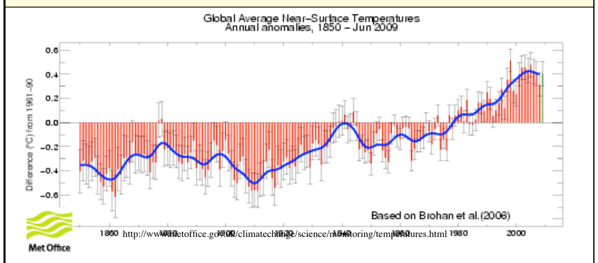
Summary

- Complexity of climate models
- Atmosphere composition (GHG) plays major role in determining climate
- Life plays a major role in the cycling of GHG
- Contemporary increases in anthropogenic GHG and global temperature are well established
- What is the evidence that there are causally related?



http://www.metoffice.gov.uk/climatechange/science/monitoring/temperatures.html

-Anomalies allow comparison to a "reference" temperature
-90% confidence ranges reflect certainty of estimate
-Running mean (solid line) emphasizes the long-term trend

Temperature and CO_2 co-vary over contemporary time scales. Does this imply a cause-effect relationship?

What is the evidence that increasing CO_2 is causing the temperature increase? What other factors affect global temperature?

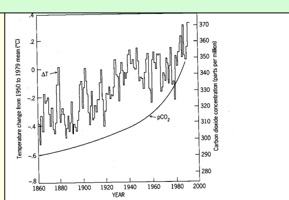


FIGURE 25.15. Changes in atmospheric temperature and carbon dioxide concentrations (*a*) over the past 160,000 years and (*b*) over the past 130 years. *Source*: From S. H. Schneider, reprinted with permission from *Scientific American*, vol. 261, p. 74, copyright © 1989 by Scientific American, New York.

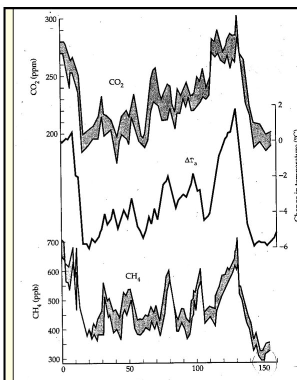


FIGURE 4 Variations in the amounts of carbon dioxide and methane, an change in atmospheric temperature (ΔT_a) over Antarctica derived from surements along a 2083-meter ice core from Vostok Station for the last 1 years. This record was reported by Chappellaz et al. (1990) and put in form shown here by Lorius et al. (1990).

Examine past climates to understand contemporary climate change (Paleoclimate Data from Vostok (Antarctica) Ice Core)

Concentrations of atmospheric CO_2 and CH_4 appear to co-vary with temperature.

But, do changes in greenhouse gases cause temperature changes or vice versa?

Are other processes implicated in global climate change?

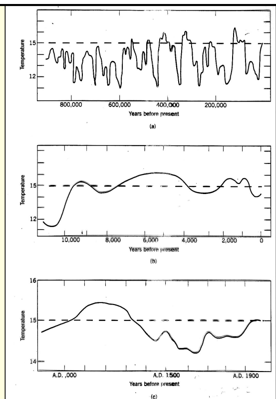
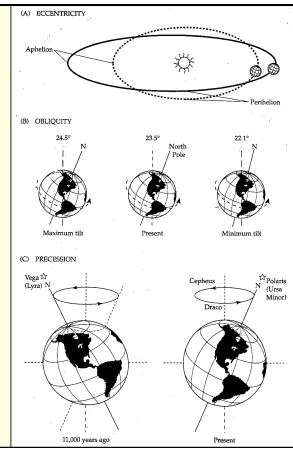


Figure 5.1 Estimated global-average surface temperature variations during: (top) past million years, (middle) past ten thousand years, and (bottom) past thousand years. The dashed line across each panel of the figure indicates the present value of 15°C.

The Earth has experienced wide changes in global average surface temperature. These are changes over the last 1 million, 10,000 and 1,000 years.

Variations in the amount of solar radiation due to changes in the Earth's orbit (Milankovitch cycles) contribute to these changes over geologic time.

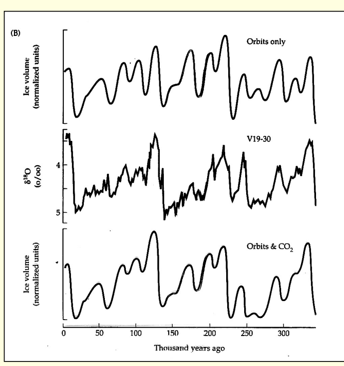


The distance between the Earth and the Sun, and the orientation of the Earth relative to the Sun vary over long-term cycles. These changes affect how much solar radiation reaches the Earth as well as the duration of the seasons.

A) The shape of the Earth's orbit around the Sun varies on a 100Ky cycle.

B) The tilt of the Earth's axis of rotation varies on a 41Ky cycle.

C) The "wooble" of the Earth's rotation varies over a 23Ky cycle.

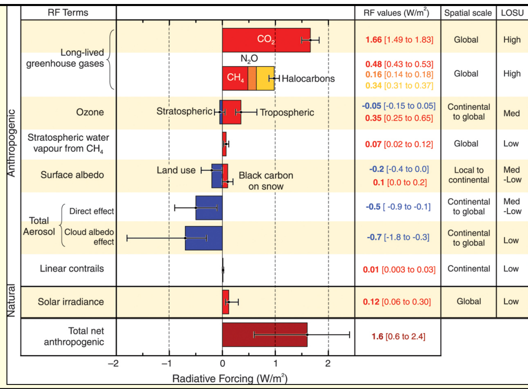


Models where both changes in solar radiation and changes in CO_2 are considered result in a better fit to the temperature trends.

What is the major factor driving contemporary global warming?

Evidence that Contemporary Global Warming is Caused by Anthropogenic GHG (CO_2 & CH_4)

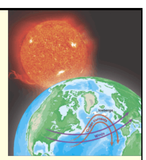
- Increase of temperature coincide with increase of anthropogenic GHG.
- Magnitude and rate of temperature increase consistent with predicted radiative forcing (change in irradiance in watts/m^2) from increased GHG concentration.
- Natural cycles such as changes in solar radiation and inter-annual climate changes (e.g. ENSO, PDO and etc.) cannot account for the observed increase in temperature.
- Large scale changes (temperature, frequency/severity of storms, glacier retreat, Arctic ice mass decrease and etc.) consistent with model predictions.
- Growing body of evidence from wide range of scientific fields and independent studies. Survey of conclusions in peer reviewed articles show consensus.



Quantification of Anthropogenic and Natural Contributions to Global Warming. Note warming (red) and cooling (blue) effects as well as the Level of Scientific Understanding (LOU) of the estimates (IPCC 2007). RF=radiative forcing (ability to restrict radiation lost to space)

Car and Driver editorial on An Inconvenient Truth

- Warming is normal consequence of being in an interglacial period.
- CO_2 from human activities is a very small contribution to the natural CO_2 cycle.
- CO_2 has a low warming effect compared to other gases (e.g. H_2O vapor).
- A climate expert questions global warming.
- Gore politics.



Oceans and Global Climate Change-B:

The C-Cycle, Fe hypothesis and Ocean Fertilization

MES Winter 2011

February 17

Dr. Gerardo Chin-Leo

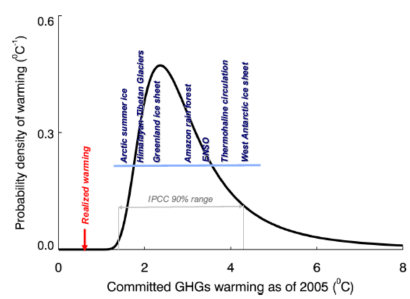
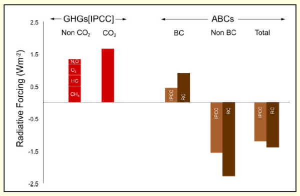


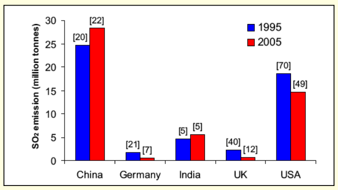
Fig. 1. Probability distribution for the committed warming by GHGs between 1750 and 2005. The normalized distribution is calculated from the probability density function given by Roe and Baker (7), and the mean and standard deviation of the uncertainties associated with feedback processes are fitted for Sanderson *et al.* (8). Shown are the climate-tipping elements and the temperature threshold range that initiates the tipping. Except those for the HKHT glaciers, the rest of the elements and the temperature thresholds are taken from ref. 6. ENSO, El Niño—Southern Oscillation.

Ranathan& Feng (2008). On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead.

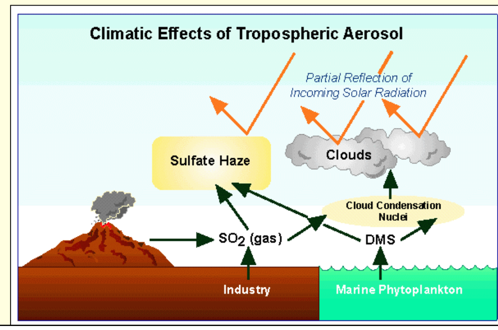


Left. Global mean radiative forcing by GHGs and anthropogenic aerosols (ABC, 2 estimates reported). BC refers to black carbon. Note the large contribution of ABC in reducing net radiative forcing

Right. Total SO_2 emission by nation. Values in brackets are the per-capita emissions (kg). OECD countries reduced SO_2 emissions. This reduction contributes to net warming by removing the cooling influence of aerosols.



S-aerosols affect climate. Fossil fuel burning is a major source. Dimethyl sulfide (DMS) is the major natural source of S (~15% of total). Biogenic DMS emissions affect global radiation balance directly through the upward scatter of solar radiation and indirectly as cloud condensation nuclei (CCN).
Source: http://saga.pmel.noaa.gov/review/dms_climate.html

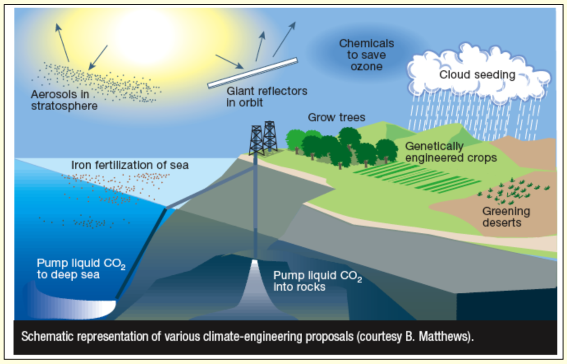


Ranathan & Feng (2008). On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. PNAS. 105(38):1425-14250

- 2005 GHG levels =committed mean temp rise of 2.4 ˚C relative to pre-industrial levels
- 25% (0.6 ˚C) of this rise has already been realized. Remaining 47% masked by cooling effect of aerosols, 8% by land-use albedo and 20% by delay in ocean warming.
- Expected temperature rise (1.4-4.3 ˚C) affects “climate-tipping” elements (e.g. Greenland ice sheet and H-T glacier melting)
- The rate at which remaining committed warming (~1.6-1.8 ˚C) will occur will be affected by the rate of removal of aerosols by pollution control
- As aerosol pollution is curbed, GHG control becomes more urgent.
- Need models that consider these complex interactions to inform policy makers of the tradeoffs involved in climate regulation strategies.

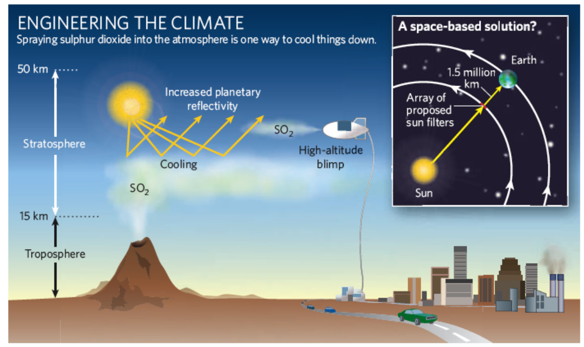
Oceans and Climate-B

- Geoengineering options
- Contemporary C-cycling, CO_2 and temperature increases
- Role of Oceans: Solubility and biological pumps
- The Case for Iron
- Fe fertilization and geo-engineering

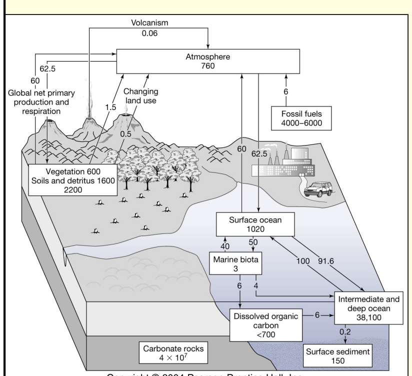


Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

From Schneider 2001



From Morton 2007



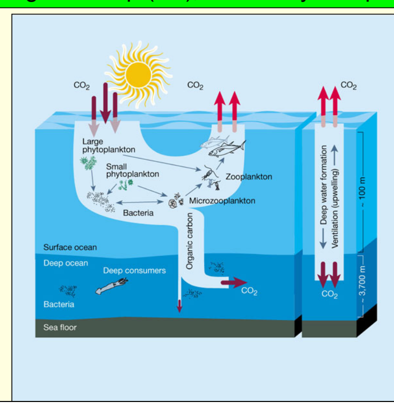
Contemporary C-cycle.

Note human inputs and role of the oceans as source/sink

Only ~50% of anthropogenic C accumulates in the atmosphere

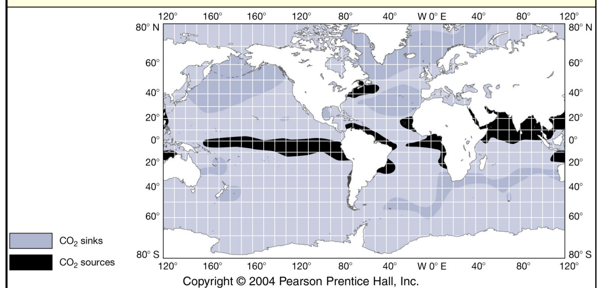
-Where is the rest?

"Biological Pump"(left), "Solubility Pump" (right)



Solubility Pump. CO_2 dissolves into water forming bicarbonate.

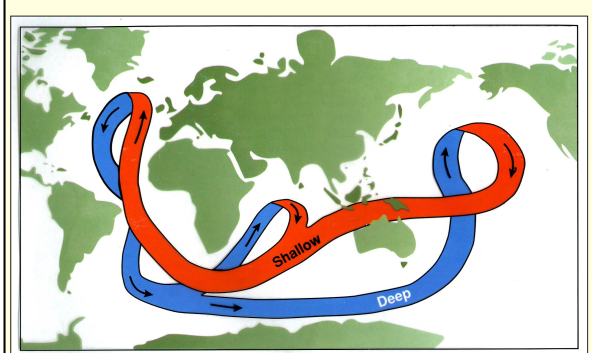
- Oceans have high capacity to buffer CO_2 because the oceanic pool is 60 X > atmosphere
- Gas transfer rates determined by differences in partial pressure at sea/air interface, temperature, wind and sea state, etc.
- Gas transfer is relatively slow and surface waters are supersaturated (>30%) over atmospheric concentrations
- High latitudes are a sink of CO_2 because low temperatures increase gas solubility
- Equatorial Pacific is a source of CO_2 because it is warmer and because of upwelling of CO_2 saturated deep sea water

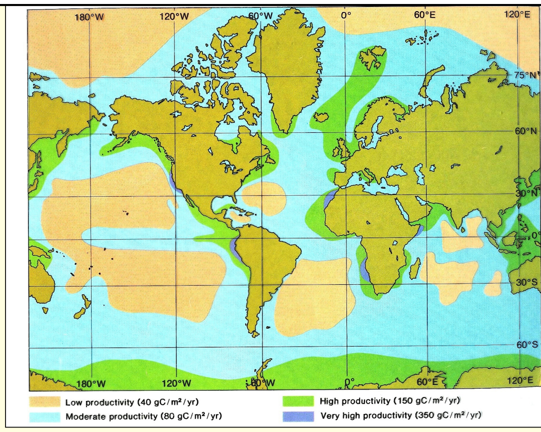


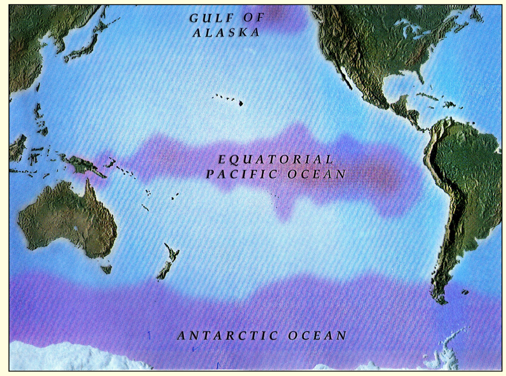
Biological Pump. Removal of atmospheric CO_2 is increased by phytoplankton uptake. Sinking of detritus and $CaCO_3$ shells transport C to the deep sea. This C is sequestered in thermohaline circulation or in marine sediments

- Efficiency of the biological pump is determined by the magnitude of phytoplankton growth (nutrient availability) and ecological factors such as species composition, grazing, decomposition and amount of sinking of organic matter.

- Thermohaline circulation removes CO_2 from the surface mixed layer for thousands of years. Further removal of C by $CaCO_3$ sediment formation can reduce the partial pressure of CO_2 in deep water thus enhancing its ability to absorb CO_2 when it resurfaces.







High Nutrient Low Chlorophyll (HNLC) Areas

Fe as a limiting micro-nutrient

- Needed for chlorophyll synthesis and synthesis of enzyme to take up nitrogen
- Source is continental erosion (water and wind) so depleted in open ocean waters that are far away from rivers or aeolian (wind) transport
- Redfield Molar Ratio for Fe is: 106C:16N:1P: 0.005Fe
- C: Fe ratio by weight = 4,625:1
- How much Fe is needed to fix 6 Gt of carbon?

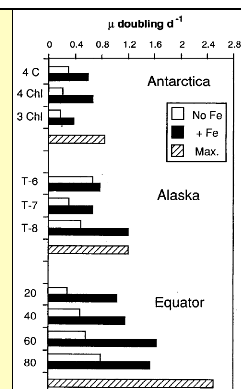
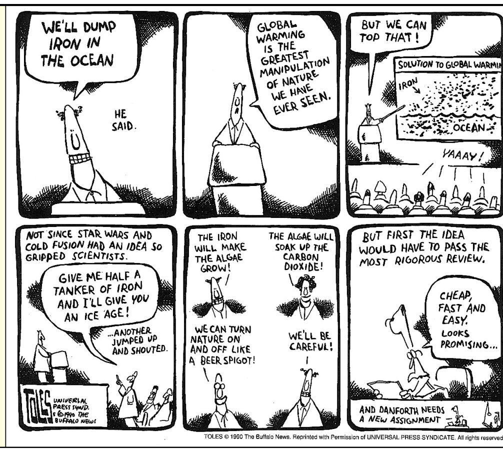


Fig. 7. A comparison of doubling rates from the Antarctic, Gulf of Alaska, and equatorial Pacific with and without added Fe (data from Table 2); theoretical maxima for various temperatures are also shown.

Fe additions result in more growth in various sites of the oceans

Some Implications of Fe-hypothesis

- Some areas of the oceans (HNLC) are growth limited by Fe not N
- Variations in Fe availability in the oceans over geological time may explain glaciations
  - More Fe-->More productivity-->More CO_2 removal--> Less Atmospheric CO_2 -->Cooler temperatures-->Glaciation-->Land covered in ice-->Less Fe



How much Fe is needed to "fix" 3 Gt of Carbon?

-Molar Redfield Ratio and Fe = 106C:16N:P:005Fe
-Convert to weight by X by mass/mole
    C= 12 g, N=14,g P=31g, Fe=56g
-Redfield Ratio by Weight = 1272C: 224N: 31P: 0.28Fe
    or 4543C: 800N: 111P: Fe
-To determine Fe needed to remove 6 X 10^9 tons of C

$$\frac{4543 \text{ tons of C}}{1 \text{ ton of Fe}} = \frac{3 \times 10^9 \text{ tons of C}}{X \text{ tons of Fe}}$$

-Solving for X = **660,357 tons of Fe**
-Assuming a Hummer is made all of Fe and weights 2,130 kg (4,700 lbs), how many would you have to sink to mitigate GW?

Possible Consequences of Fe-Fertilization

- Increased surface production may not result in increased C-pumping to the deep-sea
- Eutrophication and oxygen depletion
- Small changes in pH can affect deep-sea marine life (ocean acidification problem)
- Changes in nutrient composition may cause shifts in algal species composition
  - Harmful Algal Blooms
  - Species that do not sink make the biological pump less effective
  - Other unanticipated ecological disturbances

Science, Policy and The Precautionary Principle

"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."
Houghton - GW The Complete briefing.

"whether the uncertainties are large enough to suggest delaying policy responses is not a scientific question per se, but a value judgment."
Schneider - The GHE: Science and Policy.

TYPE I and II Errors in Decision Making

Type I error(α = alpha) – mistake made if "Act when you are sure"
Reject true Null (H_o) hypothesis (typically "no difference")
- Conclude that there is a difference when none exists
- False positive (Innocent person is convicted)
- False Alarm. Metal detector goes off when there is no gun
- **Conclude there is Global Warming when there is none**

Type II error (β = beta) – mistake made if "Better safe than sorry"
Fail to reject a false (H_o) hypothesis
- Conclude there is no difference when one exists
- False negative (Guilty person is acquitted)
- Metal detector does not go off when there is a gun
- **Conclude there is no Global Warming when there is**