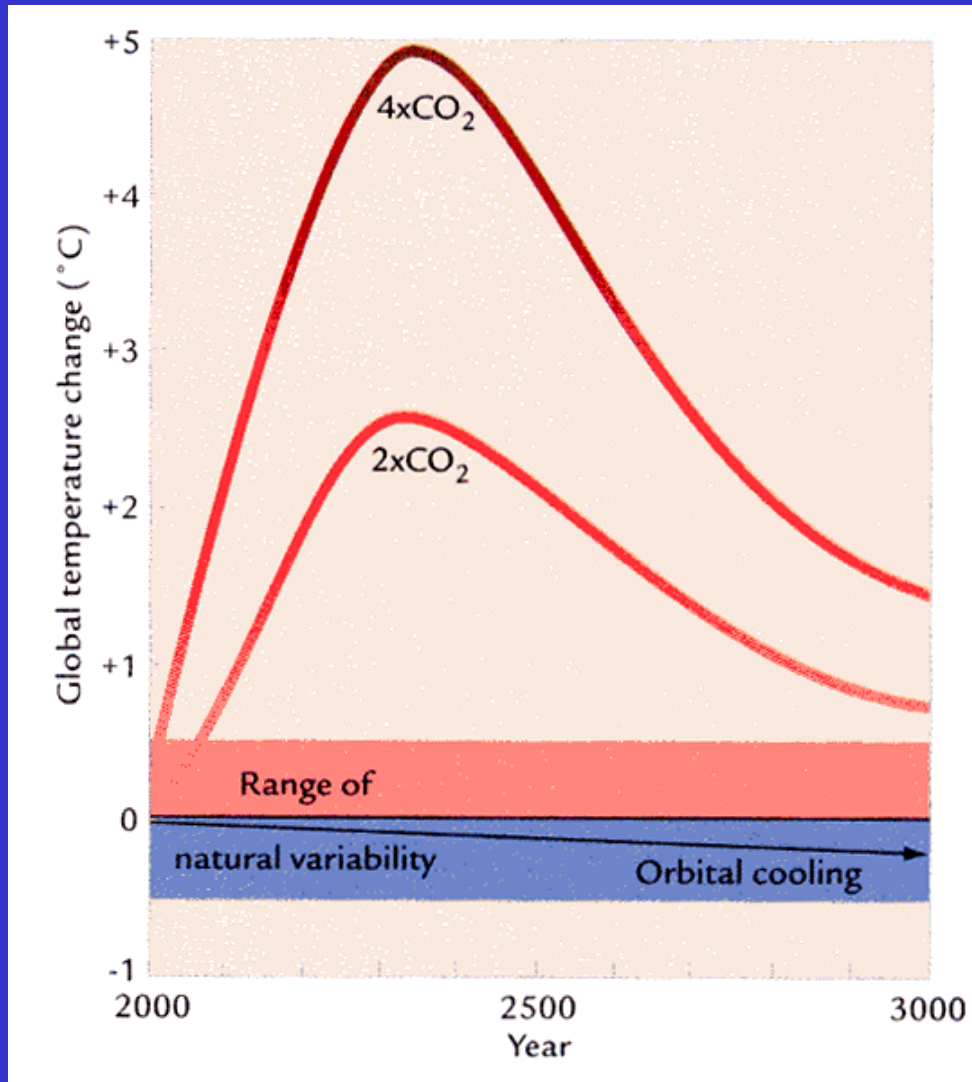


(from *Earth's Climate: Past and Future*)

- The warming effect of greenhouse gases may be partly cancelled by the cooling effect of sulfates produced by SO<sub>2</sub> emission from smokestacks.



# Future CO2 Change



(from *Earth's Climate: Past and Future*)

- Atmospheric CO<sub>2</sub> will increase within two centuries to levels at least two and possibly four times higher than those that existed before humans made their influence felt.



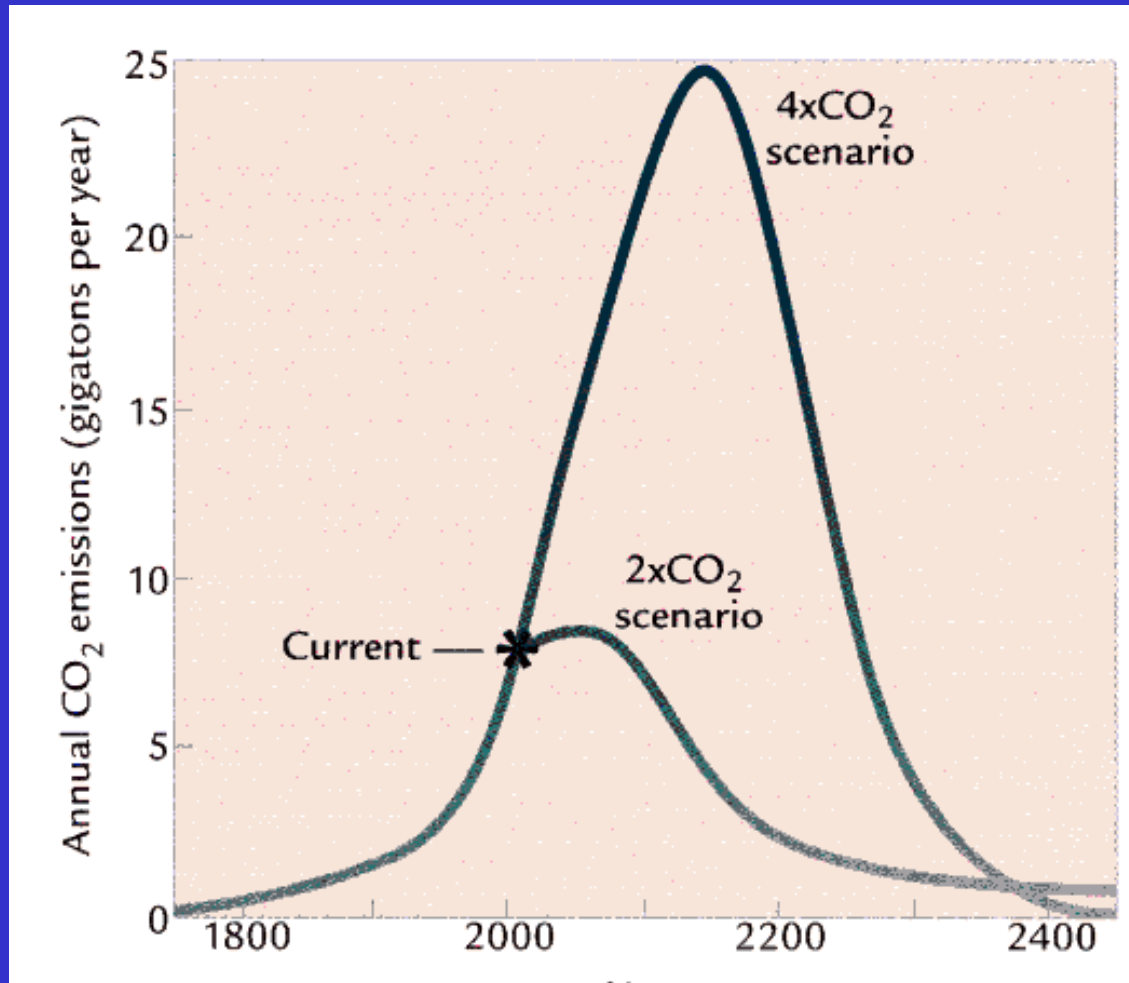
# How Future CO2 Emission Calculated?

$$\begin{array}{cccc} \% \text{ increase} & \% \text{ increase} & \% \text{ change in} & \text{Changes in} \\ \text{in carbon} & \text{in population} & \text{emissions} & \text{efficiency of} \\ \text{emissions} & = & \text{per person} & \text{carbon use} \end{array}$$

- ❑ **Global Population**: is expected to increase to 11 billion between 2075 and 2100 (100% increase).
- ❑ **Emission Per Person**: is linked to averaged standard of living (such as car and home heating or cooling).
- ❑ **Efficiency of Use**: The hardest factor to project. The efficiency depends on technologies. This is also the factor that may keep carbon emissions from increasing in the future.



# Projected Carbon Emissions

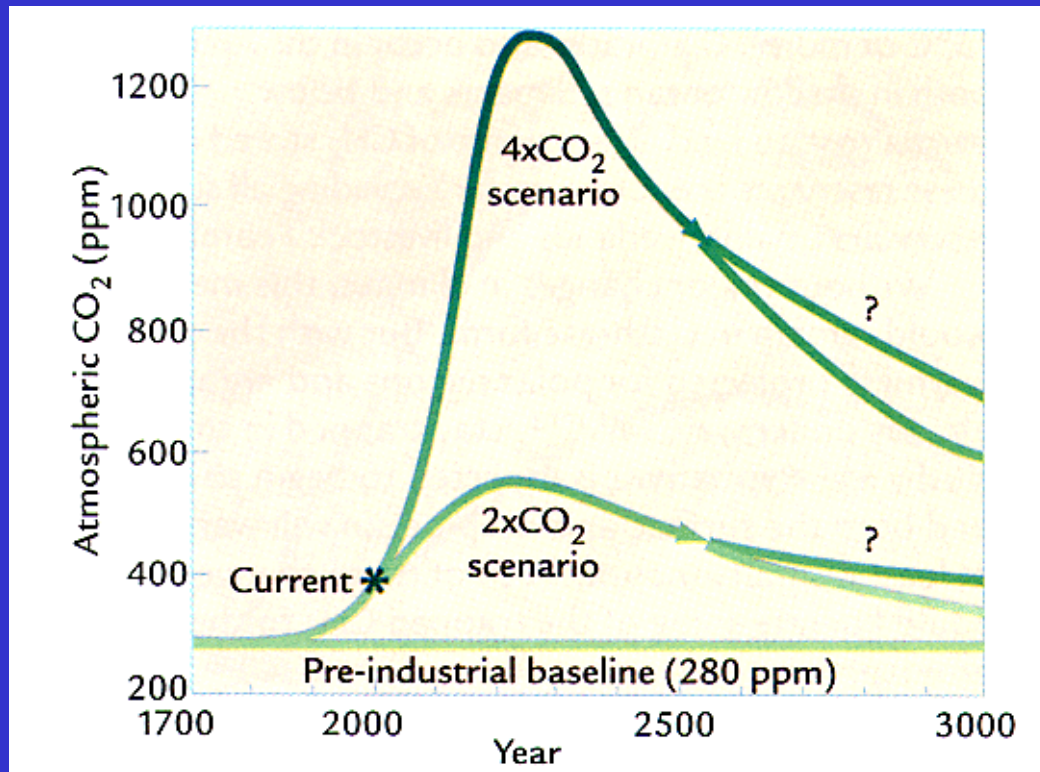


(from *Earth's Climate: Past and Future*)



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

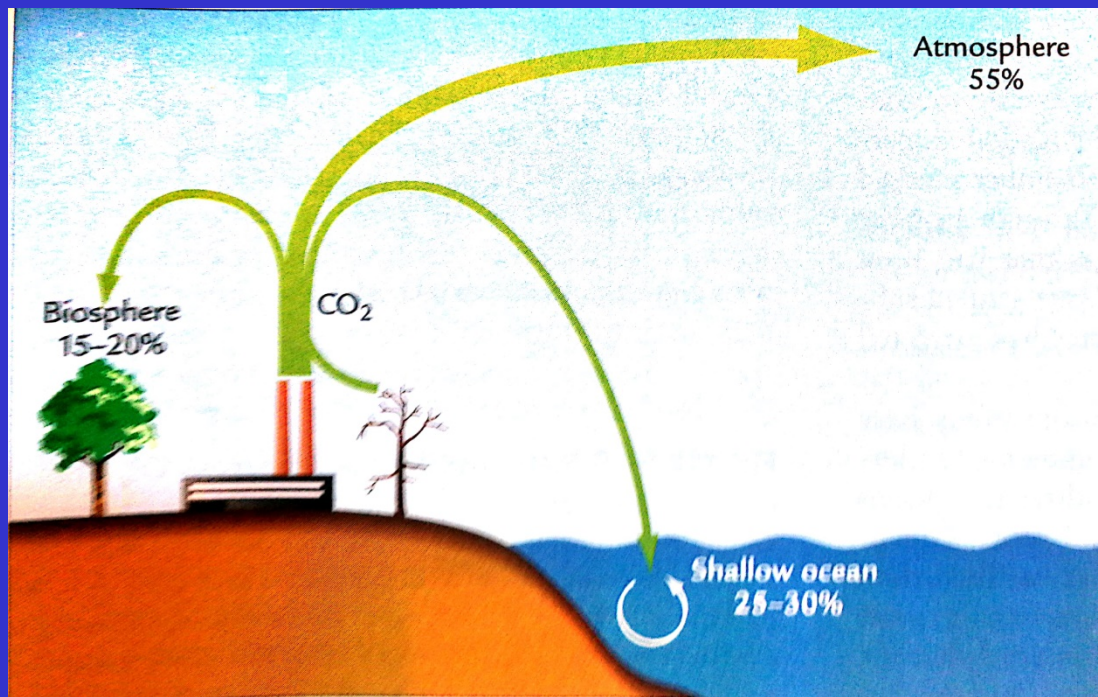


(from *Earth's Climate: Past and Future*)

- ❑ Projecting the future CO<sub>2</sub> concentration is more difficult than projecting the emission levels.
- ❑ The future concentration of CO<sub>2</sub> in the atmosphere also depends on how the climate system redistribute the excessive CO<sub>2</sub> among its carbon reservoirs (such as ocean and biosphere).
- ❑ CO<sub>2</sub> level in the atmosphere peaks centuries after CO<sub>2</sub> emission reaches its peak.
- ❑ This is related to the fact that it takes time for the ocean to remove the excessive CO<sub>2</sub> from the atmosphere.



# Where does CO<sub>2</sub> go?



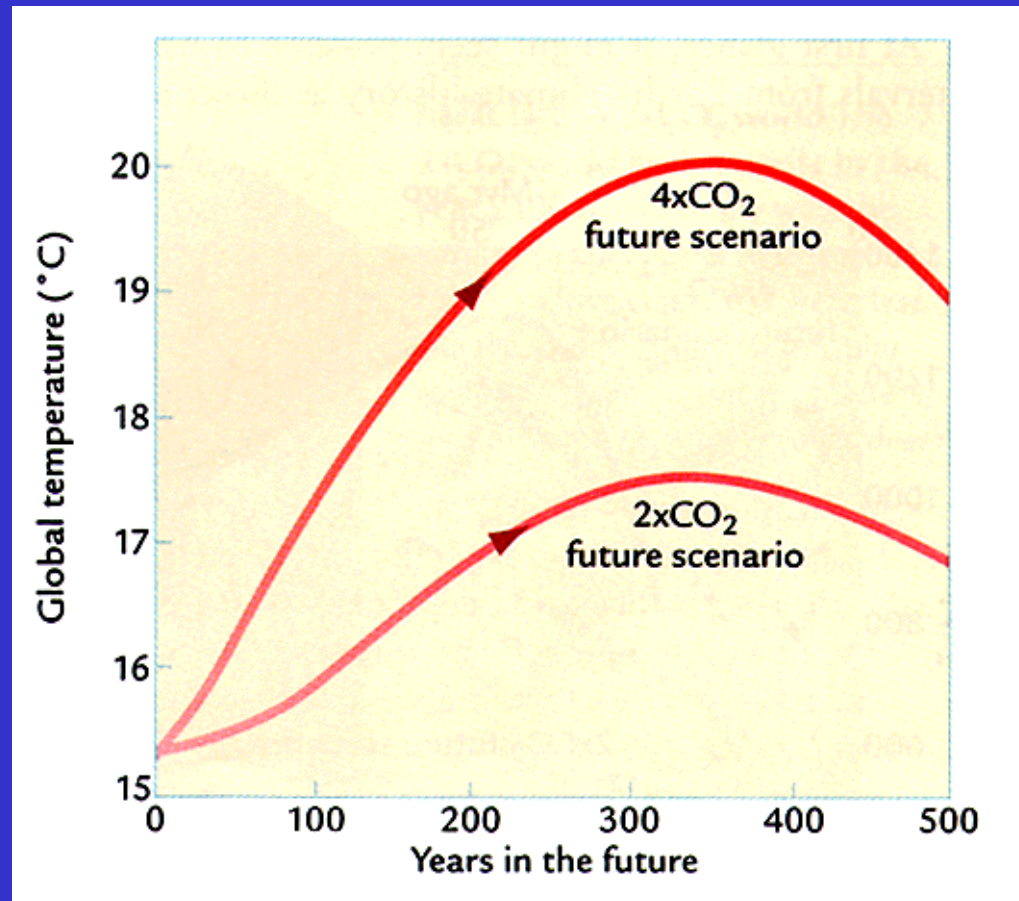
(from *Earth's Climate: Past and Future*)

- Of the carbon added to the climate system by human,
- 55% ends up in the atmosphere
- 25-30% enters the surface ocean
- 15-20% stored in the biosphere





# Projected Temperature Changes

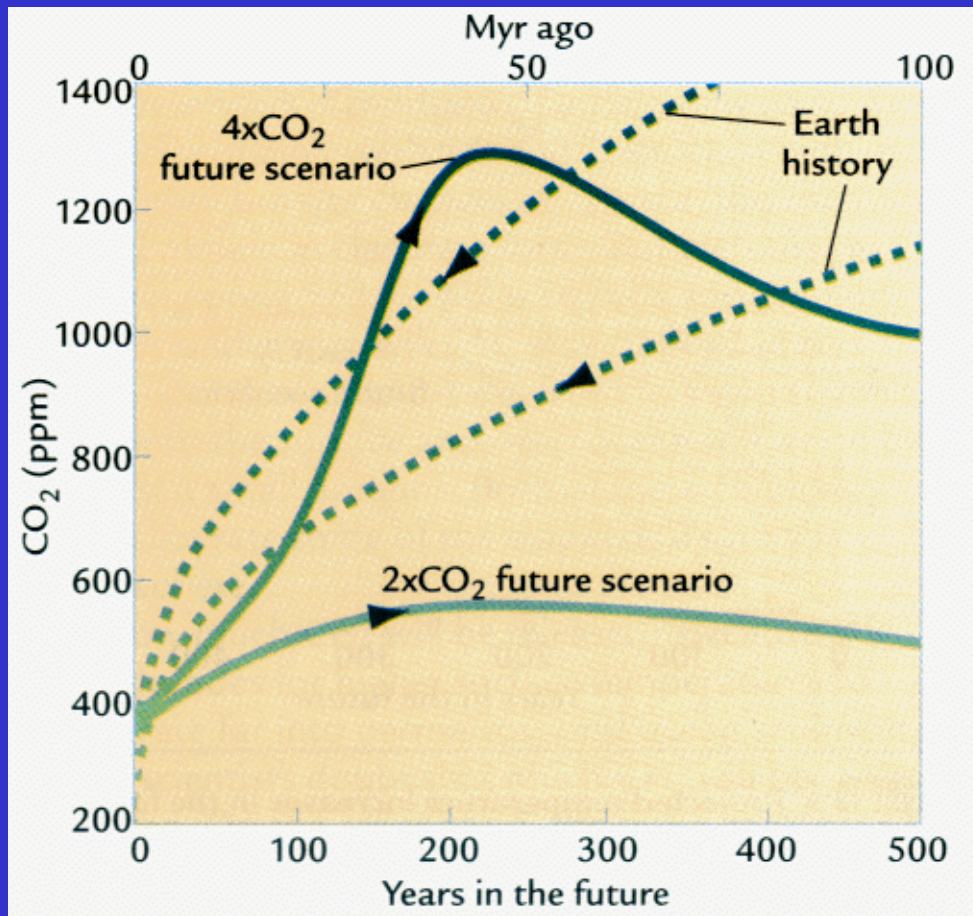


(from *Earth's Climate: Past and Future*)



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# CO<sub>2</sub>: Past and Future

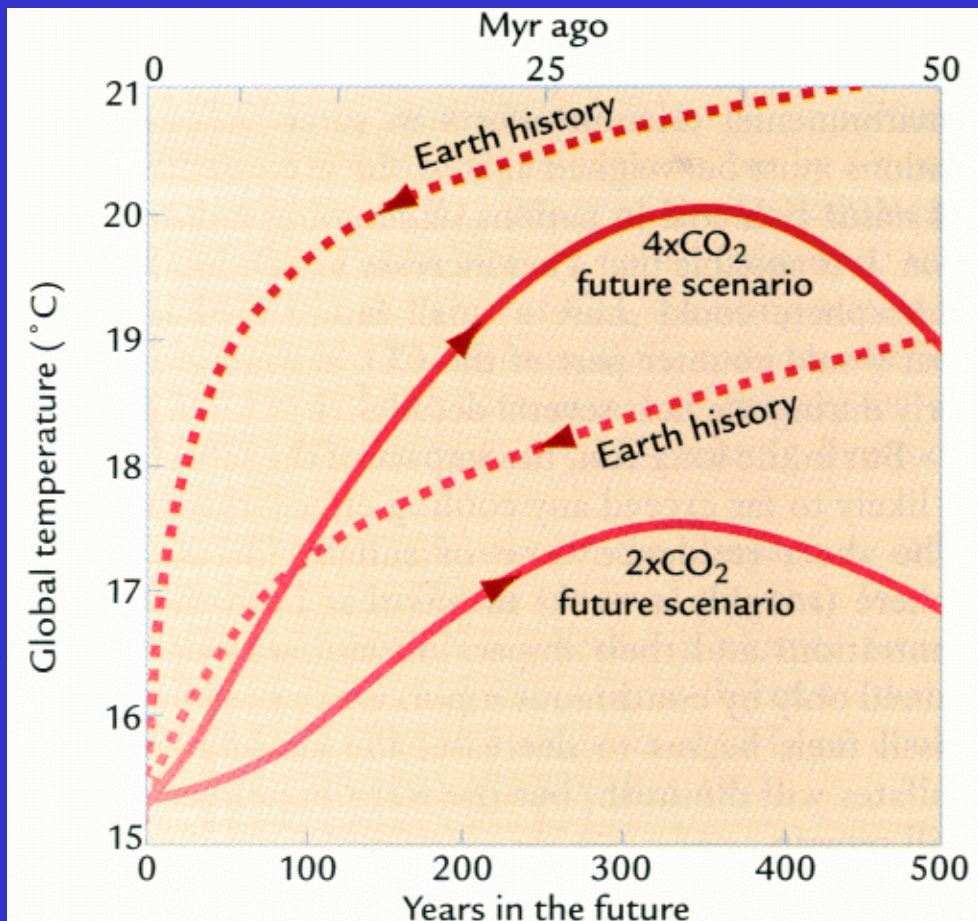


(from *Earth's Climate: Past and Future*)

- ❑ CO<sub>2</sub> levels were last at the 2xCO<sub>2</sub> value near 7 Myr ago.
- ❑ CO<sub>2</sub> levels were last at the 4xCO<sub>2</sub> value at least before 50 Myr ago and possible since the Cretaceous greenhouse world of 100 Myr ago.



# Temperature: Past and Future

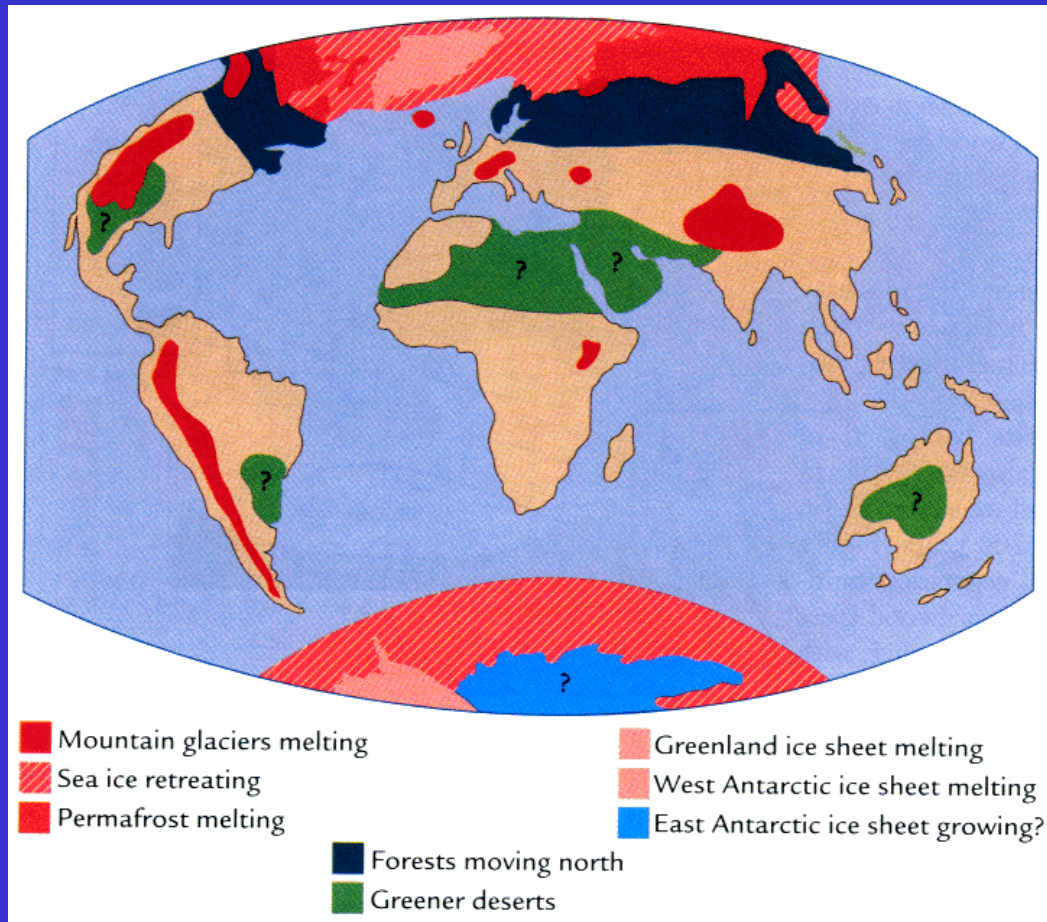


(from *Earth's Climate: Past and Future*)

- CO<sub>2</sub> emission resulting from human activities in the next few hundred years will cause global temperature changes that took natural forces tens of millions of years to produce.



# A 2xCO<sub>2</sub> World (50-100 years from now)



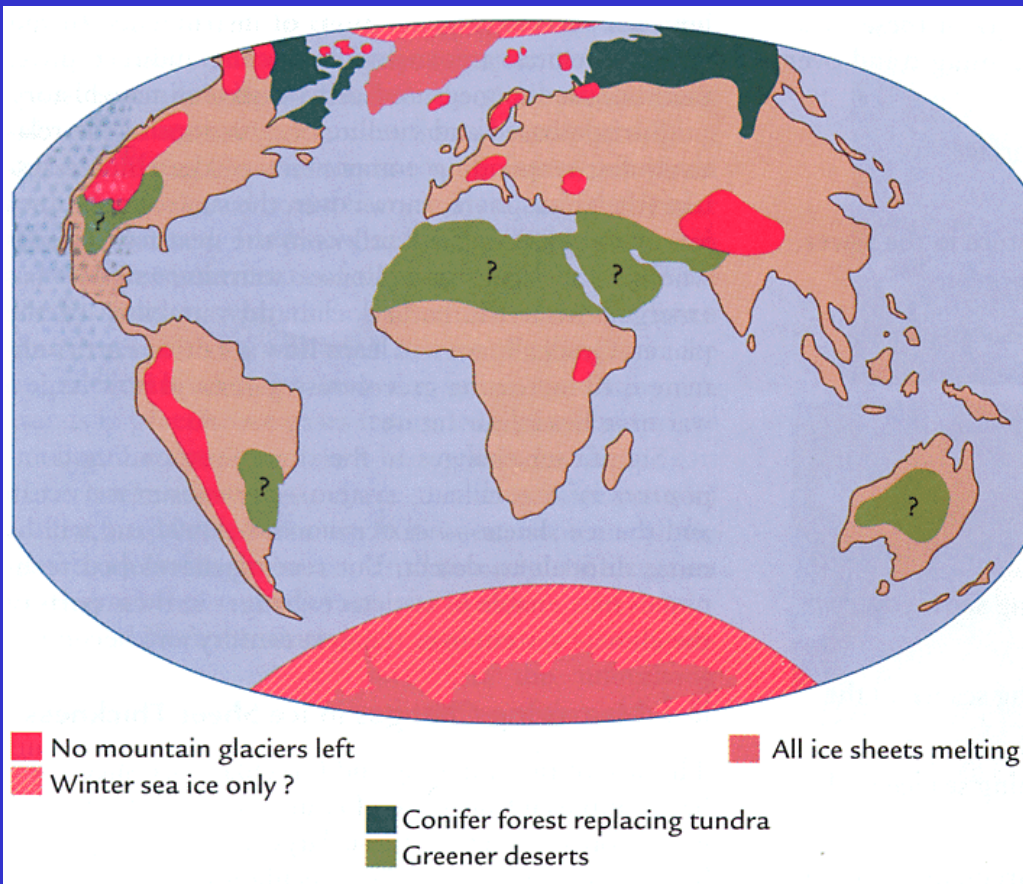
- The 2xCO<sub>2</sub> world likely to exist by the year 2100 will in many ways be similar to the world existed 5 to 10 million year ago, with less sea ice and permafrost in polar regions, few mountain glacier, and in some regions greener deserts.

(from *Earth's Climate: Past and Future*)



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# A 4xCO<sub>2</sub> World (50-100 years from now)



- The 4xCO<sub>2</sub> world that may come into existence between 2200 and 2300 would be slowly moving toward condition that exist 50 or more million years ago, when little or no glacial or sea ice was present on Earth, and forests grew in the higher latitudes of the Arctic.

(from *Earth's Climate: Past and Future*)



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