Global warming

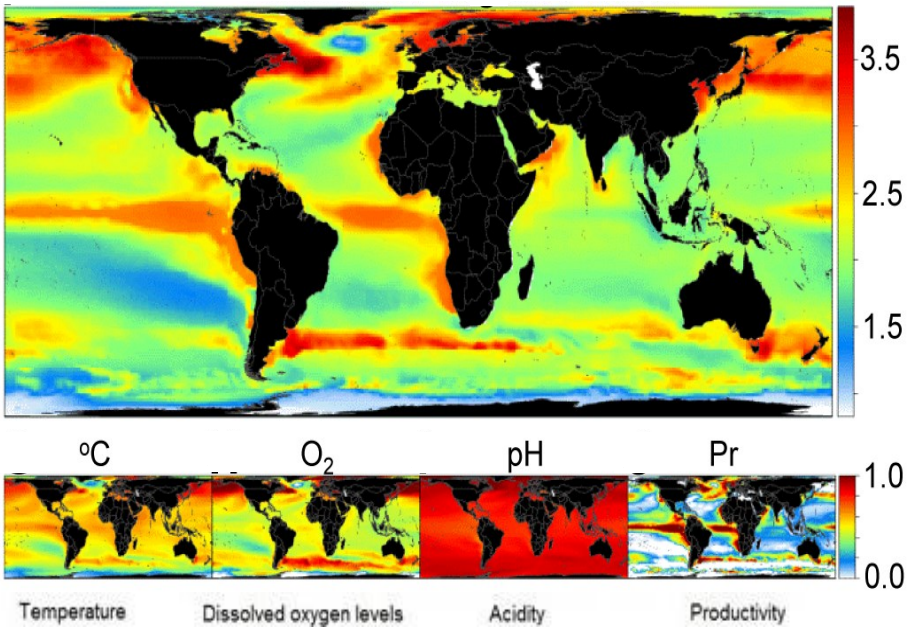
and its equally evil twin

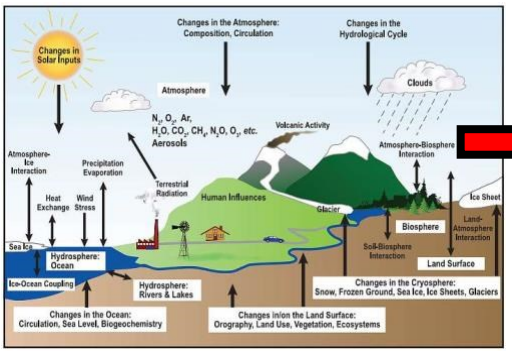
ocean acidification

Prof Roy Thompson, FRSE

(HSS conference, April 2014)

Predicted changes in the oceans





Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial \Pi}{\partial \lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial \Pi}{\partial \phi} = -\left(\frac{vw}{r}\right) + S^v$$

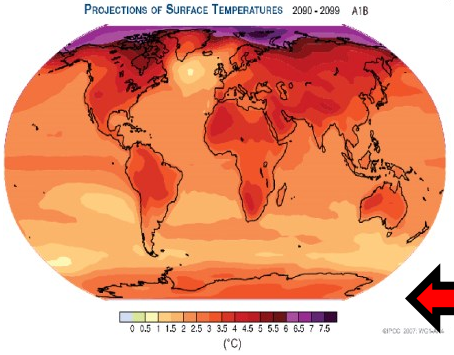
$$\frac{Dw}{Dt} + c_{pd}\theta\frac{\partial \Pi}{\partial r} + \frac{\partial \Pi}{\partial r} = \left(\frac{u^2+v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

mass continuity

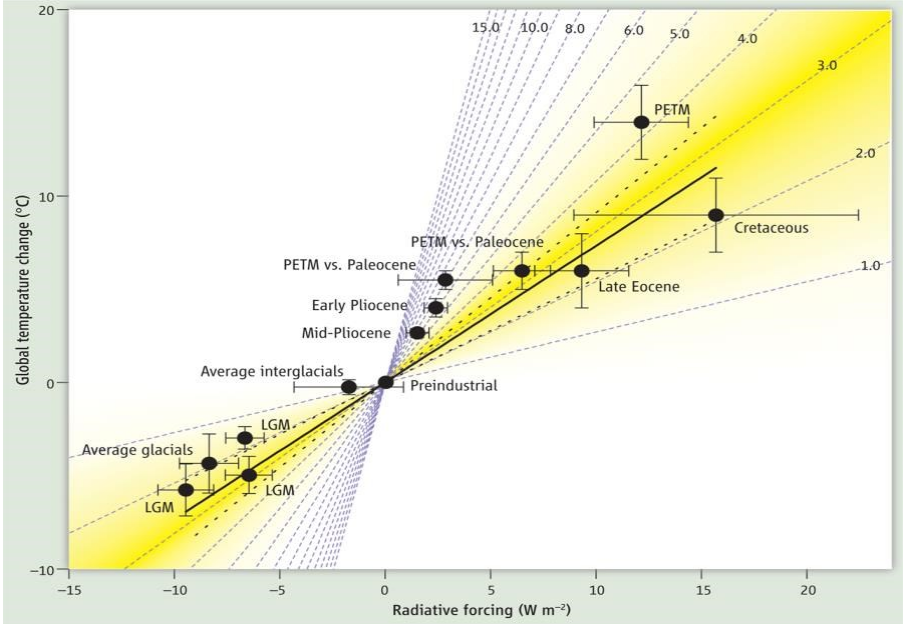
$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

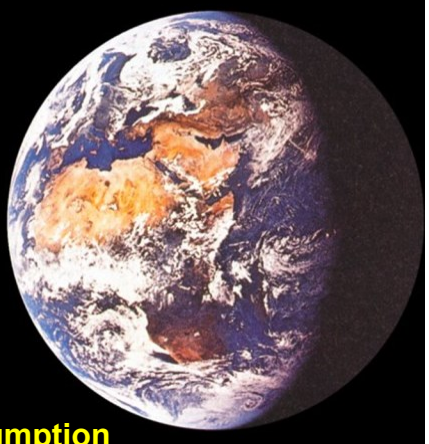


Climate Sensitivity Estimated From Earth's Climate History



Climate change

1. Common misconceptions
   (a) Weather vs. climate
   (b) The greenhouse effect
   (c) Can't organisms just move or adapt?

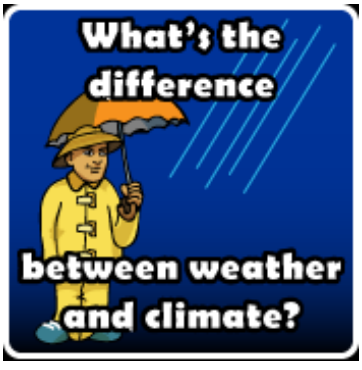


2. The geological past

3. Accelerating impacts

4. Fundamental dilemma
   - Overpopulation & overconsumption

5. The future - geology to the rescue?



Climate is what you expect.
Weather is what you get.

ELSEVIER

Journal of Hydrology 224 (1999) 169–183

Journal of Hydrology

www.elsevier.com/locate/jhydrol

A time-series analysis of the changing seasonality of precipitation in the British Isles and neighbouring areas

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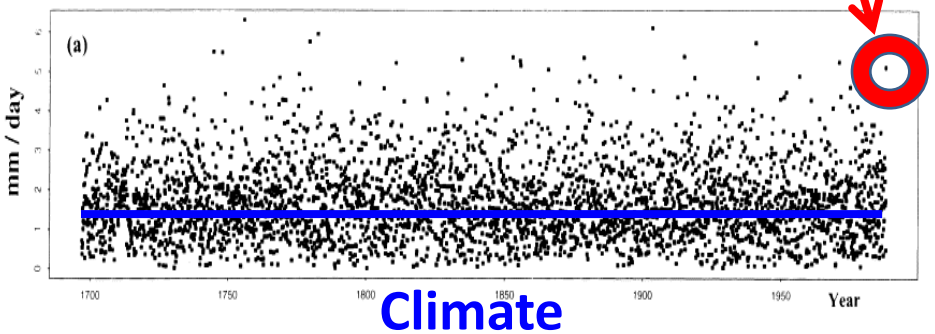
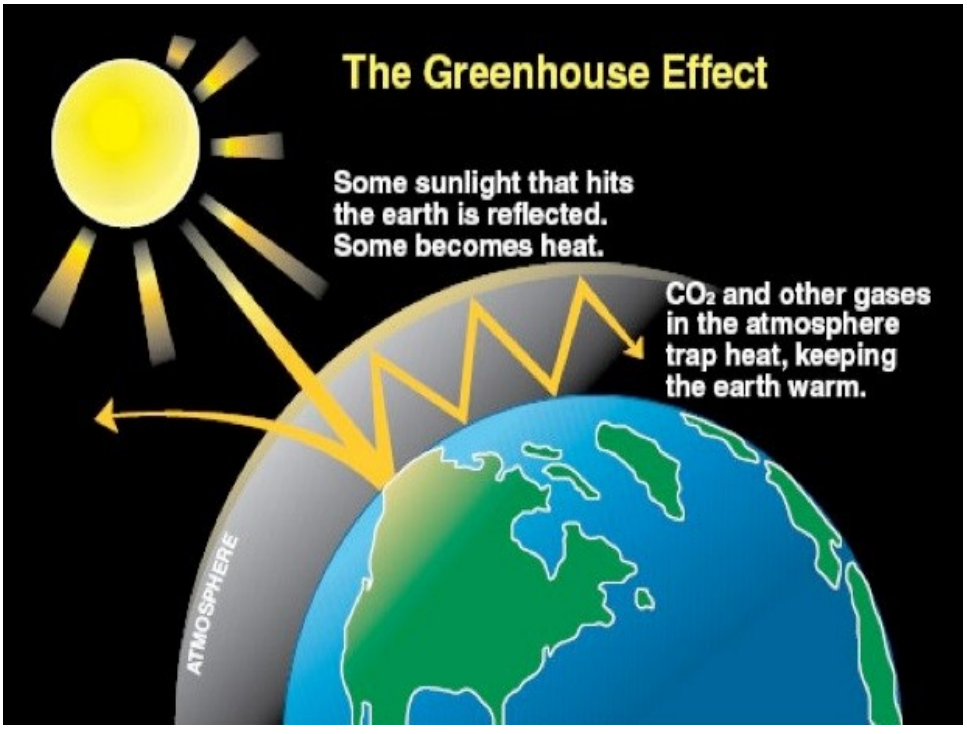
Received 2 June 1999; accepted 20 August 1999

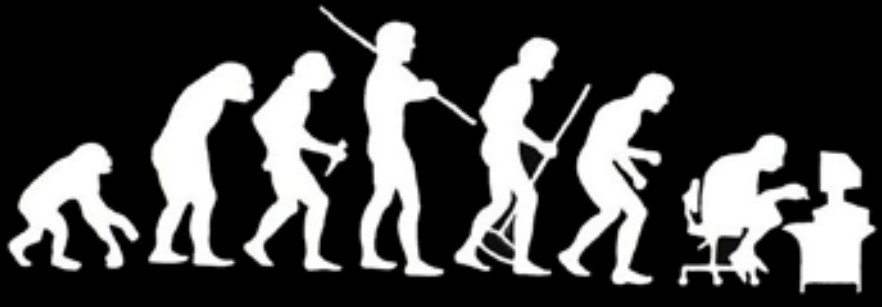
Weather

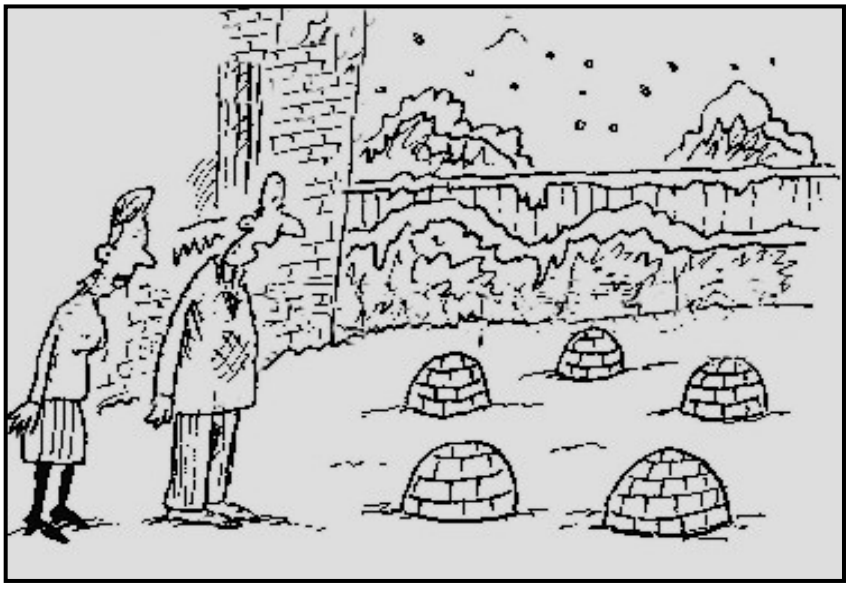


Climate



Can't animals and plants just move or adapt to global warming?

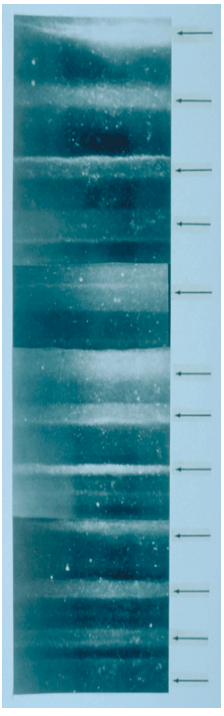




The moles have adapted to the winter weather

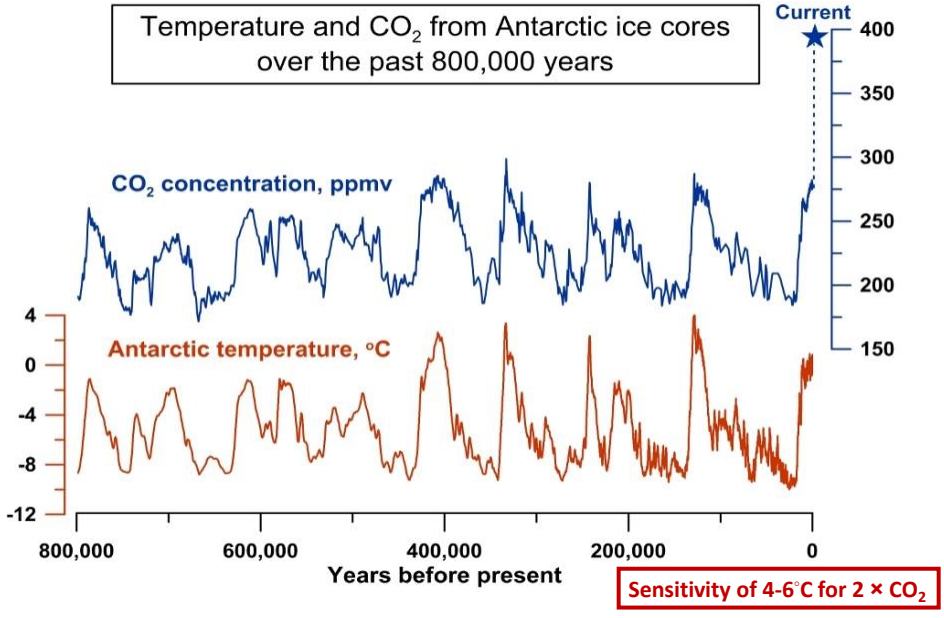
2. The geological past

Ice cores



19 cm long section of GISP 2 ice core from 1855 m showing annual layer structure illuminated from below by a fiber optic source. Section contains 11 annual layers with summer layers (arrowed) sandwiched between darker winter layers.

Antarctic ice: the world's air museum



(Climate change - recap…)

Five key ideas	Scientific discipline
1. Climate is weather averaged over 30+ yrs.	(Statistics)
2. The Greenhouse effect is simple.	(Physics)
3. Computer modelling provides a powerful tool for both NWP and climate.	(Maths)
4. CO_2 strongly controls temperature and ocean pH.	(Geoscience)
5. Many species just can't evolve fast enough to cope with rapid climate change.	(Genetics)

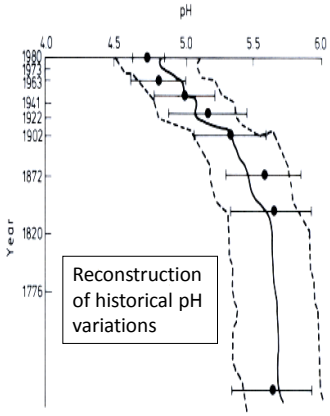
3. Impacts

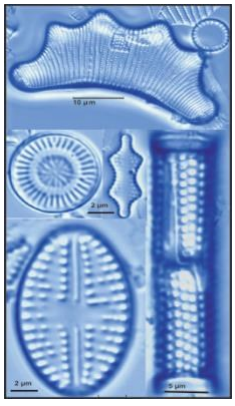
- Mountains
- Plants & animals
- Ice
- Oceans

Mountains as Early Indicators of Global Change

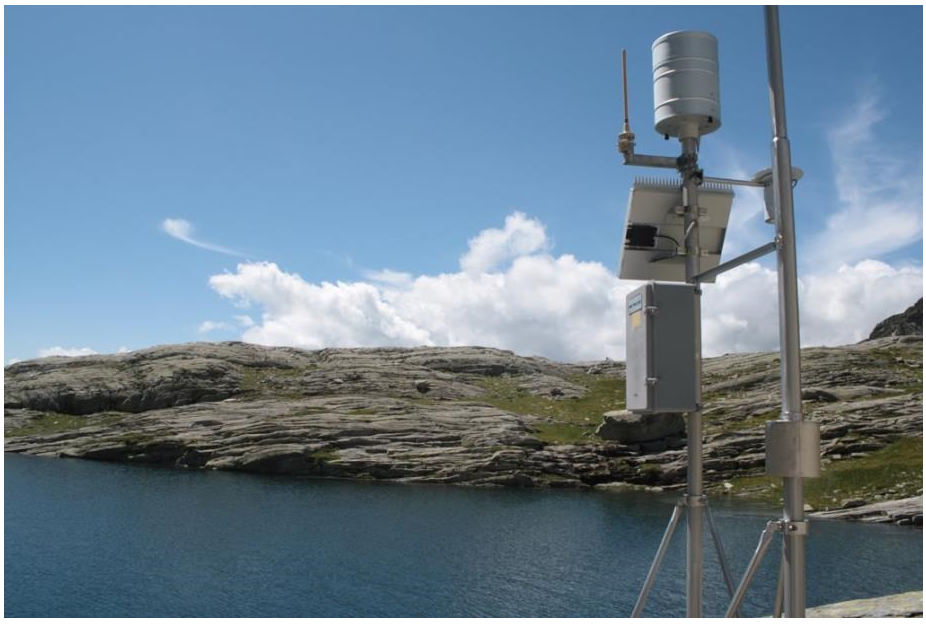
EU RTD, ENV4-CT-95-0007

A consortium of 28 laboratories
from both EU and non-EU countries.





Sulzata – 2535m – Rila Mountains – Bulgaria (Balkans)



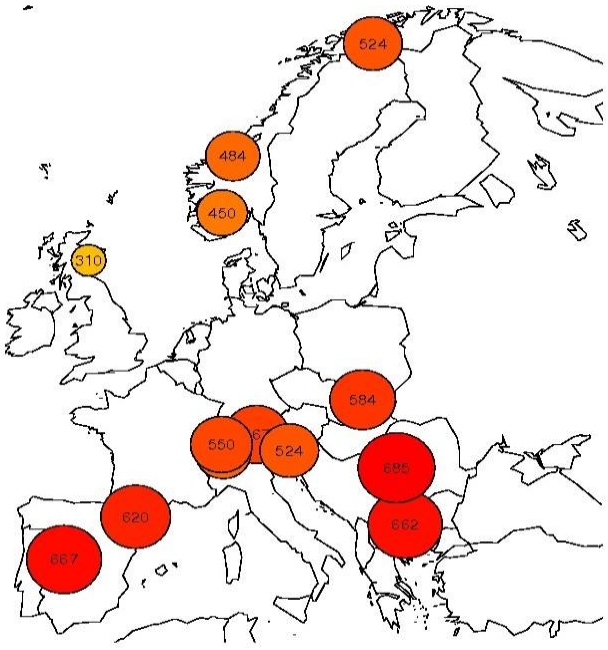
Paione Superiore – 2269m – Domodossola – Italy

Moaralmsee – 1617m – Schladminger Alps – Austria

Lochnagar – 785m – Cairngorms – Scotland

Saanajärvi – 679m – Enontekiö – Finland

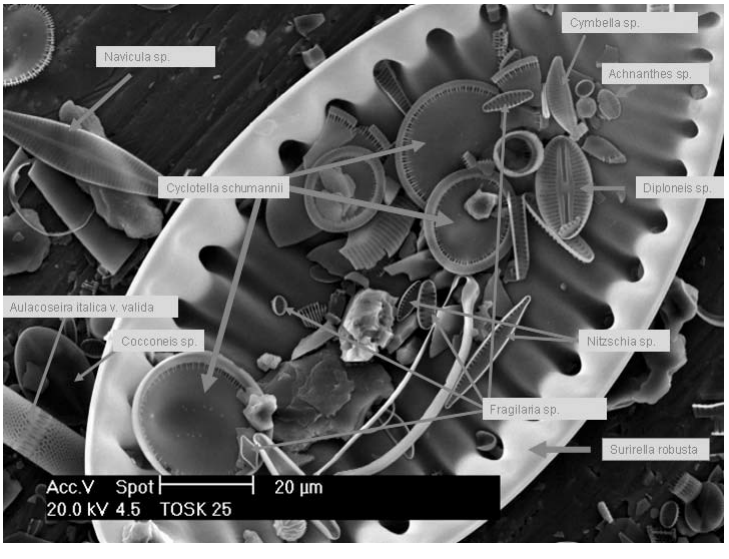
Continent-wide response of mountain vegetation to climate change (2001-8)



Projected rise of treeline (m) in European mountains

RCP 4.5 2081-2100

Acid Rain

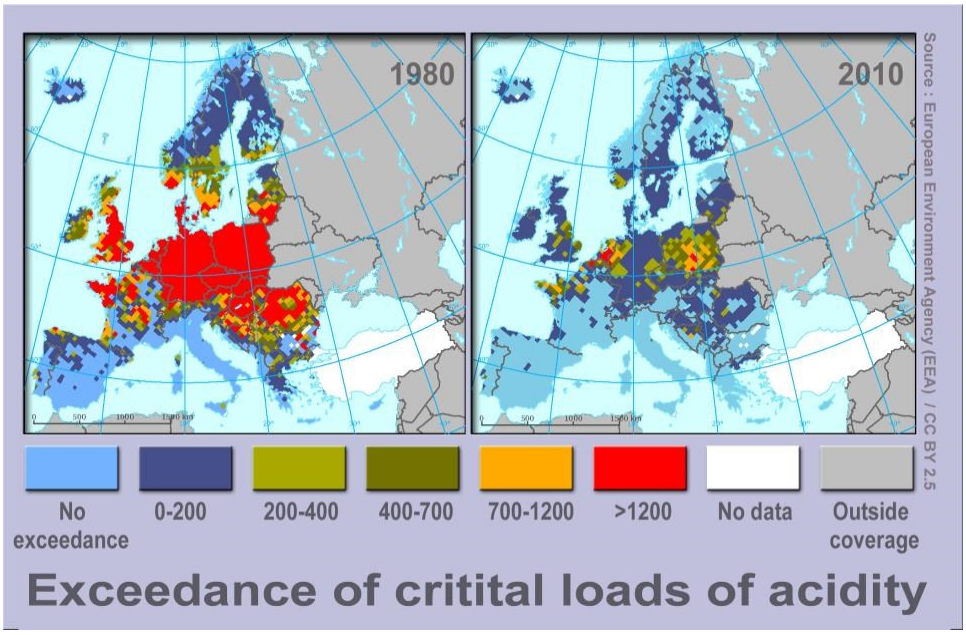


Scanning electron micrograph of diatoms from Lake Toskal, Finland.

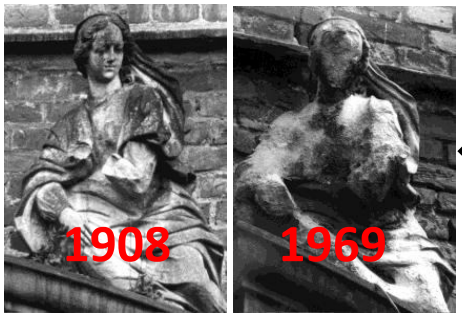
Sediment samples from remote lakes reveal worsening acidity throughout the industrial period.

Despite recent declines in sulphur emissions (long-range atmospheric impacts, biological recovery is slow.

Declining trend in acidification

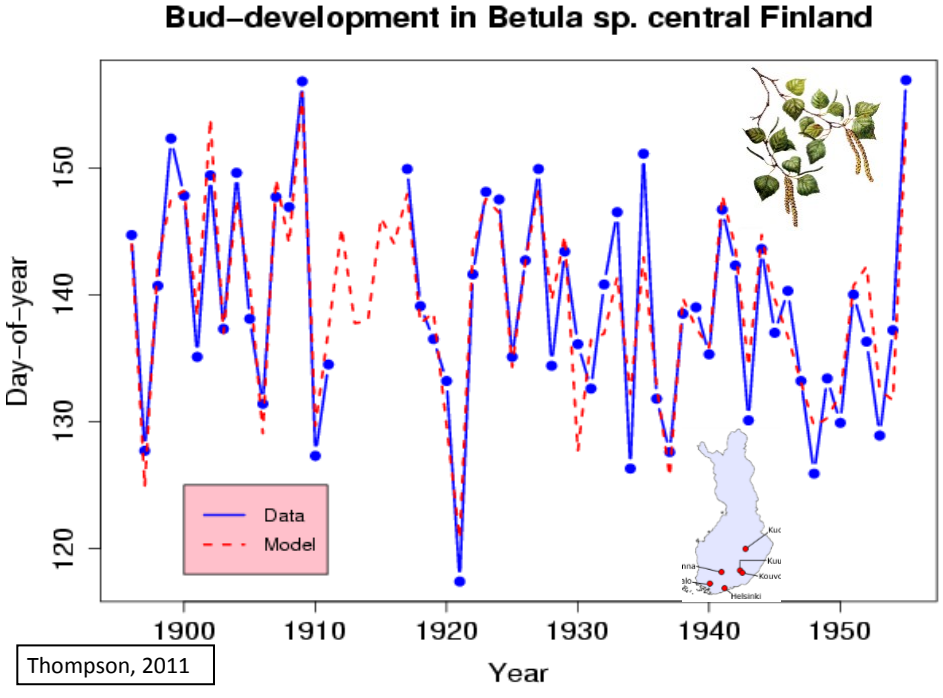


A success story…?



	1980	1990	1995	2000	2010
Europe	59	42	31	26	18
U.S.	24	20	16	15	14
Asia	15	34	40	53	79

Emission rates of sulphur dioxide have decreased by 'exporting' our manufacturing to Asia.



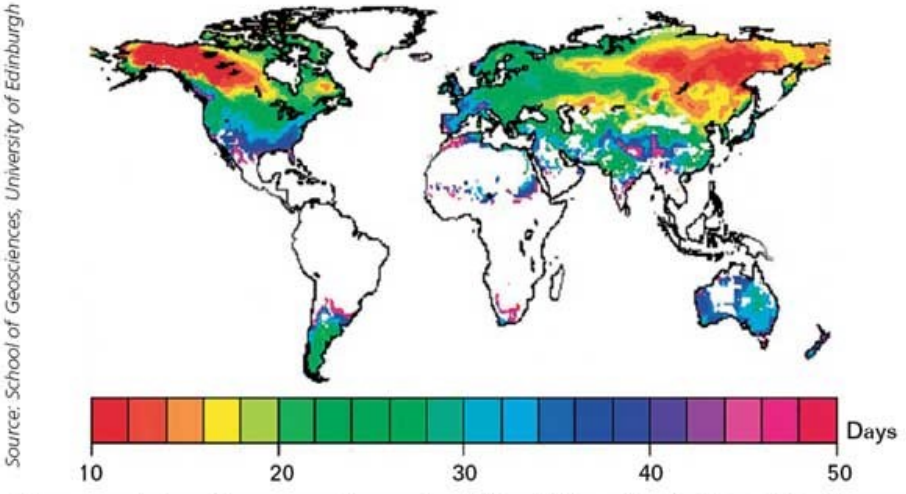
Thompson, 2011

Managing Daylength in Commercial Greenhouse and Nursery Production

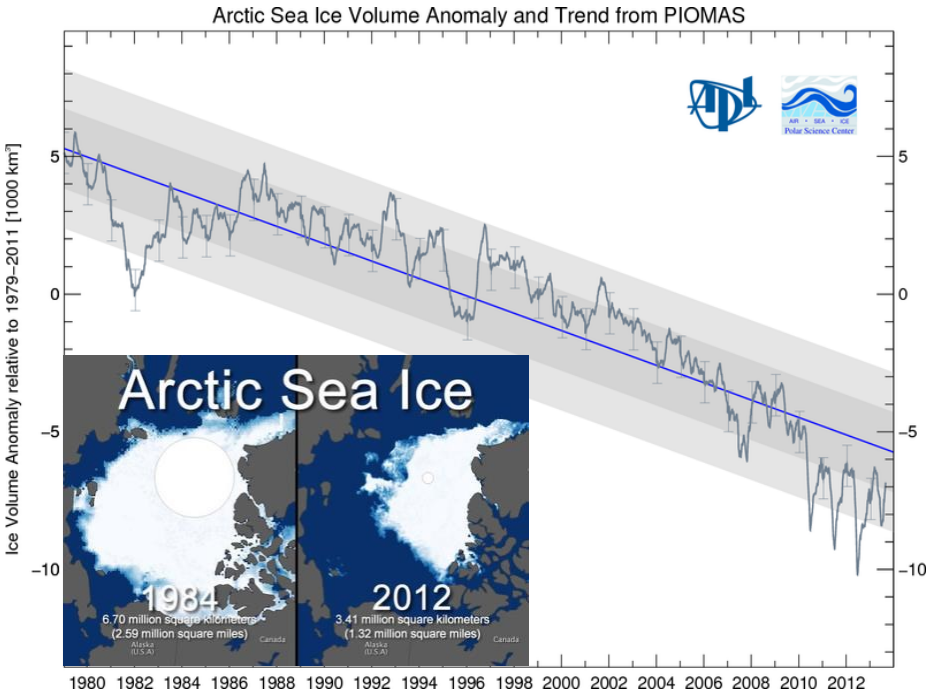
High-pressure sodium lamps with oscillating reflectors cast moving beams of light to crops below in order to increase yield, inhibit dormancy, or accelerate flowering

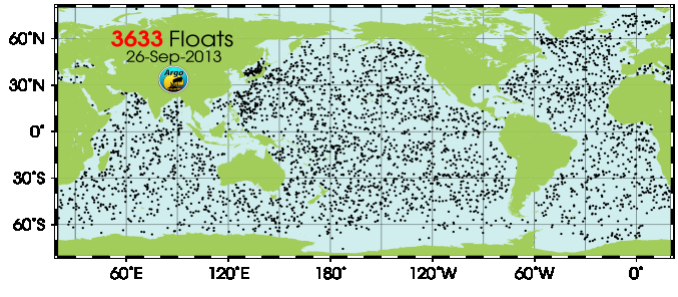
Recent developments in LED technology create new opportunities for lighting of greenhouse crops.

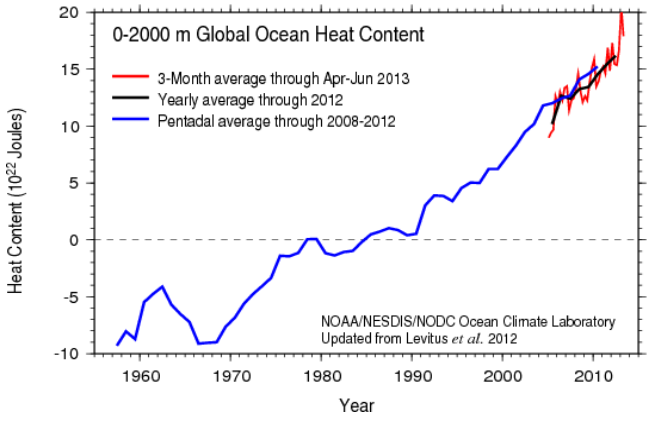
Desynchronisation



Colour-coded regions are where plant life will be affected by 2080. Figures reveal the number of days by which plants will flower earlier than expected

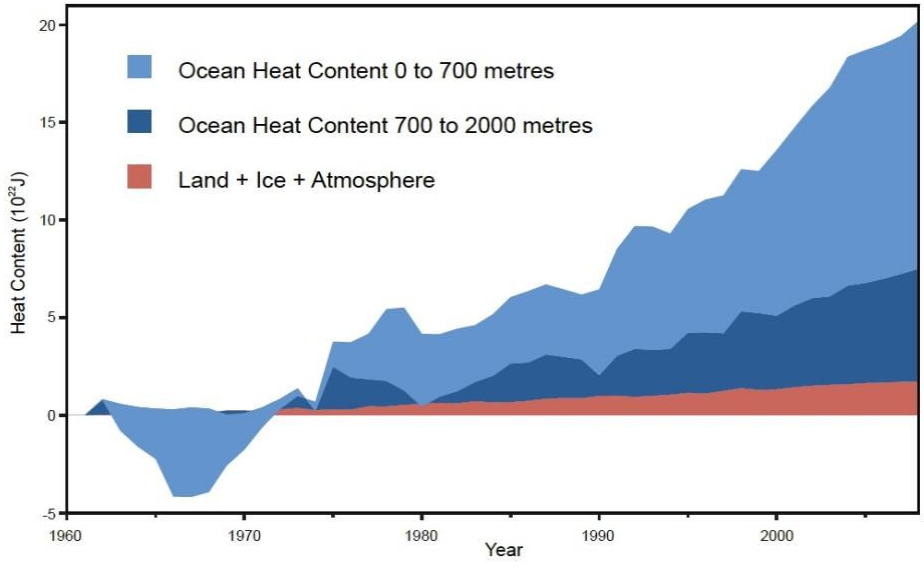

Arctic Sea Ice Volume Anomaly and Trend from PIOMAS
Ice Volume Anomaly relative to 1979–2011 [1000 km³]
5
0
−5
−10
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012
Arctic Sea Ice
1984
6.70 million square kilometers
(2.59 million square miles)
2012
3.41 million square kilometers
(1.32 million square miles)


3633 Floats
26-Sep-2013
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°

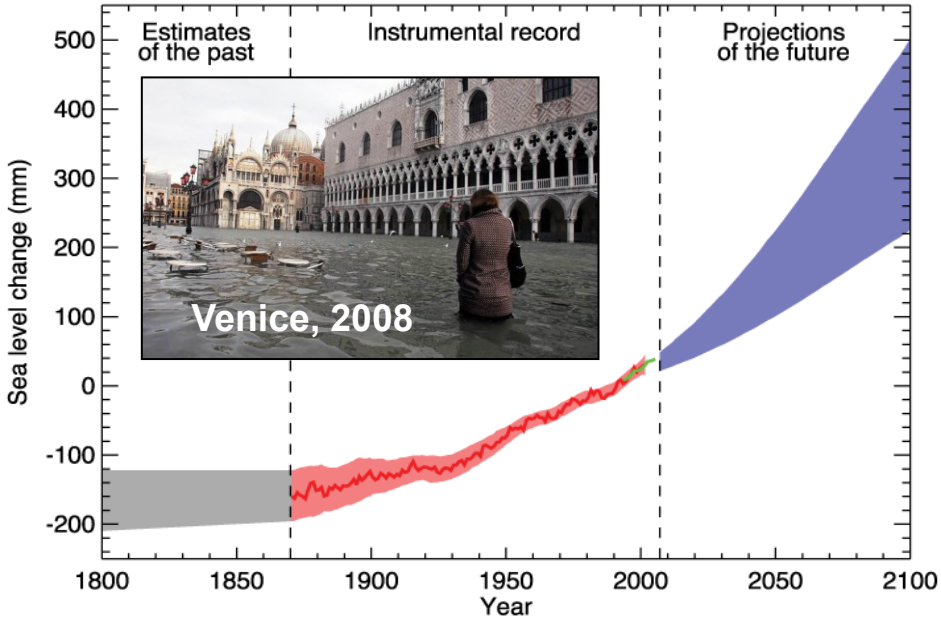

0-2000 m Global Ocean Heat Content
3-Month average through Apr-Jun 2013
Yearly average through 2012
Pentadal average through 2008-2012
Heat Content (10²² Joules)
20
15
10
5
0
-5
-10
1960
1970
1980
1990
2000
2010
Year
NOAA/NESDIS/NODC Ocean Climate Laboratory
Updated from Levitus et al. 2012

Earth is in imbalance

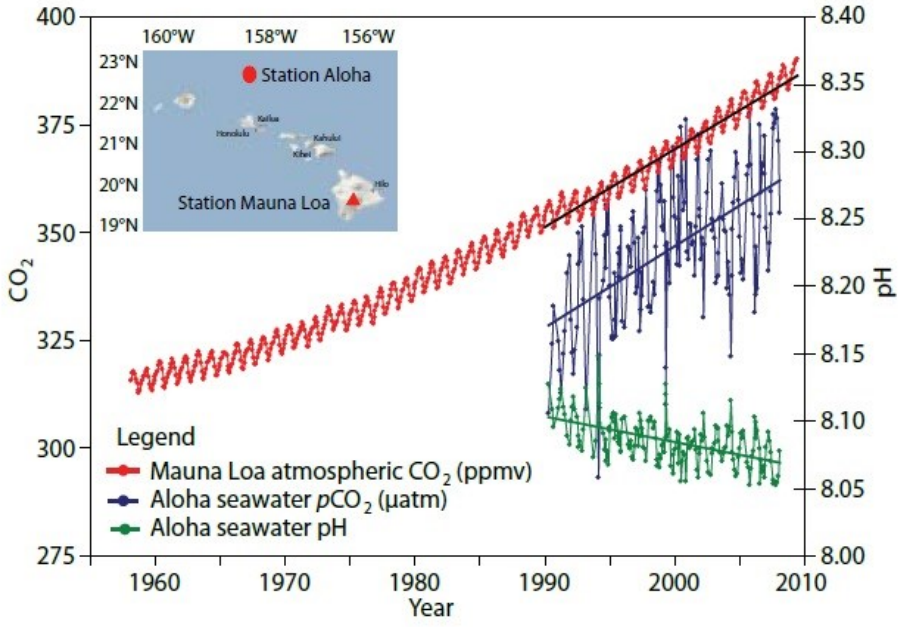
More energy is entering than exiting the top of the atmosphere. More than 90% of the heat trapped by greenhouse gases is being absorbed by the ocean.



Ocean Levels Are Getting Higher



Ocean Acidification



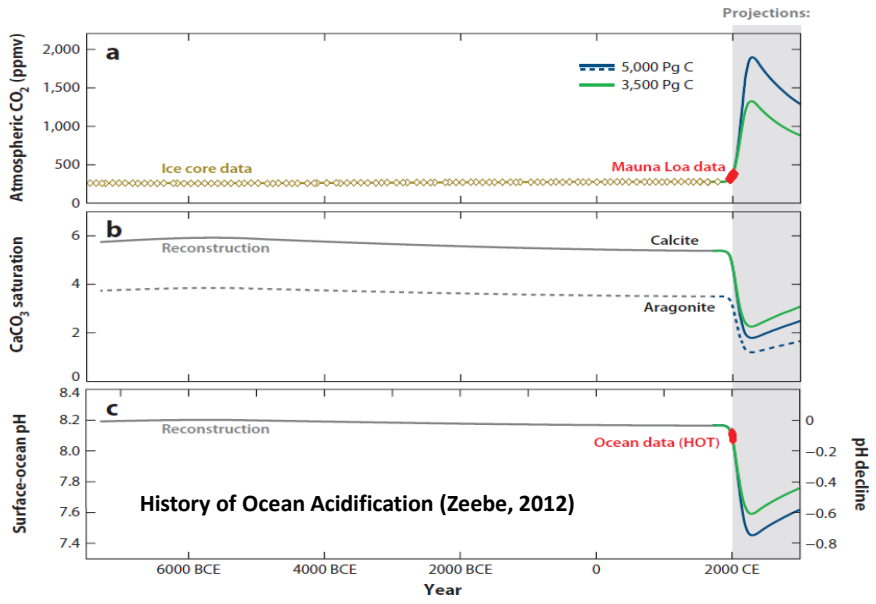
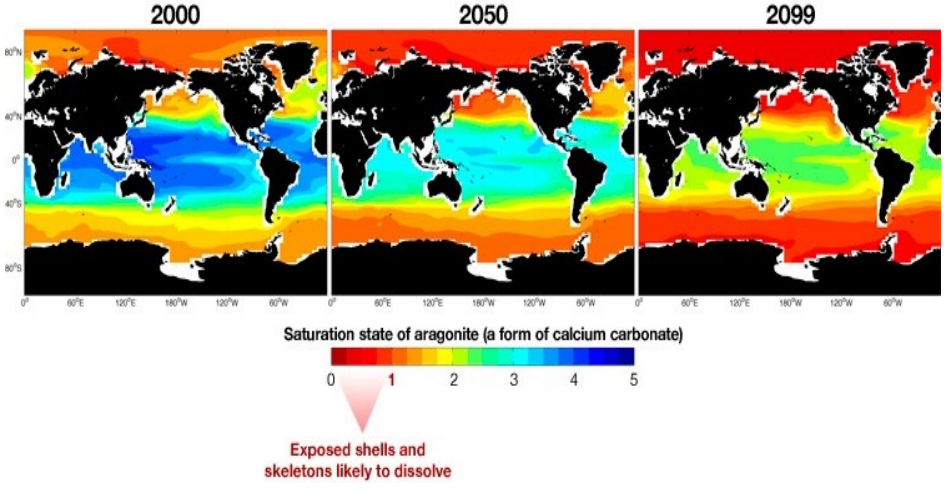


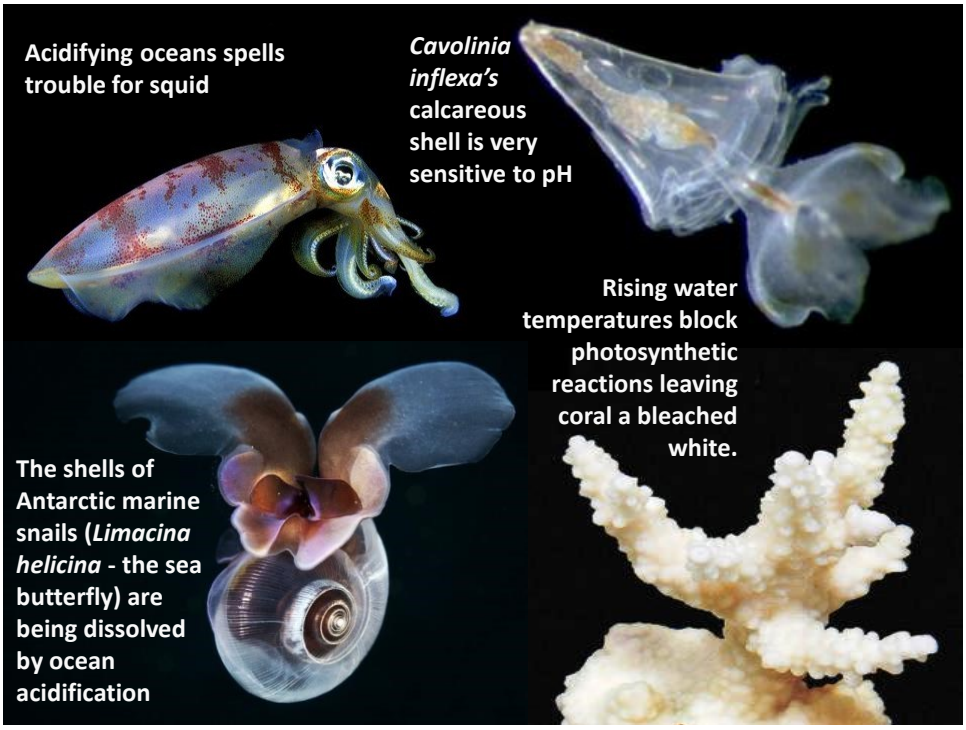
Figure 3

Holocene versus Anthropocene. (*a*) Dark yellow diamonds: Holocene atmospheric CO_2 concentrations from ice cores (Monnin et al. 2004); red diamonds: CO_2 measured at Mauna Loa Observatory, Hawaii (Tans

Effects of Ocean Acidification on Shells



By 2099 only tropical waters will be able to support the growth of calcifying organisms



Observable impacts – recap…

(from fossil fuel exploitation)

- Mountains: Biomes moving uphill. Lakes acidified.

- Plants and animals: Early flowering and longer growing and breeding seasons → Desynchronisations.

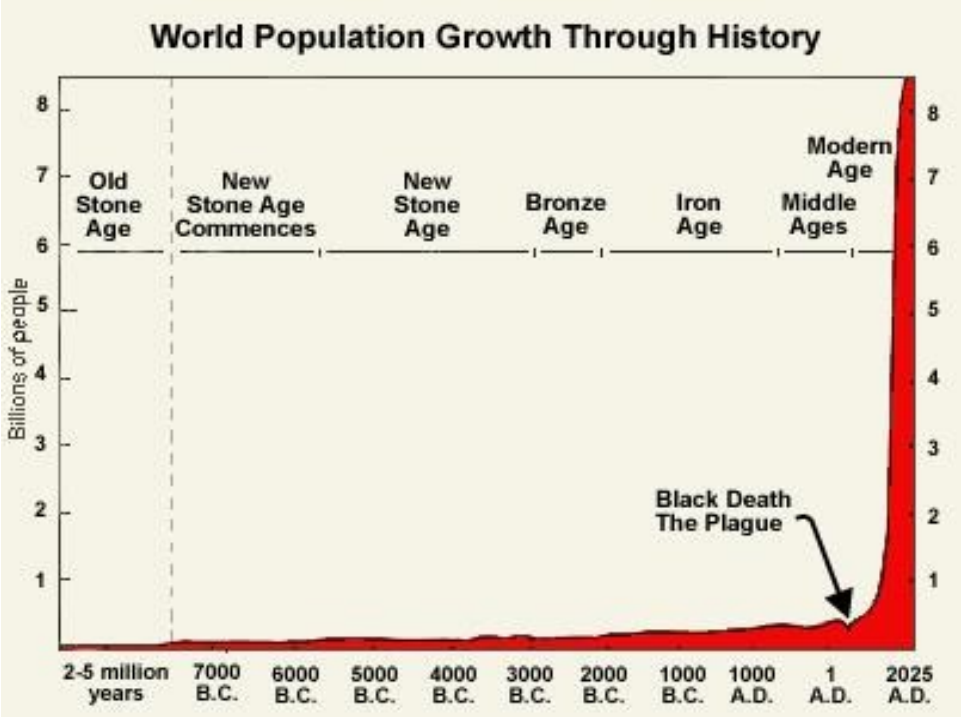
- Ice: Reduction in Arctic sea-ice extent (also in temperate and tropical glaciers).

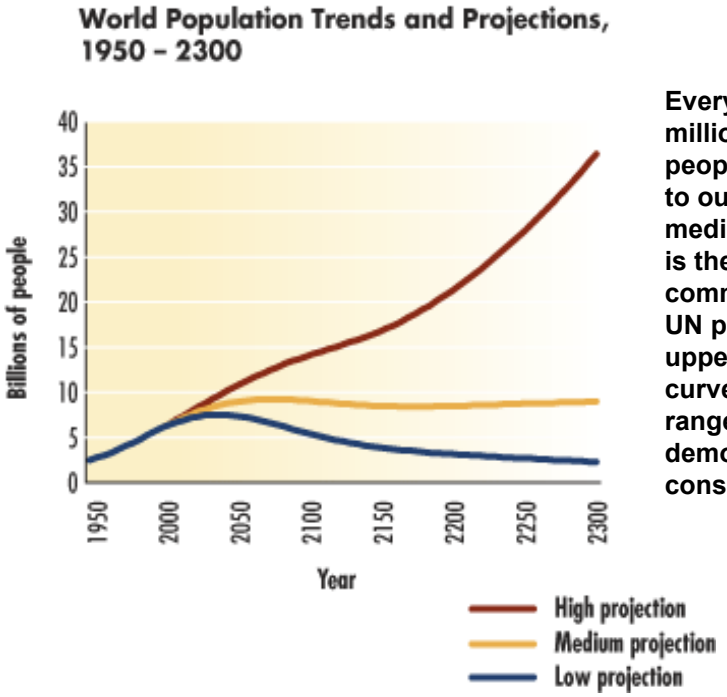
- Sea-level: Both satellite radar altimeters and Argo buoys reveal an accelerating global rise.

- Ocean acidification: Above all oysters, corals, brittle stars and molluscs are reacting very sensitively to pH.

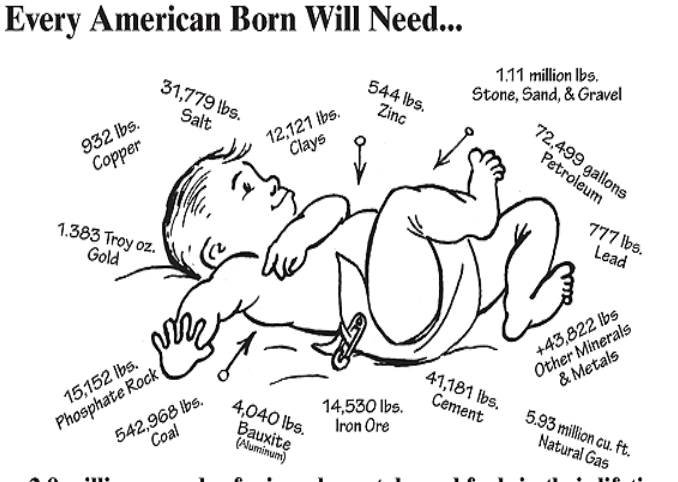
4. Fundamental dilemma

The world is getting most of the energy its economies need in ways that are wrecking the climate and the environment.

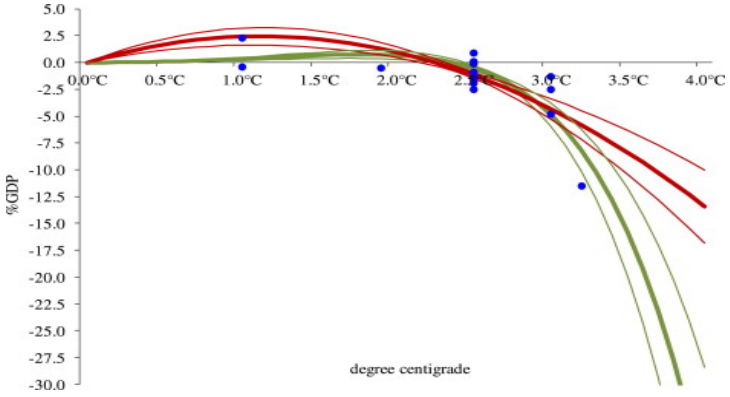




Every week 1.6 million extra people are added to our planet. The medium projection is the most commonly used UN projection. The upper and lower curves define the range of what UN demographers consider possible.



Economics of climate change



The West Lothian question

West Lothian was home to the first oil industry...

If West Lothian was one big bing - made up of all the carbon mankind plans to burn (10,000 Gigatons) - how high would the bing rise?

Global Change's Terrifying Maths

Three simple numbers that add up to a global catastrophe…

The First Number: 2°C

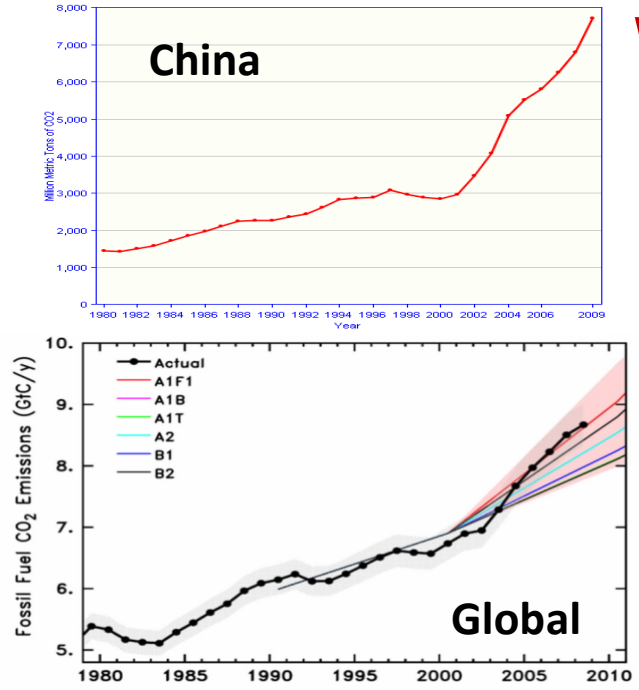
A 2°C target is often used in International negotiations as a guide line for avoiding dangerous climate change.

The Second Number: 900 Gigatons

Humans can pour roughly 900 Gt of carbon dioxide into the atmosphere and still have some hope of staying below two degrees.

The Third Number: >10,000 Gigatons

This number – the scariest of all – describes the amount of carbon contained in coal, oil, gas & hydrofracking resources. In short, the fossil-fuel mankind can burn is over 10 times higher than the 900 Gt 'limit'.



Where are we now?

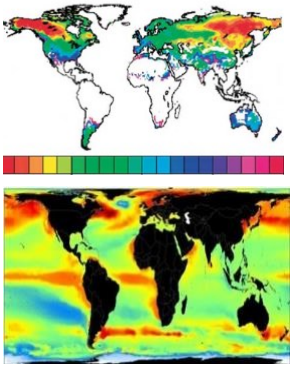
Despite Kyoto, Copenhagen, & Rio global CO_2 emissions are rising even faster than previous business-as-usual projections.

Climate change: three steps to ruin

1. Our ever rising global population, with its over consumption, generates atmospheric pollutants especially CO_2.

2. CO_2 is a powerful, long-lived greenhouse gas. It's fluctuations have been the primary driver of geological climate change and ocean pH.

3. Impacts of the two evil twins ➡ ice melt, sea-level rise, food supply & ecosystem disruption, droughts and biodiversity loss, with a 5% fall in global GDP forever.



5. Geology to the rescue?

A geologic solution?

Dispose of CO_2 through mineralization

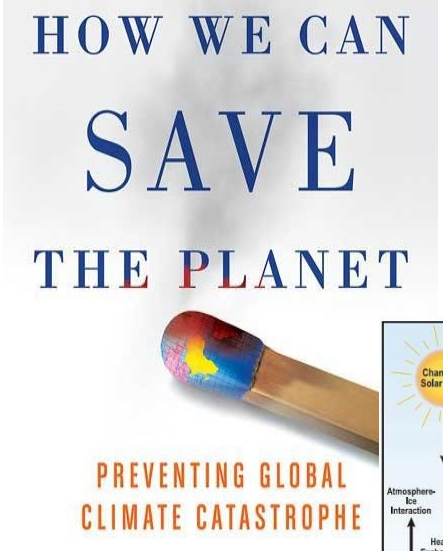
Geoengineering

- **Renewed interest in geoengineering** in the last few years has been sparked by the recognition that existing mitigation efforts are proving wholly ineffectual at the global scale.

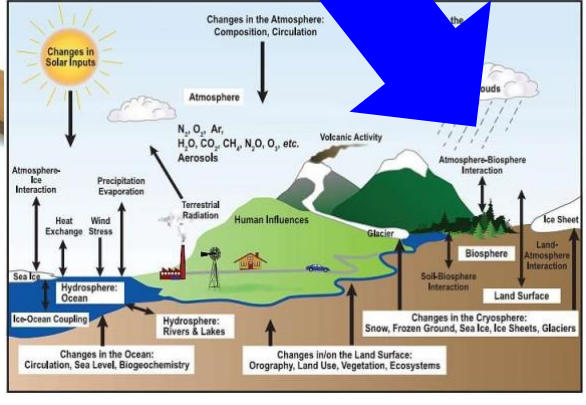
- **Mitigation (Plan A)** = **activities that reduce anthropogenic CO_2 emissions.**

- **Geoengineering (Plan B)** = **deliberate large-scale intervention in the Earth's climate system that aims to mediate the effects of elevated CO_2 concentrations.**

- **The catch** is obvious enough - The world's climate is complicated and we don't really know what the consequences might be of interfering with it.



Enhanced weathering

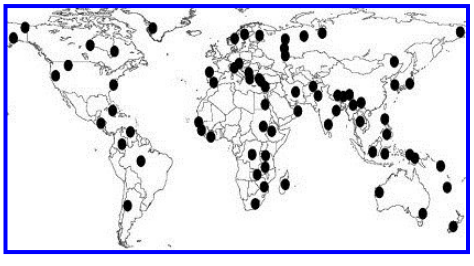


ENHANCED CHEMICAL WEATHERING AS A GEOENGINEERING STRATEGY TO REDUCE ATMOSPHERIC CARBON DIOXIDE
Jens Hartmann et al. May, 2013

(left) A "hardpan" of carbonate formed on waste slag mounds at former steelworks in Consett, United Ki
precipitation in waters egressing from a waste landfill in Scunthorpe steelworks (photograph courtesy of
e). In both cases, rainwater has percolated through the material (dissolving Ca^{2+} and Mg^{2+}) and cor
e precipitation of carbonate

"Mine it, mill it, spread it !"

The Virgin Earth Challenge - a prize of $35m for a commercially viable design to remove anthropogenic, atmospheric greenhouse gases.



Global distribution of dunite massifs (rocks that consists of > 90% olivine).

Just expose fresh rocks to carbon dioxide. The challenge lies in upscaling this natural, geological process.

Olivine (forsterite) : $Mg_2SiO_{4(s)} + 2CO_{2(g)} + 2H_2O_{(l)} \leftrightarrow 2MgCO_{3(s)} + H_4SiO_{4(aq)}$ (1a)