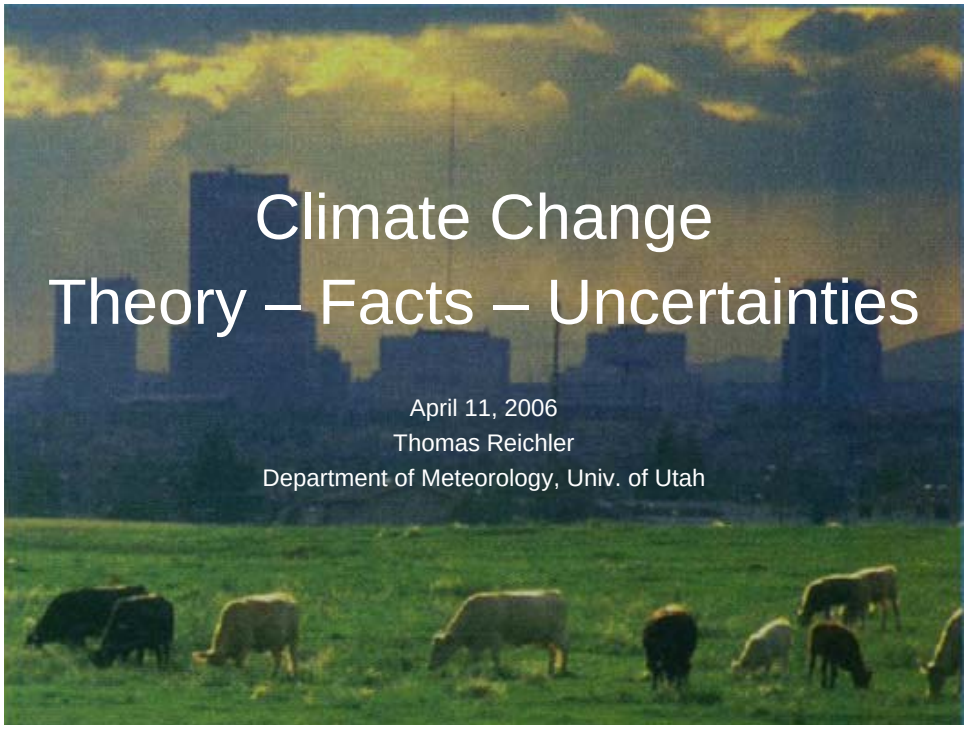


Climate Change
Theory – Facts – Uncertainties

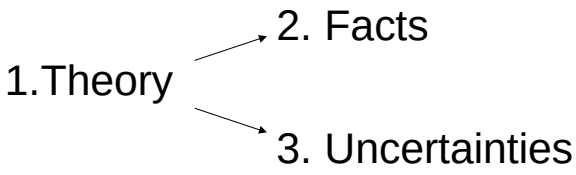
April 11, 2006
Thomas Reichler
Department of Meteorology, Univ. of Utah

Climate Change - A Tragedy of the Commons

- Garret Hardin (1968, 1998): “The tragedy of the commons”

  - Commons: A plot of land open for common usage.
  - Problem: Unrestricted access to a commons leads to over-exploitation and brings ruin to all.
  - Solution: Commons needs to be managed to make its use sustainable.
- Climate Change:
  - Air-pollution threatens the “atmospheric commons”.
  - The risk has a global reach and requires global solutions.
  - Atmosphere cannot be closed like a pasture of land.

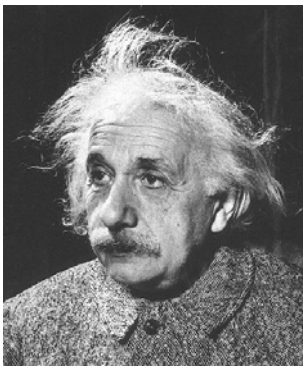
Outline



1. Theory

Scientific Theories

- Scientific theories are:
  - Testable and falsifiable hypotheses that have survived extensive testing and repeated verification.
  - The best substantiated statements that scientists can make to explain the natural world.



- Theory means almost the opposite of its colloquial use:
  - Many non-scientists think a theory is just a believe.
  - This often leads to the miss-understanding of the real meaning of scientific theories.

The Theory of Global Warming

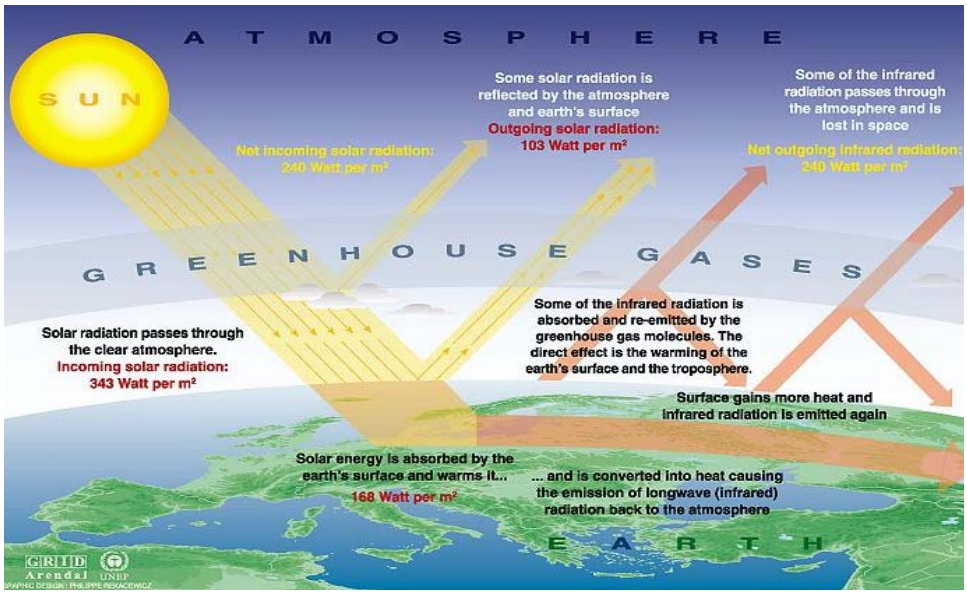
Svante Arrhenius (1859-1927)

- Nobel price in Chemistry: 1903.
- First to understand the importance of CO_2 for climate (1896).
- Realized that CO_2 was increasing and predicted that doubling of CO_2 would make Earth several degrees warmer.

The "greenhouse" effect

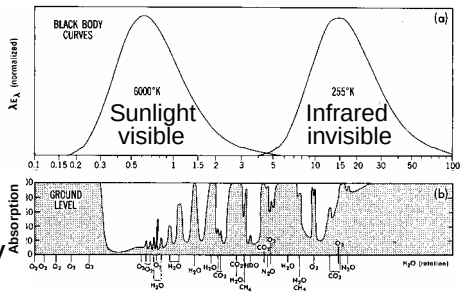
- A welcome natural phenomenon – without it the surface of the Earth would be 60°F colder.
- Its anthropogenic amplification is called global warming.
- The consequence is climate change.
- Most important greenhouse gases: H_2O, then CO_2.

The Natural Greenhouse Effect



Underlying Physics

- The underlying physical principles for the atmospheric greenhouse effect are well understood.
- The atomic structure of gases determines which part of the electromagnetic spectrum they absorb.



- Tri-atomic gases (H_2O, CO_2, O_3, N_2O …) are good absorbers for infrared radiation (longwave), but they are almost invisible for sunlight (shortwave).
- The atmosphere is almost transparent to visible sunlight but it absorbs most of the invisible infrared radiation emitted by the Earth.

Questions

- Are we confident that the atmospheric greenhouse effect is not just a wild hypothesis?
  - YES: Even the skeptics accept this!
- Can we already feel the effects of global warming?
  - YES: The overwhelming majority of climate scientists agrees on this.
- Is climate change a serious risk?
  - YES: Climate change is the most pressing environmental issue of our time. There are still many unknowns, but thousands of scientists work on better understanding this problem.

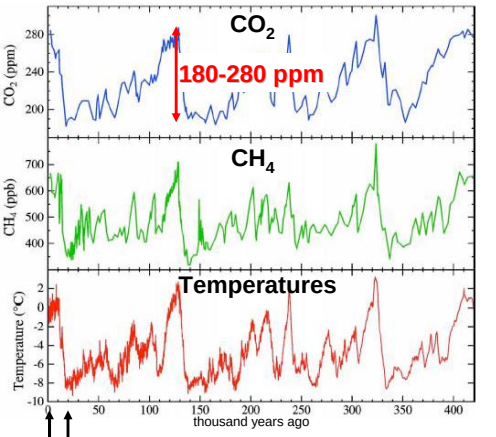
2. Facts

Some well observed changes

CO_2 Over the Last 400,000 Years

April 2006, 385 ppm

- Atmospheric CO_2 concentrations of the past can be measured very precisely from tiny air bubbles enclosed in ice cores.
- The CO_2 concentrations follow the glacial cycles.
- During the last 400k years, the partial pressure of CO_2 lies within the range of 180 and 280 ppm.



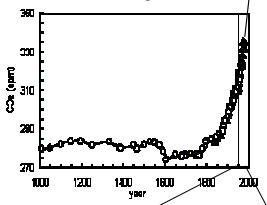
Last glacial maximum, 20,000 years ago

Today

The Rise in Carbon Dioxide

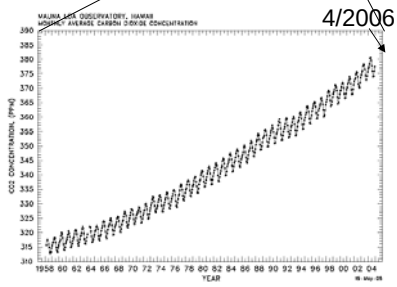
- The last 1000 years:

today

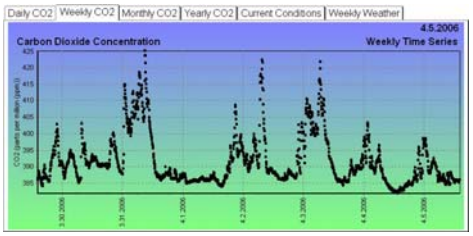


- The last 50 years:

4/2006



- The last week (Salt Lake):



- April 2006: CO_2 has reached a new record high of 385 ppm.
- CO_2 is rising rapidly (ca. 2 ppm/yr) (http://www.cmdl.noaa.gov/ccgg/trends/).

CO_2 “highest for 650,000 years”

- BBC: November 24, 2005

BBC NEWS

Last Updated: Thursday, 24 November 2005, 19:40 GMT

CO2 'highest for 650,000 years'

By Richard Black
Environment Correspondent, BBC News website

Current levels of the greenhouse gases carbon dioxide and methane in the atmosphere are higher now than at any time in the past 650,000 years.

That is the conclusion of new European studies looking at ice taken from 3km below the surface of Antarctica.

The scientists say their research shows present day warming to be exceptional.

Other research, also published in the journal Science, suggests that sea levels may be rising twice as fast now as in previous centuries.

Treasure dome

The evidence on atmospheric concentrations comes from an Antarctic region called Dome Concordia (Dome C).

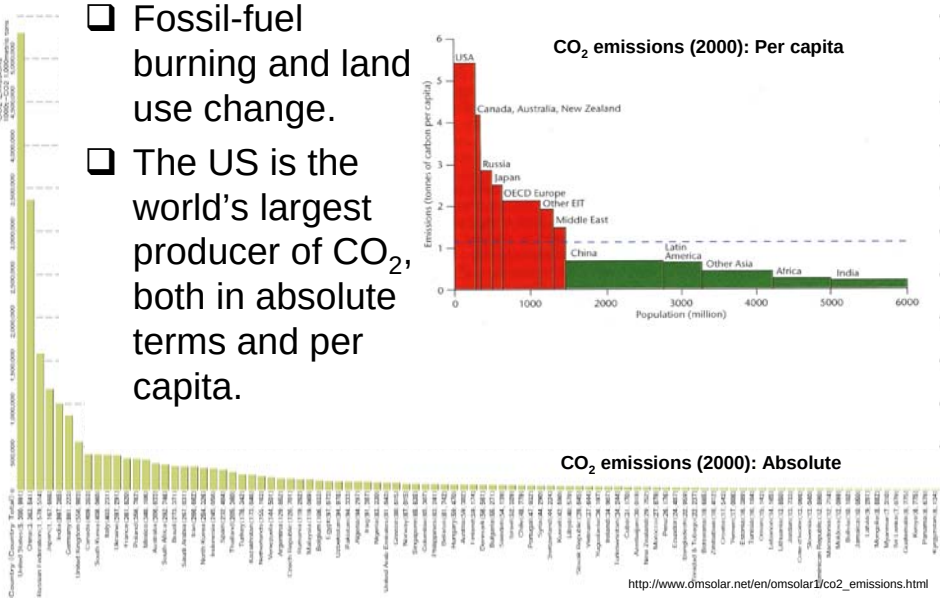
Over a five year period commencing in 1999, scientists working with the European Project for Ice Coring in Antarctica (Epica) have drilled 3,270m into the Dome C ice, which equates to drilling nearly 900,000 years back in time.

Gas bubbles trapped as the ice formed yield important evidence of the mixture of gases present in the atmosphere at that time, and of temperature.

"One of the most important things is we can put current levels of carbon dioxide and methane into a long-term context," said project leader Thomas Stocker from the University of Bern, Switzerland.

Where Does it Come From?

- Fossil-fuel burning and land use change.
- The US is the world’s largest producer of CO_2, both in absolute terms and per capita.

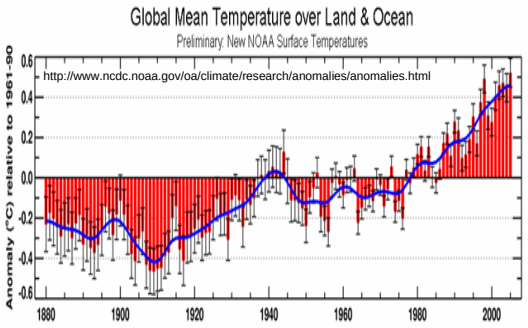


CO_2 emissions (2000): Per capita

CO_2 emissions (2000): Absolute

http://www.omsolar.net/en/omsolar1/co2_emissions.html

Observed Global Temperatures

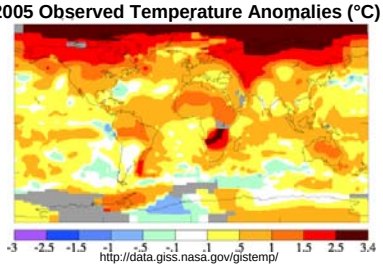


- Earth's average global surface temperature has risen by 0.8°C over the past 100 years (GISS-NASA).
- ¾ of that warming occurred since the 1970s.
- 9 of 10 warmest years on record were since 1995.
- 2005 was the warmest year on record after 1998 (which was an El Nino year) (GISS-NASA).

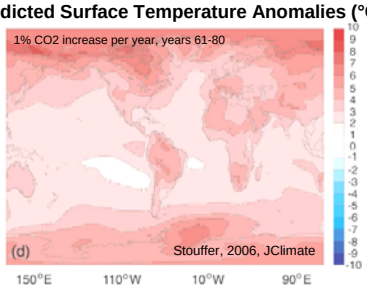
The Geographical Warming Pattern

- The recent warming trend is amplified over the high latitudes.
- This pattern of polar amplification agrees well with our theoretical understanding of global warming (ice-albedo feedback).
- It also corresponds well with climate model predictions of future warming.

2005 Observed Temperature Anomalies (°C)

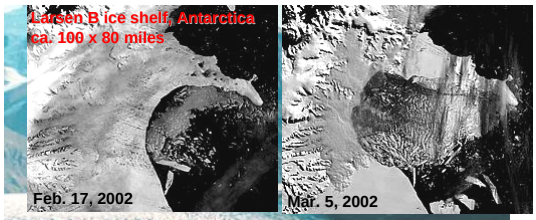


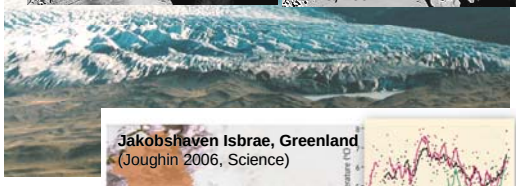
Predicted Surface Temperature Anomalies (°C)

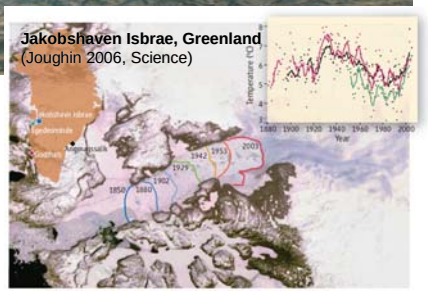


Trend of Less Ice

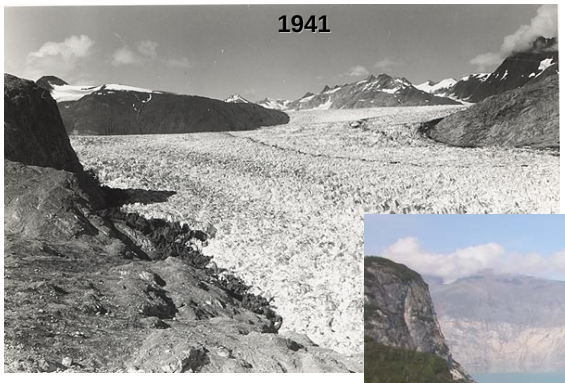
- Many ice bodies from the poles to the tropics are in retreat.
- This is the most vivid evidence for global warming.
- Sea-level rise from melting of ice is one of the largest potential threats of global warming.
- Polar warming in 2100 may reach levels of 130,000 years ago, when sea levels were several meters above today.







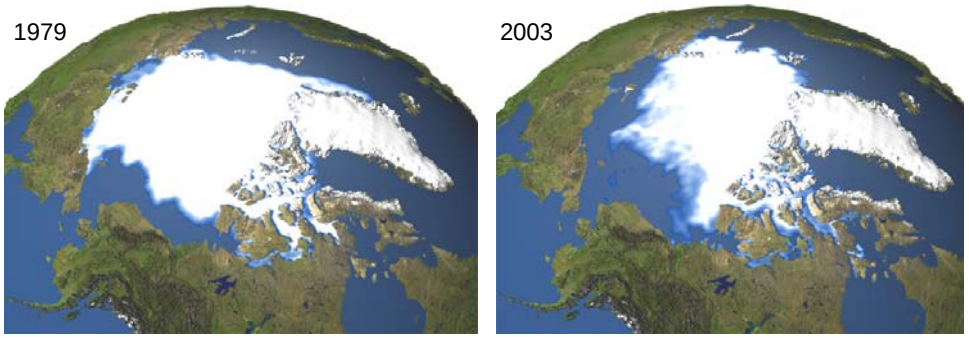
Muir Inlet, Alaska



Glacier Bay National Park and Preserve

National Snow and Ice data center
http://nsidc.org/cgi-bin/gpd_run_pairs.pl

Arctic Polar Ice Cap



http://www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html

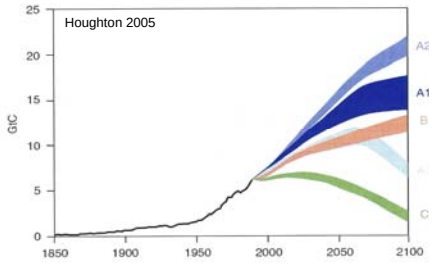
- Since 1979, the size of the summer polar ice cap has shrunk more than 20 percent.
- On Sept. 21, 2005, sea ice extent dropped to 2.05 million sq. miles, the lowest extent yet recorded in the satellite record.
- This loss is twice the size of Texas.

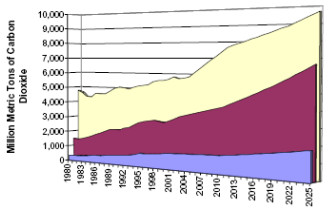
3. Uncertainties

"The climate is a beautiful system,
exceedingly rich in interconnections and complexities."
(A. H. Oort, 1986)

Future Emissions

- Predictions of future emission levels are important inputs for climate model predictions.
- Scenarios (Intergovernmental Panel on Climate Change):
  - A and B: Various business as usual assumptions.
  - C: Ecologically-driven scenario (stabilization at 500 ppm).

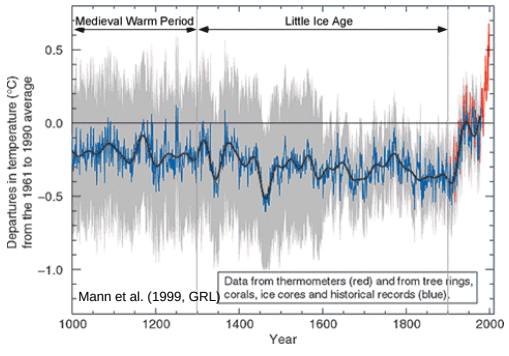




- Current emissions: 7 billions tons carbon/year. Rising rapidly
- CO_2 remains in the atmosphere for decades.

The "Hockey Stick" Curve

- Paleoclimatologists use proxy data (tree rings, corals, ice cores) to reconstruct past temperature records.
- The resulting "hockey stick" temperature curve shows an abrupt, presumably human induced warming over the last century.



- This curve is subject of intense debate.
- However, other scientists have already provided independent support for temperature trends resembling this curve.

Climate “Warmest for Millenium”

- Osborn et al. (2006, Science):

BBC NEWS

Climate 'warmest for millennium'

By Paul Rincon
BBC News science reporter

In the late 20th Century, the northern hemisphere experienced its most widespread warmth for 1,200 years, according to the journal Science.

The findings support evidence pointing to unprecedented recent warming of the climate linked to greenhouse emissions.

University of East Anglia researchers measured changes in fossil shells, tree rings, ice cores and other past temperature records or "proxies".

They also looked at people's diaries from the last 750 years.

“The last 100 years is more striking than either the Medieval Warm Period or Little Ice Age”

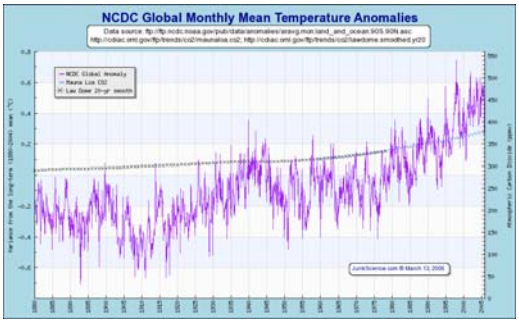
Timothy Osborn, UEA

Timothy Osborn and Keith Briffa of UEA analysed instrument measurements of temperature from 1856 onwards to establish the geographic extent of recent warming.

Then they compared this data with evidence dating back as

Detection Problem

- Because of instabilities, the climate system exhibits large natural variability (noise).
- Given the large amount of natural variability, it is difficult to detect the relatively small climate change signal.



- This situation will improve as the signal gets stronger and the record gets longer.
- However, the overwhelming majority of scientists agree that the Earth is getting warmer and that humans are the cause.
- But we cannot entirely exclude that some of the past warming would have occurred anyway because of natural factors.

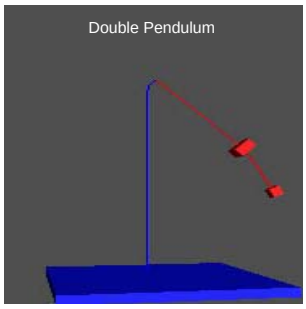
Instability of the System

- Instability is a natural property of the climate system.
- Those instabilities may lead to surprise responses and irreversible impacts.

stable

unstable

new equilibrium

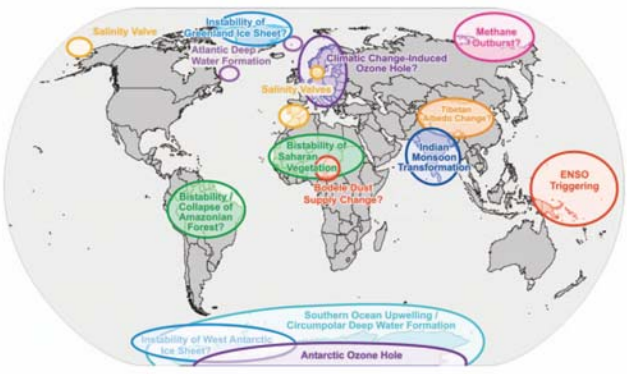


- Glacial cycles indicate the existence of multiple equilibria.
- It has been hypothesized that global warming may lead to a disturbance of the thermohaline circulation.

Thermohaline ocean circulation

Global Tipping Points

- Climate-change threats are divers and occur worldwide.
- Some believe that there are regions where the balance of a particular system has already reached the critical point.
- Think of flipping a light switch.

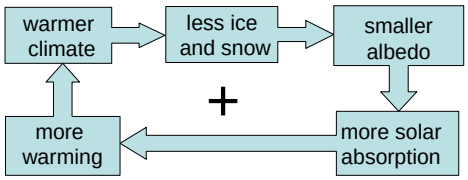


(after: H. J. Schellnhuber, Nature V. 437, 2005)

Feedbacks

- A perturbation of the climate may induce new changes.
- Those changes may in turn significantly affect the overall response. This is called feedback.

- **Ice-Albedo feedback**



- Feedbacks can be positive or negative by increasing or decreasing the magnitude of the original response.
- Most known feedbacks are positive.
- Most feedbacks are poorly understood.
- Many feedbacks are not yet discovered!

Climate Sensitivity

- A fundamental question of climate sciences is how sensitive is the climate system to external perturbations.
- This question is often stated as: “By how much do global temperatures increase if we double CO_2?”
- Scientists use complex mathematical representations of climate (climate models) to answer this question.
- The range of answers lies between 3 and 11°F, with the most likely at 6°F.
- The uncertainty is so large because of unknown feedbacks, e.g. due to the presence of clouds.
- Additional uncertainty: Cooling effect by aerosols.

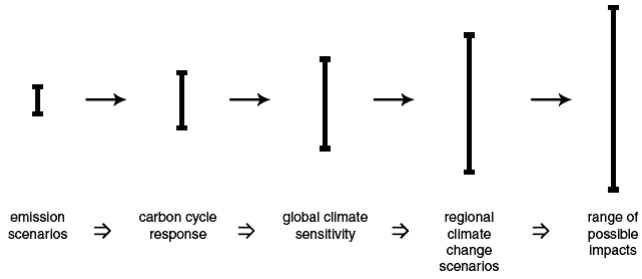
How much is 8°F?

- 8°F equals the difference between Portland and LA.
- This is only a global mean. Warming will be larger over land, high latitudes, during winter, and during extreme events.
- The expected increase in temperatures (= global warming) will lead to many additional changes (= climate change), e.g.:
  - Melt of ice sheets.
  - Thermal ocean expansion.
  - Increased intensity of the hydrological cycle.
  - Increasing number of extreme weather events.

Central Europe, April 2006: Second record flood after 2002

- The adaptation of societies to such changes will be costly, and in many cases impossible (poor nations, sea level rise).

"Explosion" of Uncertainties



Schellnhuber (2006): Avoiding dangerous climate change

- If different elements of uncertainty are combined, 'explosion' may occur.
- This does not mean that scientists cannot assign a high degree of confidence to *any* of their projected climate change impacts.
- Rather, the scope of possible consequences is quite wide.

Conclusion

Global Warming Skeptics

- Skeptics belong to a very small minority.
- Most skeptics are not leading climate change researchers.
- General strategy:
  - Denial of any scientific evidence for rapid climate change due to human activity.
  - Impacts of climate change will be small. ‘Wait and see’ strategy. ‘Fix’ the problem later.
- Strong interest groups (energy, car) spent much money in spreading their view about climate change:
  - Pat Michaels (U. Virginia, Cato Institute): Funding from the coal and energy industry. *World Climate Review* was funded by Western Fuels.
  - Fred Singer (George Mason): Support from the German coal mining industry and by oil industries (Exxon, Shell).

Teach The Controversy …

http://www.doonesbury.com/strip/dailydose/index.html?uc_full_date=20060305

… if only it were just a joke.

Saving the Commons

- Montreal (1987): To reduce O_3 depleting CFCs.
  - First successful international attempt to resolve a global environmental issue through cooperative agreement.
- Kyoto (1997): To reduce greenhouse gas emissions.
  - Harder to fulfill than Montreal.
  - Signed by ~180 countries, including the US.
  - The US pulled out in 2001.

The End