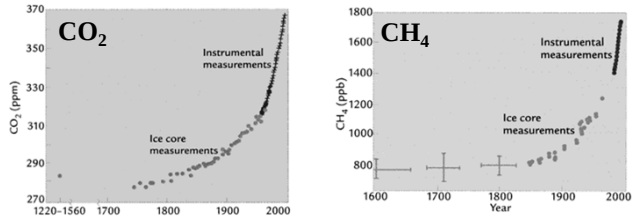
Lecture 11: Global Warming

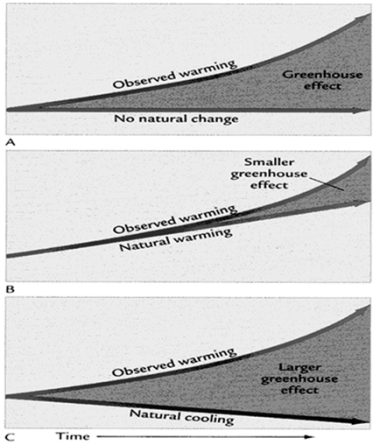


- What is the sensitivity of Earth's climate to the increases of greenhouse gases (CO2 and CH4) and sulfur dioxide (SO2)?
- What is the projection of the future climate change?

Human Acticities

- 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

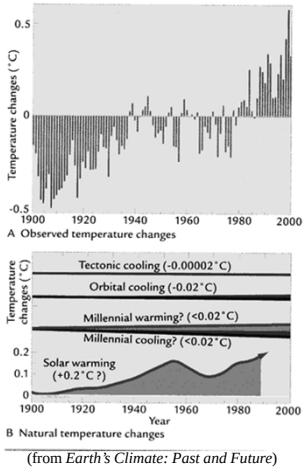
Global Warming: Natural or Man-Made



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

- Global surface temperature has ***warmed by 0.6℃*** in the last century.
- Is the global warming caused by natural climate change or by human activities?

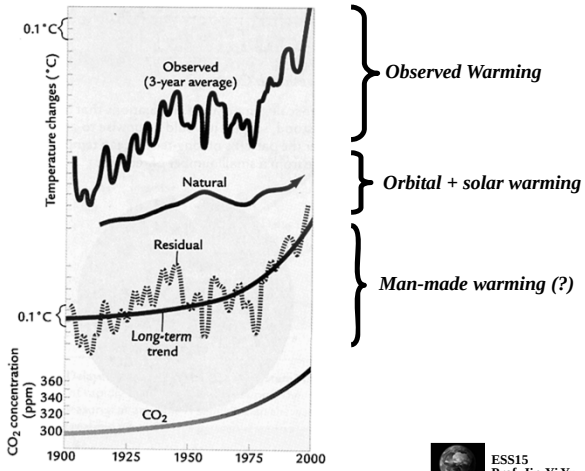
Natural Climate Changes



(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-made?



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

Greenhouse Gases

Important Atmospheric Greenhouse Gases	
Name and Chemical Symbol	***Concentration (ppm by volume)***
Water vapor, H_2O	0.1 (South Pole)–40,000 (tropics)
Carbon dioxide, CO_2	360
Methane, CH_4	1.7
Nitrous oxide, N_2O	0.3
Ozone, O_3	0.01 (at the surface)
Freon-11, CCl_3F	0.00026
Freon-12, CCl_2F_2	0.00047

Water Vapor (H2O)

- Water vapor is supplied to the atmosphere by evaporation from the surface and is removed from the atmosphere by condensation (clouds and rains).
- The concentration of water vapor is maximum near the surface and the tropics (~ 0.25% of the atmosphere) and decreases rapidly toward higher altitudes and latitudes (~ 0% of the atmosphere).
- Water vapor is important to climate because it is a greenhouse gas that can absorb thermal energy emitted by Earth, and can release "latent heat" to fuel weather phenomena.

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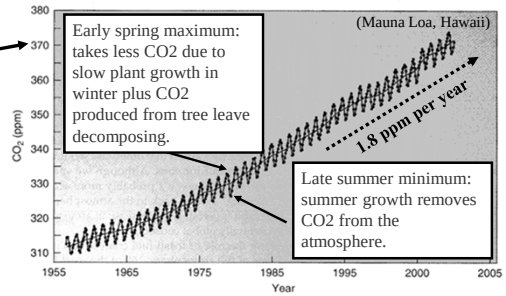
Carbon Dioxide (CO2)

current level



(from *Understanding Weather & Climate*)

- Carbon dioxide is supplied into the atmosphere by plant and animal respiration, the decay of organic material, volcanic eruptions, and natural and anthropogenic combustion.
- Carbon dioxide is removed from the atmosphere by photosynthesis.
- CO2 is an important greenhouse gas.

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Greenhouse Gases

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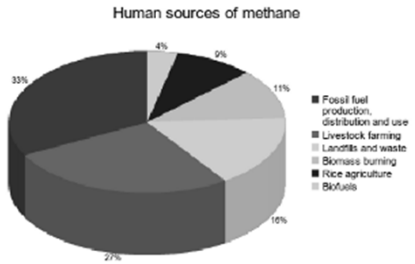
Man-Made Sources for CH4



- Methane emissions get produced wherever there are fossil fuels. It gets released whenever fossil fuels get extracted from the earth. Whether it is natural gas (which is in most part methane), coal or petroleum.
- The average cow produces enough methane per year to do the same greenhouse damage as four tons of carbon dioxide.

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Greenhouse Gases

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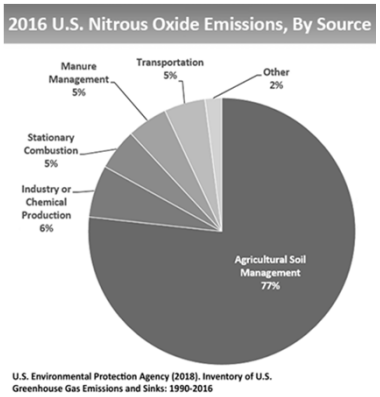
Man-Made Sources for N2O



U.S. Environmental Protection Agency (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016

- Human activities such as agriculture, fuel combustion, wastewater management, and industrial processes are increasing the amount of N2O in the atmosphere.
- Nitrous oxide is also naturally present in the atmosphere as part of the Earth's nitrogen cycle, and has a variety of natural sources.

Greenhouse Gases

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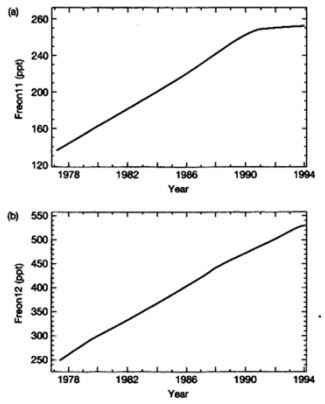
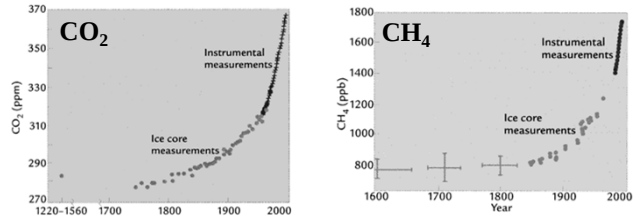
Man-Made Sources for CFCs



(from *The Earth System*)

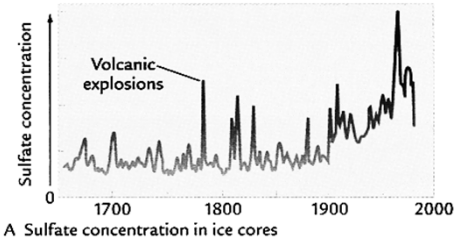
- There are two kinds of CFCs: freon-11 (CCl3F) and freon-12 (CCl2F2).
- Freon-11 has been used:
  (1) as a propellant in spray cans
  (2) as a blowing agent for producing foams
  (3) to clean semiconductor chips.
- Freon-12 has been used as
  (1) a refrigerant
  (2) working fluid in most car air conditioners.

Lecture 11: Global Warming



- What is the sensitivity of Earth's climate to the increases of greenhouse gases (CO2 and CH4) and sulfur dioxide (SO2)?
- What is the projection of the future climate change?

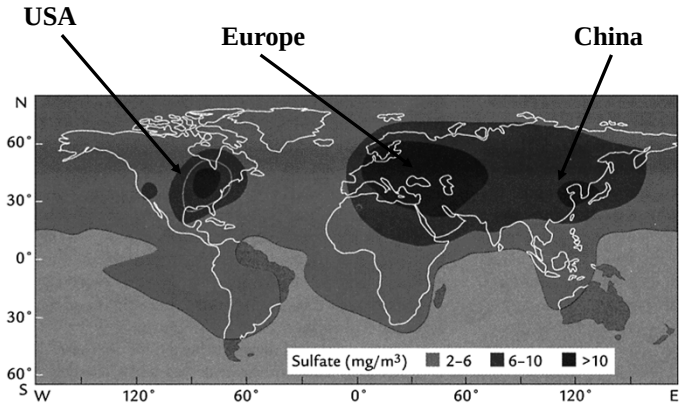
Cooling Effects of SO2



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

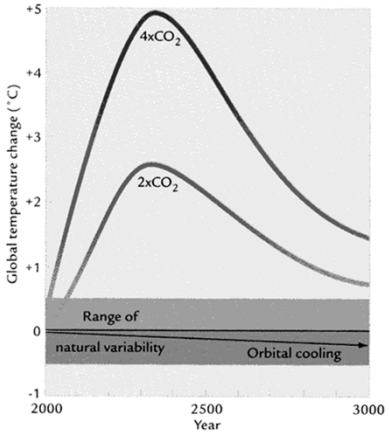
- SO2 produced by smokestacks exceeds natural emissions.
- SO2 reacts with water vapor to produce sulfate aerosols.
- Sulfate aerosols can block solar radiation and cool the climate.

Sources of SO2 Emissions



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

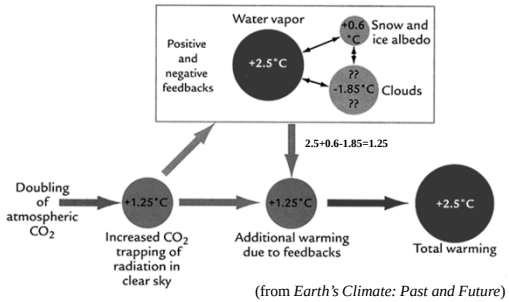
Future CO2 Change



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

- Atmospheric CO2 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.

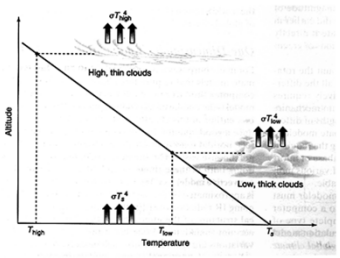
Global Warming Due to $2xCO_2$



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

- 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.

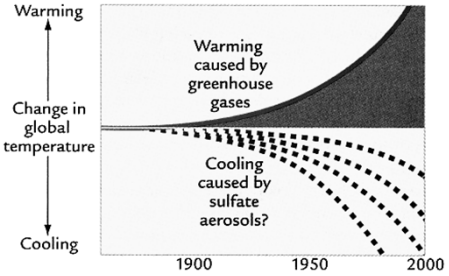
Clouds – A Major Uncertainty



(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

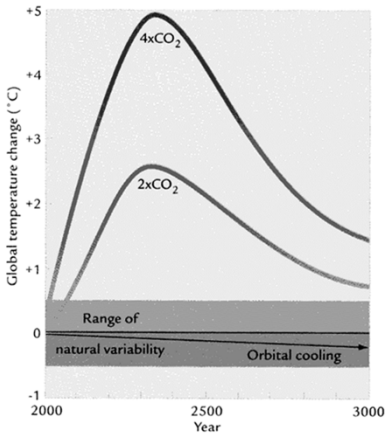
SO2 Cooling and CO2 Warming



(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 SO2 emission from smokestacks.

Future CO2 Change



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

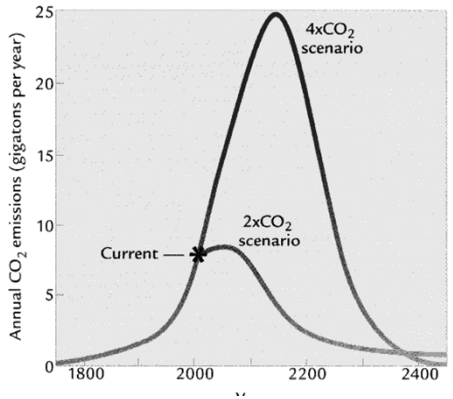
- Atmospheric CO2 will increase within two centuries to levels at least two and possibly four times higher than those that existed before humans made their influence felt.

How Future CO2 Emission Calculated?

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

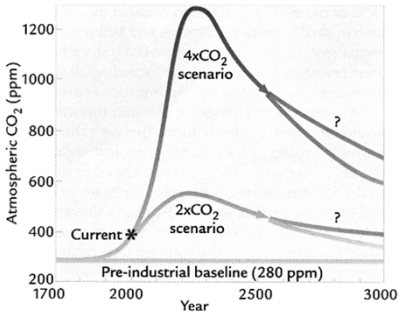
- ***Global Population***: is expected to increase to 11 billion between 2075 and 2100 (100% increase).
- ***Emission Per Person***: is linked to averaged standard of living (such as car and home heating or cooling).
- ***Efficiency of Use***: The hardest factor to project. The efficiency depends on 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*)

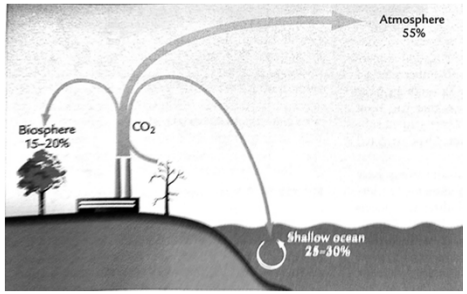
Projected CO2 Concentration



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

- Projecting the future CO2 concentration is more difficult than projecting the emission levels.
- The future concentration of CO2 in the atmosphere also depends on how the climate system redistribute the excessive CO2 among its carbon reservoirs (such as ocean and biosphere).
- CO2 level in the atmosphere peaks centuries after CO2 emission reaches its peak.
- This is related to the fact that it take time for ocean to remove the excessive CO2 from the atmosphere.

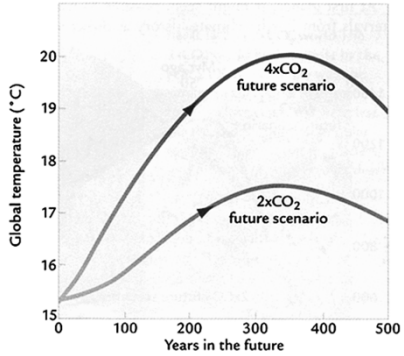
Where does CO2 go?



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

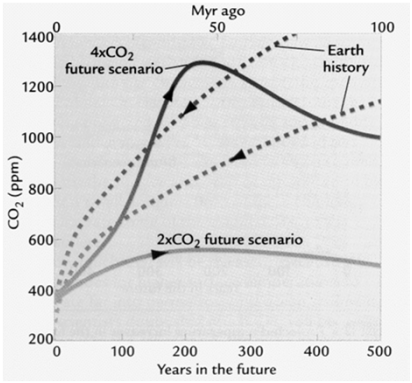
- Of the carbon added to the climate system by human,
- 55% ends up in the atmosphere
- 25-30% enters the surface ocean
- 15-20% stored in the biosphere

Projected Temperature Changes



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

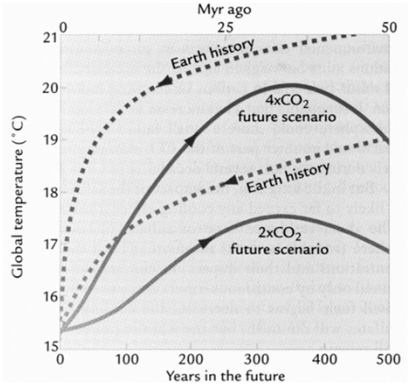
CO2: Past and Future



- CO2 levels were last at the 2xCO2 value near 7 Myr ago.
- CO2 levels were last at the 4xCO2 value at least before 50 Myr ago and possible since the Cretaceous greenhouse world of 100 Myr ago.

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

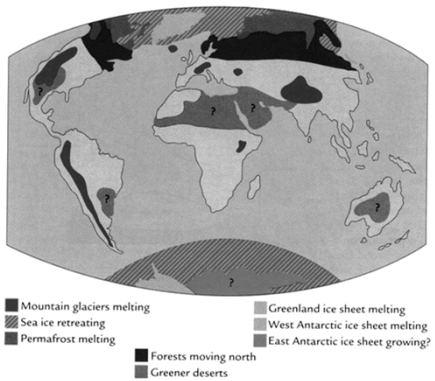
Temperature: Past and Future



- CO2 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.

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

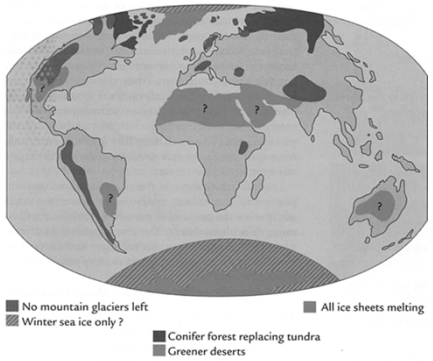
A 2xCO2 World (50-100 years from now)



- The 2xCO2 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*)

A 4xCO2 World (50-100 years from now)



- The 4xCO2 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*)