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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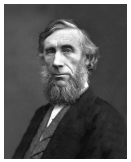
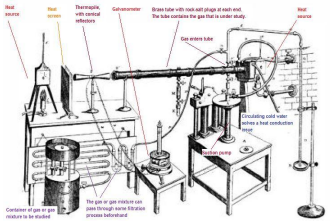
Greenhouse Effect: not a new problem

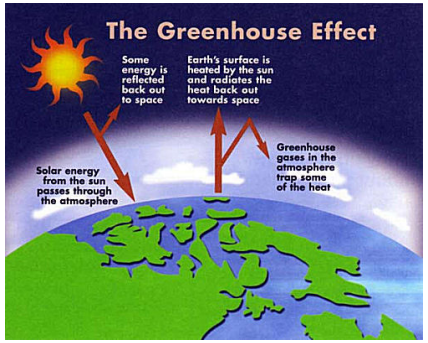
Joseph Fourier, 1827:
Recognized the earth (not the atmosphere) Is mainly heated by the Sun, and gases in the atmosphere slow the heat loss to space and make the surface of the planet warmer than it would otherwise be.



John Tyndall, 1860s:
Recognized water vapor and carbon dioxide are greenhouse gases.

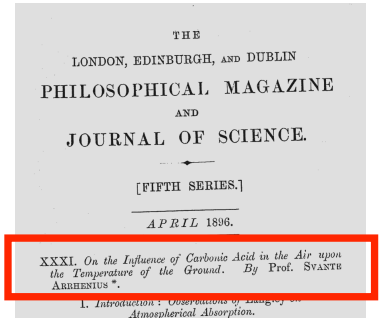


Tyndall's thermopile



Global Warming: not a new problem

Svante Arrhenius,1896



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

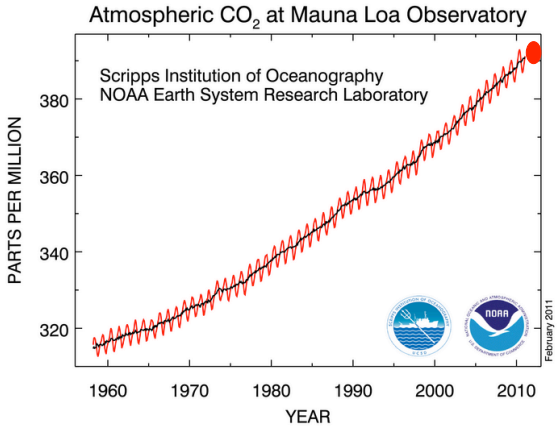
APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

1. *Introduction: Observations of Langley on Atmospherical Absorption.*

- In 1894, Hogbom 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.* ✔

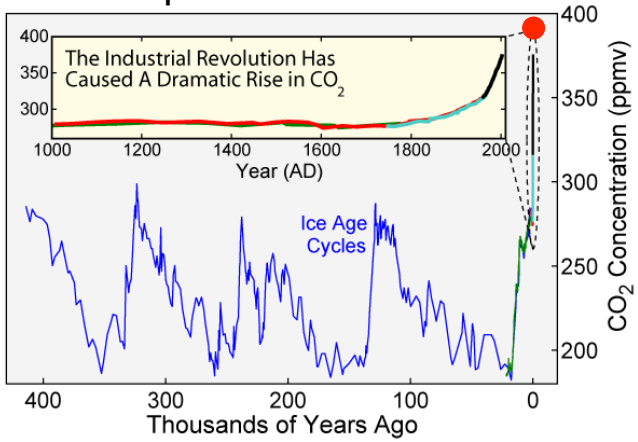
Atmospheric Carbon Dioxide



•Carbon Dioxide is increasing today because of the burning fossil fuels (85%) and deforestation (15%)

– 25% increase in the past 50 years; 10% increase since 1991;

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 CO_2

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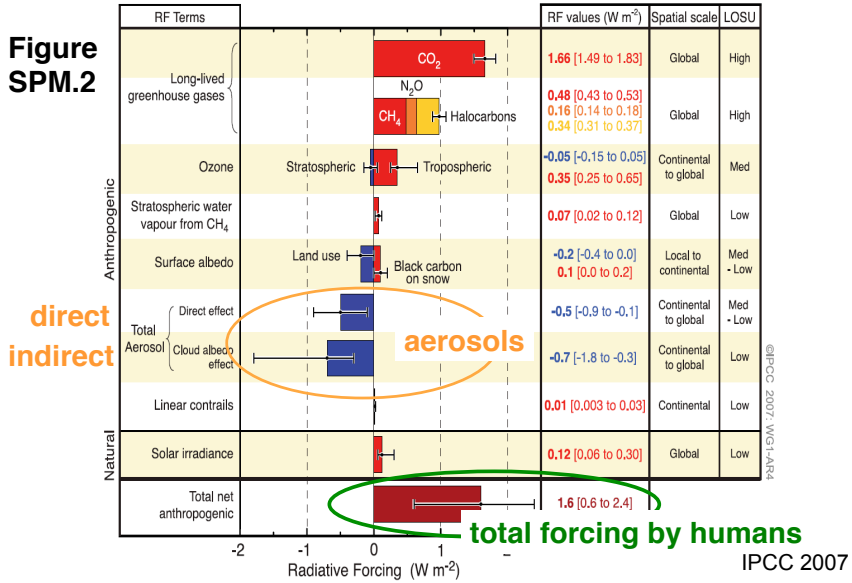
"Radiative Forcing"

- ***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 CO_2

Figure SPM.2



direct
indirect

aerosols

total forcing by humans

IPCC 2007

Human Forcing: summary

- Greenhouse gases:
  - carbon dioxide, methane, nitrous oxide, ozone, CFCs:
    - In the net, they cause a RF of +2.9 W/m^2
  - Relationship between gas concentration and radiative forcing RF is well known (typical uncertainty is ≤10%)
    - For example, the RF of CO_2 is 1.66 +/- 0.18 W/m^2

- 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/m^2
    - 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/m^2

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/m^2

    The largest single warming factor is increased CO_2: RF = 1.66 W/m^2

- Human input of aerosols cools the Earth
  - Aerosol RF = -1.3 [-0.3 to -2.5 W/m^2]
  - This cooling is localized to nearby the source region

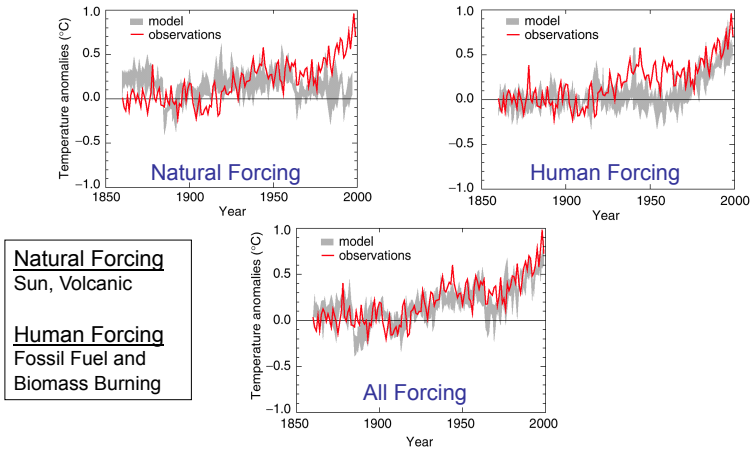
- The *net* forcing of the climate system due to human activities is positive (a warming):
  - *net* RF = +1.6 [+0.6 to +2.4 W/m^2] = +2.9 – 1.3

- 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, CO_2 - about 10,000 years.

Climate Variability and Climate Change

Modeled and Observed Temperature Change 1850-2000

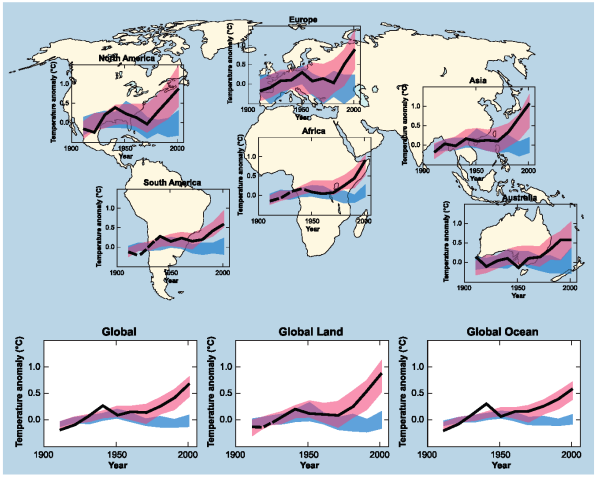


Natural Forcing
Sun, Volcanic

Human Forcing
Fossil Fuel and Biomass Burning

The trend in global temperature is consistent with what is expected due to human forcing (mainly increasing of CO_2) and too small to be explained by natural forcing or natural variability

Modeled and Observed Temperature Change 1900-2000



IPCC 2007

observations

Models using only natural forcings (Solar and volcanic)

Models using natural & human forcings (GH gases, aerosols)

What models tell us about the 20th Century temperature trends

- The trend in global temperature is consistent with what is expected due to human forcing (mainly increasing of CO_2) and too small to be explained by natural forcing or natural variability
- Other observed trends identified that agree with the response of the models to human forcing:
  - Nighttime temperature is increasing faster than daytime temperature
  - Land is warming faster than ocean
- In the 1950s-1980s: greenhouse warming partially offset by human aerosol loading over land and three large volcanoes

Climate changes (1900 to 2000) due to human activity

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]

We know this by using models

Virtually certain > 99%

Very likely >90%

Likely >66%

More likely than not > 50%

Probability "based on quantitative analysis or an elicitation of the expert views"

IPCC 2007

IPCC Conclusions on *observed* Climate Changes:

- Intergovernmental Panel on Climate Change (IPCC)
  - Major reports in 1990, 1996, 2001, 2007 that summarize thousands of peer-reviewed scientific papers
  - A consensus report with contributions from more than 1000 scientists
- Greenhouse gases (carbon dioxide, methane, nitrous oxide) have been increasing since 1750 because of human activity.
- The Earth has warmed by 0.85 ± 0. 2°C since 1900.
- The IPCC concludes:
  - "The balance of evidence suggests a discernible human influence on global climate" (1996)
  - "Most of the observed warming over the past 50 years is likely to have been due to the increase in greenhouse gas concentrations." (2001)
  - "Most of the observed increase in global average temperature since the mid-20th century is very likely [>90% chance] due to the observed increase in anthropogenic greenhouse gas emissions" (2007)
  - Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns" (2007)

3. Projections of Climate Change: 2100 and beyond

- The projected forcings
- The projected climate change: 2000 to 2100
  - Global
  - Regional
  - Sea Level
  - Cryosphere
  - Extreme Events
- The long term outlook 2100 - 2300

Projections taken from the most recent consensus report from Intergovernmental Panel on Climate Change.

- Focus on those changes that are "very likely" (i.e., those that are either deemed to have a greater than 90% chance to occur "based on quantitative analysis or an elicitation of the expert views")

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How much Carbon Dioxide will be released into the atmosphere?

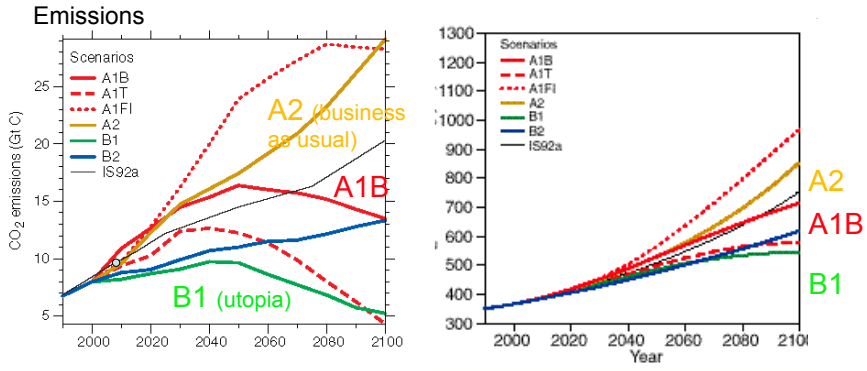
The Emission Scenarios

- **The A2 storyline and scenario family** describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
- **The A1 storyline and scenario family**: very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.
  - fossil intensive (A1FI), non fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source)
- **The B2 storyline and scenario family**: emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Emission scenarios provided by economists, policy makers, etc.

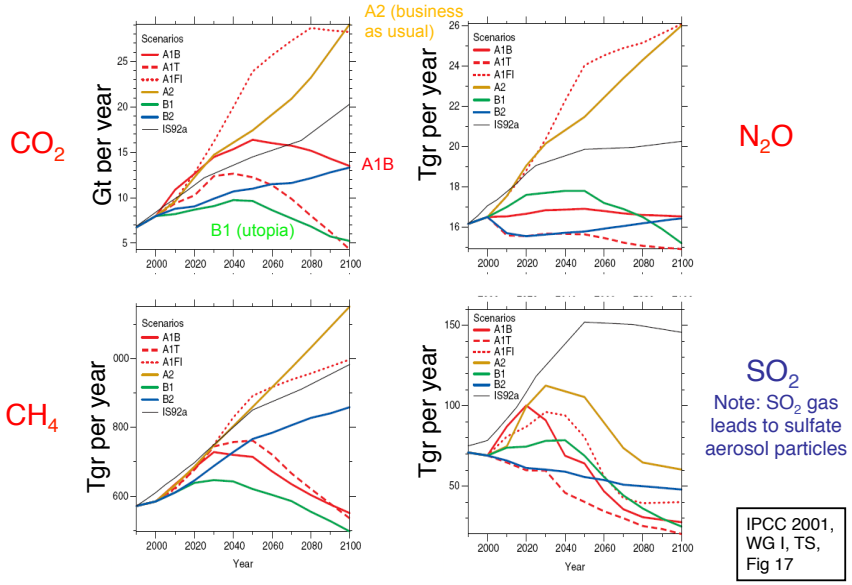
How much Carbon Dioxide will be released into the atmosphere?

Emissions



Estimates depends on population and economic projections, future choices for energy, governance/policy options in development (e.g., regional vs. global governance)

How much GH gas will be released into the atmosphere?



IPCC 2001, WG I, TS, Fig 17

How much CO_2 *do you* think will in the atmosphere?

- … in 2100 if global emissions stayed the same as today (no population increase or development)
  - Information needed (rounded):
  - Current world-wide emissions 10Gt carbon/yr
  - About 60% of the CO_2 remains in the atmosphere (the rest goes into the ocean and land)
  - There is 835Gt of carbon in the atmosphere today (394ppm)