

Global Warming: Science, Projections and Uncertainties

An overview of the basic science

1. A Brief History of "Global Warming"
2. Climate Change: 1850-2007
3. Projections of Climate Change: 2100 and beyond
4. What's new in Climate Science?
5. Conclusions

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Greenhouse Effect: not a new problem



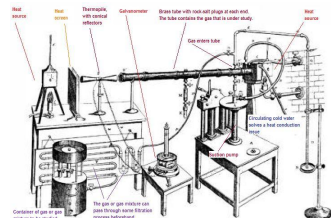
Joseph Fourier, 1827:

Recognized the earth (not the atmosphere) is mainly heated by the Sun, and gases in the atmosphere slow the heat loss to space and make the surface of the planet warmer than it would otherwise be.

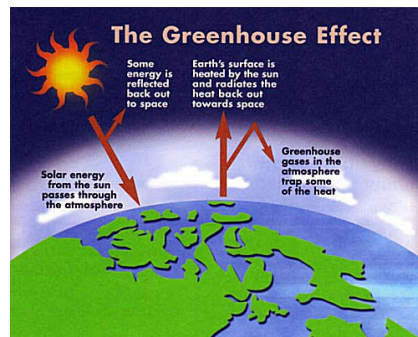


John Tyndall, 1860s:

Recognized water vapor and carbon dioxide are greenhouse gases.



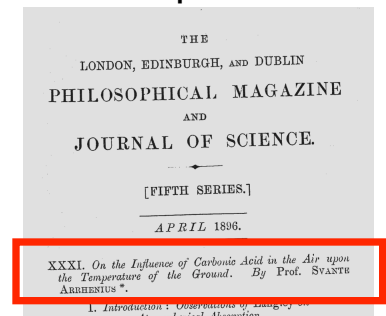
Tyndall's thermopile



Global Warming: not a new problem

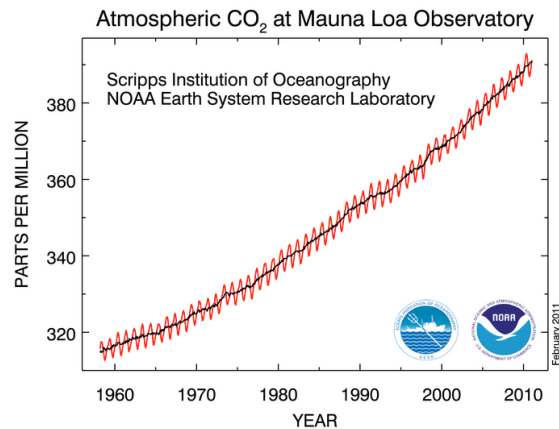


Svante Arrhenius, 1896



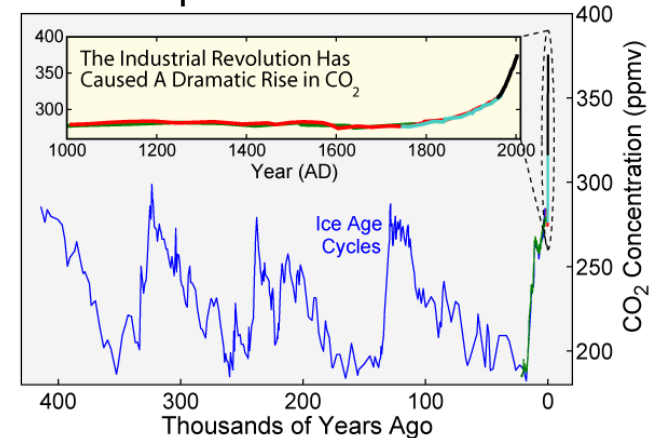
- In 1894, Hoggbon calculated the amount of carbon dioxide added to the atmosphere due to burning coal
- In 1896, Arrhenius:
 - estimated that it would take 3000 years for humans to double atmospheric carbon dioxide ✗
 - calculated that doubling atmospheric carbon dioxide would increase the global temperature by 5-6 degrees C. ✓

Atmospheric Carbon Dioxide



- Carbon Dioxide is increasing because of the burning fossil fuels (85%) and deforestation (15%)
 - 25% increase in the past 50 years; 10% increase since 1990;

Atmospheric Carbon Dioxide



- Carbon dioxide increased by 40% since 1750 because of the burning fossil fuels (75%) and deforestation (25%)
 - Fate: 40% in atmosphere, 35% in land and 25% in ocean
- The *rate of increase* is 100-1000 times faster than Nature can change CO₂

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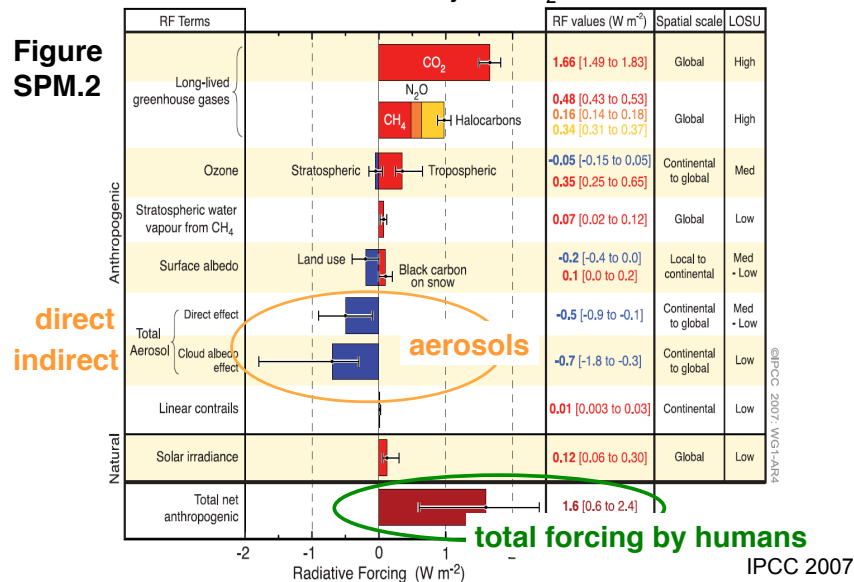
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“Radiative Forcing”

- **Radiative Forcing** (RF) is a measure of the change in the energy balance of the Earth-atmosphere system when factor(s) that affect climate are altered. (IPCC ‘07)
 - The RF is calculated instantaneously to the alteration (ie, before the atmosphere adjusts to the change)
 - Called ‘radiative’ because the process that communicates the net change in energy is electromagnetic radiation
- A positive Radiative Forcing results in a net increase in downward energy and thus will lead to a warming of the surface. Examples of RF:
 - increase in the solar luminosity
 - increase in greenhouse gas concentration
- RF allows one to assess and compare the relative importance of different natural and human-induced forcings on climate

Why has the global average temperature increased? It's more than just CO₂

Figure SPM.2



Human Forcing: summary

- Greenhouse gases:
 - carbon dioxide, methane, nitrous oxide, ozone, CFCs:
 - In the net, they cause a RF of +2.9 W/m²
 - Relationship between concentration and radiative forcing RF is well known (typical uncertainty is ≤ 10%)
 - For example, the RF of CO₂ is 1.66 +/- 0.18 W/m²
- Aerosols
 - From burning coal and biomass
 - Radiative Forcing is negative and has two contributions:
 - Direct Effect of scattering (reflecting) sunlight: RF = -0.4 +/- 0.4 W/m²
 - Indirect Effect of decreasing the size of droplets that make up clouds. The amplitude of the indirect effect is highly uncertain: -0.3 to -1.8 W/m²

Comments on Human and Natural Forcings

- Human input of GH gases (carbon dioxide, methane, nitrous oxide, ozone, CFCs) has warmed the planet:
 - net RF = +2.9 W/m²
 - The largest single warming factor is increased CO₂: RF = 1.66 W/m²
- Human input of aerosols cools the Earth
 - Aerosol RF = -1.3 [-0.3 to -2.5 W/m²]
 - This cooling is localized to nearby the source region
- The net forcing of the climate system due to human activities is positive (a warming):
 - net RF = +1.6 [+0.6 to +2.4 W/m²] = +2.9 - 1.3
- Hence, the 20th Century warming would have been much greater without human caused aerosols
- The time scale to get back to pre-industrial forcing is determined by the time it takes for nature to remove the dominant human forcing agent, CO₂ - about 10,000 years.