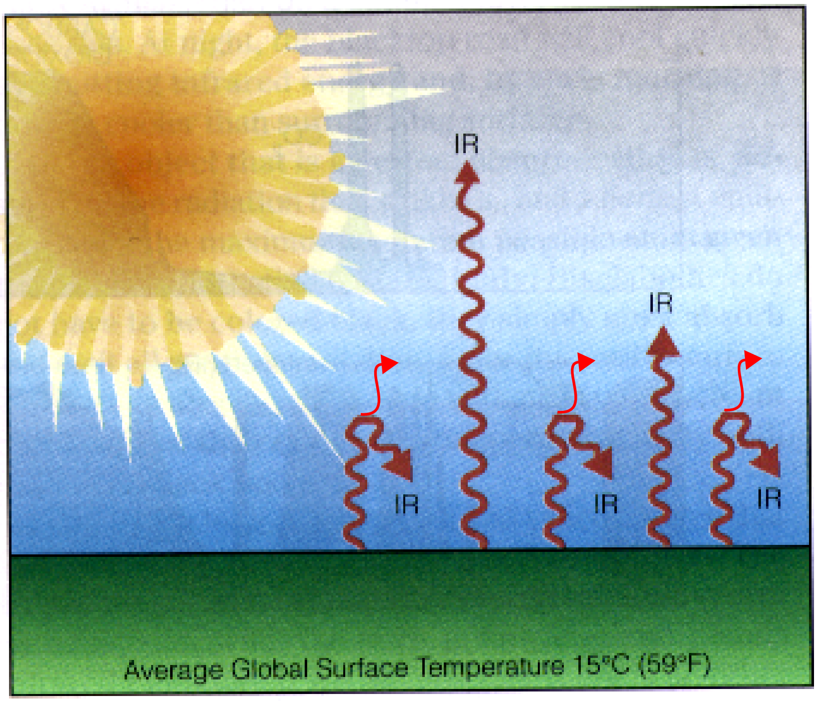
Lecture 36 Anthropogenic Effects on Climate

It is well-documented that globally averaged land and sea-surface temperatures have increased 0.5 C in the last century. Is this the beginning of man-made global warming?

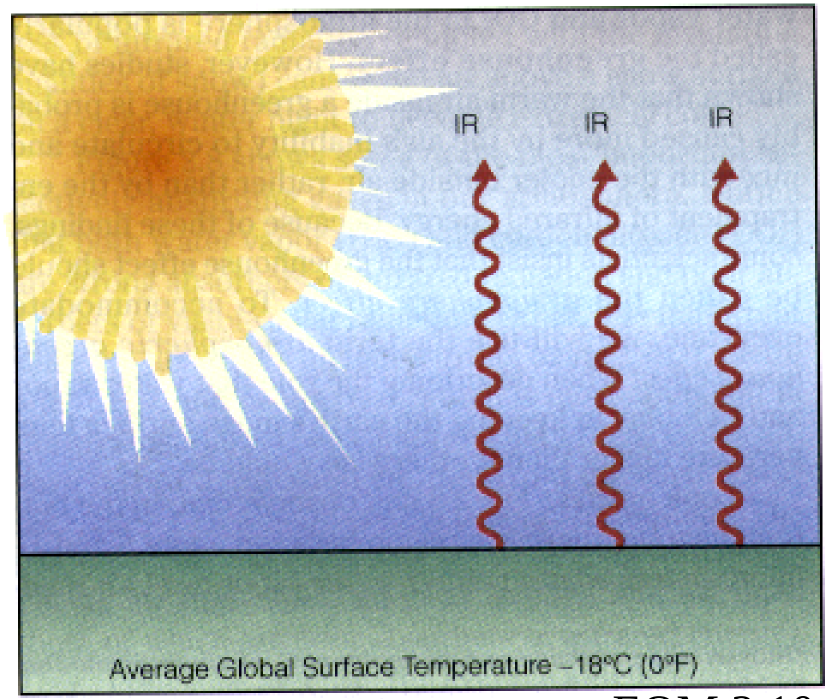
Two major anthropogenic ‘forcings’ on global climate have been identified.

1. Greenhouse gas concentrations are increasing
2. Aerosol concentrations are increasing

The greenhouse effect



(a) Earth's atmosphere *with* H_2O and CO_2



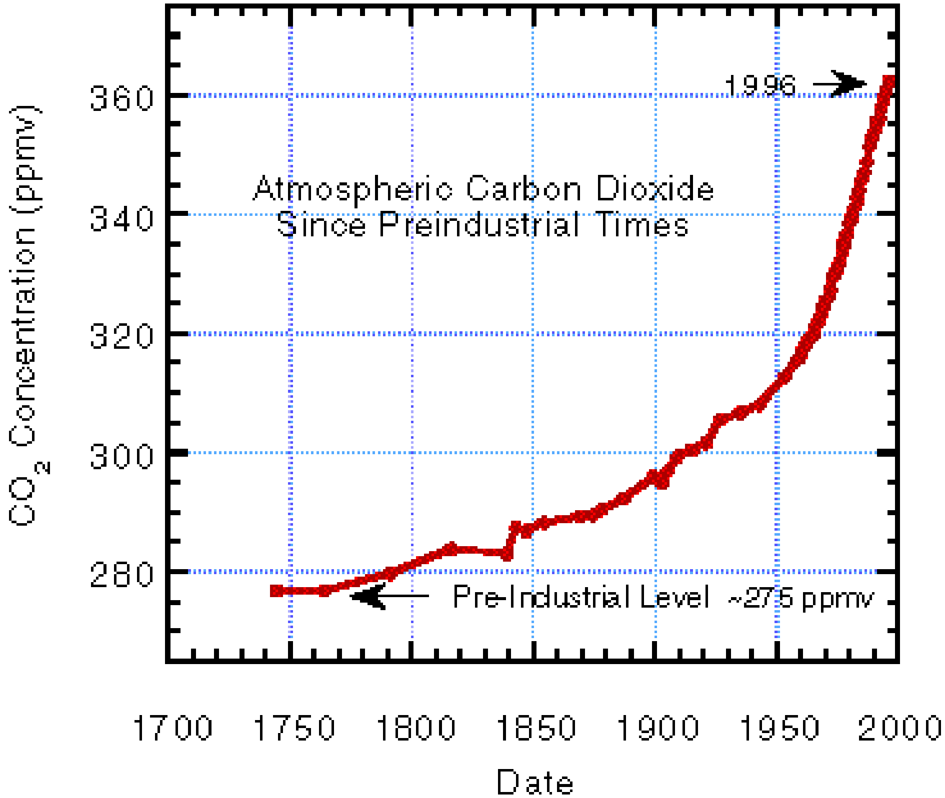
(b) Earth's atmosphere *without* H_2O and CO_2

EOM 2.10

- If the earth's atmosphere were dry, we could predict fairly confidently that doubling pre-industrial CO_2 (likely by 2100) would increase mean surface temperature about 2 C.
- The famous 19th century Swedish chemist Arrhenius was the first to predict greenhouse warming.

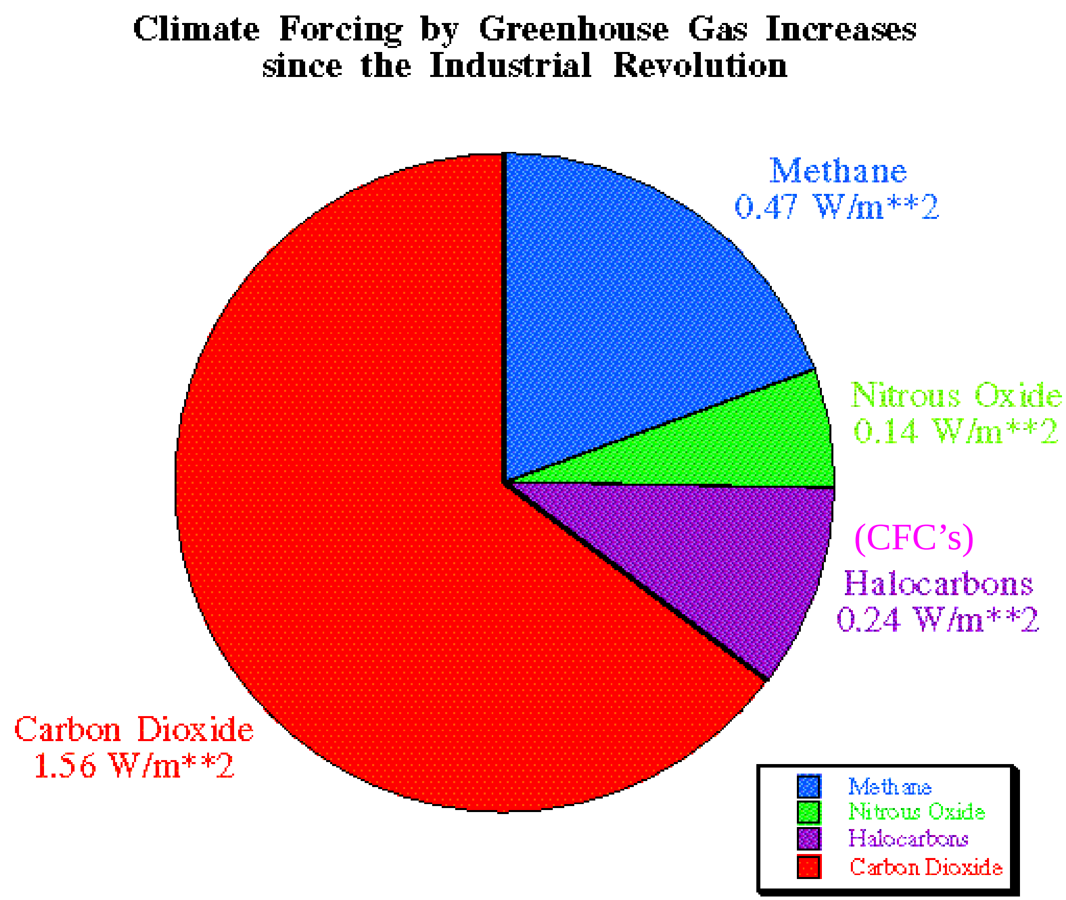
Greenhouse gas concentrations are increasing

Hartmann, fig 8.6



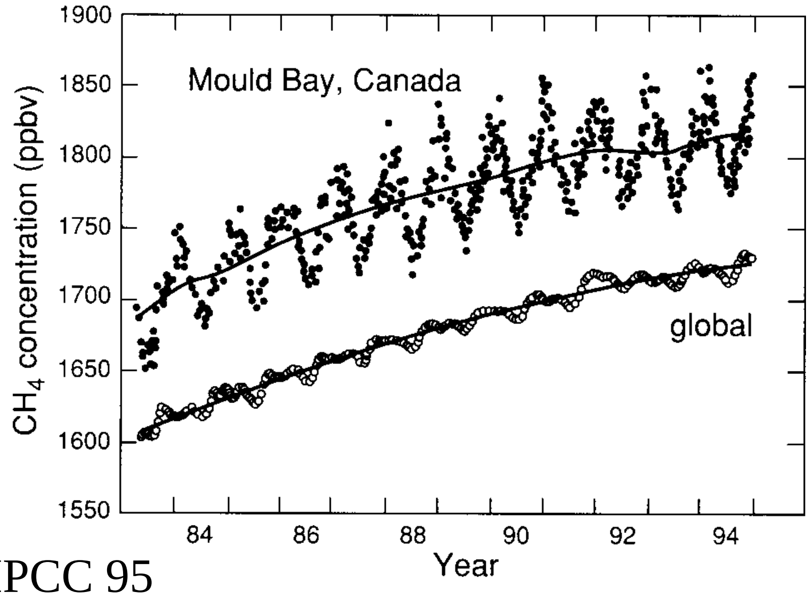
- Currently, 7 gigatons/yr of CO_2 produced by burning of fossil fuel (80%) and deforestation 20%).
- Half accumulates in atmosphere, where it has a residence time of 50+ years.
- If we totally stopped burning fossil fuels/forests, it would take 50 years for CO_2 to return half way to preindustrial levels.

Other anthropogenic greenhouse gasses



Courtesy of Dennis Hartmann, based on IPCC 1995.

Methane also increasing



IPCC 95

Aerosols

Minute hygroscopic (water-attracting) particles, usually 0.01-1 micron in diameter. Source is at surface, so most aerosol is in troposphere and is washed out in days-weeks by precipitation.

Natural:

dust, salt, soot (fires), sulfate (ocean phytoplankton, volcanoes)

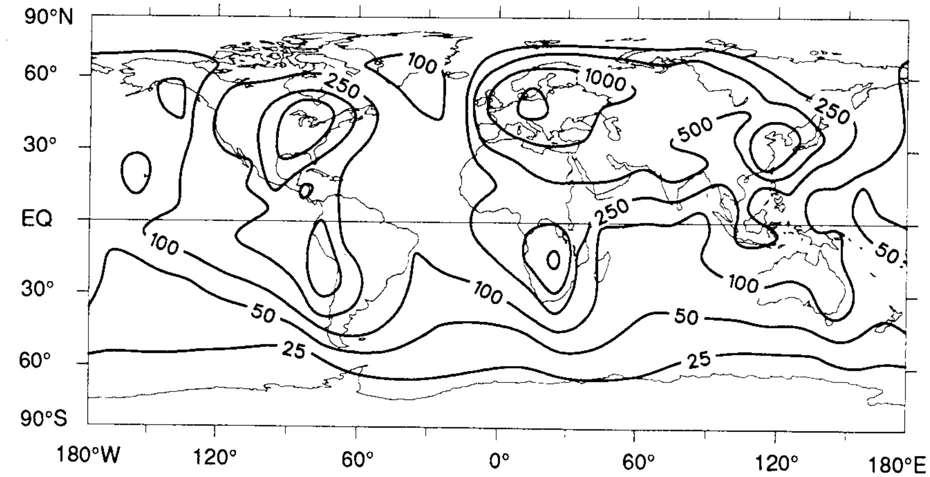
Manmade:

sulfate (coal/oil combustion), soot & organics (industrial processes, wood burning, spraying)

Aerosols and Climate

- Aerosols reflect more sunlight back to space, cooling surface temperatures.
- Some aerosols (soot, smoke) absorb sunlight, warming the atmosphere (Kuwait oil fires).

- Sulfur-rich volcanic eruptions inject sulfate aerosol into the stratosphere (Pinatubo, 1991 - 20 million tons; Tambora, 1815 - hundred million tons), where it survives for years→– global cooling of 0.5 C (Pinatubo) or more (Tambora) in next year.
- Sulfates, soot comprise the industrial haze that often blankets the eastern US, Europe in summer. Winds transport this haze over central Asia, oceans.



Extra Sunlight reflected back to space (4 → 1%)

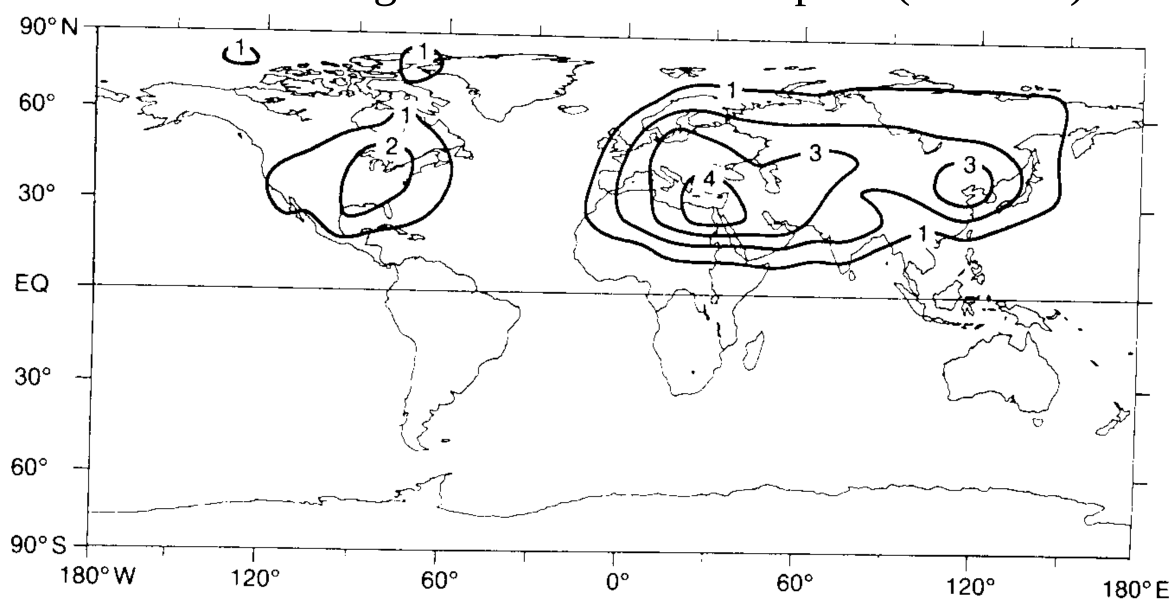


Fig. 12.5 Calculated increase of reflected solar flux caused by tropospheric sulfate aerosols derived from anthropogenic sources. Contour interval 1 W m^{-2}. [From Charlson *et al.* (1991). Reprinted with permission from Munksgaard International Publishers Ltd.] Hartmann

Indirect Effect of Aerosols

- Aerosols are the nucleii on which cloud droplets form
- More aerosol particles fi water in clouds is divided into more smaller droplets.
- Combined surface area of droplets is larger, increasing cloud reflectivity and cooling climate.
- Striking example - ‘ship tracks’.

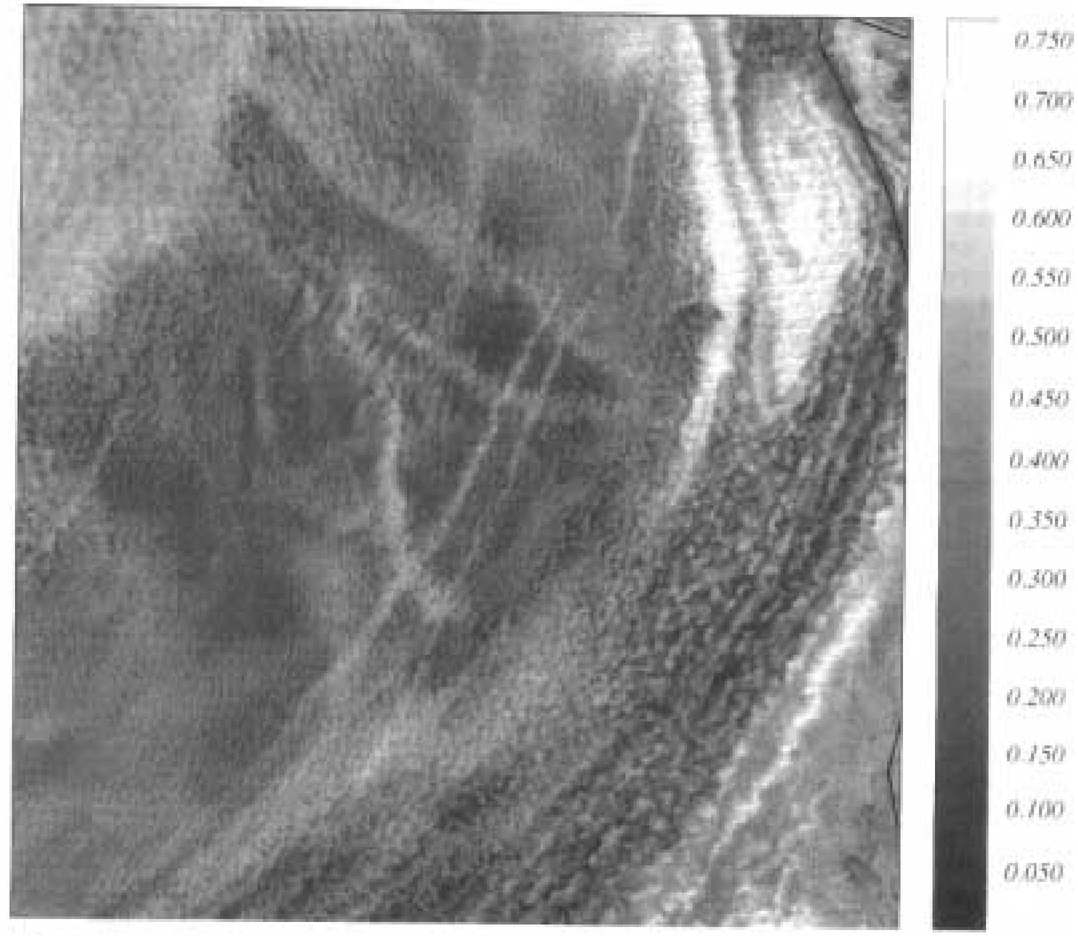


Fig. 12.6 GOES 1-km visible image of stratocumulus clouds over the Pacific Ocean on July 1, 1987 at 1615 UTC (Universal Time Coordinate). The scale of the image is approximately 5° square. The continental outline in the upper right is the Olympic Peninsula of Washington, and the one in the lower right is Cape Blanco on the Oregon coast. The linear features in the center of the image are ship tracks, enhancements of otherwise thin stratocumulus clouds caused by sulfur gas and particulate emissions of passing ships. The gray scale on the right indicates the visible albedo. (Image courtesy of Robert Pincus.)

Hartmann

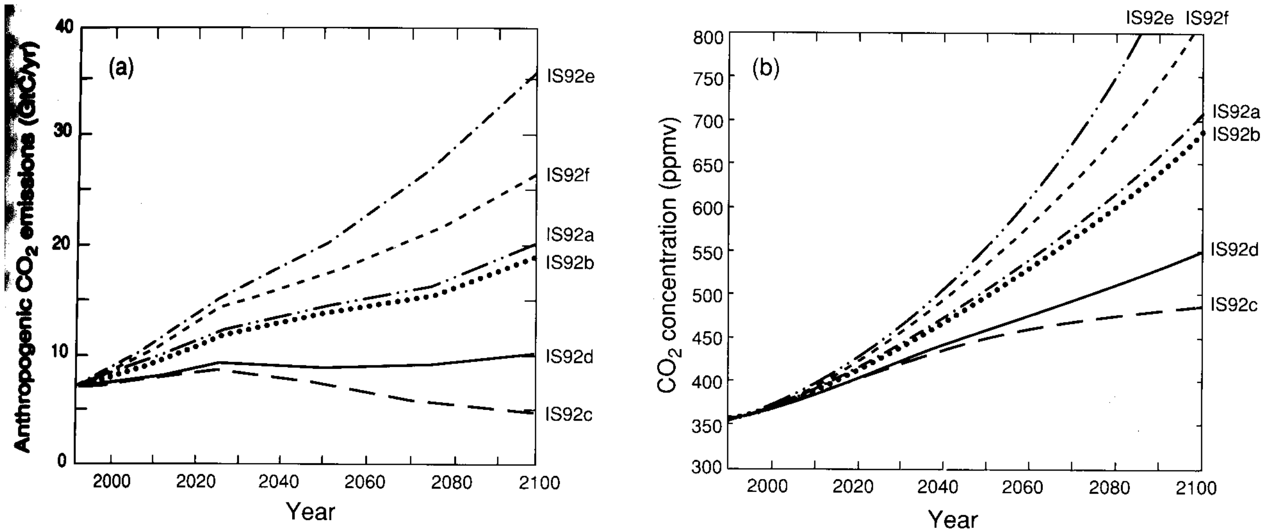
- Estimates suggest 100+% anthropogenic increase in nucleii over source areas, 25% over remote NH oceans from wind transport of aerosols, and imply indirect effect is as big as direct effect.

- Overall effect of aerosol is to cancel 20-50% of the radiative impact of greenhouse gas. Large uncertainty about aerosol absorption, indirect effect.

- If man stopped producing aerosol, would take only a week or two to approach pre-industrial levels!

Projections of Greenhouse Emissions

- Without mitigation, greenhouse emissions rise...

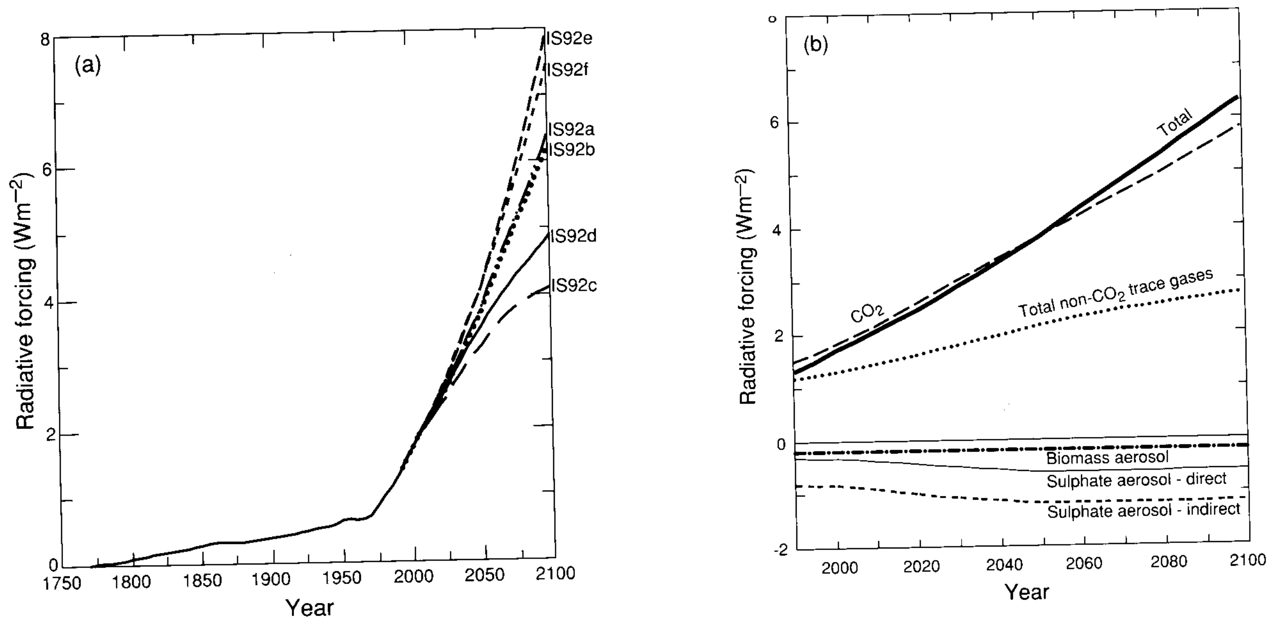


igure 5: (a) Total anthropogenic CO_2 emissions under the IS92 emission scenarios and (b) the resulting atmospheric CO_2 oncentrations calculated using the "Bern" carbon cycle model and the carbon budget for the 1980s shown in Table 2.

IPCC 1995

- Even if emissions are stabilized at current levels, CO_2 reaches double preindustrial values by 2100.

• Rapidly increasing human greenhouse effect



Climate Feedbacks

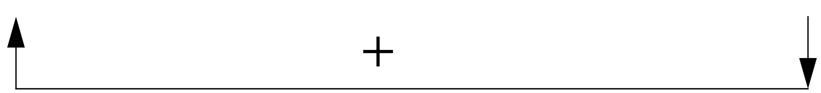
The greenhouse effect is indisputable. Nevertheless, even if we perfectly knew future CO_2, there is some uncertainty about how much warming, and how fast, it will lead to due to **natural climate feedbacks**:

Water vapor (positive)
Clouds (unclear)
Snow and ice cover (positive)
Ocean circulation (delays)

Water vapor - likely a *positive* feedback

- Water vapor is a balance between surface evaporation (faster at low RH) and precipitation (requires high RH), maintaining an equilibrium pattern of RH.
- At higher temperatures, more water vapor is required to produce this RH pattern.

$$CO_2\uparrow \Rightarrow \text{temp.}\uparrow \Rightarrow \text{water vapor}\uparrow \Rightarrow \text{greenhouse}\uparrow$$



Other feedbacks

- temp.$\uparrow \Rightarrow$ snow and ice $\downarrow \Rightarrow$ albedo $\downarrow$ (+)
- Clouds are complex to model, feedback uncertain
- Oceans slower to warm, short-term heat sink.

Global climate models (GCMs) interactively coupled to computer models of ocean circulation simulate these climate feedbacks

- Weather forecast models with coarser grid spacing of 200-500 km $\Rightarrow$ can simulate 100 or more years.
- Careful representations of relevant physical processes: clouds, radiation, surface characteristics, sea ice, etc.
- Tested on past/current climate, seasonal march, weather.
- In US, two main models are run at NCAR (Boulder, CO) and GFDL (Princeton).
- GCM predictions have uncertainties, and different plausible models produce slightly different results but are our best current guess at climate change in next 100 years.

Predictions of Climate Change in Next 100 Years

While many uncertainties, best current information suggests climate will warm alarmingly (2-5 C global average, larger toward poles) in next 100 years unless strong measures are taken to curb fossil fuel consumption/greenhouse gas emission. US (5% of world population) creates 25% of problem now.

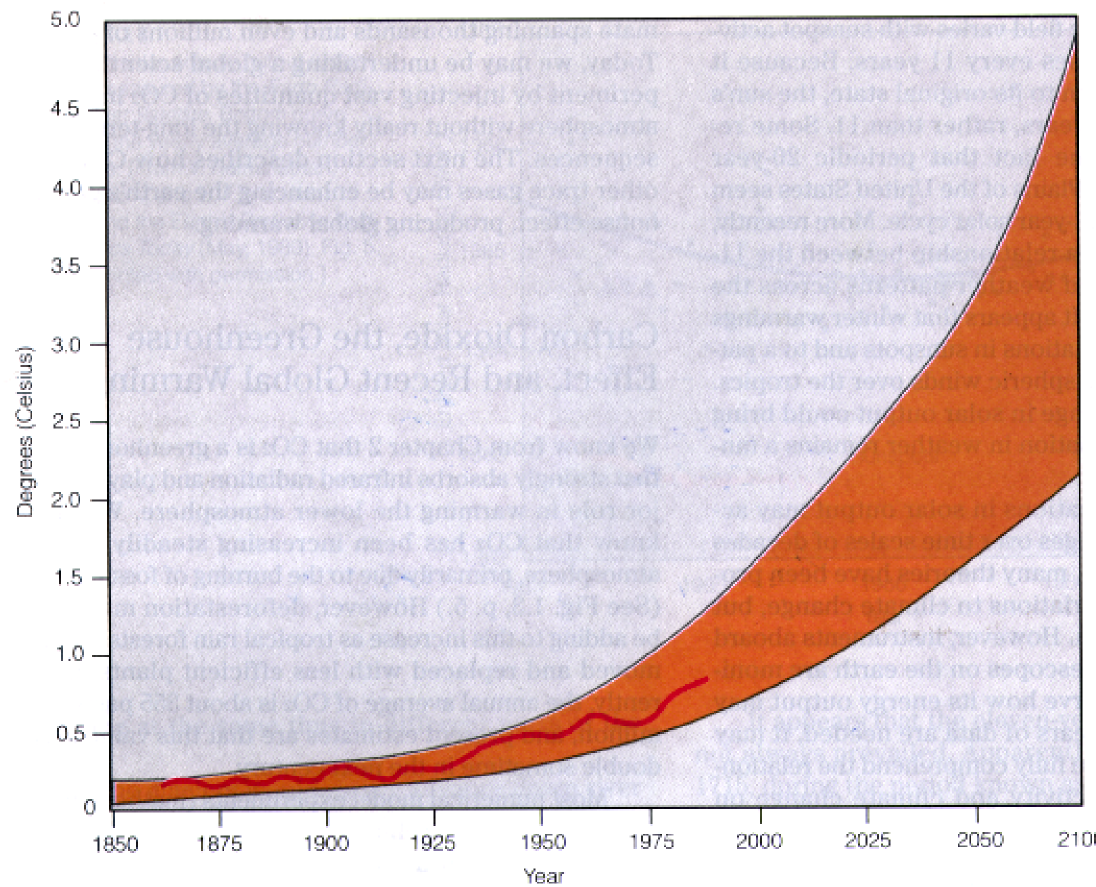


Figure 13.13 (EOM old edition)
Projected warming of the earth's surface by various computer models due to increasing levels of greenhouse gases. The range of the warming (orange shade) shows that the models predict a warming of between about 2°C and 5°C by the year 2100. If these predictions are correct, mean global temperatures within the next 100 years will be higher than they have been in the previous 150,000 years. The red line shows the change in earth's mean surface temperature from about 1860 to 1990. (Data from Intergovernmental Panel on Climate Change and National Academy of Sciences.)

Predicted warming is much larger in polar regions

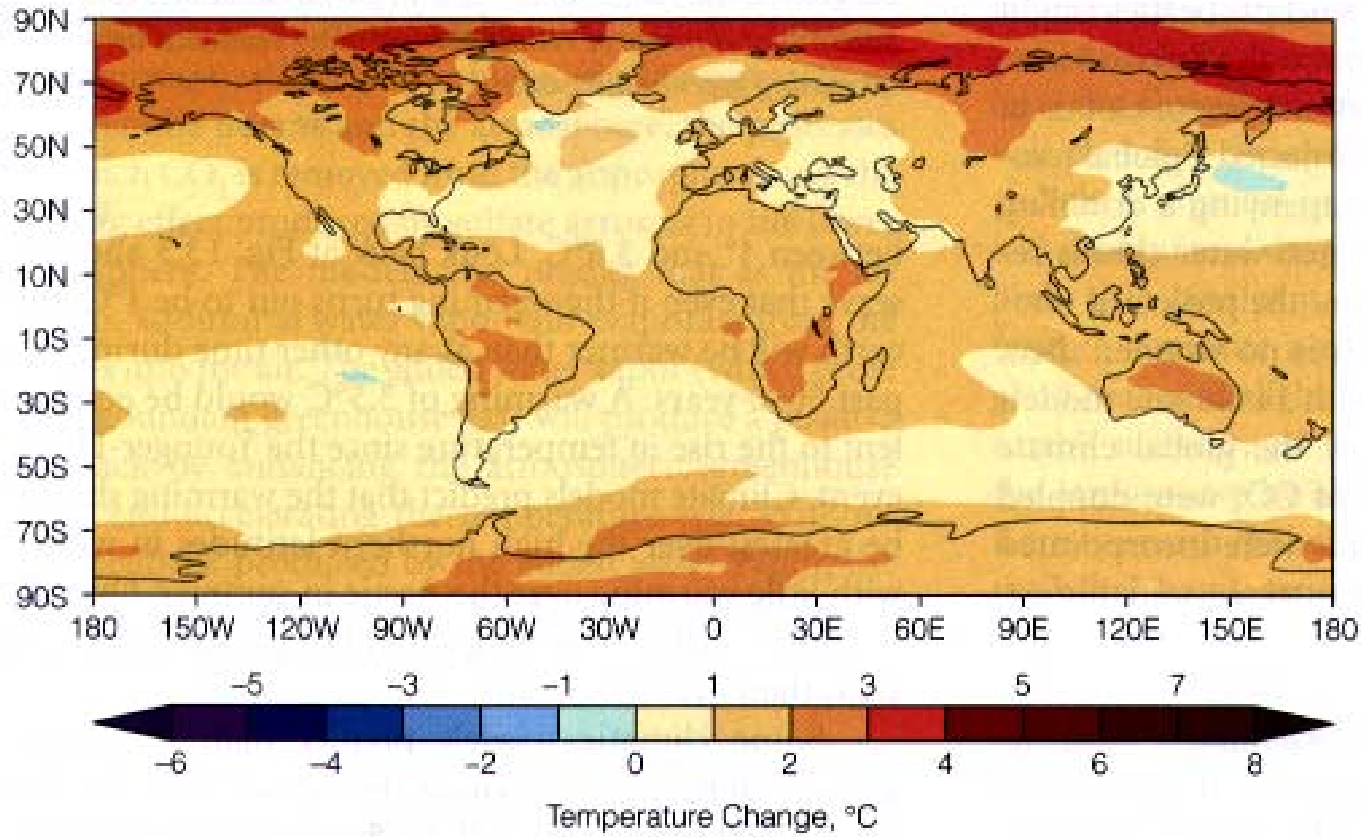
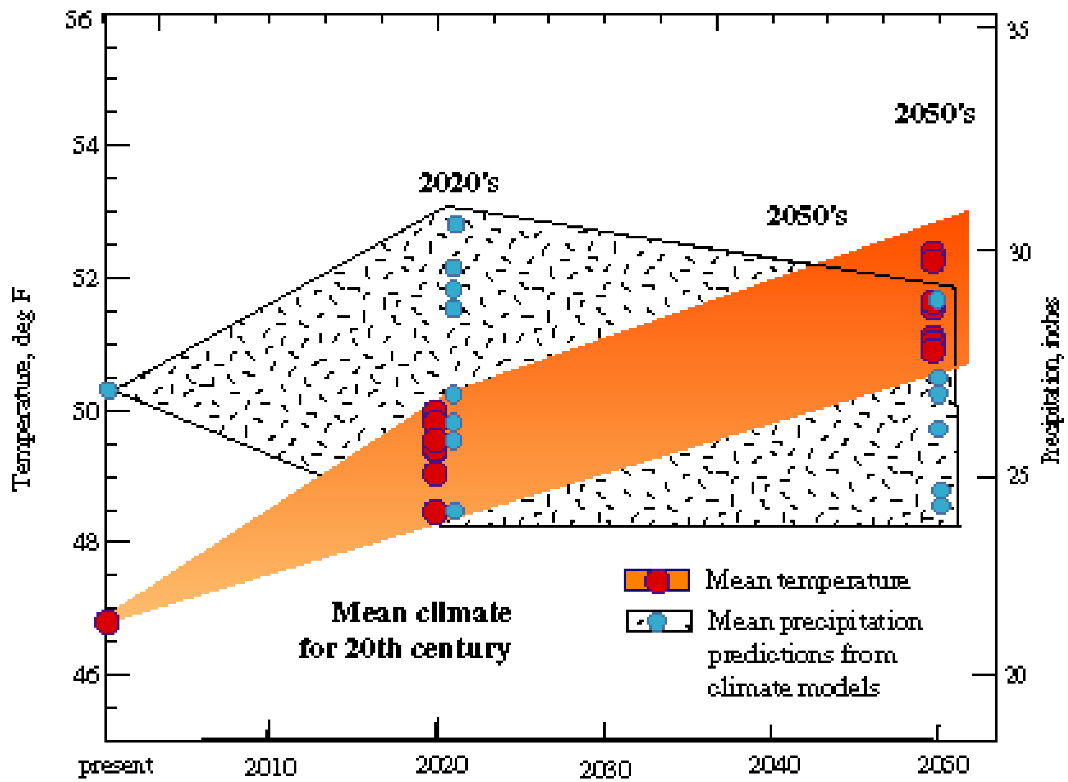


FIGURE 13.16
Projected changes in surface air temperature due to doubling of CO_2 and human-induced sulfur emissions with an Atmospheric-Ocean General Circulation Model (AOGCM). Notice that the greatest warming is projected for the northern polar latitudes. [After J. F. B. Mitchell, et al., "Transient climate response to increasing sulphate aerosols and greenhouse gases," Nature *(1995) 376: 501–504.]*

Climate Change in the Northwest

(Scenario: 1% per year CO_2 increase 1990-)



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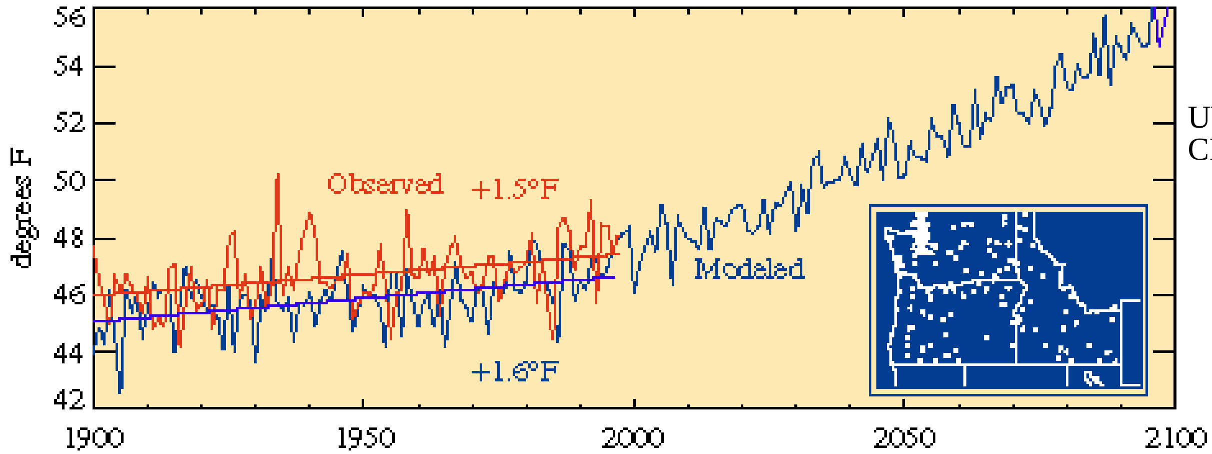
Results from one model



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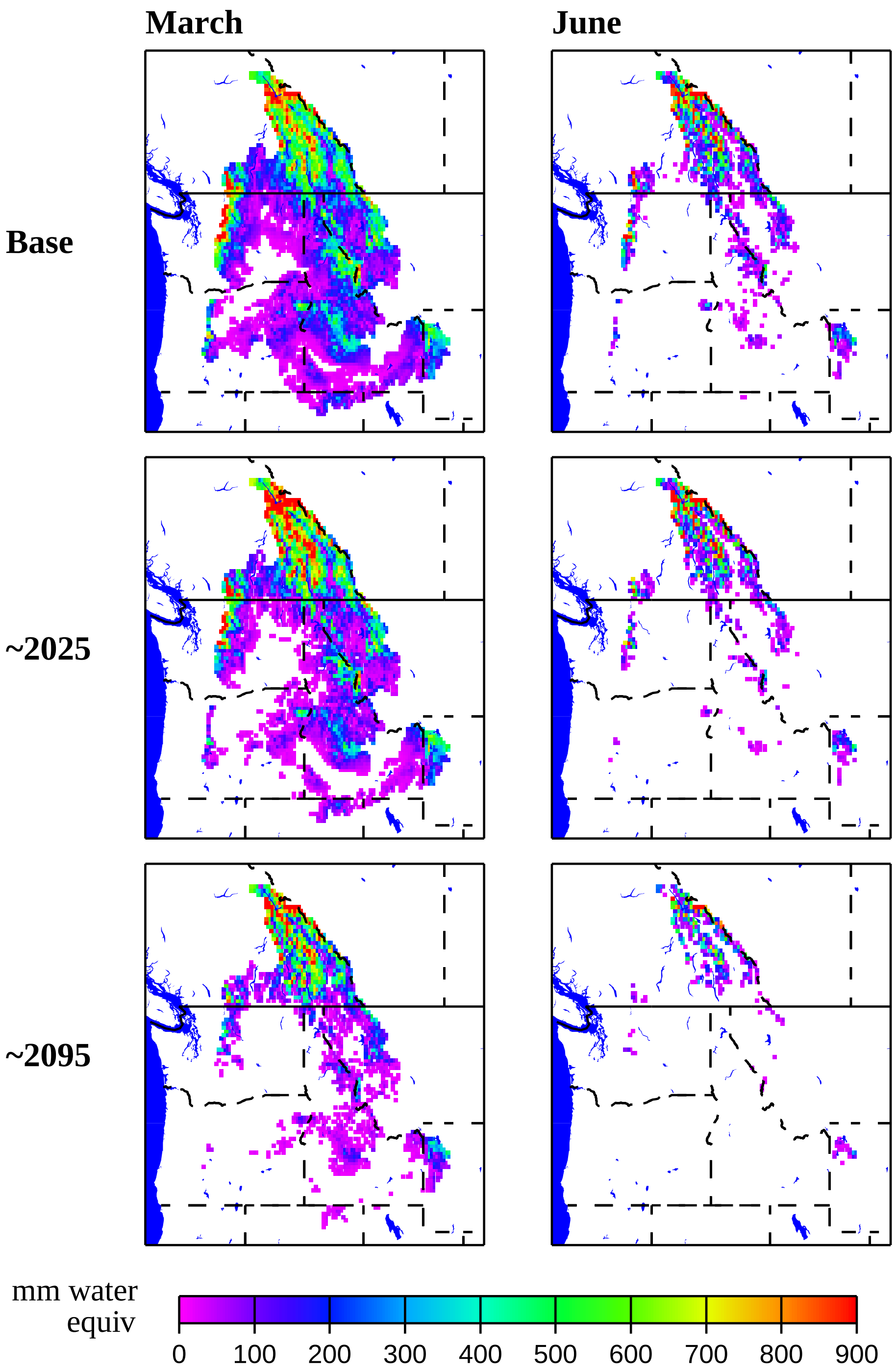
Each 2 C (3.5 F) of warming causes snowline to rise by 300 m (1000 ft)...2500´ (2000) → 5500´ (2100).

Predicted snowpack reduction >50% by 2050.

Impacts:
- **Summer water**
- **Forests**
- **Salmon**
- **Skiing**



So what are we to do...

- Precaution suggests that we try to stabilize climate before enormous changes occur.
- Internationally, greenhouse warming is recognized as a serious problem.
- Kyoto protocol is a good start, but US Congress has refused to ratify or support attempts to implement an energy policy that might significantly curb greenhouse emissions.
- Elect and support leaders and organizations who will provide vision.